



ROMANS KIRENSKIS
(ROMAN KIRENSKY)

A HOLISTIC METHODOLOGY FOR VALUE-DRIVEN
CONCEPTUALISATION OF PASSENGER CABIN INTERIORS

SCHOOL OF AEROSPACE, TRANSPORT AND
MANUFACTURING

PhD in Aerospace
Academic Year: 2023 - 2024

Supervisor: Dr. Craig Lawson
Associate Supervisor: Dr. Huamin Jia
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ABSTRACT

The design of aircraft cabin interiors is a multi-disciplinary, multi-domain activity challenged by the need to satisfy technical, operational, and commercial product requirements simultaneously. Addressing these in isolation proves ineffective in delivering cabin interiors destined for long-term success in the modern market driven by holistic forces. However, no unified approaches exist for their integrated co-development. Engineering tools like Multi-Disciplinary Optimisation resolve the technical challenges, but are unable to integrate the commercial factors. Resource-efficient innovation is further perplexed by the competitive data-sharing practices and conflicting priorities pursued by the many cabin stakeholders. As a result, the parties involved in cabin interior design lack awareness of each other's preferences, needs, and constraints. The integration of contrasting stakeholder priorities can be streamlined by conceiving a holistic methodology for early-stage cabin product design. It shall implement effective decision-making practices into a collaborative cabin design toolset to facilitate co-creation. This thesis proposes such a methodology, which was developed in a multi-step approach. First, the identification of a suitable design assessment basis is enabled by deriving a synoptic taxonomy of discrete Multi-Criteria Decision Analysis tools. It is then employed to map the diverse multitude of drivers relevant to cabin interior design and prioritise among them using context-based logic defined by the case being addressed. Industry expertise was gathered to consolidate multiple stakeholder preferences into a robust capability for the evaluation of potential interior design solutions. Finally, the holistic cabin design approach proposed is used to assess the sustainability of cabin interior products as the most pertinent issue faced by the industry at the moment. This is achieved in a cost-efficient manner at a scale unachievable with existing Life Cycle Assessment methods. The effectiveness of the toolset proposed is validated by its application to a hypothetical case study.

Keywords:

MCDA, MADM, Cabin Design, Sustainability, Holistic Design, Passenger Cabin

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LIST OF ABBREVIATIONS

ADS	Aerospace, Defence, Security and Space
AFRA	Aircraft Fleet Recycling Association
AGI	Artificial General Intelligence
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
ARAS	Additive Ratio ASsessment
ARAS-F	Fuzzy Additive Ratio Assessment Method
ARGOS	Aid to the Ranking to be made by a Group of decision makers using an Outranking Support
ARGUS	Achieving Respect for Grades by Using ordinal Scales
ARIADNE	Alternative Ranking Interactive Aid based on DomiNance structural information Elicitation
ASTRIDA	Advanced STRategic Intelligent Decision Aid
ATI	Aerospace Technology Institute
BEES	Building for Environmental and Economic Sustainability
BEIS	Department for Business, Energy and Industrial Strategy
BEIS	Department for Business, Energy & Industrial Strategy
BIPAD	Best Industry Practices for Aircraft Decommissioning
CA	Certification Authorities
CE	Circular Economy
CEM	Cabin Equipment Manufacturer
CFRP	Carbon Fibre Reinforced Plastics
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CR	Consumer Retailers

DA	Decision Analysis
DA	Design Agency
DM	Decision-Maker
DMA	Dimethylaniline
DMO	Destination Management Organisation
DP	Decision Problem
DSS	Decision Support System
EASA	European Union Aviation Safety Agency
EF	Environmental Footprint
EI	EcoInvent (an LCA database)
EIS	Entry Into Service
ELECTRE	Élimination Et Choix Traduisant la Réalité (French for: Elimination and Choice Translating Reality)
EM	Eigenvector Method
EOL	End-Of-Life
EP	Environmental Prices
EPS	Environmental Priority Strategies
ER	Epoxy Resin
EU	European Union
FF	Flexible Foam
FN	Fuzzy Numbers
FU	Functional Unit
FUCAM	FUture Cabin for the Asian Market
GDM	Group Decision Making
GFRP	Glass Fibre Reinforced Plastics
GHG	Greenhouse Gas

GHP	Ground Handling Provider
GU	Government Units
IATA	International Aviation Transport Association
IC	Impact Categories
IFE	In-Flight Entertainment
ILCD	International Life Cycle Data system
IMPACT	IMPact Assessment of Chemical Toxics
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LOPA	Layout of Passenger Accommodations
MADA	Multi-Attribute Decision Analysis
MADM	Multi-Attribute Decision-Making
MCDA	Multi-Criteria Decision Analysis
MCDM	Multi-Criteria Decision-Making
MCVM	Multi-Criteria Value Models
MDO	Multidisciplinary Design Optimisation
MECE	Mutually Exclusive, Collectively Exhaustive
ML	Machine Learning
MODM	Multi-Objective Decision-Making
MOO	Multi-Objective Optimisation
MRO	Maintenance and Repair Organisation
MS	Microsoft
NN	Neural Netrowk

NPDI	New Product Development and Introduction
NRC	Non-Recurring Costs
OEF	Organisation Environmental Footprint
OEM	Original Equipment Manufacturer
OEW	Operating Empty Weight
OR	Operations Research
PA	Polyamide
PAS	Publicly Available Specification
PAX	Passengers
PBDE	Polybrominated diphenyl ethers
PC	Polycarbonate
PEEK	Polyetheretherketone
PEF	Product Environmental Footprint
PEI	Polyetherimide
PEKK	Polyetherketoneketone
PET	Polyethylene Terephthalate
PF	Phenol Formaldehyde
PMMA	Polymethyl Methacrylate
ProBCA	Problem-Based Characterisation Approach
PROMETHEE	Preference Ranking Organization Method for Enrichment of Evaluations
PS	Product System
PSK	Passenger-Seat Kilometre
PU	Polyurethane
PVC	Polyvinyl Chloride
QFD	Quality Function Deployment

RC	Recurring Costs
RF	Rigid Foam
RFP	Request For Proposal
SA	Stakeholder Analysis
SAF	Sustainable Aviation Fuels
SC	Sum of Contributions
SDG	Sustainable Development Goals
SSAPTI	Synergistic Sustainability Assessment of Passenger Transport Interiors
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TO	Trade Organisations
TRACI	Tool for Reduction and Assessment of Chemicals & other environmental Impacts
UN	United Nations
UTA	UTilités Additives (French for: Additive Utilities)
VIP	Very Important Person
WAVE	Water Accounting and Vulnerability Evaluation
WEF	World Economic Forum
WSM	Weighted Sum Method

1 INTRODUCTION

The term “holism”, from the Greek “holos” (meaning entire, whole), captures the idea that the qualities of any whole system are greater than a simple combination of its constituent element properties. Holism accepts that indirect connections between system elements mutually reinforce and expand their functioning and thus, must be taken into account when appreciating the quality of the whole system. Holism antagonises reductionism, which considers any complex system as a direct sum of its fundamental constituents and reduces the role of its synergistic effects involved. Both these terms originate from scientific observations of the natural systems and their evolution and constitute the different schools of thought practised in the scientific and industrial domains.

Holistic approaches have proven effective in product design and development applications, subsequently winning in popularity since the later part of the 20th century as a more natural baseline for engineered systems. Stimulated by the advent of computational technology and better knowledge management across all scientific and industrial domains, a holistic mindset has driven the derivation of such capable tools as MBSE (Model-Based Systems Engineering) and MDO (Multidisciplinary Design Optimisation) [1]. These are two separate tools, but often applied in conjunction to form a holistic product engineering approach.

Best suited for developing complex systems, MBSE-MDO is widely applied in domains involving advanced product engineering in the presence of uncertainty and a combination of quantitative (targeted by MDO) and qualitative (addressed by MBSE) drivers. The MBSE-MDO approach is popular in aerospace applications, where it has deeply affected the evolution of all major parts of a modern aircraft (airframe, propulsion, controls, and other systems) except for passenger cabin interiors.

The key reason behind the sub-par application of the MBSE-MDO approach to cabin interiors is their different product nature as opposed to the rest of the aircraft. Aircraft passenger cabin interiors are a commercial product, unlike the rest of the aircraft being an industrial type. Conceptual cabin design involves a

considerable amount of subjectivity and context variability between versions, which must be considered before the detailed development of separate cabin components can be initiated.

The quest for coherent and prescriptive instruction on how to develop a holistic cabin interior concept has returned no results. This thesis presents the contents and output of a doctoral research project resolving this lack of a formalised cabin conceptualisation practice. Dedicated to offering a suitable approach for early-stage cabin interior development, it delivers a complete methodology for passenger cabin product conceptualisation implemented as a flexible, application-ready toolset.

1.1 Research Motivation

Traditionally, aircraft interiors were derived by optimising functional parameters of cabin contents based on analytical development and inspiration from the design of other living spaces existing at the time, namely the automotive, maritime, and home interiors. Its evolution flattened during the 1960s after a sharp rise in quality when the technological opportunities of the time reached the optimum balance with the limits of profitable aircraft operations. The need to minimise fuel burn while adhering to numerous stringent safety and operational requirements has constrained cabin innovation since, causing a stagnation in its standard.

Consistently high levels of cabin safety and reliability, combined with rapid capability improvement and expansion in other technology-reliant industries drove passenger experiential expectations for aircraft interior contents to rapidly evolve over the past decade. Conditioned by their strong demand for comfort, service quality, and the variety of in-flight activities available, cabin differentiation has become a crucial enabler to operators' competitiveness and ultimately, survival. Facing the need for innovation in cabin design and technology, the aircraft interior industry is characterised by unresolved conflicts between the multiple contradictory limitations, expectations, and requirements imposed upon

it by its various stakeholders. The following sub-sections present relevant factors driving the aims and objectives of the research work dedicated to resolving this conflict, and the resulting outputs.

1.1.1 Cabin Interior Design Challenges

The current aerospace design practices consider the aircraft and its systems as industrial products developed through engineering activities, as demonstrated in [Section 2.2](#). Existing design textbooks and standards address the technical and organisational aspects of the fuselage and cabin layout, but fail to address the initiation of commercially viable cabin concepts. In-flight safety and human factors references exclusively consider emergency and evacuation procedures, and airworthiness certification of airborne equipment. Detailed instruction on how to integrate the conflicting priorities of many stakeholders into a coherent and holistic cabin interior product specification is absent.

The absence of a crystallised practice for early-stage cabin design is conditioned by the mismatching product types involved: the aircraft is an industrial product while the cabin is a consumer product [2]. The two have different requirements, longevity, and customisation scope, each of which poses a separate optimisation challenge. In addition to delivering the desired technical goals, design-driven cabin innovation must account for the preferences, constraints, needs, and responses of all stakeholders to be successful. A problem of this kind features multiple conflicting design criteria, which must embrace subjectivity and imperfection to marry such a diverse range of perspectives.

Cabin evolution is currently realised by incremental improvements within single stakeholder remits, and is limited by the disrupted communication between its many stakeholders who uphold conflicting priorities. The existing practices are unable to effectively satisfy the drive for designing new passenger cabins that would be effective in progressive industry conditions discussed in [Section 2.2.2](#). To address this challenge, major aerospace players have identified the need to

update the existing cabin design practices and derive a holistic and collaborative approach that would harmonically integrate the needs of all stakeholders [2].

The research work presented in this thesis was initiated to answer this call, informed by three projects occurring in parallel and providing the practical substance to test research results. The first was the EU Horizon-2020 FUCAM (FUture Cabin for the Asian Market) project set up by Airbus Defence and Space GmbH in 2016 to address the challenge of market-specific cabin conceptualisation, as reported in [3] and [4]. It was followed by two projects addressing cabin innovation and sustainability: the UK Cabin Opportunity [5] and FlyZero Sustainable Cabin Design [6], both led by the ATI UK (Aerospace Technology Institute). The presented research was initiated by evaluating the existing approaches to aerospace product development. Enabled by the selection of the most appropriate analytical basis for early-stage cabin conceptualisation, it enabled identifying a methodological gap to be filled.

1.1.2 State-of-the-Art Cabin Design Practices

The go-to reference outlining the standard aerospace product development process [7] distinguishes several product development activities that can be categorised into 3 general maturity stages:

- i. Product concept design: a top-down process concerned with capturing the design intent into a specification for product requirements;
- ii. Product engineering: a bottom-up development process aimed at embodying the specified function to satisfy the outlined requirements;
- iii. Implementation: a horizontal process that links outputs to the original design intent through a series of validation and documentation activities.

This basis is reflected in most industry-standard textbooks on aircraft design reviewed in Section 2.2, of which the most widely used by both industry and academia are Raymer [8] and Howe [9] for overall aircraft design, and Moir, Seabridge [10] for the development of individual aircraft systems. The focus of

these books is to guide the user through the full cascade of aircraft or systems development activities treating it as an industrial product. The reviewed sources offer very little if any, consideration on how to design passenger cabin interiors. Inevitably, their perspective is limited largely to suppliers' point of view and omits the consideration of other cabin interior stakeholders, rendering it insufficient for informing a holistic approach to developing cabin products.

The core sources addressing the non-engineering aspects of cabin interior development are Vink and Brauer [11] covering passenger comfort and ergonomics in great depth; and IATA best practices [12] guiding the organisation of cabin interior projects. Solely focused on the ergonomic and management considerations of cabin design, these sources are also insufficient for consolidating a comprehensive set of cabin development principles relevant to all stakeholders involved in cabin interior life cycle.

None of the sources reviewed are sufficient on their own to inform the integration of multiple cabin interior design factors (commercial, engineering, certification, operational, servicing, and many more) into a single prescriptive methodology. In the absence of such, existing approaches to aerospace product development had to be reproduced in the specific context of cabin interior design. A common analytical basis identified among the existing best practices is MVO (MultiVariate Optimisation) [9] and MDO, which has evolved from MVO to better facilitate product development applications.

1.1.3 Cabin Design Capability Gap

The reliance of the MBSE-MDO approach on complex facilities (like supercomputers or dedicated test laboratories [13]) justifies its application on large-scale, low-TRL (Technology Readiness Level), state- or conglomerate-funded R&D (Research and Development) and innovation projects. Naturally, the aerospace domain fits these criteria and hence this is where MBSE-MDO is applied most on projects like conceptualizing a new passenger aircraft [14] or developing a new space launch system.

MBSE-MDO has been applied to develop aerospace products since the 1990s [14], offering the ability to consider various design perspectives. These include technical performance (structural architecture, flight mechanics, propulsion); operational quality (cost of in-flight and ground servicing, maintenance); supply chain efficiency (production procurement, in-service spares) [15]. Characterised by its ability to manipulate multiple design aspects and sifting through numerous design variants to achieve a single objective, the MBSE-MDO process is iterative and involves many separate analytical workstreams. These include CAD (Computer-Aided Design), FEM (Finite Element Modelling), CFD (Computational Fluid Dynamics), and other engineering as well as non-engineering domains. MBSE-MDO application offers the most potential at a high level of detail where moderate analytical depth allows streamlining the refinement of many product characteristics, however diverse, into a holistic design evolution flow. Each development workstream, however, may be sophisticated and expand at a great level of detail.

MBSE-MDO finds most of its applications in whole-aircraft preliminary design and detailed design refinement of its separate systems. While it can be used for designing cabin interiors at later maturity stages, its application is ineffective for early-stage cabin conceptualisation and interior product RFP (Request for Proposal) generation by aircraft operators and primary OEMs (Original Equipment Manufacturers). The multiple priorities of cabin interior stakeholders are expressed as subjective and objective parameters of both qualitative and quantitative nature. These are managed using a dynamic product specification that is continuously updated through product engineering, certification testing, customer validation, and concept review cycles. A high level of complexity associated with full-scale MBSE-MDO application across the whole fidelity range [13] makes it an inefficient tool for conceptualising such a product whose definition involves numerous requirements of varying nature.

The weak suitability of MBSE-MDO to passenger cabin design is demonstrated by the scarce availability of relevant past cases, indicating that interior designers opt to avoid using it despite its status as the go-to approach for developing

complex aircraft systems. Its cabin design application was solely limited to driving fuselage sizing as a part of higher-level aircraft optimisation activities until a recent study [16] applied it to define the PSU (Passenger Service Unit) dimensions and positioning. No past examples have been identified where MBSE-MDO would be used to conceptualise the whole cabin interior or its elements, nor it was found to be the tool for considering the requirements of its many stakeholders.

The absence of a suitable cabin conceptualisation approach motivates the need to create one. This is achieved by identifying a suitable analytical basis to drive cabin development before it reaches sufficient maturity for effective MBSE-MDO application to engineering its elements. The solution was found by reviewing the available analytical methods and tools that share a similar capability with MDO i.e., allow reviewing multiple goals and criteria when making design decisions. The overarching scientific domain dealing with this type of analytical problem is OR (Operations Research), with existing examples like [17] that link MDO and OR methods through their shared capabilities.

The exploration of OR methods available to expand the core capabilities of the MBSE-MDO approach has resulted in the following reasoning cascade to find the most suitable sub-category of tools:

- **MVO:** a mathematical technique that extends the traditional (single-variable) optimisation by considering multiple variables. Uses special optimisation algorithms represented by a sequence of mathematical formulae. Rejected as the basis for new cabin design approach due to no capability for involving many stakeholder perspectives, which implies multiple goals of optimisation.
- **MDO:** MVO basis adopted to complex product engineering applications. Uses multiple workstreams representing the various design perspectives that may involve MVO and other analysis techniques. Rejected as the basis for new cabin design approach due to sole focus on engineering perspective.
- **MOO** (Multi-Objective Optimisation), a subset of MODM (Multi-Objective Decision-Making) tools: an evolution from MVO basis that accepts multiple

task objectives (each representing an individual design scenario) to derive a pareto set of equally suitable solutions. Each solution offers a different balance between the goals pursued, and the best one is selected depending on the specific DP (Decision Problem) context. Rejected as the basis for new cabin design approach due to requiring a strictly objective definition of goals with optimisation variables expressed on a continuous scale.

- **MCDA** (Multi-Criteria Decision Analysis): a subset of methods sharing a similar purpose with MODM (seeking the best solution to many simultaneous DP purposes) by accepting multiple criteria of varying nature expressed on a discrete scale. These can be subjective or objective, and take both quantitative and qualitative forms including immeasurable solution attributes.

MCDA was accepted as the basis for the new design approach representing the nearest equivalent to MDO capabilities in the context of aircraft cabin interior conceptualisation as a multicriteria DP. The application of MCDA methods informs early cabin design by evaluating the considered solution options in a measurable manner to enable their comparison and value-based prioritisation.

1.1.4 Aims and Objectives

The core assertion of this thesis is that neither MBSE-MDO nor MOO/MODM are suitable for cabin interior conceptualisation and thus, the new approach for early-stage cabin design shall use MCDA. It allows harmonious integration of the perspective of any stakeholder into a holistic design process, disregarding the nature of their involvement across the cabin interior life cycle. This assertion drove the definition of the core research aim: to conceive a modern approach to conceptualising viable passenger cabin interior products, which carries the following implications:

- **“To conceive”** implies deriving the novel approach in a structured and sequenced manner. It starts with identifying a suitable analytical basis and building a coherent process flow upon it and concludes with proving its practicality and effectiveness by applying it to a hypothetical case study.

- **“Modern”** implies a set of qualities that the new approach must deliver in line with current best development practices for aircraft design. These include holism (i.e., the ability to coherently integrate any type of requirements imposed by all stakeholders involved), relevance (i.e., good fit with existing cabin interior development context), and efficiency (i.e., addressing typical constraints and considerations of cabin project organisation in the industry).
- **“Approach”** implies a collection of practical methods, analytical instruments, useful references, and relevant considerations integrated into a coherent methodology and implemented as a shareable toolset that can be applied by a broad spectrum of users operating at various levels of skill.
- **“Conceptualisation”** implies early-stage design activities aimed at developing a detailed common view of the emerging product and formalising it into a comprehensive set of relevant requirements.
- **“Viable”** implies the ability of the new approach to ensure that the developed cabin concept is set for a high likelihood of commercial success. This requires facilitating the inclusion of the newest technological and innovation opportunities into cabin synthesis in a way that resolves any conflict with commercial constraints respected by all involved stakeholders.
- **“Passenger cabin interior products”** implies a flexible scale of the product in question, which may be a whole cabin interior shipset, its separate system (e.g. entertainment solutions), or even individual elements (e.g. a passenger seat). Furthermore, the absent reference to the aerospace domain in research aim definition implies that it could be applied, with some adjustment, to other modes of transport that use passenger cabins (i.e., mass transportation [18]).

This overarching aim translates into three constituent objectives to be satisfied:

- I. Identify suitable MCDA methods to use as the basis for new cabin concept design approach;
- II. Formulate a holistic methodology for streamlined definition and value-driven assessment of cabin interior concepts;

- III. Apply the proposed methodology by assessing a selected aspect of cabin interior products at a deeper refinement level to validate effectiveness.

These objectives, combined with cabin interior design context and considerations presented above and in Section 2, drove the philosophy for attaining the core research aim pursued. Its implementation has resulted in the conception of a new methodology for holistic early-stage cabin interior product design titled HCCA (Holistic Cabin Conceptualisation Approach) presented in this thesis.

1.2 Research Philosophy

The work performed to meet these objectives was based on the presumption that a paradigm shift in cabin design is long due. The mentality where cabins had to satisfy a generic set of airline requirements by offering recognisable technology content, 3-class layouts, and common product types is outdated. Future cabins shall not be constrained by any set of common needs or configurations, and be highly customisable to offer relevant experiences based on unique passenger profiles. A “one-size-fits-all” mentality needs to transcend into one that is equally able to satisfy any traveller profile while also improving revenues across the industry that has always faced profitability challenges. Cabin equipment shall be fully customisable from one airline to another, and switchable from one route to another by the same airline in a matter of hours. New technologies shall be utilised to the fullest extent to align with users’ experiential expectations defined by their ground-based environments. And yet, capturing the available technological opportunities must remain profitable, safe, and sustainable.

This section presents the means employed to derive HCCA as the means of achieving the declared research aim and its constituent objectives.

1.2.1 Research Approach

HCCA derivation is challenged by the absence of any existing standards or previous examples dedicated specifically to aircraft cabin interiors. The initial

research was concerned with reviewing the existing aerospace product design practices and identifying the potential synergies between the systems thinking and design thinking principles in alignment with the mindset suggested in [2]. A relevant philosophical baseline for HCCA was borrowed from [19] recommending a dual push-pull philosophy for designing novel aerospace systems in the absence of a previous baseline, where:

- **Pull (top-down side):** uses a systems thinking approach to capture stakeholder viewpoints and interdependencies by identifying their relevant design considerations and categories;
- **Push (bottom-up side):** uses a design thinking approach to define and structure the specific design drivers and their assessment criteria based on pull-side outputs
- **Analytical model (push-pull connection):** imposes an analytical model to process push-side outputs in line with pull-side mindset using MCDA methods

The systems thinking aspect drove the definition of HCCA top-level structure by identifying all the parties impacted by cabin design i.e., the stakeholders involved at any stage of the cabin supply chain (cabin design, delivery, in-service support, phasing out) and value chain (all commercial and strategic effects of cabin sales and enabled by its operations). It also informed the structuring of stakeholder drivers into a comprehensive set of key themes based on their internal priorities (preferences, needs, constraints, reactions) and external interfaces (commonalities, interconnections). Thus, the core logic behind HCCA derivation is to introduce a new NPD (New Product Development) framework as the means to address the overarching research aim.

The design thinking aspect drove the definition of bottom-level HCCA contents that link stakeholder needs and priorities to the full scope of cabin products potentially affected. This link is embodied in the decision criteria used to characterise the potential solution options for in-scope interior products in relation to each design driver identified. Design thinking constitutes the underlying mindset behind mapping the applicability of each design driver to all stakeholders and interior product types identified.

Lastly, the holistic, iterative process (steps, sequence) for processing and aggregating the Decision Information (DI) involved was derived to join the push and pull sides of the process. This included the selection of specific MCDA methods that allow appropriate modelling of cabin stakeholder values and views to form the analytical basis for HCCA. The MCDA methods allow processing a diverse set of preferences to identify maximum overall benefit by embracing subjectivity where inevitable and accepting some level of granular dissatisfaction. This closely aligns with cabin design DP context and thus, serves as an effective connector between the systems and design thinking components of HCCA.

The resulting HCCA development process flow is presented in Figure 1-1:

- **Step 1:** MVO derivatives in the surrounding scientific domains were reviewed to identify a suitable analytical basis for HCCA, resulting in the acceptance of MADM methods (Sections 1.1, 2.1);
- **Step 2:** a novel taxonomy for MADM methods is introduced accompanied by an associated selection framework titled ProBCA (Problem-Based Characterisation Approach) and implemented as a tool to enable identifying the most suitable MADM methods for HCCA application (Section 3);
- **Step 3:** HCCA was derived by identifying, systemising, and processing the design drivers pursued by cabin interior stakeholders, implemented as a practical, user-friendly framework (Section 4);
- **Step 4:** a case study of a single high-impact driver (cabin sustainability) is delivered to demonstrate how HCCA can drive cabin design evolution by motivating and informing the derivation of a deeper-level, highly focused assessment framework titled SSAPTI (Synergistic Sustainability Assessment of Passenger Transport Interiors), also implemented as a tool (Section 5);
- **Step 5:** HCCA is presented as holistic capability delivered by its 3 constituent frameworks (ProBCA, HCCA core, SSAPTI) by revealing the possibilities, advantages, and limitations of their combined application (Section 6).

The derivation of each HCCA core pillar is justified by a detailed literature review in Section 2.

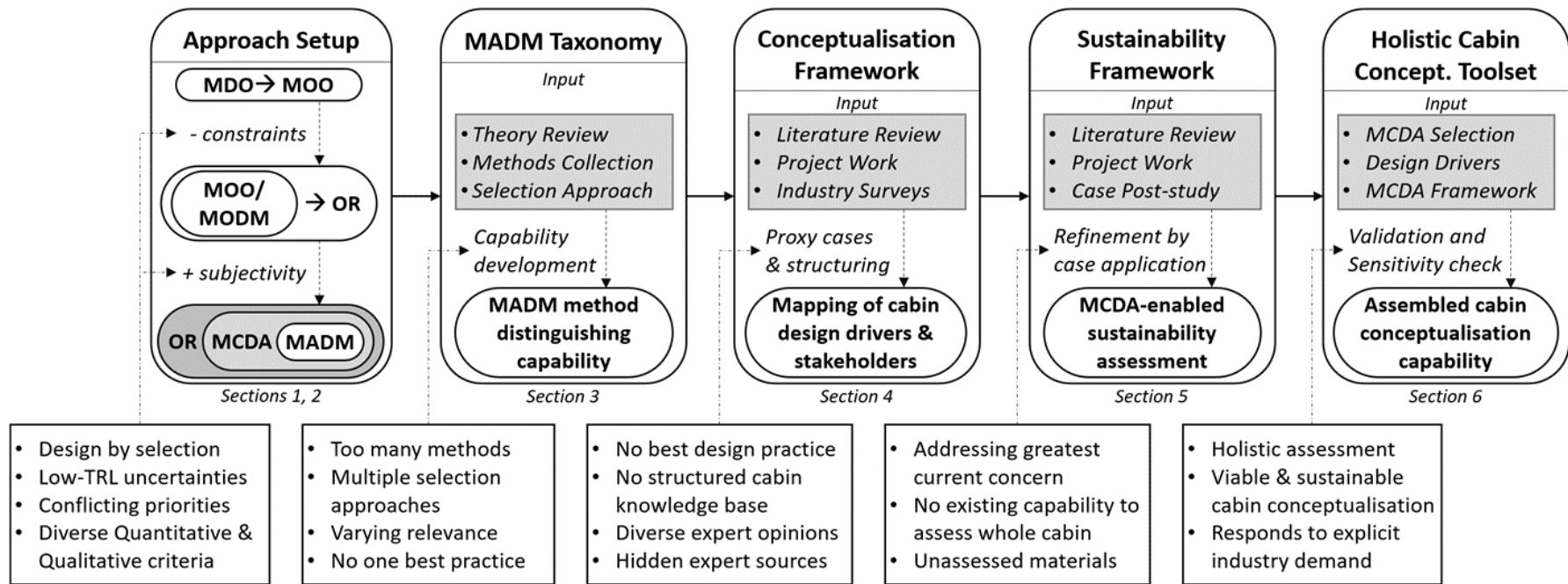


Figure 1-1: The development of a holistic passenger cabin design toolset

1.2.2 Research Methods

The derivation of HCCA has followed the order of decreasing confidence and increasing relevance:

1.2.2.1 Literature Review

The research work was initiated by identifying and reviewing a range of existing literature covering the specific aspects judged relevant for cabin concept creation, such as:

- Existing approaches to developing aerospace products and complex systems, such as MDO [14] and V&V (Verification and Validation) [7];
- Existing research covering the individual aspects affecting cabin interior design across its life cycle:
 - Factors affecting passenger satisfaction, willingness to pay, and loyalty;
 - Factors driving the design, integration, and performance of cabin systems;
 - Operational and commercial considerations affected by cabin qualities;
 - Cabin product life cycle processes, interactions, and mutual impacts between stakeholders.
- Non-academic information sources illuminate stakeholder-specific considerations and subjective viewpoints, which hold particular value when developing an all-new product design approach e.g.: industry reports, trade articles, practice manuals and guides, magazines, industry news, etc.

This process was used to construct a comprehensive, multi-level body of knowledge related to cabin interior design. It was iteratively restructured and re-systemised by testing the application of candidate MCDA tools to build the analytical basis for modelling cabin conceptualisation logic as a DP.

A similar reciprocal process was applied to develop ProBCA by iteratively revisiting the sources at different levels of detail. These spanned general MCDA theory books, MCDA method selection approaches, and detailed guides to individual MCDA methods and tools.

Careful selection of relevant sources was practised by checking their origins (authors, organisations) and credibility (references, reviews, mentions, clients, partnering organisations). Furthermore, any data point (e.g.: opinion, design driver, stakeholder interface, evaluation score) was triangulated before deciding whether to record it for use in the frameworks developed or not. Triangulation involves the identification of at least three independent sources to confirm information validity.

1.2.2.2 Expert Interviews

It was found during the research process that the available literature is insufficient to build a holistic view of all stakeholder processes, interactions, and priorities. The literature covers relevant knowledge stored as fragmented information across many sources of varying quality. It was deemed that expert opinions are required to uncover the common, holistic mindset that holds the full body of uncovered knowledge together and gives it sense, sequence, and purpose.

External industry projects referred to in [Section 1.1.1](#) provided the platform for gathering opinions from industry experts representing the entire range of stakeholders involved in or affected by cabin interiors. [Appendix B.2](#) lists expert opinion sources, with survey questions presented in [Appendix B.3](#).

Two methods of different refinement levels were used to gather expert opinions:

- i. **Workshop Contributions:** the first stage of expert opinion gathering was implemented as an expert workshop when preparing the UK Cabin Opportunity report [5]. This workshop was attended by representatives from the key cabin interior suppliers and R&D stakeholders and was focused on identifying a comprehensive set of relevant factors affecting cabin design. This has resulted in a collection of over 500 individual opinions, anonymised to protect the commercial identity of their sources and categorised into top-level design driver themes.

- ii. **Survey Interviews:** the second stage of expert opinion gathering involved identifying the individual experts from across a range of cabin interior stakeholders, reaching out to them with interview requests, and running survey interviews with those who accepted invitations. Survey goals were focused on understanding the wider business perspective of the core cabin stakeholders and how they interact with others across the cabin interior life cycle. The interviews included an element of knowledge verification whereby the inferences made from the literature review were tested with the experts interviewed. This has helped to identify the strengths, weaknesses, connections, and gaps in the knowledge base being built, and adjust the way it is modelled using MCDA tools. A total of 30+ experts were interviewed in the course of conducting the research work presented.

Expert interviews were only conducted to inform the derivation of HCCA and not for MCDA taxonomy since it is a lower-level enabler that also benefits from a rich bibliography available. Once the literature-based body of knowledge was fulfilled, tested, and extended with help from industry experts, it was validated using a hypothetical case focused on a high-priority driver used as an example.

1.2.2.3 Case-Based Validation

Choosing a validation method for HCCA serves two major purposes:

- i. To demonstrate how the user can apply it to inform the organisation of deeper-level cabin interior design work by following the sequence of priorities outlined. This is particularly valuable for the design drivers assessed on a continuous scale (e.g., passenger experience, physical properties, or cabin sustainability) as opposed to binary “yes/no” drivers (such as airworthiness compliance).
- ii. In providing a representative example framework application, to also address reasonably the most challenging issue faced by the modern cabin interiors industry by assessing cabin sustainability and identifying its improvement priorities. Sustainability is not the only challenge involved in cabin design, and also not the top priority identified in the map of cabin design drivers that

constitutes the associated framework. However, its novelty complicates the solution by the absence of a robust knowledge basis, effective previous solution examples, or any substantial opinions in the industry.

Any driver presented requires expansive and detailed effort to inform a justified evaluation of potential cabin solution performance against multiple assessment criteria related to each driver. Some of it is highly analytical (like the assessment of cabin sustainable quality, passenger satisfaction, and commercial viability) and likely requires a separate, lower-level framework built upon the principles aligned with the top-level framework (i.e. an MCDA-based assessment of multiple views to prioritise the solutions). Other drivers, although requiring a considerable amount of work to evaluate, may involve less analytical work and more of a synthetic kind, like engineering or laboratory testing. This kind of work enjoys a well-developed selection of existing knowledge and methods, and it is thus less able to offer a useful challenge to demonstrate cascaded HCCA application.

1.3 Research Outcomes

This thesis demonstrates that MCDA methods offer a suitable alternative to the MDO-based approach for cabin interior conceptualisation. The MCDA-based mentality is aligned with the true nature of passenger cabin interiors as a mixed industrial-commercial product. HCCA features 3 main pillars described below.

1.3.1 Cabin Conceptualisation Toolset

HCCA is implemented as an MS Excel-based toolset consisting of 3 major blocks presented in the chapters below, as informed and enabled by the literature review presented in Section 2.

1.3.1.1 A Taxonomy of MADM Methods

A total of 300 MADM methods were identified with no suitable system available for distinguishing and selecting the most suitable among them to address the problem at hand. The review of numerous pre-existing MCDA selection frameworks and their application attempts have proven them ineffective in distinguishing among the 300 MADM methods identified due to offering either too superficial or excessively detailed refinement level. A synoptic review of the MADM methods available was performed to devise a balanced system for their characterisation. The resulting taxonomy is available in [20] and presented in Section 3, enabling the identification of methods suitable for use with HCCA.

1.3.1.2 Cabin Conceptualisation Framework

The HCCA itself constitutes a holistic source outlining all stakeholders involved in a cabin life cycle and mapping their relevant design drivers and interfaces. It is implemented as a tool-based framework that uses MCDA to model stakeholder priorities and interfaces as assessment criteria with importance weights and processes the related performance evaluations to prioritise potential solutions. The HCCA body is available in [21], with its development process presented in detail in Section 4.

1.3.1.3 Cabin Sustainability Assessment Framework

Addressing sustainability is a key cabin interior design challenge nowadays and thus, was used as a valuable application example to validate the coherence, functionality, and relevance of HCCA. Dummy product data for a hypothetical sustainability assessment case was inspired by the FlyZero Sustainable Cabin project [6] to substantiate the development of the new framework titled SSAPTI (Synergistic Sustainability Assessment of Passenger Transport Interiors). It combines LCA (Life Cycle Assessment) and MCDA to assess the sustainable quality of existing or potential cabin products when designing a sustainable cabin interior. SSAPTI is described in Section 5 and demonstrated in [22].

1.3.2 Intended Benefits

The benefits delivered by HCCA are enabled by 4 distinct areas of potential application (using both the combined capability of the 3 blocks applied together and on their own in isolation). These are most suitable for products at TRL (Technology Readiness Level) 1 – 4 [23]; each application area is associated with a range of beneficiaries served.

1.3.2.1 Industrial Applications

The primary HCCA application target is to enable, improve, and streamline the early-stage concept development process in the cabin interiors industry. It may be used at any product level: individual cabin products, element sets associated with particular cabin zones, or whole cabins. It may also be used for any task requiring product conceptualisation: new product design, evolution of an existing product version, derivation of a new product by combining and/or optimising from several existing functions, deriving a version of an existing cabin product for a particular destination, and others.

The scope of potential HCCA users spans a broad range of industry experts and professionals from the cabin supply chain (OEMs) whose benefits depend on the product designed. For a designer, the HCCA application facilitates holistic product qualities by guiding their work, the scope of considerations addressed, and interactions with others within and outside of their function. Product managers and division heads may use HCCA themselves or via the PMO (Project Management Office) to organise major cabin interior projects, define project scope, and sequence the associated activities. The core benefit is offered by HCCA when used as a holistic process guide and knowledge management framework, which is a capability currently unavailable in the industry.

1.3.2.2 Academic Applications

HCCA use in the academic environment may serve R&D and educational purposes, whether or not concerned with the design of a specific product. Its integral nature offers academic benefits in both combined form and as a set of separate tools as a source of knowledge for a wide range of available MCDA approaches and their application to complex decision problems in product design. Potential applications may exist within or outside of the aerospace domain as discussed in Section 1.3.2.4 below.

The scope of HCCA academic users spans a range of roles across all functional levels, such as whole research teams investigating the variety of potential approaches to conceiving the hypothetical configuration of a future cabin; individual researchers exploring design options for a low-TRL concept of either theoretical or industrial nature; or study programme directors devising student group design projects or building study courses on MCDA, cabin interior design, or sustainability assessment.

1.3.2.3 Strategic Applications

HCCA can motivate, inform, facilitate, and streamline the evolution of aerospace product design best practices by creating its separate branch dedicated to passenger cabin interiors. The fulfilment of capability gaps for the benefit of the whole industry at a national level or higher is normally ensured by strategic institutions placed at the interface between the government, industry, and academia. HCCA's relevance to the work of such strategic organisations is proven by the alignment between the process and purposes of the presented research and that of ATI UK [6] delivered in parallel. The key benefit of HCCA for strategic users is in offering a single source that aggregates a diverse set of factors, considerations, and methods affecting passenger cabin design, presented in a practical format.

1.3.2.4 Non-Target Applications

HCCA is suitable for non-target applications both as a whole and as separate tools. Its assembled capability may help design user spaces outside of the aerospace domain e.g., for mass transport or other interiors. Its separate blocks can be used for purposes other than interior design, for example:

- The MCDA taxonomy can be used by any practitioner in any industry to better understand their DP and select a suitable analytical instrument for any DP that involves discrete solution attributes;
- The core HCCA framework can guide the mapping of stakeholder drivers and processing solution performances for non-aircraft cabins, for aerospace design problems involving qualitative or subjective criteria but not related to cabins, and for uses fully dissociated from cabins or aircraft.
- SSAPTI can be used to assess the sustainable quality of complex multi-material arrangements and prioritise the specific areas for improvement. This may or may not involve any kind of passenger cabins or aerospace technology, and may apply as a separate prioritisation initiative or as a target-setting and scoping exercise preceding a formal LCA study.

Ultimately, HCCA has a vast potential for applications within and outside of the aerospace domain, and in topics that may or may not involve user spaces. The range of its potential applications is limited by matching the available budget against the effort required to adapt and re-target the constituent tools.

1.4 Research Scope and Structure

Presented below is the scope covered by the delivered research work and the structure of this thesis.

1.4.1 Research Scope

The delivered research is associated with scope boundaries limiting the selection of considered product development phases (with related terminology specifications) and aircraft components affected.

1.4.1.1 Product Development Phase

By formal terminology definitions, product concept design is concerned with gathering a wide selection of relevant conditions imposed upon the desired product by the many stakeholders involved across its life cycle and translating it into a coherent product specification. Product engineering entails the development of a physical or digital product (including the operational processes involved) to satisfy all requirements outlined in the associated specification. Its verification is concerned with the legal requirement to prove product compliance to specified requirements by analytical or experimental means, which is protected by contracts and regulations.

Using this terminology, an industrial product is primarily delivered by engineering activities to perform a function. For example, an airframe or a space launch vehicle must deliver their function safely even if this requires an aesthetical sacrifice. A commercial or consumer product is delivered by both design and engineering activities combined to different extents depending on the specific product nature. Some products are associated with a complex design function to satisfy the intricate needs of multiple stakeholders while only involving a simple manufacturing process and thus, are design-heavy.

In relation to [7], HCCA primarily addresses the Concept Development phase with some overlap with the Function, Architecture, and Design elements of the Product Development phase. Concept Development focuses on research and preliminary design to determine the overall configuration, architecture, intended operational parameters, and technology content of a product. It precedes the Development Phase preoccupied with detail engineering and specifying product build, test, and operational inputs into the Implementation Phase.

HCCA also focuses on cabin interior development as a commercial product (enabled by concept design), which takes place before the detailed design activities (enabled by engineering). Conceptual product design is referred to as “design” or “conceptualisation” further in this text. Also used is the NPD term, which covers the first half of the product supply process i.e., the full scope of the product concept development phase, and a part of the design refinement phase that leads up to its detailed engineering. The adjunct process is NPI (New Product Introduction), which covers product engineering, verification, and EIS (Entry Into Service) activities and is out of the scope of this thesis. Together, NPD and NPI form the NPDI (New Product Development and Introduction) process, which, in similarity to [7], is the standard process for driving commercial product delivery outside of the aerospace domain.

1.4.1.2 Aircraft Cabin Content

This thesis defines passenger cabin interiors as any component directly interfacing with passengers or cabin crew, or having a direct effect on their experience through comfort, services, or perception. These are partially or fully covered by ATA (Air Transport Association) chapters [24] listed in Table 1-1.

The resulting product scope exhibits a high degree of mixing and cannot be attributed to any particular ATA chapter. A single product often links to several ATA chapters e.g., a business-class seat will feature the parts covered by chapters 11-30, 23-30, 24-00, 25-20, 26-00, 33-20, 44-20, and 44-30. This nature of the existing market offering makes it impractical to arrange product scope using the ATA chapters. Instead, existing cabin interior products are categorised into a generic breakdown defined in separation from any specific OEM as presented in Appendix B.1-1. It was derived using the list of current products available on the market and categorised per function and a view from [10].

Table 1-1: ATA chapters in scope of aircraft passenger cabin design

ATA Chapter	Cover	Relevant Content
11-30	Full	Interior placards and markings
21-21	Partial	Ducting related to cabin air vents
23-15	Partial	Satellite communications related to cabin communication
23-30	Full	Passenger address, entertainment & comfort
24-00	Partial	General electrical power systems related to cabin wiring
25 (all)	Full	Equipment and furnishings
26 (all)	Partial	Fire protection related to fire insulation and fire-retardant materials
33-20	Full	Passenger compartment lights
33-30	Full	Cargo and service compartment lights
33-50	Full	Emergency lighting
35 (all)	Full	Oxygen
38 (all)	Full	Water & waste systems
44 (all)	Full	Cabin systems
46-40	Full	Passenger cabin information system
46-50	Partial	Miscellaneous information systems related to IFE and CMS
50-60	Full	Cargo compartment insulation

1.4.2 Thesis Structure

This thesis features 7 sections to deliver a thorough description of HCCA with relevant justification:

- **Section 1**: introduces the presented research thesis by outlining its contents, motivation, and scope.

- **Section 2:** lays out the relevant contents retrieved from the literature review conducted in the scope of research. Section 2.1 is dedicated to MCDA background review, Section 2.2 outlines relevant cabin design considerations, and Section 2.3 presents the basis for cabin sustainability assessment.
- **Section 3:** outlines a synoptic taxonomy of discrete MCDA methods, supported by the original taxonomy file uploaded in [20].
- **Section 4:** presents HCCA and its features, which include a map of design drivers and stakeholders, its detailed assessment criteria, and the tool for processing relevant decision information. The resulting analytical tool is uploaded in [21] as a set of framework screenshots in .pdf format.
- **Section 5:** describes the development and features of a synergistic MCDA-LCA cabin sustainability assessment framework titled SSAPTI, which is uploaded in [22].
- **Section 6:** discusses HCCA value, applications, strengths, limitations, and potential future improvements. Relevant reflections of a similar nature that are specific to each HCCA constituent are discussed in their associated chapters (Sections 3, 4, 5) and are left outside of Section 6 scope.
- **Section 7:** presents the concluding remarks and the potential future work to improve the HCCA.
- **Appendices:** numbered in accordance with relevant chapters, these include the detailed data and considerations relevant to each constituent framework of HCCA to support its practical application or adaptation as required.

The core sections of this thesis are built around the respective framework files created in MS Excel format. The creation of these files was assisted by guidance and advice from several experts who shall be the named co-authors on academic journal submissions planned for further evolutions of the content presented. These experts have supported the preparation of this thesis by providing their opinions, knowledge, and validation of the relevance for the work conducted by the author. All generation activities, outputs, and wording that constitute the present thesis were fully and exclusively prepared by the author with no other direct inputs. This thesis and appendices benefit from the following contributions:

- **Dr. Craig Lawson:** the leading academic supervisor for the research work delivered, offered directional guidance and advice throughout the progress;
- **Prof. Konstantinos Salonitis:** expert advice and validation of approaches considered for Sections 3 and 5;
- **Ben Orson:** expert advice and validation for Sections 4 and 5;
- **Dr. Jacquetta Lee:** expert advice and guidance on approaches for Section 5.

The presentation of a detailed literature review informing HCCA construction follows in Section 2.

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2 LITERATURE REVIEW

This section contains a detailed account of the literature review carried out to enable HCCA conception. It constitutes a comprehensive knowledge base informing HCCA from a wide range of scattered and mostly unrelated sources. The sections below are ordered per HCCA development chronology.

The literature review provided in this section does not include any reflection on how the three frameworks constituting the HCCA enable its combined capability and align with its overall purpose. Instead, their role within HCCA is examined in the related discussion chapters (Sections 3, 4, 5) and the overarching discussion of the proposed methodology (Section 6).

2.1 Multi-Criteria Decision Analysis

This section presents a review of relevant MCDA theory, challenges, existing selection approaches, and their limitations. It drives the derivation of a new taxonomy for its subset of MADM methods in Section 3, whose role is to facilitate the subsequent development of MADM-based HCCA components.

2.1.1 MCDA Taxonomy Motivation

Robust capability for objective decision analysis is an important enabler to making complex decisions in the modern world. It is applied in everyday life [1]; public policy, [2]; finance [3]; management [4]; sustainability [5], healthcare [6], aviation [7], manufacturing [8]; and other practical applications resulting in far-reaching impacts [9]. The branch of science that deals with complex decision-making is known as MCDA (Multi-Criteria Decision Analysis) and is a subset of the Operations Research domain.

The need to carry out a systematic analysis of MCDA methods available is recognised in the OR domain [10]. Effective integration of subjectivity into an objective decision-making process requires that an extensive collection of

existing MCDA methods is viewed holistically by using a formal set of parameters describing their shared principles. The introduction of a synoptic taxonomy for MCDA methods presented in this thesis is conditioned by the breadth of potential applications across multiple industries needing it to prioritise among sets of candidate solutions.

The choice of an MCDA method affects how the DP (Decision Problem) is modelled and analysed [9]. Often driven by DM's (Decision Maker) familiarity with specific methods and an affinity for using them, inappropriate method choice may provoke DP re-structuring to fit with one's preferences [11]. This conflicts with MCDA best practices, whereby an informed DM should explore the widest possible range of relevant methods and select the one most capable of modelling their DP and attitude precisely [12].

The first attempt to hone in on a small set of MCDA methods capable of addressing the DP conditions of cabin interior design involved testing all existing taxonomies identified. All attempts have resulted in either too many methods suggested as potentially suitable without the means to further down-select, or no method suggestions produced at all.

A holistic taxonomy of MCDA methods titled ProBCA (Problem-Based Characterisation Approach) is proposed in [Section 3](#) in response to the issues described above. Its complete version is attached to [Appendix A.1](#) and uploaded in [13] as an MS Excel-based matrix. It aims to enable the widest spectrum of users at different familiarity levels to select a suitable tool for their DP effectively.

2.1.2 Scope of Relevant Methods

Over 400 MCDA methods were reviewed as candidates for enabling the new approach to aircraft cabin design, with 300 methods addressing the ranking DP type selected for the final version of the taxonomy proposed. The multitude of existing MCDA tools stipulates the issue of identifying the most appropriate one for the task faced by the DM, thus inhibiting the benefits of the variety available. Each tool offers distinct powers and limitations, but no method is universally fit

for all DP types [11]. Most methods will produce dissimilar results despite using similar inputs, which include the definition of criteria, their importance weighting, and option evaluations [14]. The scope of included methods was defined by top-down funnelling from the high-level MCDA definitions and guiding considerations:

2.1.2.1 MCDA Method Types

The new taxonomy is aimed at enabling the prioritisation and selection among pre-defined sets of solution options. This task is best served by the application of MADM (Multi-Attribute Decision-Making) methods, a subset of MCDA dedicated to dealing with discrete DP. The other branch of MCDA methods is MODM (Multi-Objective Decision-Making), which helps to design the solutions by adjusting variable parameters along their continuous scales until an optimum (best-fit compromise) solution is obtained.

The precise split between the MADM and MODM definitions is debated among MCDA practitioners. This paper adopts the definition of key terms from [15] to distinguish between the two method types:

- **Criterion** = “a condition or fact used as a standard by which something can be judged or considered”. It measures the contribution of intrinsic system qualities to meeting the goal.
- **Attribute** = “a quality or characteristic that something has”. It is a fixed, measurable, and independent quality that reflects the degree to which a given option satisfies a particular part of the goal.
- **Objective** = “something that you aim to do or achieve”. A statement about the desired state or condition of a system, which can be influenced or controlled by the operator.

Subsequently, “criteria” may address both objectives and attributes depending on the DP nature. The latter two terms are considered mutually exclusive and are used to uniquely identify the DP context. The use of “attributes” defines a discrete DP type, and “objectives” is used with a continuous type. This split was first proposed in [16] and subsequently discussed in many sources from [17] to [18].

For ProBCA, MCDA is viewed as the discipline overarching both MADM and MODM branches. MADM is more popular among audiences outside of the MCDA domain and represented by a larger number of distinct methods due to the lighter nature of mathematical and operational principles used. ProBCA exclusively focuses on the discrete MADM-type methods in alignment with its goal to prioritise among the existing solution options, which are characterised by their intrinsic and uncontrolled performance against a set of fixed attributes. Extended ProBCA applications allow deriving attribute performances for an ideal solution sought where not readily available based on the assessment of existing options.

2.1.2.2 MCDA Problematics

The Discrete MCDA methods are traditionally described by the three key problematics [19]:

- Ranking problematic addresses the need to order the solution options by their contribution to solving the DP i.e., how good of a compromise they offer.
- Sorting problematic is concerned with grouping the solution options into equivalent classes by some pre-defined rules or parameter boundaries.
- The selection problematic aims to select the smallest possible set of suitable solution alternatives that meet the DP conditions based on adherence to some rules or parameter boundaries.

The DP type served by ProBCA is concerned with ordering the available options to allow ranking (see [Section 4](#)). Sorting problematic is irrelevant to the task pursued; besides, a comprehensive outlook on the existing MCDA methods for sorting is already provided in [20]. The selection problematic falls between Ranking and Sorting depending on the method used. Some use outranking to eliminate unsuitable or underperforming options one by one until a set of suitable solutions is identified e.g., ARGUS [21]. ProBCA includes this type of methods due to its ability to produce immeasurable orders that allow several options at the same rank position. Other methods group the solutions into the smallest possible set of priorities; these are excluded from ProBCA as sorting type equivalent.

2.1.2.3 MCDA Process Functions

ProBCA allows distinguishing among the 300 MADM methods identified and categorised by their purpose. The available methods serve different purposes, which may be partial (focus on a particular segment of the MADM process) or full (cover the full start-to-end process). Numerous MCDA process versions have been presented in the past 60 years at various levels of detail, from generic flow descriptions [16] to elaborate instructions for complex DP types [22]. A simplified view of the complete MADM process is motivated by [12] and presented in [Figure 2-1](#), which was used to structure ProBCA:

- **Step 1 (Formulate Options):** explore the scope of solutions available, both known and unknown; formalise into a set of distinct and discrete descriptions.
- **Step 2 (Define criteria):** explore the DP context and goals to define the decision framework by setting criteria, structure, and metrics to best represent stakeholders' attitudes and preferences.
- **Step 3 (Set Criteria Parameters):** codify intrinsic stakeholder attitudes and goals by setting and adjusting criteria parameters (weights, interactions).
- **Step 4 (Rate Option Performances):** explore and reflect on solution option performances using numerical or ordinal expressions against the criteria.
- **Step 5 (Aggregate preferences):** apply a suitable analytical tool (MADM method) to aggregate the decision information (criteria parameters, option ratings) into an aggregated value for each option.
- **Step 6 (Process outputs):** present the aggregated performances of all options in a comparable form using the selected MADM method and derive the resulting prioritisation (e.g., a ranking).

Each MADM method in ProBCA enables one, several, or all these phases:

- Methods for dealing with criteria definition exclusively, which is the most subjective part of the process and may have a profound effect on its outcome;
- Methods for rating the performance of ill-defined or uncertain alternatives;
- Methods offering aggregation tools to process specific decision information;
- Self-sufficient MADM methods facilitating the execution of most or all of the process phases.

The sequence of steps I / II and III / IV is interchangeable depending on the DP context, stakeholder goals, and available information. Criteria definition occurs first if the DP seeks to identify the set of most suitable solutions to a task. Option performances are rated first in cases when the DM is tasked with prioritising among a set of pre-existing solution alternatives. Solution options may constitute a set of answers available to the DM and could be limited by what is available under current DP conditions. They may be retrieved as a Pareto set of non-dominated alternatives from a preceding MODM activity.

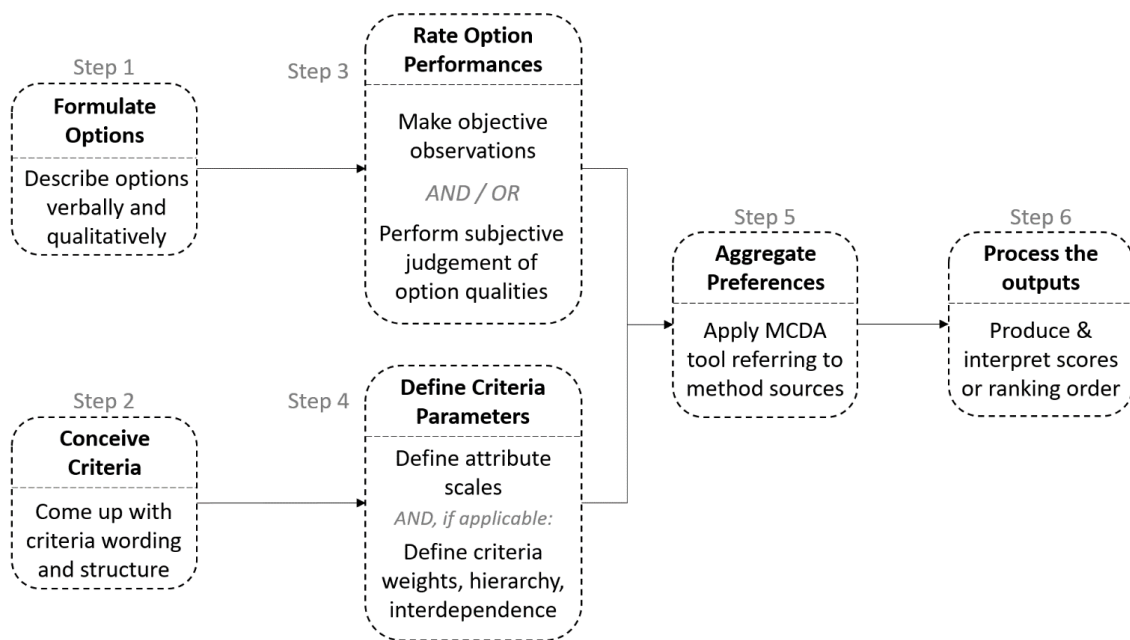


Figure 2-1: Top-Level View of the MADM Process Flow

Some MADM methods fit the purpose of ranking the available options but do not formally belong to the MCDA domain due to originating elsewhere e.g., from the Management Sciences. These typically address a unique challenge, such as Cost-Benefit Analysis used for describing the options with financial and non-financial attributes. Other non-MCDA methods aid criteria definition or options formulation for MCDA. For example, the criteria may be defined using Quality Function Deployment [23] by deriving technical requirements from customer needs; or by SWOT analysis [24]. Despite not originally regarded as part of the MCDA domain, these methods are listed in ProBCA due to their high relevance.

2.1.2.4 MCDA Tool Types

Each MCDA method offers a specific approach to describing the DP, structuring its information, and processing it. In addition, the spectrum of MCDA tools also includes DSS (Decision Support Systems) – software systems incorporating pre-existing MCDA methods into combined toolkits. A DSS may also serve as a software-based embodiment of individual methods, like the ASTRIDA system [25] built from the original method. DSS are intended as an automated, user-friendly implementation of such methods that may be challenging for an inexperienced practitioner to understand and use in their original form. They may also serve specific DP contexts e.g., ARGOS [26] implements ELECTRE and PROMETHEE methods for GDM (Group Decision-Making) contexts. ProBCA includes the original MADM methods disregarding the existence of its software implementation; but excludes the DSS toolkits themselves.

2.1.3 MCDA Selection Frameworks

Numerous taxonomies have been developed attempting to codify the available MCDA methods and tools. These typically consist of a collection assessed by the authors, which may include all methods they know or a limited selection relevant to their specific field of work; and a selection approach to distinguish between the included set of methods using some common characterising parameters.

A total of 20 existing taxonomies, collections, and selection frameworks were studied in detail to identify a suitable approach to selecting the best MCDA tool for aircraft cabin design. The review focus has spanned from the earliest [27] to the most recent [22] versions offered. In addition, multiple textbooks, discussion papers, technical reports, and manuals discussing the intricacies of MCDA application were reviewed, such as: [9], [28], [29], [30] to name a few. Nevertheless, this effort did not allow deriving a streamlined approach to selecting a suitable MCDA tool for cabin design. The reviewed taxonomies exhibit significant variety in the extent of methods covered and characterisation depths, specifically:

- **Sufficiency:** [11], [14], [19], [31], [32], [33], [34] are unable to characterise among the 300 methods;
- **Complexity:** [22] & [35] require advanced knowledge of MCDA principles and application specifics;
- **Capability:** [36] are descriptive collections listing the methods without selecting among them;
- **Actuality:** [27] and [37] were compiled before most of the current methods have been introduced;
- **Applicability:** [38], [39], [40], [41], [42], [43] collections only serve a specific function or industry;
- **Problematic:** [20] and [44] discuss the methods for sorting DP type, which is irrelevant to this study.

Observations made from scrutinising the existing taxonomies are reinforced and extended by MCDA theory textbooks, discussion papers, technical reports, and practice manuals. Although not constituting standalone taxonomies, these have informed the understanding of method differences. Furthermore, most original MCDA method sources offer brief overviews of the related tools and their unique characteristics. These primarily serve to justify the introduction of new tools by the authors (e.g., the ARAS method [45]). This section excludes their detailed account since their relevant features informing the derivation of ProBCA are reviewed in [Section 3.1](#); method references available in [Appendix A.1-3](#).

2.1.4 Available MADM Methods

The complete list of MADM methods is presented in [Appendix A.1-3](#) with more detailed information on each method provided in [Appendix A.1-1](#). The ongoing expansion and rising popularity of the MADM sub-domain are illustrated in [Figure 2-2](#), which groups the methods collected in ProBCA by their introduction year. It shows a predominantly growing trend in the number of new methods proposed over the past 80 years. Irregularity in this growing trend between 1990 and 2010 could be related to a significant shift in the focus of research activities towards

the AI (Artificial Intelligence) domain. It has been developing rapidly over a similar timeframe and continues to date, possibly catalysed by the advent of modern computing technologies. Discrete MCDA methods, however, promise fruitful AI co-implementation potential enabling powerful decision-making and human interaction capabilities across industries industry. This could explain the recovery in the rate of new MADM method introductions after 2010.

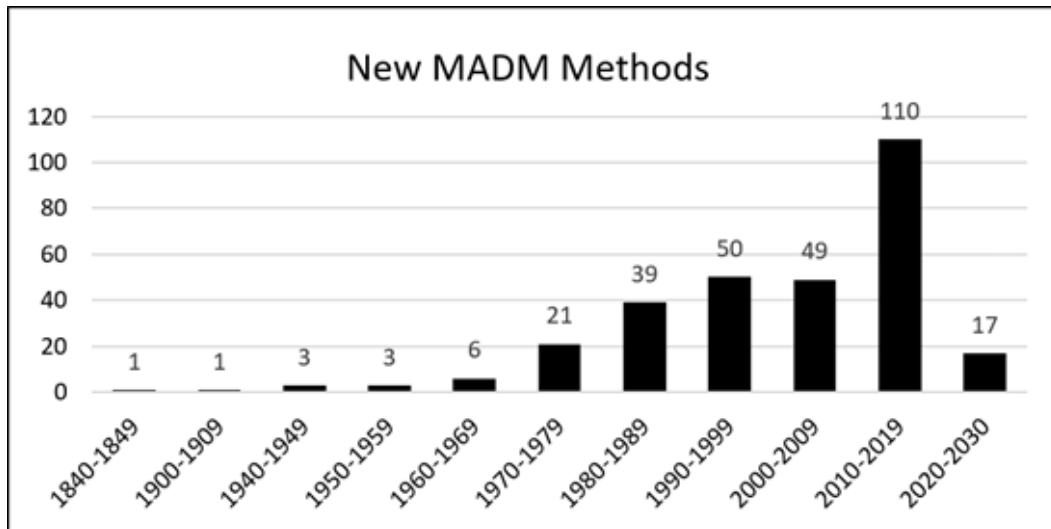


Figure 2-2: Introduction trends for new MADM methods over time

2.2 Aircraft Passenger Cabin Design

This section presents the background to building the core HCCA component by describing the context for passenger cabin interior design as a DP. It assembles the many facts and considerations relevant to cabin design; and defines the boundaries of available knowledge to inform an effective expert survey.

The literature review on the principles of cabin interior design and the context of the associated industrial projects has covered the following source types, which offer varying relevance:

- Engineering design textbooks addressing the design of the whole aircraft ([46], [47]) or its systems [48], as well as the analytical methods employed for this purpose ([49], [50]);

- Textbooks solely dedicated to discussing the specific aspects of aircraft passenger cabin design and operations, such as comfort and ergonomics [51], safety and human factors [52], and history [53];
- Aerospace design standards on both generic processes [54] and cabin-specific project setups [55];
- Academic journal publications addressing various topics affecting passenger cabin design, airline operations, service quality, passenger experience and satisfaction, loyalty and willingness to pay, etc. (the related references are provided as appropriate further in this chapter and [Section 4](#));
- Industry and trade publications, such as the Aircraft Interiors International magazine issues [56], Airline Interiors Expo [57] show features and interviews;
- Cabin interior stakeholder websites describing the specific cabin solutions, products, whole cabin concepts and configurations, and relevant market and industry insights.

The reviewed literature was not identified to provide any comprehensive instruction on how to design aircraft cabin interiors. Engineering textbooks tend to separate the technical perspective from the commercial aspect. Journal publications are focused discretely on e.g.: passenger satisfaction, comfort, air conditioning, airline operations, etc. This fragmented nature of the available literature serves an observatory purpose and not a prescriptive one for identifying the holistic principles for cabin design.

2.2.1 Cabin NPD Evolution Impetus

The aircraft cabin interiors serve as the interface between passengers and the airline by defining the physical, mental, and social aspects of the passenger experience in flight and beyond. Its design drives passenger demand, thereby contributing significantly to the commercial success of a diverse set of stakeholders involved. Aircraft cabin interiors are updated through NPDI managed by cabin integrator.

Shareholder value growth is conditioned by the effectiveness of adopted NPD processes in the cabin interiors industry. Traditionally, cabin product evolution is based on incremental improvements where every stakeholder pursues their own set of goals that are often conflicting. The current NPD practices described in [55] do not excite holistic collaboration in an industry suffering from weak stakeholder integration and instead growing through one-to-one relationships. This obstructs the introduction of design thinking practices [58] for better process efficiency and effectiveness, but could be solved by adopting holistic NPD practices inspired by [59] & [60]. Additional factors motivating the introduction of such practices include ever-accelerating technology development, shifting passenger expectations, and increasing pressure due to societal and regulatory expectations. The development, qualification, and introduction of disruptive technology in passenger cabins necessitate an evolution in its standard.

Optimising the progression of cabin product maturity among the many stakeholders contributing to or affected by it requires sequencing their engagement strategically during the interior development project. The HCCA is introduced in this thesis to facilitate this, inspired by the breakthrough innovation method for conceiving fundamental system changes in the absence of previous similar iterations [60]. The approach adopted ensures that no party is neglected, each player knows their project interfaces, and all interactions are initiated at the right time. Better alignment between project parties at its early stages prevents repetitive errors, minimises the certification approval test iterations, and helps the airline to adapt its business model well in advance of a radically new product being introduced [61].

The HCCA serves to enable such a streamlined cabin product NPD process by offering a framework that accounts for a range of factors characterising the related operating environment for the cabin:

2.2.1.1 Technological Innovation

Aircraft interiors evolve by incremental optimisation [62] to reduce weight, expand capacity, satisfy passengers, or achieve other effects. Innovation in aviation technology, regulations, and business pursues several predominant values where efficiency, differentiation, and sustainability are the top 3 [63]. Genuine cabin disruption occurs in multi-year cycles, often leaving a significant gap between cabin standard and passengers' ever-accelerating expectations for the available technical capability [64].

The growing diversity of the traveller population further complicates cabin innovation, rendering the "one size fits all" mindset ineffective. Passengers yearn for smart customisation, which means re-segmenting the airline offer per user type in line with user preferences, needs, and expectations [65].

These circumstances drive cabin innovation to achieve a deeper level of differentiation by balancing complexity against commonality. A good, but easily repeatable solution becomes widespread and loses its differentiating effect. Smart innovation enables a unique, customisable, yet irreplicable offer that resonates with the fluid preferences of the re-segmented market. Recent concepts reflect this by focusing on reconfiguration and modularity e.g., Airbus Transpose [66] or Aim Altitude Ultraflex [67].

2.2.1.2 Product Specification Flexibility

Cabin mock-up inspection by the customer often leads to late specification changes, causing major project inefficiencies. These are stipulated by the cabin development cycles taking longer than the evolution in passenger trends and preferences. The impact of specification changes on product delivery is often underestimated: concepts must be re-designed and mock-ups updated; the supply chain has to adjust to the revised provisioning needs; certification test scope and schedule need updating; eventually, production delays incur budget overruns and sustainability impacts for all. These situations are rooted in a lack of stakeholder understanding about each other's needs, drivers, and constraints.

2.2.1.3 Ancillary Revenues

Shifting passenger satisfaction needs means that LCC (Low-Cost Carriers) can no longer use discounting as the single competitive advantage lever. Travellers demand tangibles, aesthetics, in-flight services, on-time performance, and more [68]. Ancillary revenues form a significant part of airline profits [69], forcing the operators to unbundle, diversify, and renew their services and products [70].

The perception of one's in-flight experience accumulates over the whole journey [71], affecting overall passenger satisfaction, willingness to pay [72], and loyalty [73]. A failure to cater for this cumulative effect may damage the carrier's image [74], with potential consequences as severe as route suspension [75]. On the contrary, passenger satisfaction yields better service productivity and improves overall airline performance [76]. Non-ticket revenues from customized services help airlines differentiate, serving as a strategic beacon to gaining competitive advantage [77]. The design and content of cabin interiors offer the most effective opportunity for boosting passenger demand by differentiation [73].

2.2.1.4 Economic Efficiency

Recovering airline profitability after major crises is attained by service or product differentiation and business model redefinition [65]. The power of traditional cost optimisation strategies like operational streamlining have plateaued. Passenger services offer a low potential for reducing operational costs once most known improvements are applied [78]. Further operational efficiency improvements and facilitation of new revenue streams are enabled by cabin interior evolution [65].

2.2.1.5 Wider Economic Impacts

The air transport industry reinforces local economic development by involving airports and its wider transport network [79]. Local airlines contribute to regional economy by affecting traffic intensity, providing an impetus for the "Aerotropolis" future urban organisation model [80]. Cabin interiors facilitate this contribution by attracting passenger demand and improving airport utilisation [81].

2.2.1.6 Cabin Sustainability

The sustainability impacts of cabin interior design and operations have varied environmental, economic, and social implications. Environmental protection is among the key corporate social responsibility factors affecting the assessment of airline business performance [82]. Conserving energy and reducing emissions are the most crucial concerns in modern aircraft design [83]. To achieve the 2030 sustainability goals, technology breakthroughs in aircraft design and production processes are required for both existing and future aircraft [84]. Assessing cabin interior sustainability impacts deserves a separate study due to task scale and significant importance for the industry. One of the first studies of this kind conducted specifically within the cabin interiors industry and research domains is presented in Section 5, along with its practical outputs uploaded in [85].

2.2.2 Aircraft Cabin Design Challenges

Air transport is a complex socio-economic system intertwined into a multi-level hierarchy [59] run by multiple stakeholders pursuing their own processes and goals. Their higher-level collaboration is well streamlined and harmonised due to the complexity of technologies involved in the creation of airframe and propulsion technologies. The management of aircraft passenger cabin interior development processes, however, is less rigorous due to a lower level of technological complexity involved thus far. The scope of parties negotiating innovation in it is often incomplete [75], complicated by uncertainties [86] and discrete collaboration characterised by sets of disintegrated one-to-one relationships.

This section describes the existing state of affairs in the cabin interiors industry and presents the principles driving cabin product innovation. The associated knowledge base was compiled through literature review, project workshops, and expert consultations. It was initiated during the FUCAM (Future Cabin for the Asian Market) project led by Airbus Defence and Space GmbH [87], [88]. It was further refined following the delivery of the “UK Cabin Opportunity” [89] and “FlyZero: Sustainable Cabin Design” [90] projects, both run by the ATI UK.

2.2.2.1 Cabin Project Organisation

Aircraft cabin interior development is realised through individual projects covering different product scopes (from lone components to a full cabin) at various scales (from minor product changes to whole new product and configuration concepts). Some terms specific to the aircraft interior projects are clarified in [Table 2-1](#) to benefit a wider range of readers. Some of these terms are overlapping, for example: a completion project on an operational aircraft may be retrofitted whereas cabin interior modification will likely include a refit of some components.

Table 2-1: Common Terminology Used in Aircraft Cabin Interior Projects

Term	Implication
Line-Fit	Fitting cabin equipment into the aircraft at the manufacturer's final assembly line
Completion	Designing & installing custom cabin interior products on a particular aircraft type
Modification	Changing an existing cabin interior at any scale (single placard to complete refit)
Refit	Repeated installation of an existing cabin interior product (partial or complete)
Retrofit	New cabin interior installation (partial or complete) to replace original equipment
Repair	Fixing damage (typically resulting from operations) to existing cabin equipment
Shipset	A complete set of items to be installed on a given aircraft unit ("ship") within a given project e.g., a set of 10 shipsets caters for a fleet of 10 identical aircraft

2.2.2.2 Cabin Project Context

The specific setup adopted for a cabin interior project depends on its context, which is defined by:

- The list of involved stakeholders, which guides relevant commercial and strategy considerations;
- Affected cabin products, which specifies the physical scope of project activities in a cabin;
- Specific project requirements representing stakeholder needs and motivation for new products.

[Section 4](#) offers a generic framework for setting and managing the context of cabin interior projects.

2.2.2.3 Cabin Design Stakeholders

The term “stakeholder” relates to the role performed by a business entity in developing a cabin interior and is separate from the nature of the organisation executing this role. An airframer may have an internal design team to develop cabin interiors for their aircraft so the same entity (a manufacturing company) performs the roles of two functional stakeholders: the airframer and the DA (Design Agency).

Cabin stakeholders may relate to each other as customers, providers, or partners. Their priorities differ and often contradict each other [59], which may depend on the business needs or mutual expectations. Work is driven by the timeframe imposed by the intended EIS (Entry Into Service) date for target aircraft e.g., the first of the fleet [91]. The airline (aircraft operator) collects the core revenue streams from passengers for the entire value chain and is thus perceived to drive the decision-making on cabin projects. Passenger value creation, however, results from the collaborative effort by all stakeholders involved, whose decisions and contributions are all critical for the success of a cabin product [61].

2.2.2.4 Cabin Content Scope

The typical arrangement on a cabin interior project is described in [55] where an airline selects equipment from the CEM's (Cabin Equipment Manufacturer) product catalogue for the airframer to install onto their new aircraft. Most real projects, however, are served by crafting custom setups e.g.:

- The airframer or CEM supply their own design of a cabin interior;
- A DA is appointed to customise existing products from a pre-selected supplier;
- Several suppliers deliver cabin products for the same project with no single leading vendor.

Cabin project scope is defined by listing the specific components it covers, which is normally picked from a pre-existing cabin product breakdown reflected in CEM's catalogue. A generic version of it is presented in the “Cabin Breakdown” sheet in [92] and also presented in [Appendix B.1-1](#) listing the complete range of

cabin content used in the current passenger cabins that is agnostic to any specific CEM's product line. The scope of products offered differs between vendors depending on the nature of their business and is occasionally extended by novel solutions enabled by the new technology.

2.2.2.5 Cabin Project Requirements

Cabin project requirements reflect the specific needs imposed by customer entities on their providers, or the goals identified internally by the manufacturers in line with their product strategy. The requirements are funnelled from multiple sources of different nature, including but not limited to:

- **Project Statement of Requirements:** captures product features requested by the customer or identified internally at the CEM e.g., by formal capture, expert opinion, emails, meetings, etc.
- **Technical Purchase Specification:** imposed by the airframer to ensure compliance with the design envelope provided regarding features, performance, documentation, traceability etc.
- **Maintenance Organisation Exposition:** a subset of requirements addressing the approved maintainability practices e.g. by EASA Part-145 legislation [93].

A small portion of requirements is directly informed by the aircraft certification specification like EASA CS-25 [94]. This diverse set of requirements is usually managed by the responsible cabin integrator and is excluded from this thesis due to its varying nature that depends on the specific product. There is, however, a set of certification requirements that are common for any product designed for cabin implementation – these cover crashworthiness and FST (Fire, Smoke, and Toxicity) product qualities. A prospective assessment of how well a new technology can meet these requirements, what costs the certification process would incur, and a range of other implications constitutes the fulfilment process for Driver 7, Factor “d” when applying HCCA to prioritise the potential cabin product concepts [92].

2.3 Aircraft Passenger Cabin Sustainability

The aviation sector is one of the major contributors to the global effort to improve the sustainability of mass transportation. Ambitious goals were agreed upon by the international aviation organisations for 2050. Its achievement is addressed by breakthrough innovations in aerospace technologies: more efficient propulsion, sustainable aviation fuels, and high-performing bionic structures.

While the technologies used in aircraft propulsion and structures receive the most attention, passenger cabins have been previously overlooked [90]. Despite making roughly 10% of the aircraft's weight, sustainable improvements to cabin interiors other than weight reduction have not been prioritised for several reasons. The primary cabin development focus is aimed at addressing passenger needs [62] by aesthetic and functional product qualities as the key source of value for the entire cabin supply chain. Although essential for commercial success, holistic collaboration towards operational, technological, and sustainable innovation in cabins is challenged by the existing silos and data-sharing practices.

The journey towards more sustainable cabin interiors begins with benchmarking its current quality. To do this, the sustainability of cabin products needs to be assessed holistically across the whole cabin and not at the level of isolated products. The standard approach to doing this is LCA (Life Cycle Assessment), which is ongoing at most major aircraft manufacturers for their cabins internally with no public access to results. Existing academic publications report on full LCA studies of isolated products only. FlyZero project [90] is the first exercise delivered in the public domain covering the whole cabin.

The key challenge encountered when assessing the sustainability of the whole cabin on the FlyZero project was the reluctance of the supply chain to share detailed product data. This aligns with conclusions made from [Section 2.2](#) addressing innovation in cabin interiors and poses the major challenge in delivering a formal LCA of the whole aircraft cabin. Therefore, simplified LCA options were considered to enable a semi-qualitative cabin sustainability evaluation. The MCDA methods were identified as the most potent enabler to cabin LCA based on past examples [95].

The incipient approach to aircraft cabin sustainability assessment on the FlyZero project [90] has evolved into a synergistic framework titled SSAPTI (Synergistic Sustainability Assessment for Passenger Transport Interiors) described in Section 5 and uploaded in [85]. It uses the latest MADM method selection capabilities embodied by ProBCA and introduced in Section 3. The environmental perspective offered by SSAPTI is enriched by the consideration of strategic cabin design drivers systemised in HCCA in Section 4 and uploaded in [92]. This ensures that cabin development informed by SSAPTI aligns with the business environment, stakeholder relations, and preferences prevailing in the industry.

This section justifies the introduction of the novel SSAPTI framework by presenting the current state of cabin sustainability affairs, followed by an outlook on the existing LCA approaches. Its purpose is to motivate SSAPTI creation, which also serves as an example of how the design drivers can be addressed at a greater level of rigour when applying HCCA for cabin conceptualisation.

2.3.1 Aircraft Cabin Sustainability

Achieving prosperity by unconstrained consumption of planetary resources has proven unsustainable in the long term, causing persistent extreme weather events, ecosystem damage, and rising global temperature. The environmental impact created by human activities is addressed by the UN SDG (United Nations Sustainable Development Goals) 2030 [96] dedicated to preventing a global climate disaster by 2050 [97].

The aviation sector contributes to achieving the UN SDG primarily by reducing fossil fuel consumption. An action plan [98] was agreed upon by a cohort of international aviation organisations, authorities, and corporations to reverse the environmental impact created by aviation. Tackling the sustainability of cabin interiors grows in criticality as novel airframe, propulsion, and fuel technologies progress [90].

2.3.1.1 Cabin Sustainability Matter

Sustainable aircraft design traditionally aims at improving fuel efficiency through weight reduction [99]. While this remains a priority for aerospace technology development, it is recognised that ambitious emission targets cannot be achieved without utilising smaller improvement opportunities. These include optimised production [100] and product designs using novel materials or configurations [98].

The world's total GHG emissions were roughly 50 Gt in 2019 [101] and may reach 75 Gt by 2060 [102]. Aviation has contributed at least 2% of this in 2019 ([103], [104]), which will double by 2060. Non-operational emissions create an additional 31% of impact above the operational baseline [105] due to supply chain, infrastructure, and EOL (End-of-Life) treatment [106]. Aircraft interiors constitute 10% of this, based on the proportion of its weight in aircraft OEW (Operating Empty Weight) [90]. Thus, the total addition of aircraft cabins to the global GHG impact amounts to 0.262% overall, or 131 Mt/year now and 400 Mt by 2060.

Non-operational emission contributions were 63% for road transport and 155% for rail transport in 2009 [105]. This trend will likely extend into aerospace when sustainable aviation fuels and propulsion technologies enter service [107], increasing the share of the non-operational element. The contribution of cabin interiors to the global climate impact due to aviation may noticeably surge when this happens.

2.3.1.2 Sustainable Cabin Opportunity

Breakthrough innovation in sustainable technology must align with stakeholder value creation [63]. Airlines and aerospace manufacturers shall align their sustainable strategies by defining relevant product KPI (Key Performance Indicators). This could be used by airlines to describe the desired product features and set the expectations for its performance via the RFP (Request For Proposal) process. KPI definition starts with assessing the current product (aircraft, engines, cabins) to measure its sustainable quality, and using it to inform the identification and benchmarking of the product performance sought.

Preliminary aircraft design requirements help major OEM (Original Equipment Manufacturers) develop relevant KPI for their supply chains [106]. Aircraft cabin interiors were not prioritised as a concern until a recent study funded by BEIS [90] discovered the detrimental state of sustainability awareness in the industry. Disintegrated communication and a lack of stakeholder collaboration across the cabin supply chain curbs effective resolution of existing or impending sustainability issues and concerns. The key issue causing this is the reluctance of involved stakeholders to share critical data [90].

Human behaviour is the key sustainability enabler and thus, the attitude of all stakeholders involved shall change [108]. Passengers should demand that service providers implement effective sustainable solutions; airline leadership must seek to operate sustainable aircraft cabins; CEM should invest in making sustainable cabin interiors. The effectiveness of new products must be assessed to enable comparison against the original impacts. An ambiguous sustainability assessment may lead to accepting seemingly effective solutions that cause greater long-term harm than the original products [109]. To avoid this, relevant sustainability targets must be incorporated as an integral part of the design requirements alongside product certification and customer satisfaction.

The primary concern of Airlines and CEM when developing new cabin products is weight reduction and operational improvements, which minimizes project risks and keeps project timescale predictable. Breaking this cycle requires the airlines to include their sustainability KPI in product RFP with support and protection from airframe OEM, regulatory authorities, investors, and international aviation organisations. In response, the CEM need to direct their research and development to revise the regulatory landscape and develop appropriate certification approaches for new technologies that enable sustainable cabin solutions. The mutual prosperity of all stakeholders ultimately depends on passenger demand for sustainable cabins, who also need to be educated about the paths to achieve true sustainability in aircraft cabins (as opposed to its seeming improvements) first of all [90].

Thus far, air travellers lack an understanding of the sustainability implications within the cabin supply chain. For example, CE (Circular Economy), a philosophy concerned with product recycling, is in high demand despite not always offering the most sustainable solutions. Airlines do not control the full life cycle of plastic products and thus, cannot ensure efficient recycling practices. Passengers' relationship with airlines is the key educational lever for affecting mindset changes. Automotive sector experience like [110] or [111] may offer inspiration on how to address the users' sustainability expectations.

2.3.1.3 Circular Cabin Life Cycle

Around 85% of the whole aircraft material is recyclable [103]. Most of the remaining material that is not recycled after aircraft decommissioning is comprised of [112]:

- Products made out of composite materials: CFRP (Carbon Fibre Reinforced Plastics), GFRP (Glass Fibre Reinforced Plastics), NOMEX core (a particular blend of meta-aramid material [113]);
- Cabin products and materials containing fire retardants: cabin carpets, seat cushions, seat covers, cabin linings (sidewall and ceiling panels), insulation blankets, and other polymer components;
- Products that use toxic materials: avionic microprocessors, display screens.

Materials that contain toxic fire-retardant chemicals are not recycled for the safety of potential users, whereas viable recycling of composite materials is not yet achieved with the current level of technology [114]. The only cabin products typically dismantled for partial re-use are the seats, whose fate depends on the specific type, model, IFE (In-Flight Entertainment), or kinematic systems installed. Unrecyclable components are typically incinerated to recover a part of stored energy, or landfilled [112].

The two key sources guiding sustainable aircraft decommissioning are IATA (International Aviation Transport Association) best decommissioning practices [112] experimentally informed by the PAMELA project [115], and best practices

by AFRA (Aircraft Fleet Recycling Association) [116]. Neither of these extends to cabin interiors, with academic publications attempting to address this [117]. Increasing the proportion of cabin interiors recycled remains the last frontier of sustainable aircraft EOL to conquer.

The key issue preventing the consolidation of recycling approaches for most cabin equipment is a lack of adequate legislation controlling the EOL processes for aerospace products [118]. Regional differences lead to inconsistent national regulations and expectations for sustainable aircraft operation and utilisation. A potential solution is to build it upon relevant legislation from other industries, like automotive, maritime, electronic, or chemical. The first hurdle on this path in the interiors industry is to align the current knowledge and priorities among all involved stakeholders. This would enable the integration of considerations for EOL activities and their impacts on preliminary aircraft design [118].

2.3.2 Sustainability Assessment

The standard approach to sustainability assessment accepted by industry and academia is LCA. It evaluates the sustainability of products, services, or processes across their life.

2.3.2.1 Life Cycle Assessment

LCA methodology is formalised in the ISO (International Organization for Standardization) 1404x-series standards, such as ISO 14040 (LCA Principles and Framework [119]) or ISO 14041 (CA Goal and Scope Definition [120]). Numerous regional adaptations exist [121], such as ILCD (International Life Cycle Data system) [122], PEF (Product Environmental Footprint) [123], or OEF (Organisation Environmental Footprint) [124] in the EU (European Union). Another standard practised in some developed countries is PAS (Publicly Available Specification) [125]. It is dedicated to helping organisations measure both direct and indirect GHG emissions on the way to achieving carbon neutrality by 2050, 2060, and 2080.

An LCA study evaluates the environmental impact of a PS (Product System) across all life cycle stages [126]. A life cycle consists of all activities included in its upstream supply chain (raw material extraction, manufacturing, transportation) and downstream value chain (operation, servicing, and disposal) [106]. The main function of LCA is to support decision-making by distinguishing between scientific facts and subjective views, which are used for various purposes depending on context e.g., from [121]:

- Identify product or service hotspots to address by assessing its key sustainability impacts;
- Objectively compare the sustainability of products to avoid misleading reporting (“greenwashing”);
- Verify product compliance with formal sustainability standards against a performance benchmark.

A strategic thinking approach embodied in a set of tools, LCA is an essential but insufficient element of informing sustainable action like technology procurement [126] or system “ecodesign” [127]. An LCA study should be combined with other established strategy and NPDI (New Product Development and Introduction) tools like risk assessment or roadmap development to offer actionable insights.

A detailed outline of a typical LCA workflow and the specific activities that it involves are omitted from this thesis. Numerous sources offering a detailed account of how to design and conduct an LCA study are available besides ISO documentation, such as [126], [127], or [128]. LCA implementation in an industrial setting can be supported by [129] informed by 200+ global industry leaders.

2.3.2.2 LCA Challenges

Real-world LCA application is not free of detriments and inherent capability limitations e.g., from [126]:

- LCA outputs are an indicator and not a complete depiction of truth, it depends heavily on the modelling approach and the specific LCIA (Life Cycle Impact Assessment) method used;
- LCA uses subjective judgement extensively: while the source data stored in LCA databases is based on objective measurements, the case-specific interpretation of LCIA results is inherently subjective;
- LCA reliability depends on data quality: LCA database content itself is not enough to represent a PS in full detail so an accurate model of involved transformational and logistical processes is required.

Setting up a case-specific LCA study shall address these limitations by appropriately defining its goal and scope that accounts for the needs of all stakeholders involved in upstream and downstream PS supply chains [121]. LCA success relies on stakeholder support in providing appropriate data [126].

Another limitation of LCA is the requirement to keep the approach consistent across the whole study while accepting that some components or materials may be better or worse suited for it. For example, the beneficiary of an LCA study (referred to as “user” further in this chapter) may have detailed information about material composition and supply chain processes for some products but not others. A failure to apply the same approach to all study objects may lead to the multi-fold difference between output value scales [130], thus distorting the comparability of LCA results for the different items.

The various limitations and challenges associated with executing an LCA study cannot always be solved effectively due to gaps in the available information or the reluctance of some stakeholders to engage. That has motivated the introduction of Simplified LCA offering adaptability to various real conditions.

2.3.2.3 Simplified LCA

Generally, an LCA study must follow a recognised, standard process like ISO guidelines, and is an elaborate exercise requiring considerable temporal and financial resources pulled both from the user and their partnering stakeholders

involved in the PS supply chain. The idea of a streamlined, or simplified LCA was first introduced in [131] to counter this requirement and expand LCA applicability. Several LCA simplification levels exist, tailored for handling the different project conditions [125]:

- **Formal LCA:** requires detailed data in absolute terms to validate decision-making and policymaking;
- **Simplified LCA:** a comprehensive screening assessment that covers a complete PS life cycle at a superficial level of detail using a mixture of generic qualitative and quantitative data;
- **Conceptual LCA:** a qualitative assessment in relative terms to help identify the overall strategy.

A simplified LCA study is typically designed by tailoring the definition of its goals and scope for reduced complexity while keeping sufficient relevance and reliability, which is driven by two conditions [126]:

- The specific study is associated with limitations preventing its full-scope delivery (e.g., limited resources or data, uncollaborative stakeholders), and
- Case-specific conditions allow the acceptance of an incomplete LCA scope (e.g., the task is a conceptual study to inform the definition of a full-scope LCA study that follows).

Simplified LCA uses generic assumptions and replaces the absolute data with relative estimations where necessary. It serves to reveal the key hotspots or issues among the different life cycle stages, products, or IC (Impact Categories) to inform user priorities. It also offers the capability to validate the reliability of results, given that assumptions and evaluations made are tracked appropriately.

One of the key benefits of using a simplified LCA is minimising the cost and time of a sustainability assessment task while achieving a sufficient level of quality for the purpose [127]. This is not always an optional feature: in some cases, a full LCA study would consume an amount of time and finance at a scale beyond the user's budgetary limitations. This, for example, is the case with aircraft cabin

interiors, where projects are constrained on both resource types while the diversity of products is extensive.

Tailoring a simplified LCA approach to the given case often requires the application of tools originating from outside the formal LCA methodology remits. A popular tool for creating bespoke LCA frameworks is MCDA [95], which has proven effective in enabling partial LCA implementation.

2.3.3 MCDA and LCA

MCDA is a sub-domain of Operations Research that combines analytical tools, behavioural economy principles, and systems thinking for modelling complex problems to inform the user's decision-making.

2.3.3.1 MCDA Capabilities

The consideration of MCDA methods for SSAPTI application is limited to its MADM branch since the task of cabin interiors LCA involves the review and assessment of existing products or technology candidates whose performance and attributes, like density or material composition, are pre-defined.

2.3.3.2 MCDA in LCA

The MCDA tools are effectively used for simplified LCA applications offering the basis for case-specific assessment frameworks. MCDA guides the collection of LCA-related information, allows the integration of subjective considerations like varying stakeholder competence and data quality confidence levels, and provides the mathematical means for aggregating the different data types involved. Integrating LCA with MCDA was first proposed in [132] and later applied at every LCA process step [133]. Previous examples of integrating the sustainability assessment with MCDA capabilities include:

- The derivation of relative IC importance weights using open-source information [134];
- An assessment of multi-stakeholder contribution to the corporate-social airline performance [82];
- Integrating MCDA, LCA, and Risk Assessment to counter the emerging environmental threats due to new technology development [135].

MCDA is used with LCA in two general setups [133], with the latter one applicable to the current study:

- MCDA-centric: uses LCA to evaluate the environmental factor among others within an overarching MCDA process;
- LCA-centric: uses MCDA to aggregate and help the interpretation of results in the scope of an overarching LCA process.

The few past examples addressing the sustainability of aircraft cabins were all performed as full LCA studies addressing the selected components in isolation ([136], [137], [138]). An MCDA-LCA synergy improves the usability of LCA principles [139] for delivering a simplified sustainability assessment of the whole cabin due to the complementary characteristics shared by both methodologies [133], thus offering a suitable basis for SSAPTI development.

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3 A SYNOPTIC TAXONOMY OF DISCRETE MCDA METHODS FOR RANKING

The application of MCDA methods spans a wide variety of modern decision situations. These are associated with conflicting DM opinions, driving values, differing criteria importance, and contrasting performance of the solution alternatives. The DM lacking thorough academic knowledge in the MCDA domain is unable to appreciate the breadth of methods available and choose the most suitable one for the DP they are facing. This section presents a new taxonomy of discrete MCDA methods for ranking titled ProBCA presented in [Appendix A.1](#) and uploaded in [1] to enable efficient selection of methods appropriate for the DP at hand. In contrast with other MCDA taxonomies, ProBCA is based on the problem-centric philosophy. It is presented in an easily comprehensible format that makes it practical for the widest spectrum of potential users and tasks. ProBCA features a collection of MADM 300 methods dedicated to 3 purposes: formulate the solution alternatives, define relevant criteria, and aggregate the decision information to rank the pre-defined alternatives. ProBCA is applied by filtering for appropriate problem descriptors grouped into 17 pre-defined parameters to reveal the most suitable methods for ordering options by merit. The introduction of ProBCA seeks to popularise the use of MADM methods across various industries and operational levels by guiding the users through problem characterisation.

ProBCA serves as a functional enabler for HCCA in the broader context of this thesis. User-centric future cabins shall offer value to all stakeholders by satisfying multiple viewpoints and conflicting objectives within narrow time and resource constraints. A novel methodology for passenger cabin concept design, HCCA requires prioritising among the most viable cabin product and technology options. Its reliance on MADM capabilities allows a wide spectrum of potential users to effectively address such a complex DP. This is achieved through a sequential process that includes ProBCA application at several stages to identify the MADM methods most appropriate for modelling the context of specific cabin design DP.

This section describes how ProBCA was developed and discusses its benefits to close the capability gap discussed in [Section 2.1](#). It addresses the lack of a taxonomy that would offer sufficient discernment for the 300 MADM methods it contains. Inspired by [2] in its design, ProBCA acts as a user-friendly and intelligible guide through the decision process for any DM disregarding their level of MCDA expertise. ProBCA is industry-agnostic and serves prioritisation and selection decision-making at any functional level. [Section 3.2](#) describes the collection of methods it lists and [Section 3.3](#) outlines the system for their characterisation. [Section 3.4](#) discusses ProBCA uses, benefits, and limitations in relation to the literature reviewed, with [Section 3.5](#) offering concluding suggestions for further work.

3.1 Taxonomy Development Process

ProBCA was developed in iterations as a response to the observations presented in [Section 2.1](#):

- i. Existing MCDA taxonomies, selection approaches, comparisons, and method collections were investigated to retrieve the parameters used to distinguish among the methods they cover;
- ii. All parameters used in the identified publications were gathered into a single table and sorted by function, context, or purpose;
- iii. The considered approaches to method characterisation were compared by identifying their similar and unique parameters;
- iv. Multiple parameter sorting and regrouping iterations enabled the identification of underlying philosophies used in existing taxonomies, with method-centric characterisation surfacing as the predominant MCDA selection philosophy even for taxonomies that appear highly dissimilar;
- v. Problem-centric philosophy was adopted as the guiding principle for defining characterisation parameters to ensure a practical taxonomy, disregarding whether these are newly introduced or inspired by a multitude of descriptors used in existing taxonomies;

- vi. Method characterisation was performed in stages starting with well-known method families, then well-known individual methods, and eventually the lesser-known methods;
- vii. Progressive characterisation has enabled refinement and reselection of suitable characterising parameters until the final version was achieved after over 50 iterations.

A deeper look at the challenges associated with using the existing taxonomies is offered by an outline of key MCDA differentiation aspects impacting the ProBCA structure, as presented below.

3.1.1 Characterisation Refinement

A taxonomy is a collection of individual items distinguished using some common parameters. In an MCDA taxonomy, these may include problematic, aggregation approach, criteria type and hierarchy, software availability, and many more. Some collections are dedicated to a specific cause and use up to 10 parameters relevant to their case e.g., MCDA in economics [3]. While easy to understand, these are ineffective in characterising the full variety of MCDA methods existing. The more sophisticated taxonomies like [4] or [5] are developed to considerable depth and breadth, offering a multi-level hierarchy of the descriptive parameters. Nevertheless, these have also proven ineffective in offering a unique distinction among the 300 methods recorded in ProBCA. For example, [4] uses 63 possible values under 14 parameters, as opposed to 66 values under 17 parameters used in ProBCA. Despite a similar number of descriptor values used in such comprehensive taxonomies, their breakdown does not offer sufficient refinement to enable the unique discernment of over 100 methods.

ProBCA philosophy aims to strike a balance between depth and intelligibility for improved applicability. It includes a sufficient number of parameters to distinguish among the 300 methods covered, while also making it as simple as possible for the broad spectrum of users to apply for method selection.

3.1.2 Parameter Originality

Some taxonomies like [6] or [5] represent original developments. Others compile the relevant parameters from pre-existing versions e.g., [7] uses 9 frameworks to improve their distinction function. ProBCA combines both architectures: existing selection approaches were reviewed to identify the complete scope of parameters previously used and then refine them for improved effectiveness:

- Some ProBCA parameters are directly borrowed from other methods e.g., “Resource Needed” [8];
- Some ProBCA parameters are combined from several other characteristics observed elsewhere to represent their overarching idea e.g., “Ambiguity Presence” is driven by [9], [10], and [11];
- Some ProBCA parameters are indirectly inspired by multiple conclusions made from reviewing the existing MCDA taxonomies and theory sources e.g., “Weighting Basis”;
- Some parameters used elsewhere misalign with ProBCA philosophy e.g., software availability [7] and were thus excluded from the new taxonomy despite appearing in most existing alternatives.

Most ProBCA parameters use the original descriptor values defined and justified in [Appendix A.1-2](#) (“Characterising Parameters” sheet in [1]). This section omits the detailed outline of sources used to define each parameter but some are presented within parameter definitions where applicable.

3.1.3 Parameter Objectivity

Some practitioners recommend involving subjective DM preferences in selecting an MCDA method i.e., considering one’s familiarity, affinity, or capability [12]. Others disagree, arguing that method selection should be exclusively objective and suited to the problem at hand and not the DM’s preferences [11]. ProBCA embraces the latter mindset by only involving objective selection parameters.

3.1.4 Custom Taxonomies

While most MCDA taxonomies are made generic to stay relevant across a wide range of applications, some method reviews are dedicated to specific industries e.g.: portfolio management [11], chemical engineering [13], offshore wind turbines [14], or criteria weighting in healthcare context [8]. Some collections address individual MCDA process steps, for example: [15] and [12] distinguish among the DSS but not the individual MCDA methods; [16] helps to select criteria weighting approaches; [5] addresses the selection of an aggregation procedure for discrete DP types. These customised collections may benefit the teams dealing with specific problems, but omit the instructions on how to distinguish among the many MCDA methods. Although ProBCA is motivated by a specific problem, it retains generic applicability in isolation from any particular DP context within ranking problematic.

3.1.5 Method coverage

The largest collection of MCDA methods to date covers 205 individual methods across different problematics [17], while most available taxonomies include less than 100 methods. In similarity to the encompassing applicability of the taxonomy presented in [6], ProBCA is developed to be effectively applicable for any MADM ranking method, existing or future, even if not covered in its original version.

3.1.6 Characterisation Basis

Most existing taxonomies are based on MCDA method qualities and capabilities. This opposes the motivation for MCDA domain existence, where the DP context drives the rules for method application [18]. Ideally, the selection of an MCDA method should align with the DP context rather than focus on method specifics [10]. The logical basis of ProBCA challenges the traditional method-centric characterisation philosophy by adopting a problem-oriented mindset, thus

inspiring the “Problem-Based” part of its name. This aligns with [4] and [19] both using method and problem descriptor sets.

3.1.7 MCDA Comprehension Challenges

Several MCDA caveats cause significant challenges for non-expert practitioners to grasp its core principles. These were experienced by the authors and later confirmed through literature review and open-source research of informal sources like online user forums.

i. Discrete-Continuous Overlaps:

Sometimes, mathematical optimisation tools typical for MODM methods are applied to assess discrete options. For example, MCVM in [20] technically belongs to both MADM & MODM. Such methods are included in the ProBCA collection since they are dedicated to ranking a set of discrete solution options.

ii. Available literature:

A very large volume of literature is available within the MCDA domain, covering a variety of its narrow aspects at great depths. Different sources use their preferred terminology, classification parameters, and structuring of the involved process steps. No sources were found offering a universally accepted approach to systemising all MCDA methods into a single set. Multiple organizations and institutions explore the frontiers of MCDA practices, but the diversity of their research topics hinders blending the different MCDA work streams into a unified domain [4]. ProBCA attempts to offer a single reference for codifying all identifiable MADM methods for ranking, although it may omit some rarer ones.

iii. Delivery Style:

Simplicity is an important quality for a taxonomy to be intelligible for the widest possible range of users. In many cases, comprehension of the MCDA theory or method application specifics is perplexed by the complicated delivery style of its key sources [11]. This limits the capability of those DMs who lack expert familiarity with MCDA terminology or are unaware of the suitable methods for their DP.

ProBCA adopts a common language where possible to simplify the understanding of MCDA terminology. This mindset is aligned with some selection frameworks existing like [11] or [7], which are presented in a language accessible to readers with limited prior experience in the MCDA domain.

3.1.8 Terminology

The many MCDA references reviewed during ProBCA creation vary significantly in their terminology. Oftentimes, this implies interchangeable or confusing use of the terms involved, for example:

- The same term may imply different meanings: "weights" usually refer to the measure of relative criteria importance. However, some sources like [21] use it to describe the contribution of a hypothetical "reference" alternative to evaluating the performance of the real ones.
- Different terms may imply the same meaning: the terms "rating", "scores", and "performance values" all represent how well the solution alternatives perform against their related criteria.
- Similar names: ARGUS method [22] and ARGOS DSS [23] are deliberately used in [Section 2.1](#) to highlight the issue of similar naming. An unaware reader may confuse the two or perceive it as a typing error, reinforcing the challenge of understanding the theory and scope of available methods.

Partial glossaries of MCDA terms are offered in multiple recognized sources like [24] or [25]. However, no formalized agreement on a consistent set of MCDA terminology exists [26]. This paper does not attempt to correct the state of affairs with terminology formalisation, nor it is intended to be the single, commonly accepted source of MCDA terms. The selection of ProBCA language serves convenience and best-fit with its purpose to offer an intelligible taxonomy that appeals to the widest range of users. Three terminology issues, however, deserve special attention for the reader's benefit:

i. Look-alike Abbreviations:

The MCDA domain has produced a large variety of 3- to 5-letter abbreviations that all start with the letter “M”. These often have equivalent meanings with different spelling, or vice versa. For example, this paper distinguishes between MCDA as the domain and MADM as its discrete branch. However, MCDA is equivalent to Multi-Criteria Decision-Making (MCDM), and MADM is sometimes spelt as Multi-Criteria Decision Analysis (MADA). A list of relevant abbreviations is compiled in [Appendix A.3](#).

ii. Options vs. Alternatives:

This paper accepts the presumption that “solution options” can be co-implemented jointly or applied individually, whereas only one solution has to be chosen from among the “solution alternatives”. Therefore, the term “options” is adopted by ProBCA as the one less restrictive. Options may relate to physical options to rank and choose from, imply non-object actions to take, or generally refer to the possible directions of system state changes addressed by the DP description.

iii. The uses of Objective:

The term “Objective” as a noun refers to the overall DP goal. In MODM tasks, the objective drives the controlled variables towards producing a solution that best satisfies the desired state. In MADM, the objective acts as the beacon for prioritising among a finite set of options based on their fixed attributes.

Some sources misalign with this definition e.g., [27] proposes the AHP (Analytic Hierarchy Process) to optimise the strategic importance of customers and their related risks with reference to [28]. Risk optimization is indeed covered in [28], but the evaluation of customer importance implies ranking the customers based on independent attributes and thus is a discrete DP and not an optimization task.

3.2 Method Collection Process

This chapter describes the process of compiling the collection of MADM methods covered by ProBCA.

3.2.1 MADM Method Sources

The search for MADM methods suitable for inclusion in ProBCA has started by identifying and reviewing the most comprehensive of all sources available, spanning several reference categories:

- Textbooks and thematic paper collections describing the MCDA principles through a presentation of the methods existing, such as [9] or [29];
- MCDA method collections of two kinds:
 - Encompassing collections covering various discriminated tools e.g., [30];
 - Collections dedicated to specific method types e.g., sorting [31], [32];
- MCDA method taxonomies of two kinds:
 - dedicated to distinguishing among the methods serving a fragmentary purpose e.g., criteria weighting [8] or discrete aggregation of scores [5];
 - a large taxonomy featuring a broad selection of complete ranking and sorting methods [17].

Smaller collections restrict the opportunity to find the one most suitable for the DP at hand. In most cases, these repeat a selection of the most well-known methods and omit the rare ones created outside of the MCDA focus areas for dealing with unique tasks e.g., [33] addressing waste management.

3.2.2 Method References

ProBCA provides the references to original method sources on its “References” sheet in [1] by listing the earliest source describing the application of a given method to ranking DP. Some methods are based on mathematical concepts not originally intended for MCDA application; for these, the sources point to the first publication describing it as an MCDA tool and not a mathematical concept.

The majority of recorded methods are served by more than one useful source: an introductory reference is often followed by several publications presenting its practical applications. Newer reports are often built from experience and thus, offer a clearer method description. The original reference may be less elaborate due to serving an introductory function; or could be detailed to the level that makes it challenging to comprehend without significant MCDA expertise. The user shall always review several references beyond their original source to fully understand the method suggested by ProBCA. It is recommended to identify at least one of the following reference types for any method studied:

- **Introduction:** a reference presenting the baseline concept of the method and its core theory;
- **Application:** a reference presenting an example of practical method application to a DP;
- **Discussion:** a reference comparing one method of interest to others to propose its extension or combination with another method, arguing its weaknesses, or offering any other learning basis.

It is advised that any method recommended by ProBCA is studied in detail before DP implementation.

3.2.3 ProBCA Collection

The resulting extent covered by the ProBCA collection features 300 individual methods, of which the full-ranking type generally falls into two categories:

- **Unique methods:** developed as a one-off version and often originate from the working groups who do not focus on MCDA but use it for their specific area of work, such as [33].
- **Method families:** groups of several methods that share some common basis. These are well-known within the MCDA domain, for example: UTA, ELECTRE, or PROMETHEE families [9]. These typically evolve as improvements by incremental evolution of their earlier versions. This

distinction also applies to methods offering compound functionality to MCDA tasks, such as the family of five criteria weighting methods from [34] and [35].

The resulting collection features 300 MADM methods for ranking, of which:

- 226 are full MADM methods offering a complete scoring and ranking capability operating on at least two sets of data (criteria and solution options);
- 57 methods are dedicated to weighting among a single set of options by importance (e.g., criteria weighting, or solution options without criteria) in similarity to the approach in [36];
- 17 methods aid DP definition and structuring by helping to formulate the options or the assessment criteria.

Once the collection of methods and the definition of their characterising parameters for use with ProBCA was completed, these inputs were assembled into a complete taxonomy tool presented below.

3.3 ProBCA Assembly Output

ProBCA is implemented as an MS Excel matrix [1] shown in [Appendix A.1-1](#). The methods it covers are listed in dedicated rows ordered alphabetically as the most effective layout of all tested. Its first 5 columns contain useful method data:

- **Column B:** abbreviation or short code name for user's convenience
- **Column C:** full method name or its appropriate explanation
- **Column D:** the year a method was first introduced as an MCDA tool
- **Column E:** a brief description of the method's function and key differentiating features to aid user's understanding, especially where several similar methods need to be compared for an application
- **Column G:** the count of uniqueness i.e., how many methods in ProBCA have an identical characterisation

The resulting taxonomy structure is presented in [Appendix A.2](#) also indicating how many methods correspond to each descriptor. Methods are characterised by defining DP modelling considerations from the reviewed literature to inform the

selection of the most suitable descriptor value. ProBCA is applied by the opposite process where a DM selects the most relevant descriptor in each parameter to characterise the DP appropriately and reveal a recommendation of the most suitable methods for it.

3.3.1 Overview of ProBCA Parameters

The resulting taxonomy embodies a universal tool for distinguishing among the 300 MADM ranking methods by filtering parameter values. ProBCA parameters were structured in line with the MECE (Mutually Exclusive, Collectively Exhaustive) principle [37]. It implies that each parameter in the list is unique, parameters do not overlap, and the complete set of parameters covers sufficient breadth. In accordance with the MECE principle, some parameters represent a multi-level hierarchy. For example, parameters 2.3 to 2.5 are sub-descriptors to item 2.2 indicating whether criteria weights are used.

Each parameter in the original ProBCA version includes a set of pre-defined values to choose from and no other values may be entered. Some values will automatically follow from the selection in higher-level parameters. For example, if criteria importance (2.2) is “Equivalent” (meaning that criteria weights are not used), subsequent parameters (2.3 to 2.5) must be set to “N/A”.

Some parameter values may appear superficial e.g., “preference thresholds” is binary (“yes” or “no” only) and does not allow specifying threshold types. This reflects a compromise aimed at balancing characterisation depth and taxonomy sophistication to allow the ubiquitous applicability of ProBCA.

A bespoke characterisation system defined for ProBCA differs from the terms used in original method references. The most appropriate method descriptors were defined using the authors’ judgement where necessary. For example, not all methods with “Interacting Criteria” clearly state that there is interaction among the criteria, but the formulae used in it indicate the presence of relevant variables.

The reader may benefit from reviewing additional considerations presented below, which are either related to ProBCA parameters or featured extensively in other taxonomies but omitted from ProBCA:

3.3.1.1 Parameters included in ProBCA

Several additional considerations may help the user's understanding of how to effectively operate ProBCA parameters that differ in their definition from other taxonomies existing:

i. Value Functions:

Value functions are a mathematical representation of attitude, where each shape characteristic models a particular behaviour or value [38]. For example, a convex value function models the case when the DM's preference for lower-performing options is similarly low, but increases significantly with each performance improvement step for the top-50% performing options. A concave function models the opposite: the DM does not mind what option to prefer as long as it scores in the top 50%, but the desire falls as performance reduces. Value functions are often involved in the more complex MCDA methods, enabling the ability to effectively work with refined intricacies of mathematical psychology. These tools require a sufficient understanding of relevant mathematical and decision-making theory from the DM.

ii. Method Complexity:

A rough indication of complexity is among the key MCDA method selection parameters used in many existing taxonomies. Some authors recommend choosing the simplest MCDA method from the several suitable ones to streamline the modelling process [39]. The notion of complexity is often ill-defined and vague and generally reflects the capability of a method to navigate the intricate specifics of a complex DP. Elaborate methods are resource-demanding but offer results that are more refined and less susceptible to bias, which may be critical in some industries [8]. Appropriate method selection should be aligned with the level of analytical depth required for the DP and the resources available to the DM.

ProBCA answers this debate by offering a more objective indicator of method complexity embodied by parameter 1.5 (Resource Requirement). This title indicates the likely resource utilisation consequences due to method application, which is inspired by the "Resource metric" parameter used in [8].

iii. Fuzzy Numbers Format:

FN (Fuzzy Numbers) are used in the MCDA methods to reflect uncertainty. It is represented as an array containing the maximum, minimum, and most likely values to reflect the performance of an option within a given attribute. Graphically, FN share a similar appearance with statistical distributions except:

- The graph features straight lines only
- The graph is built using 3 or 4 values and not a data cloud

FN of two types are distinguished:

- Triangular FN are characterised by min/max boundaries and one vertex (triangle graph);
- Trapezoidal FN feature min/max boundaries and two vertices, with the unknown value having an equal likelihood of taking any position between the vertices (trapezoid graph).

The inclined part of the graph between one extreme and its nearest vertex reflects the increasing likelihood for the variable to take a particular value. It is thus appropriate to treat Trapezoidal FN as intervals. Triangular FN may be treated by methods dedicated to statistical distributions, as per [40].

3.3.1.2 Parameters omitted from ProBCA

ProBCA only includes essential parameters to ensure practicality, and omits some parameters that are included in many other taxonomies existing. Presented below are the considerations relevant to some of these parameters whose elaboration extends the readers' understanding beyond ProBCA:

i. Irrelevant Parameters: Software Availability:

Software availability parameter does not and should not affect method selection. If a method is relatively simple, a suitable analytical tool can be developed by the DM; if it is complex, the available software would not help the DM understand the key background behind decision recommendations.

ii. Excessive Refinement: Binary Relations:

Several threshold types can define binary relations for the options characterised by quantitative attributes. Specifying the threshold and binary relation type may help the DM understand the intricacies of method application better. However, this level of detail has proven unnecessary at the distinction level achievable by ProBCA and may be more suitable for the wider MCDA taxonomies.

iii. Insufficient Refinement: DM Competence:

Different stakeholder opinions may have varying influences on the overall GDM result depending on their involvement or competence. Although an expression of DM's competence rating may be useful, only 7 methods were found to include it in the process. This is too insignificant to dedicate a separate ProBCA parameter and is reflected in searchable methods descriptions instead.

iv. Intrinsic Parameters: Normalisation:

Most MCDA methods that use quantitative inputs involve normalisation as a pre-processing activity. It is used to transpose all data onto the same scale to allow fair treatment of preference information disregarding its original units. ProBCA does not include normalisation among method descriptors since a comprehensive list of available normalisation techniques is available in [41].

3.3.2 ProBCA Taxonomy Content

The structure of the resulting ProBCA taxonomy parameters is presented in Appendix A.2. It also counts the number of methods that use each descriptor value i.e., the total number of methods for each parameter is always 300. Value

counters are also positioned next to their listed positions in the top section of the ProBCA taxonomy in [1]. The counts are automatically updated as the user filters the list of visible methods by selecting appropriate descriptor values. These type counters always show the number of methods remaining that correspond to the selection of values already provided by the user. This helps further DP characterisation or progressive identification of the suitable methods remaining.

3.4 ProBCA Discussion

ProBCA taxonomy aims to promote the utilisation of ranking MADM methods across a wide spectrum of industries, contexts, and operational levels of its practitioners. The application instructions, advantages, and limitations of ProBCA are presented below to complete the top-level user guide.

3.4.1 ProBCA Application

The selection of a suitable method is the key part of an MCDA task co-dependent with the DP definition:

3.4.1.1 Case-Based Validation

An example of ProBCA application to characterise a MADM method is presented in [Appendix A.4](#). It validates the logical coherence of ProBCA by demonstrating the process of how the MADM methods were described when fulfilling its contents. The description and justification of the parameter values used in ProBCA are presented in its “Characterising Parameters” sheet [1] and in [Appendix A.1-2](#).

ARIADNE method is used to provide an example due to its intermediate complexity, which allows a suitable demonstration of the thinking process applied for its description in all parameters involved. It uses no “N/A” values and is described using a single source (its original reference [18]) that offers a clear

information delivery style. It avoids much of the misinterpretation risk and uses statements that can be directly linked to ProBCA parameters. This is not the case with more intricate methods, particularly where the delivery style of the source is aimed at the audience with deep MCDA expertise. ARIADNE is also one of the few methods that use a problem-based development philosophy at its core in line with the ProBCA baseline philosophy.

ProBCA capability shall be further validated by project application where a MADM method is selected for a real DP to achieve its goals effectively. Case studies are presented in Sections 4, 5 applying ProBCA to select the most appropriate MCDA methods for two tasks: assess the measure of stakeholder involvement in aircraft cabin projects and weigh the importance of their design drivers using HCCA core, and prioritise the key areas of sustainability concern in a cabin using SSAPTI.

3.4.1.2 Application Requirements

ProBCA is intended for use as the DP structuring guide by sequential filtering for appropriate descriptor values. The parameters lead the DM's contemplation about how to model the DP precisely. The structuring of a DP model, however, is not constrained to the selection of suitable descriptor values and requires exploring its context to define the most accurate representation. The DM must thoroughly understand the full DP context: its goals, stakeholder needs and constraints, and the information available. The uncertainties related to choosing the right values are resolved by scrutinising the DP as a team effort. Ultimately, the choice of parameters depends on what values represent the most realistic DP model; what data is available to model the DP, its type and quality mix; and the DM's ability to handle the computational and logical modelling involved in applying a suitable MCDA method.

3.4.1.3 Application Intent

One of the key functions of any MCDA selection framework is to highlight the DM's knowledge gaps about the DP and inform further research and information

gathering [19]. Similarly, ProBCA incarnates a particular way of thinking about the DP and is most relevant at the early stages of a DA (Decision Analysis) task. Filtering for appropriate values in ProBCA will either recommend the most suitable method for the given DP or invite a revision of its model structure.

It is important, however, that the DP is characterised as objectively and realistically as possible. The parties involved shall avoid the tendency to fit the DP description with their preferred MCDA methods [18]. For example, criteria definition must not be forced to be exclusively ordinal or quantitative; nor certain uncertainty types should be unreasonably simplified. ProBCA requires minimising subjectivity when modelling a DP to ensure optimum method selection.

3.4.1.4 Application Process

The selection of appropriate parameters starts as a direct assignment (selecting what applies) in the order that fits best with the information available. When all known parameter values are filtered, further characterisation by direct assignment becomes difficult due to uncertainties and ambiguity in the team's understanding of the DP at hand. The next phase involves the sequential elimination of inapplicable options to deduce the remaining descriptors. The resulting values need to be tested on whether they represent the DP appropriately. It may occur that several values remain considered for some parameters e.g., where the DM is undecided about their elimination; testing should resolve this.

3.4.2 ProBCA Taxonomy

Where ProBCA recommends more than one method, its final selection should be based on studying the available method references. The DM should understand the operational principles of a specific method, the benefits it offers, and its unique weaknesses that may be detrimental in the context of a specific DP. The DM must be confident in their ability to use the selected method and clear about its purpose. If the DM cannot decide on which method to choose out of several

candidates, one may apply all to observe the differences or select the newer one representing the latest state of the art.

ProBCA is designed to achieve a balanced level of complexity to categorise its 300 methods almost uniquely, which the existing taxonomies reviewed in [Section 2.1](#) are unable to offer. Its complexity is controlled by defining the right number of criteria to benefit from important distinguishing features, but also to not pose a challenge to understanding their use. ProBCA offers a unique characterisation for 250 methods out of the total 300 recorded. Thus, in 83% of cases, the DM will receive a unique recommendation to a correctly characterised DP. The remaining 50 methods repeat each other's functionality to some extent. Several method groups in ProBCA share identical functionality: 11 pairs, 4 triplets, 2 quadruplets, and one set of 8 basic methods. This is not unexpected since the various teams working to develop new MCDA methods might have their own methods invented independently. These differ at the level not distinguished by ProBCA parameters:

- **Aggregation function type:** additive, multiplicative, exponential, logarithmic, or mixed;
- **Normalisation:** some methods may include the normalisation process step and others don't;
- **Aggregation direction:** some methods distinguish between maximising and minimising criteria, while others require that all attributes be pre-processed for maximisation before application.

In some cases, ProBCA will recommend no methods. This results from two possible scenarios:

i. Prohibited Value Combinations:

The DP might be characterised using prohibited combinations of parameter values. For example, a DP may feature criteria of equivalent importance while the "weights basis" parameter is set to "pre-defined" value. To prevent this, DP descriptors should always be checked for logical consistency.

ii. Missing Methods:

If the DM is certain that the DP is characterised correctly but ProBCA still suggests no methods, it is likely the case that ProBCA excludes any method that could be suitable for the DP at hand due to either:

- a) A suitable method was not found for this DP type and is missed out from ProBCA collection;
- b) A suitable method does not yet exist for the given DP and needs to be devised anew;
- c) A suitable method exists for the given DP, but its definition requires a set of parameters that are not used in ProBCA and parameter values used in it are not suitable or sufficient.

Scenario “c” above is unlikely since ProBCA is built from MCDA first principles and thus, made all-encompassing albeit at a more superficial level than required for characterising some existing methods. However, the DM cannot know which of the above scenarios applies when presented with no method suggestions. In these cases, one is advised to consider crafting a hybrid method for a unique DP.

3.4.2.1 Hybrid MCDA Methods

Hybrid methods are a type of bespoke approach for dealing with unconventional DP. It reinforces the decision capability of the constituent methods by combining their strongest features [42]. Pulling the most appropriate elements from the existing methods to combine into new, bespoke approaches is considered the most effective way to solve a tricky DP that no existing methods are fit to deal with [25]. It is worth warning that sometimes, crafting hybrid methods or making minor modifications to the existing ones uncovers sufficient novelty to create whole new branches of MCDA research [43]. Hybrid methods may originate from within the MCDA domain like ISM-DEMATEL [44], or spawn from coupling MCDA with other domains e.g., DEMATEL-ANFIS [45] combining MCDA and AI.

3.4.3 ProBCA Benefits

Adequate DP solution primarily relies on the quality of information gathered about it and the model of stakeholder preferences reflecting the real value system involved [4]. Selecting an appropriate MCDA method is a crucial part of effective decision-making. Therefore, it too shall be primarily based upon the appropriate understanding of the DP and not on method features or DM's familiarity.

ProBCA serves to offer a concise, clear, and sufficient means for categorizing and selecting among the MADM methods for ranking. It allows the DM to understand their knowledge gaps about the DP and select methods based on it. This shall motivate the DM to study the problem deeply enough by guiding the direction of investigation in a structured, logical, and effective process to enable:

- i. Quicker DA progress due to consolidated access to methods:
 - a) Rapid comprehension of the variety of methods available to enhance DA task planning;
 - b) Significantly reduced time to identify the MADM methods to study deeper on a given DP;
 - c) Increased value of available methods by exposure: while some methods are popular, the lesser-known ones may find novel applications and have their unique strengths popularised.
- ii. Short time to grasp the core MCDA concepts:
 - a) Avoidance of extensive literature review that would be required to identify the 300 methods available, understand their application intricacies, and pick the most suitable ones;
 - b) Accelerated grasping of the MCDA basic principles for the less aware practitioners by their thorough understanding of the 17 descriptive parameters used in ProBCA.
- iii. Potential for automating the MCDA method selection process:
 - a) A suitable format to automate method selection techniques based on pre-defined inputs;
 - b) The ability to integrate MS Excel with other digital capabilities to retrieve relevant DA data.

3.5 ProBCA Conclusion

The new taxonomy of MADM methods for ranking is introduced. It features a collection of 300 methods identified, but may omit some methods if missed by the searching activity. ProBCA is the first taxonomy of MCDA methods of this size focused specifically on the discrete methods for ranking. It uses 17 characterising parameters deliberately defined in an unadulterated manner to facilitate quick comprehension of the MCDA principles by a wide spectrum of potential users. ProBCA is built from MCDA first principles and other existing taxonomies to allow the characterisation of complex MADM methods efficiently. It enables quick identification of the methods suitable for a task with the ultimate goal of popularising MCDA application across industries and organizational levels.

3.5.1 Future Work

The baseline version of ProBCA may be further improved and developed by:

3.5.1.1 Taxonomy Validation

An example of how to characterise a MADM method is provided in [Appendix A.4](#). A demonstration of how to apply ProBCA to a real DP is available in [Sections 4 and 5](#). Its further validation invites other practitioners to use it for MADM method selection on a real project or for a hypotheticalal DP.

3.5.1.2 Further ProBCA Development

ProBCA could be extended to cover the full scope of existing MCDA methods and DP types. Combined with more sophisticated MCDA taxonomies like [6], MODM, and AI, it could pave the way to enabling “Artificial Intuition” [46] as a step towards achieving the true Artificial General Intelligence (AGI).

ProBCA is developed with automation potential in mind and shall be an integral part of an AI system capable of independent decision-making. Combined with

existing capabilities for sophisticated data collection and analysis, image and natural language processing, it could enable automated subjectivity. Such an AI system would reveal subjective preferences from humans and combine it with objective decision rules to derive optimum solutions. This may be achieved by:

i. Full MADM Coverage:

ProBCA should be extended with methods not covered in its baseline version. This may be addressed by focusing on the DP types for which the original ProBCA version gives no method suggestions.

ii. Full MCDA Coverage:

ProBCA should be extended with sorting MADM methods and the available MODM methods. This likely requires extending it with additional parameter values to choose from, or adding more top-level parameters. ProBCA could also be integrated with other MCDA collections and more complex taxonomies existing.

iii. ProBCA Automation:

Subsequent advancement of a ProBCA-based system could replace practitioners with existing AI capabilities, such as ML/ NN, image or natural language processing, and computational neuroscience considerations. Eventually, such a system could pave the way to the creation of Artificial Intuition [46] by embodying “System 1” capabilities from [47], which could help achieve the true AGI frontier.

The discussed AGI capability could enable the introduction of holistic, globally distributed systems that use surveillance, learning, and recommendations to interact with local societies in harmony with their values. For example, such a system could be involved in developing transport cabin interiors offering the best compromise between the carrier’s objective goals (lower fuel burn, easy maintenance, cheap manufacturing) and subjective user preferences that will differ from one location to another (e.g., Asian versus European). Ultimately, it may become the backbone of the future socio-economical systems used by governments and organisations to balance human subjectivity with objective global benefits. A discussion of the potential architecture for such a system is outside of the scope of this thesis.

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4 A HOLISTIC CONCEPT DESIGN FRAMEWORK FOR PASSENGER CABIN INTERIORS

The success of multi-stakeholder innovation is achieved by aligning their conflicting needs with project objectives. A widely applied approach to facilitating innovation in a multi-stakeholder environment is MCDA [1] with examples in [2] and [3]. This mindset has spurred the creation of the new MCDA-based NPD framework for holistic cabin product concept design (HCCA). Enabled by ProBCA, its development is presented in this thesis with the resultant framework attached to [Appendix B.1](#) and uploaded in [4].

The presented framework aims to resolve the disintegration among cabin interior stakeholders and aid mutual understanding by serving as a holistic scoping toolset. It identifies all stakeholders involved in or affected by the delivery of a new cabin product, assesses their contribution, maps their key design drivers, and weighs their relative importance. The HCCA shall be applied as the project organisation backbone and may be adjusted to specific projects or stakeholder views by tailoring the relevant input values on a case-by-case basis. The ensuing sequencing of project interactions uncovers the far-reaching decision impacts for all parties and helps to streamline the associated NPD processes.

The HCCA is informed by an iterative literature review, project workshops, expert consultations, and research delivery sequence. The description of stakeholder roles and their drivers is dispersed within the industry as knowledge specific to individual business entities. This thesis is the first to offer it in a generalised form, informing cabin interior research and development for the wider audience.

The scope of this thesis is primarily concerned with airliner passenger cabins. The baseline HCCA version does not cover lower deck cargo compartments, the VIP (Very Important Person), or Business Jet cabins; but can address it appropriately by tailoring relevant inputs. Similarly, freighter aircraft interior projects could use the HCCA with the omission of passenger-related drivers.

The methods used to obtain the knowledge feeding the foundation of the HCCA are outlined in [Section 4.1](#), and the methods used to process this information are

presented in [Section 4.2](#). [Section 4.3](#) demonstrates the assessment of the cabin design task context, followed by [Section 4.4](#) discussing the importance and implications of the research work conducted. [Section 4.5](#) summarises the research delivered and what future work the HCCA implementation invokes.

4.1 Knowledge Gathering

The identification of cabin stakeholders and the analysis of their design drivers was performed using a 3-stage approach. It pursued the translation of stakeholder goals stipulated by their top-level business context and process interfaces into bottom-level cabin qualities. These qualities are intended as criteria for assessing the relative feasibility of potential solutions for a specific product concept. Furthermore, these can also inform the specification of detailed cabin product requirements at its later design stages.

This section is dedicated to describing each of the 3 knowledge gathering stages in detail, namely:

- i. Gather and systemise relevant information about cabin design processes and dependencies,
- ii. Identify cabin design stakeholders and analyse their contribution to the cabin design process,
- iii. Derive the applicable multi-level cabin design drivers and assess their relative importance.

4.1.1 Literature Review

The top-level inventory of the reviewed literature is outlined in [Section 2.2](#), followed by the conclusion that there are currently no design methods dedicated to cabin interiors available in the open sources. Furthermore, existing aerospace design methods (like MDO) are only applicable at later development stages of a cabin product (such as detail design and engineering), and do not offer a complete coverage of non-technical design aspects that must be taken into

account. For example, MDO helps to design the technical content of passenger seats but does not offer a fulfilling insight into its intangible aspects like passenger mood, willingness to interact with fellow travellers or subjective cabin sentiment.

These observations have motivated an extension of the knowledge-gathering approach from literature-based (planned originally) to experience-based. The new approach was oriented at using the smaller-scale, highly focused literature (academic papers dedicated to individual passenger experience and cabin design aspects) extended with industry expertise available on projects linked to this thesis. The detailed inventory of all literature reviewed is not summarised in this thesis due to counting over 200 original sources that exhibit significant repetition, overlaps, and common omissions. Relevant references are listed against the individual cabin design drivers and their lower-level factors defined in the HCCA, which are listed in [Appendix B.1-2](#) (column “References”) and decoded in [Appendix B.1-6](#).

The available literature did not allow systemising the knowledge collected into a single framework and thus, the next research step was to engage the industry.

4.1.2 Project Workshops

Literature review conclusions were refined by collaborative effort applied on the 3 projects (see [Section 1.1.1](#)) informing the presented. These featured various workshops attended by the key ambassadors from the cabin interiors industry. Over 500 unique opinions reflecting relevant industry context were collected in an anonymised format and systemised to draw refined conclusions informing the new NPD approach. While the opinions gathered generally aligned among each other, the relative importance imposed upon the different cabin design aspects varied significantly between different stakeholder types. For example, the MRO prioritises seat architecture above its visual appearance, which conflicts with Operator’s perspective. Strong discrepancies were observed when comparing industry opinions against literature inferences. This may be conditioned by an isolated perspective that some research publications take when focusing on a

narrow topic of investigation, as opposed to industry views conditioned by collaborative business experience. Expert validation representing authoritative views of the various cabin stakeholder types was required to consolidate the gathered knowledge basis. This thesis does not represent the detailed list of anonymised stakeholder opinions recorded in workshops.

4.1.3 Expert Surveys

Securing expert involvement from a wide range of stakeholder types was challenging due to the competitive nature existing in the cabin interiors industry. The resulting sources of expertise informing the knowledge validation activity are outlined in [Appendix B.2](#) as anonymised expert credentials.

Expert consultations were conducted for final-stage refinement and consolidation of workshop inputs to ensure that the HCCA uses a reliable basis. The baseline list of survey questions is presented in [Appendix B.3](#). Each consultation involved 2 interviews where possible: an open-ended questionnaire followed by anonymous cross-validation of opinions. Multiple expert responses were triangulated by side-by-side comparisons, with any inconsistencies addressed in subsequent interviews both with the original respondents and with other experts. Additional rounds of targeted literature review were also carried out to address the key inferences or inconsistencies in expert responses, although this proved ineffective in most cases due to the unique nature of the opinions gathered. The knowledge collected was used to inform the definition of cabin design drivers and their relative importance for each entity.

4.2 HCCA Development Method

This section describes the methods applied to develop the core modules of HCCA. These include the list of stakeholders with their weighted contributions to a typical cabin interior development project and a collection of relevant design drivers with importance weights.

4.2.1 Stakeholder Analysis

The SA method was originally introduced in [5] and elaborated in detail in [6]. Proposed in [7] as a methodological basis for developing future air transport systems, it was selected as the backbone for building the new NPD approach. Its previous applications in relation to air transport systems include:

- Developing an international network of airline routes [8],
- Evaluating challenges and potential solutions for Ground Handling [9],
- Analysing the effectiveness of airline mission statements for realising their business strategy [10].

SA is deemed effective for introducing a collaboration-oriented mindset into product innovation [1]. It facilitates stakeholder identification and assessment as a precedent for structuring their design drivers.

4.2.1.1 Stakeholder Identification

No publication precedes this paper in defining a comprehensive list of all stakeholders involved in or affected by cabin interior design and delivery. Their identification began by exploring the following list:

- Organisations mentioned in the reviewed literature
- Participants of the three projects informing the research presented herein
- Business interfaces (suppliers, customers, peers) of the interviewed experts
- Cabin interior trade show participants like those at the annual Aircraft Interiors Expo in Hamburg

The stakeholders are defined by function and not business entity type, split into:

- **Primary:** directly involved in making cabin design and delivery decisions
- **Secondary:** indirectly affect cabin design by acting as its users or interfaces

Although the secondary stakeholders are not involved in the cabin development process by the current practices, obtaining their opinions to inform early product development could contribute to its success.

4.2.1.2 Stakeholder Analysis

The SA methodology uses an influence-interest grid [6] to map stakeholder perspectives in relation to cabin projects using a set of subjective scoring values to reflect their relative position on two axes:

- **Influence axis:** reflects the level of power that a stakeholder holds in imposing rules and decisions;
- **Interest axis:** reflects the level of concern that a stakeholder has for the subject of a given project.

SA method source [5] proposes a 10-point scoring system assigned directly by the decision-maker, which is deemed too frivolous to offer a reliable representation of existing cabin business interactions. The SA approach adopted was tailored by combining a 5-point scoring system from [11] with a more elaborate, bespoke definition of the scoring values (Table 4-1). The wording avoids generic, potentially misleading expressions like “Good” or “Poor” akin to the scoring definition process used in [12].

The scoring refers to “cabin technology” since any design decision has to be embodied as a technology-based product. Even minor updates like the new armrest colour are defined as a new product version.

When assessing cabin stakeholders, the user shall select an appropriate score based on observations like business process parameters or the exact nature of stakeholder interactions to ensure objectivity. Despite subjectivity is unavoidable where project workshops and expert consultations are involved, it may be controlled by choosing the most objective processing tool available. A source for such tools is found in the MCDA domain previously used for SA in [2], [13], and [14]. Its subset dedicated to assigning criteria importance weights is similar to the purpose of SA task:

- Both task types allow deriving the relative positioning along some scale for a set of discrete options;

- Both task types are solely characterised by the description of items available (one problem dimension) and involve no other set of criteria, parameters, or options (no other dimensions).

Table 4-1: Pairwise Comparison Scoring System for Stakeholder Analysis

	Influence	Interest
Score	Authority of “i” vs “j” when introducing new cabin technology from “i” view	Whose satisfaction is prioritised when introducing new technology to cabin?
0.00	i has no authority over j; i must comply with j; j makes decisions independently of i	i is not impacted by j's use of technology
0.25	i has weak authority over j; i's needs may be considered by j; j may change decisions for i	i is impacted by how j uses technology and needs to be informed
0.50	i and j have equivalent authority, have no effect on each other, or decide together	both i and j have comparable or conflicting interest, or make joint decisions
0.75	i has strong authority over j; i is in charge but considers j needs; i may change decisions for j	i informs j about their use of technology; j is impacted by how i uses technology
1.00	i has full authority over j; j has no effect on i; i dictates to j; j's needs have no effect on i	j fully serves i's interest; i dominates interest in using cabin technology

The most appropriate MCDA tool to aid cabin SA task was selected using ProBCA presented in [Section 3](#). It uses a set of 17 problem descriptors to identify the most appropriate MCDA tool for the task. The values describing the cabin SA task are presented in [Appendix B.4](#), resulting in 4 tools suggested by ProBCA: AIP (Aggregated Individual Priority), CBS (Count-Balanced Sum), EM (Eigenvector Method), and SC (Sum of Contributions). The EM was the primary processing tool of choice for the cabin SA task as the most elaborate of all, with the other 3 used to validate the results. The EM constitutes the functional core of the classic AHP (Analytic Hierarchy Process) method used in [15] to assess innovation partners but is free from a specific scoring scheme or driver hierarchy imposed by the original AHP.

The relative stakeholder influence and interest levels are assessed by entering the defined scoring values into two pairwise comparison matrices in [Appendix B.1-4](#). The matrices list all cabin stakeholders in columns titled “i” and rows titled

“j”. The comparison is performed by evaluating stakeholder “i” against stakeholder “j”. The EM is implemented in accordance with [16] by compiling the comparison values into a pre-set R code using the instruction provided on the “R input” sheet in [4]. Running this core will produce Eigenvector values to copy back into “R input”, which feed back into SA normalised on a [0, 1] scale to allow visual mapping of the relative stakeholder positions on a per cent scale.

4.2.2 Design Driver Assessment

Multi-level drivers for cabin design pursued by each stakeholder involved were identified and mapped, and their relative importance was weighted. Each driver consists of several lower-level factors affecting the overall effectiveness of cabin interior product and service innovations. Factors are supported with bottom-level criteria examples representing measurable product requirements to help the definition of a real cabin NPD project. The design drivers remain fixed, but the applicability of their lower-level factors and the specific definition of criteria may change between projects and products. Driver and factor definitions followed the MECE principle [17], with the resulting structure laid out in [Appendix B.1-2](#) or the “Cabin Design Drivers” sheet in [4]. The drivers proposed may not cover the entire range of factors relevant to cabin interior design and omit some irregular or non-critical considerations.

4.2.2.1 Design Drivers and Factors

The identification of cabin design drivers was informed by the literature review ([Section 2.2](#)) and the industry ([Section 4.1](#)). The reviewed literature has exhibited varying relevance and applicability to cabin design, but enabled defining the 12 key drivers and provided the context for systemising expert opinions. The drivers were structured into a coherent system using profitability as the only KPI common across all stakeholders and product life cycle phases. The profitability equation is derived using [18]:

$$P = R - C = ([P - RC] \times V) - NRC \quad (4-1)$$

Where: C = Costs, split into RC (Recurrent) and NRC (Non-Recurrent) costs [19]; P = Price, R = Revenue, V = Volume. These drivers are disaggregated into factors and ordered using various relevant sequences:

- The sequence of profitability calculation
- Passenger journey chronology and interaction with cabin equipment
- The sequences of cabin equipment life cycle, supply chain, and value chain

Bottom-level design criteria help ensuring the fulfilment of each design factor by guiding project work. The criteria reflect the quality of cabin solutions considered in an NPD project that uses the HCCA.

4.2.2.2 Factor Applicability Mapping

The design factors are not universally relevant to all stakeholders at once since each one pursues its own goals on a given cabin interior project. Thus, two types of factors are mapped per applicability:

- **Applicable Factor:** relevant to a particular stakeholder's business by affecting their operations or influenced by their decisions (indicated by tick marks on the green background in the map).
- **Inapplicable Factor:** irrelevant to given stakeholder on a project due to not representing any of their profitability streams (indicated by empty cells). For example, the MRO is concerned with repairing cabin equipment with no regard for passenger experience enabled by that equipment.

The resulting map is presented in [Appendix B.1-5](#) featuring 56 factors of varying relevance across the cabin stakeholders. The total applicability count is indicated for each factor to reflect its popularity, and for each stakeholder to indicate their relative scope on a typical cabin project.

4.2.2.3 Design Factor Weighting

The HCCA uses MCDA as the weighting tool to identify the relative importance of the design factors derived. Factor count does not constitute a reliable weighting basis due to the mismatch between factor popularity and its impact. For example, factors a (Environmental Impact) and b (Circularity) of driver 8 (Sustainability) affect most stakeholders at count 16 out of 18. However, their influence on cabin design decisions is not higher than factor 7-a (Fuel Burn) with a lower applicability count. Although these factors are correlated, the airline business is heavily dominated by other impacts related to Fuel Burn (fuel costs, mission range) that are separated from Sustainability in the HCCA.

The hierarchical structure of cabin design drivers suggests a staged weighting approach in similarity with [3]. Relative pairwise comparison is judged most appropriate since no other knowledge is available to inform weighting. This is best served by MCDA as per examples pursuing similar goals in [2] and [20].

SA problem descriptors presented in [Appendix B.4](#) for use with ProBCA were reviewed to select a suitable MCDA tool for the task of factor importance weighting. Its purpose was judged identical to the SA task at both hierarchy levels and thus, tool selection remains unchanged. EM-based approach with R-enabled implementation was selected at the drivers' level. At the factors' level, however, the number of pairwise matrices involved renders the EM approach with R-code implementation cumbersome for users who may have constrained resources. Among the other 3 tools, SC was selected to process factor comparisons due to offering the highest output similarity to Eigenvector value as observed during the SA task. It uses a bespoke 5-point scoring scale to compare the design factors as shown in [Table 4-2](#). The resulting pairwise assessment of design drivers and factors is presented in [Appendix B.1-3](#), which feeds directly as factor weights into the "Design Factors Map" sheet if [4] is used ([Appendix B.1-5](#)). These represent a compromise between all parties and constitute a generic version of the HCCA. The user may update the comparison values to reflect their unique perspective e.g., the scores entered by an airline will likely differ from CEM evaluations.

Table 4-2: Pairwise Scoring System for Design Driver & Factor Weighting

Score	Which design driver/factor is more important when considering new design solutions?
0.00	i has trivial importance comparing to j
0.25	i is less important than j
0.50	i and j are equivalent / interdependent / incomparable
0.75	i is more important than j
1.00	j has trivial importance comparing to i

Two additional considerations shall be accounted for:

i. Adjustment for Applicability:

Where a design factor is inapplicable to a given project, the user shall adjust its weight to 0. Since all weight calculations are automatically normalised to [0, 1] scale in the tool, the remaining factor weights within the same parent driver will adjust to sum 1.0 to not disturb the threshold normalisation function.

ii. Threshold Normalisation:

The user has an option to impose weighting thresholds to limit the influence range between drivers and factors. For example, limiting factor importance to stay within [20%, 80%] range noticeably reduces the difference between each driver's relative contribution. The unbounded weight of Driver 7 (Integrated Cabin Quality) is 0.159, and 0.016 for Driver 9 (Implementation NRC) yielding a roughly 10-fold difference. Driver 7 is normally more critical for the commercial success of a cabin. However, some projects may involve high NRC due to technology integration and thus, are characterised by a narrower weight difference between these drivers. Normalising it between [0.1, 0.9] bounds yields the weights of 0.227 / 0.113 for Drivers 7 / 9 respectively, attaining a 2-fold difference in importance.

Normalising the driver weights bound by the user-imposed thresholds shall be normalised to ensure coherence between the different weighting versions. For example, a project may address two different products associated with different design criteria weights and the two must be comparable to prioritise different workstreams for each product. Different importance weight thresholds may be

required for each product, in which case the importance scales will not be comparable. For example, product A may fall within the [0.1, 0.9] threshold range while product B is bound on a [0.2, 0.8] scale. Normalisation brings the importance scores bound by the different thresholds into the same [0, 1] scale. While this means that the extreme importance weights may take a value outside of the thresholds defined, their normalised values are already adjusted by the thresholds so the bounds remain represented. Using the example above, normalised importance values for drivers 7/9 adjusted by the [0.1, 0.9] thresholds read 0.114 and 0.056 respectively, thus retaining a 2-fold difference but now having the sum of all weights equal 100%. Other thresholds put on another set of eigenvalues for product B will also sum to 100%.

The generic formulae used to transpose driver and factor weights to bounds is:

$$t_h = w_{max} + p_h \quad (4-2)$$

$$t_l = (r_w \cdot p_l) + (w_{min} \cdot p_l) \quad (4-3)$$

$$w_{ti} = t_l + \left(r_p \cdot \frac{w_i - w_{min}}{r_w} \right) \quad (4-4)$$

$$r_w = w_{max} - w_{min} \quad (4-5)$$

$$r_p = p_h - p_l \quad (4-6)$$

Where:

- p_h = upper threshold setting (provided, in percent units)
- p_l = lower threshold setting (provided, in percent units)
- t_h = upper threshold value (calculated)
- t_l = lower threshold value (calculated)
- w_i = original driver weight (pre-threshold) i.e., comparison matrix eigenvalues
- w_{max} = maximum weight (pre-threshold)
- w_{min} = minimum weight (pre-threshold)
- w_{ti} = weight i being adjusted by thresholds
- r_w = original weights range
- r_p = percent range between thresholds

Threshold adjustment can apply at both structure levels and may affect factor importance ranking. The effectiveness of the approach selected is demonstrated by the extreme values of the adjusted scores. For example, setting the thresholds to [10%, 90%] in the original HCCA version produces the minimum importance weight of 11.3% (i.e., not less than 10%) for Drivers 9 & 10 (Implementation NRC & RC); the [20%, 80%] limit sets the minimum value to 20.9% (i.e. not less than 20%) for Driver 9. The maximum value does not reach the higher threshold because the weighting transposes the original pairwise comparison values that sum to 100%. With that, some scores weighing 90% would require other scores to be disproportionately small – which is the exact issue the thresholds are intended to solve by aligning all weighting scores on a similar scale.

iii. Adjustment by Driver Weight:

The accumulated factor weights must be adjusted by the corresponding higher-level driver weights. A higher-weighting factor of a low-importance driver must not outweigh the medium-weight factor of a high-importance driver so the overall factor ranking represents the user's true value system.

The design factor weights are first adjusted for zero importance if inapplicable factors are present, and normalised to $\sum 1.0$ within each driver to yield the total sum of 12 for all factors (from 12 drivers). Factor weights are then transposed by factor-level thresholds (if any are defined by the user) and multiplied by their parent driver weights (which are adjusted by their own thresholds separately). Finally, factor weights adjusted across the two levels and combined into a single set are normalised so all 56 items produce a sum of 1.0. These can be used elsewhere e.g., to inform bottom-level criteria weights in the assessment of existing cabin equipment or to prioritise potentially disruptive solutions.

4.3 Design Context Assessment

The methodology outlined in [Section 4.2](#) enabled identifying the 18 cabin stakeholders and their 12 design drivers consisting of 56 factors. Both sets are weighted by relative contribution or importance.

4.3.1 Cabin Stakeholders

A total of 18 cabin interior supply and value chain stakeholders have been identified, of which 9 are primary and 9 are secondary. They are presented in Appendix B.5 in the order of descending influence. The definition includes stakeholder name, acronym, function, and the nature of their involvement. Two stakeholder-related decisions may be challenged by some readers depending on their perspective:

- The Environment may be seen as a stakeholder [21] or an external factor [7]. The HCCA treats it as a design driver since stakeholder definition implies its embodiment by an organisational entity [22].
- Up until 2021, the Dismantlers had a very low influence on cabin design, which has now changed due to the increased importance of aircraft cabin sustainability. Their position in the influence hierarchy has risen since they are directly responsible for product EOL (End of Life). Product phasing out is the key impact point for the inherent product circularity and environmental design qualities. The Dismantlers influence score is similar to that of the MRO due to the high importance of these considerations for driving material selection and design decisions in a modern cabin. Dismantler's high influence score does not reflect the industry's past but aligns with its sustainable future [23].

Two parties are not commonly associated with the cabin interiors industry; using UK-specific examples:

- Trade Organisations: these ensure a coherent and streamlined functioning of the cabin interiors industry as a part of the wider aerospace sector at the national level. In the UK this is the Aircraft Interiors Group, a part of the ADS (Aerospace, Defence, Security & Space) Group UK Limited [24].
- Government Units: these drive industry development in line with the top-level national objectives for business and economic growth. In the UK these are the ATI [25] and the UK BEIS (Department for Business, Energy & Industrial Strategy) [26].

Each business entity could be subdivided into constituent departments holding their own views on their attainable influence and exhibited interest in a cabin project. This level of detail is outside of the scope of this thesis. Each business entity involved in a project should consolidate its multiple views on stakeholder contributions and design factor weights to represent its top-level value system.

4.3.1.1 Stakeholder Assessment

Manual scoring is used to fill the top-right halves of both stakeholder comparison matrices. For example, the CA is used as “i” and the MRO is used as “j” when comparing the interest of the CA against the MRO. [Appendix B.1-4](#) indicates a score of 0.25 for this comparison, which means: “the CA has some interest in how the MRO benefits from a cabin solution. Conversely, the MRO has to inform the CA about its impacts”. The bottom-left halves are populated automatically with the values opposite to their respective top-right cells using the formula: $1 - \text{Provided_Score}$. The diagonal is populated with 0.5 scores by default to reflect comparison equivalence between the same entity types (e.g., CEM to CEM).

Normalised EM outputs are used to map the stakeholders on the interest-influence grid. Validation has produced good alignment, with the following output diversions among the 4 methods:

- **Influence:** 5 stakeholders with 2 or 3 rank points difference (medium reliability), 13 stakeholders with 0 or 1 rank points difference (high reliability);
- **Interest:** all stakeholders within 1 point rank difference (high result reliability).

The two sets of EM outputs were combined using vector length (equation 7) to derive the overall contribution weight of each stakeholder:

$$l = \sqrt{s_{inf}^2 + s_{int}^2} \quad (4-7)$$

where l = total contribution weight, s_{inf} = influence score, and s_{int} = interest score of each stakeholder.

Contribution weights may be used as input into the MCDA-based NPD process to assess the existing and prospective cabin solutions with consideration given to unequal stakeholder involvement. They are ordered by contribution in the generic driver applicability map, which may differ from the individual participant's points of view. For example, the DA may see the Operator at the top of the influence chain as their key customer; the Airframer may see its influence equal to Operator as the provider of fixed design envelope; but the CEM may see their own influence higher as they develop the new products.

Each score contained in the baseline version of the HCCA is based on specific ideas resulting from the research, project work, and consultations conducted. Each cell in the baseline applicability map is also based on a specific rationale justifying whether to leave it empty or mark it as applicable. The reasoning for the provided scoring and mapping is specific to the views of the author and the experts consulted, and tracked internally. Its revelation is left outside of the scope of this paper due to the significant volume of information involved. Exclusion of the authors' reasoning also motivates the user to update the scores based on their own rationale offering the best reflection of their perspective on a project.

4.3.2 Cabin Design Drivers

The one KPI common to all activities in the cabin interiors industry is concluded to be the profitability of the businesses involved [18]. Each stakeholder achieves profitability by a different means: an airline seeks to sell more tickets and in-flight ancillaries, while a CEM and its suppliers strive to sell more products. The parties involved typically contend about project goals, scope, approach, and the key success metrics [27] except cash flow. CA and ANSP pursue non-financial goals, but their involvement can also be reflected using monetary measures since meeting their expectations and needs imposes costs on other parties. Profitability is thus selected as the baseline for deriving cabin design drivers. Top-level design value implications are presented below with drivers grouped into related sets:

4.3.2.1 Revenue Potential (Profit, Volume)

Cabin design drivers 1 and 2 represent the capability of the supply chain to attract sufficient demand for a particular cabin interior project, which is driven by sales volume and baseline pricing. Considering revenue-oriented partnerships beyond the capacity of an individual entity helps to share investment costs and reduce financial risks [28]. For example, a DA may engage in profitable unity with equipment and material suppliers to derive feasible product ideas and promote each other to operators or CEMs.

4.3.2.2 Passenger Perspective (Profit, Volume)

Drivers 3 – 5 are responsible for variable revenue by providing demand control levers. These operate by accumulating passenger satisfaction through the diversification of the in-flight experience [29] to increase ancillary revenues [30]. For example, new a-la-carte comfort options [31], IFE solutions, or two-way external communication may justify fertile pricing without losing potential for volume growth.

4.3.2.3 Cabin Quality (Cost)

Drivers 6 – 8 represent intrinsic cabin qualities impacting the cost-efficiency of cabin interior operations. These could be direct impacts like the contribution of cabin equipment to fuel burn due to weight, or indirect effects like cabin safety implications due to hardware design features [32].

4.3.2.4 Cabin-Related Costs (Cost)

Drivers 9 – 12 address the contribution of direct costs involved in cabin development and operations to the overall stakeholder profitability. Cost categorisation into Recurring and Non-Recurring [19] was selected. It is typically used by the operators to evaluate significant decisions like equipment purchase [18], and by the manufacturers to evaluate product feasibility across its life cycle

[33]. Excluded are the costs unaffected by cabin interior design – for example, MRO hangar rentals and office supplies [34].

4.3.3 Cabin Design Factors

The design factors in [Appendix B.1-2](#) reflect the contribution of various cabin product aspects to top-level profitability. These solely relate to cabin interior design and do not represent a comprehensive scope of all business metrics and product characteristics of concern to the involved business entities. Factor applicability differs on a case-by-case basis due to the arrangement of partnerships, participant roles and responsibilities, project motivation, etc. Factors may be interdependent based on context:

- **Positive Dependence:** strong performance of the considered design solution in one factor may enhance the fulfilment of another factor. For example, passenger demand is affected by brand image, which itself is facilitated by effective promotion opportunities enabled by the product.
- **Negative Dependence:** a stronger performance in one factor implies a weaker performance in another factor. For example, a greater extent of product commonality weakens differentiation.

The Operators make the majority of important design decisions before appointing their manufacturing partners. This helps to boost innovation by liberating a conceptual product from the constraints, capability limitations, and standardisation impulse of CEMs and suppliers at early development stages. The map of design factors applicable to each party is shown in [Appendix B.1-5](#).

4.3.4 Cabin Design Criteria

Each design factor in the HCCA is extended with specific criteria examples that could embody it on a cabin project. These criteria represent precise design considerations, targets, requirements, product features, and other details considered within a cabin interior project scope. Their applicability will differ

significantly between projects depending on their technical, operational, and business contexts. The user shall fulfil and extend the presented criteria examples to appropriately reflect their project scope.

4.4 HCCA Output Discussion

The HCCA is a holistic collaboration framework for designing passenger cabin interior concepts by outlining a weighted multi-level design driver hierarchy of the stakeholders involved. The core HCCA elements are presented in [Appendix B.1](#); the full HCCA is uploaded to [4]. Its application procedure is presented in [Appendix B.6](#). The HCCA is proposed as an efficient and effective cabin interior NPD practice to enable a collaborative mindset for the cabin interiors industry. It is the first consolidated framework offering such capability, as evidenced in [Section 2.2](#), and confirmed by industry experts.

4.4.1 Cabin Product Breakdown

Presented in the [Appendix B.1-1](#) is a manufacturer-agnostic breakdown of a typical aircraft passenger cabin interior composition. It is presented as an empty Product-Driver matrix to allow the user to map relevant design drivers against the applicable product scope for a given project. When completed in [4], this matrix allows product prioritisation based on factor applicability count calculated automatically for each product. The project scope shall include products directly addressed by the intended activities as well as any products interfacing with or affected by those addressed. The presented cabin product breakdown has the following implications:

- The breakdown presented is not intended to match the product selection offered by any specific CEM or Tier 2+ organization. For example, there are CEMs offering galleys, lavatories, cabin linings, cabin storage, and flooring, but not passenger seating in their catalogues.

- The presented breakdown may be more or less refined than the product lines offered by the CEM or Tier 2+ organizations existing. For example, some seat suppliers offer multiple economy seat versions as opposed to a single entry for Economy Seating listed in [Appendix B.1-1](#).
- The complete product line of any existing supplier for cabin interiors shall fully align with product types listed in the attached breakdown i.e., there shall be no state-of-the-art products without a match in [Appendix B.1-1](#). Exceptions include novel products that do not constitute a typical state-of-the-art cabin e.g., VR glasses recently tested in some cabins but not currently adopted for wide-spread use in flight.

The baseline product breakdown as offered embodies the starting point for cabin interior projects and may be extended by the user if new technologies, functionality, or configuration are being developed.

4.4.2 Stakeholder Relations

The stakeholder influence-interest grid shown in [Figure 4-1](#) exhibits a roughly linear trend with <30% outliers, suggesting that one's interest level corresponds to their influence. The implications due to each stakeholder's position in the chart are discussed in [Table 4-3](#). The resulting map features 4 asymmetric quadrants reflecting stakeholder benefit-power imbalance:

- Engage:** have a direct stake in cabin interior projects and drive its value chain via both their influence on project decisions made and their concern about how to benefit from its outcomes;
- Satisfy:** have no direct stake in a cabin project, but have a critical influence on cabin design and material selection decisions;
- Collaborate:** do not impose critical influence on cabin design decisions, but have interest in its outputs and may enable new revenue opportunities;
- Consider:** although may not be involved in every cabin project, their needs must always be considered to ensure appropriate cabin functioning and technology development.

The grid reflects the relative positioning of stakeholders against each other. For example, Suppliers, MRO, Airframer, Dismantlers, and Lessors all exhibit significant influence on cabin design decisions despite scoring below 50% on both axes. Similarly, seemingly unimpactful logistic partner selection may incur a cost burden of sufficient magnitude to eradicate cabin profitability.

Table 4-3: Impact of Stakeholder Positioning on Relative Influence-Interest Map

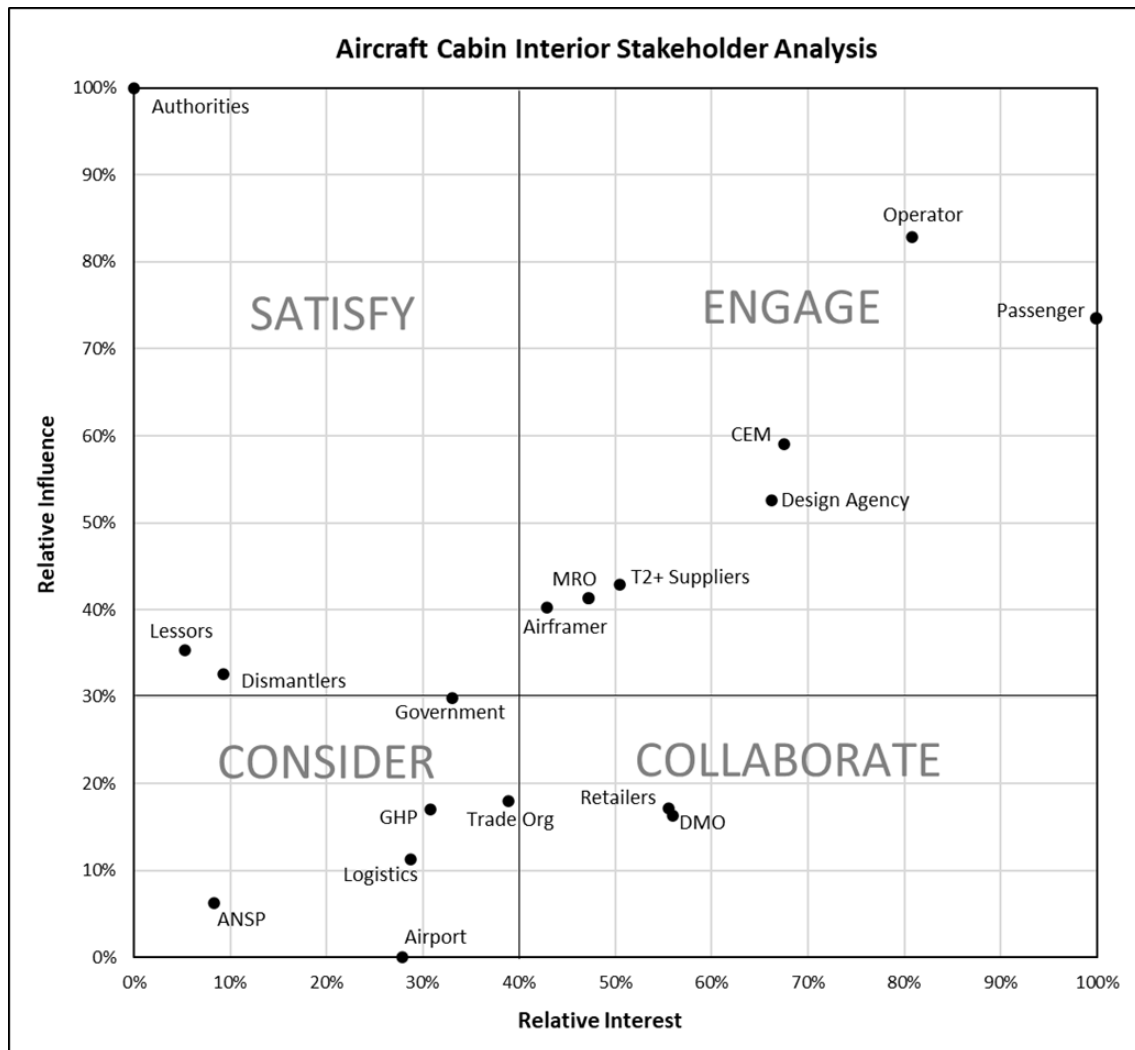
Q	Stakeh'r	Implications
ENGAGE	Operator	The positioning of airlines in the map suggests their strongest position in driving the definition of new cabin interiors and its products. Despite their overall vector is marginally smaller than that of Passengers, it is the Operators who request, provide most funding, and judge product adherence to their specification.
	PAX	Cabin interiors are designed to serve Passengers' needs and thus, their interest is the strongest of all stakeholders. Passengers do not have a direct influence on cabin design; however, their desires, needs, and complaints have the potential to impose the direction for the definition of core cabin qualities, if accounted for.
	DA	The DA collect product requirements through multiple stakeholder interfaces to deliver product concepts. The requirements may be hard (e.g., colours. shapes) and soft (e.g., cabin ambience). DA interfaces are direct (collaboration with the Operators and CEM) and indirect (e.g., research of user needs). Their interest in cabin success is comparable to CEM, but it has a lower influence.
	CEM	The CEM is responsible for the detailed design & definition of an airworthy cabin interior. It interfaces a larger number of other stakeholders to align on a wide range of product requirements to meet (e.g., CEM will discuss integration specifics with the Airframer and prove airworthiness testing to the Authorities). Their interest is only sub-par to Passengers & Operators, with very high interest.
	T2+ Sup.	The attitude to cabin design of components, equipment, or raw technology suppliers is similar to that of CEM but at a lower scale since their responsibility is proportional to the size of their contribution to total product composition.
SATISFY	MRO	Although the MRO are not directly involved in product design, accounting for their needs is essential to ensure cabin components are serviceable at reasonable cost. Similarly, their high interest in cabin design quality is driven by risks & costs.
	Airframer	The last stakeholder actively engaged in cabin design, Airframers provide the design space for interior products and significantly influence solutions. As a manufacturer, their interest is aligned with the drive to win aircraft demand.

SATISFY	Authorities	The Authorities ensure the operational safety of a cabin with little concern about its commercial function and thus, are able to reject a sub-par product altogether.
	Lessors	Although the aircraft owners are not concerned about specific cabin qualities, meeting their needs for return through the Operator's commercial success is critical to motivating the continuation of aircraft lease so the value chain is alive.
	Dismantler	While the dismantlers are not involved in cabin operations and the wider value chain of cabin products, their profitability is heavily affected by cabin design.
COLLAB.	Retailers	The Retailers benefit from novel distribution channels for their products despite their little influence on cabin design, which may be beneficial for the entire value chain through their collaboration or co-branding with the Operator or the DMO.
	DMO	DMO may influence cabin design by channelling PAX needs and take a noticeable interest in marketing successful cabin concepts to stimulate travel demand
CONSIDER	Govt. Units	The indirect involvement of government units in cabin design is conditioned by their goal for overall industry success, innovation, and expansion creating jobs.
	Trade Org.	Trade Organisations facilitate industry collaboration and thus, take a noticeable interest in the health of cabin supply and value chains. Their influence is generally low, although they can take a key role in enabling fruitful supplier collaboration.
	GHP	The positioning of GHP on the map is subject to similar considerations to MRO but at a smaller scale due to the shallower level of cabin servicing they conduct.
	Logistics	With little regard for the specific cabin qualities, Logistics service providers earn from the various transportation activities involved in the cabin supply chain. Their influence, however, may transpire if a poor, high-cost choice is made by the CEM.
	ANSP	With very low involvement in cabin design, ANSP may have to be consulted when a new cabin product interacts with their operations – such as live flight maps.
	Airport	Despite their minimum influence on cabin design, airports serve as passenger journey interface before and after the flight. Opportunities for commercial collaboration with Operators, DMOs, or Retailers result in their elevated interest.

The Stakeholder Interest-Influence map serves as the guide for checking the sensibility of stakeholder assessment performed on a given project. It helps to highlight the deficiencies in the existing attitude to stakeholder involvement in cabin projects. For example, the baseline stakeholder map shown in [Figure 4-1](#) indicates that Passengers should be involved heavily in defining cabin qualities

to implement – which is not the case for most current project setups. This could involve focus groups, surveys, or the feedback gathered through online booking systems. Thus far, this extent of passenger involvement has only been observed on research projects dedicated to disruptive concepts e.g., ultra-long flights [35].

Figure 4-1: Influence-Interest Map of Aircraft Cabin Interior Stakeholders



4.4.3 Design Factor Weighting

Cabin design factor weights presented constitute a generic view and may differ from the individual stakeholder's point of view. The baseline weights are validated with the ranking provided: the original unbounded weights show the top 5

important factors to be Safety, Fuel Burn, Passenger Capacity, Operational Needs, and Cabin Environment, which aligns with the mindset adopted herein:

- i. An unsafe solution must not find a way into the cabin
- ii. The considered solution must minimise cost and sustainability impact to enable profitability
- iii. The available value-generating passenger capacity shall not be reduced
- iv. Expendable material consumption shall remain limited to stay viable
- v. The passengers must be able to sustain a healthy presence in the cabin for several hours; etc.

Design factor weights shall feed into the MCDA-based assessment of potential cabin design solutions. Baseline weights are presented in [Appendix B.1-5](#) also showing design factor rank positions by importance to aid sanity checking. Factor ranking represents stakeholders' value system on a project.

Factor weights may be adjusted by the user in line with their value system by updating the comparison values in [Appendix B.1-3](#) or entering the weights directly into [Appendix B.1-5](#) (i.e., the respective sheets in [4]). The latter may be used to enter weight "0" where a factor is irrelevant to a project. For example, communication capabilities may not apply on a cabin environment project, in which case the remaining factor weights are auto-adjusted to sum 1.0. This example, however, is not fixed: a hypothetical cabin environment project may use communication to transfer cabin air and filtering data for instant analysis.

4.4.4 HCCA Application

The HCCA application process is shown in [Appendix B.6](#) that may be used in passive and active modes. Passively, it informs collaboration planning and information structuring for a cabin design project using the baseline values provided without any adjustment. In active mode, input values may be updated:

- Cabin Breakdown shall reflect relevant factors and products

- The comparison matrices in Appendix B.1-4 are used for relative assessment of stakeholder interest and influence; white cells may be updated accordingly
- If Appendix B.1-4 is updated, the R Input sheet in [4] must be used to update Eigenvector values.
- Appendix B.1-3 contains several importance comparison matrices for the top-level drivers and their constituent factors. Values in white cells may change:
 - No further action is required after updating the design factor importance comparisons.
 - R Input sheet in [4] serve to update the respective Eigenvector if the importance comparisons of the 12 top-level design drivers are updated.
- Applicability indicators on the map shall reflect the involvement of partners.
- Factor explanations and criteria examples shall guide the definition of detailed parameters to drive new cabin product concept design through the application of MCDA-based assessment.

The last point above can be illustrated by defining the “Weight impact” criterion, for example. Another 5-point scale could be used to reflect a higher (score 0.0), equivalent (score 0.5) or lower (score 1.0) weight of the new solution versus baseline product, with appropriate interim scoring like in Table 4-2.

4.4.5 HCCA Benefits

The HCCA is best used as the guide at project start and at major product maturity milestones to check alignment. This enables the user to test their value system by assessing the sensibility of factor ranking and stakeholder contributions. The conclusion may be used to tailor the entries for the specific project e.g., by updating importance, influence, or interest comparison values where necessary.

The HCCA also enables the evaluation of future cabin innovation feasibility. Novel cabin equipment should be introduced by linking top-level stakeholder needs with the technological opportunities available to resolve some issues persistent in the industry, such as:

- Improve airline passenger experience by accelerating the introduction of new technology onboard
- Facilitate technological breakthroughs to achieve ambitious sustainability targets imposed on the air transport industry by the higher-level international and sector-specific legislative powers
- Provide a readily applicable, practical method to integrate technology development into high-paced, resource-constrained cabin NPD processes
- Instigate a holistic mindset and improve stakeholder collaboration efficiency

The HCCA helps cabin project scoping and stakeholder interaction planning. It offers the SA capability to compare partner contributions, the tools to reflect project priorities through design driver and factor weighing, and pre-filled templates to map factor and product applicability on a project. It informs the sequencing of the core cabin NPD activities by structuring the information-gathering and work-sharing tasks as a multi-criteria assessment workflow. This approach allows the evaluation of design solutions considered for each product by managing stakeholder contributions in a balanced and holistic manner.

4.5 HCCA Conclusion

Presented in this section and in [4] is the NPD framework for holistic passenger cabin interior design. It provides the definition of key design drivers and their constituent factors, and lists the stakeholders involved in aircraft cabin projects. Their functional interactions are described by presenting a map of their weighted design considerations. The HCCA aims to facilitate better NPD practices in the cabin interiors industry, ultimately fixing its disintegrated collaborative habits. Holistic project practices driven by the HCCA shall improve the yields across the cabin value chain by satisfying all stakeholder goals. Condensed into a single source available for use by anyone from the industrial and academic audience, the HCCA may be of particular interest to designers and PMOs at any entity.

4.5.1 Future Work

The improvement of NPD practices existing in the cabin interiors industry shall be achieved by adapting the MCDA-enabled HCCA framework offered to real projects. This includes the following next steps:

4.5.1.1 Hands-On Application

The presented toolset should be used to assess the quality of the state-of-the-art cabin configurations. This would likely lead to exploring the attractiveness and viability of prospective technology-based design solutions or structuring and planning out new cabin interior projects with better collaboration.

4.5.1.2 Extended Applications

While the current paper solely concentrates on the air transport industry, the HCCA may be adopted for effective use with other transport industries: automotive, maritime, or railroad [36]. This conclusion is based on comparing the aspects of interior design and passenger satisfaction in both aircraft and railroad cabins [29]. The available literature does not differentiate between approaches to win passenger satisfaction applied in these industries; instead, it demonstrates how success principles can be transferred beneficially between them. This is presumed possible due to the similar nature of the functional stakeholders involved in passenger transport applications. Relevant functions include passengers, operators, designers, manufacturers, certification authorities, servicing companies, etc.

4.5.1.3 Sustainable Cabin Design

The cabin sustainability driver should be assessed separately from other design drivers for two reasons. The first is its highly outward-looking nature exposed to multiple external interfaces and inputs. The second is related to the significant potential for developing sustainability expertise and building the related capability

in the cabin interiors industry. At the moment, this topic is emerging in cabin interiors with one of the latest outputs presented in [23] and has a significant amount of new knowledge to uncover. It could be convenient to consider weight and sustainability drivers together since both are interdependent and quantifiable in absolute, measurable terms based on objective observations.

The research work presented in this thesis, particularly industry expert interviews and the attendance of the Aircraft Interiors Expo in Hamburg, has led to the conclusion that Sustainability represents the key concern for the industry at the moment. Although it has not transpired as the most critical design driver in the Design Applicability Map (Appendix B.1-5), industry concern justifies addressing it in more detail within present research. The development of a new cabin sustainability assessment approach was selected as the subject for case study implementation presented in Section 5 of this thesis.

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5 SYNERGISTIC MCDA-LCA METHOD FOR SIMPLIFIED SUSTAINABILITY ASSESSMENT OF CABIN INTERIOR

Passenger cabin thus far has not been widely recognised as a priority for sustainable improvements despite making roughly 10% of the aircraft's operating empty weight. When propulsion technologies switch to new fuel types and eliminate most of the associated ecological harm, sustainability concern of a passenger cabin is expected to rise above all other aircraft elements. Future-proofing the ecological impact of aircraft cabins requires benchmarking the sustainable performance of all its components across their life cycle using high-quality product and process data.

This data, however, is unavailable for most cabin products due to the competitive strategies of the cabin supply chain. This section presents SSAPTI (Synergistic Sustainability Assessment of Passenger Transport Interiors), a cost-efficient approach for assessing product sustainability across the whole cabin. It uses the minimum material and dimensional data provided by the suppliers or measured directly from products. It uses MCDA as the analytical core and allows circular economy considerations.

Appendices C.1 / C.2 and uploaded in [1], SSAPTI offers a holistic and cost-effective alternative to effort-consuming formal LCA approaches that require detailed product life cycle data. SSAPTI assesses the sustainable performance of cabin products in relative terms using a combination of material impacts obtained from official LCA databases and qualitative judgement based on expert opinions. It iteratively translates material inventory into a granular view of the ecological impacts. SSAPTI is validated by case study application using conventional cabin products to test its functionality, relevance, and benefits.

This section describes the methodological basis of SSAPTI, demonstrates its application, and discusses its value to potential users. It does not attempt to introduce a formal LCA method and instead lays out what specific strengths a simplified LCA enabled by SSAPTI offers over formal LCA. SSAPTI application allows translating the user's product-based view into an informed appreciation of

granular material-based impacts in an efficient and relatively simple process with reduced input needs. It can be used to address the whole cabin at a fraction of the cost, time, and resources versus formal LCA. SSAPTI capabilities stem from a case study in the aviation sector but can be applied to other transport modes.

This section is structured to offer a sequenced introduction to the new framework proposed. It builds on the literature review on cabin sustainability challenges and potential assessment approaches in [Section 2.3](#). The motivation for SSAPTI development is elaborated in [Section 5.1](#). Its core functionality is described in [Section 5.2](#) and applied to a case study in [Section 5.3](#). The observed value enabled by SSAPTI is discussed in [Section 5.4](#), with conclusions and further work areas outlined in [Section 5.5](#).

5.1 Development Motivation

The development of SSAPTI was informed by the FlyZero Sustainable Cabin Design [2] and the “UK Cabin Opportunity” [3] projects, both led by the ATI UK (Aerospace Technology Institute). These projects provided the context for gathering material inventory of a typical cabin and conducting expert surveys to elicit their attitudes, preferences, and challenges in assessing cabin product sustainability. The questions informing SSAPTI logic were included in the list of survey topics presented in [Appendix B.3](#) for [Section 4](#), with key inferences made from the literature review outlined in [Section 2.3](#).

5.1.1 Development Approach

The Sustainable Cabin Design component of the ATI FlyZero project assessed the sustainability of existing aircraft cabin interiors to inform the identification of the most promising solutions based on emerging technology. An absence of any pre-existing tools or approaches tailored to this purpose was discovered. A new toolset for aircraft cabin sustainability assessment was required to deliver FlyZero

project goals. Improving and expanding this embryonic capability from FlyZero has evolved into SSAPTI.

SSAPTI was initiated by reviewing the existing LCA landscape and investigating the applicability of its tools. The business environment and data-sharing specifics of the cabin supply chain have rendered the full LCA approaches impractical. Fruitful synergy opportunities were identified by combining the consideration of simplified LCA options with ProBCA [4] capabilities for MADM method selection.

5.1.2 Functional Requirements

SSAPTI is intended to enable cost-efficient cabin interior sustainability assessment for a wide spectrum of users limited by narrow time and resource constraints. Formal LCA of a whole cabin in absolute terms is concluded impractical due to posing an overwhelmingly difficult task [5]. Cabin products feature multiple materials (up to 100 across the cabin) that heavily differ in their content (up to 1000-fold difference by volume and weight). This informs several baseline qualities that SSAPTI must offer:

- Balance simplicity to ensure clarity of the assessment process and the interpretation of its results, and sophistication that underpins framework credibility by enabling sufficient analytical rigour;
- Be capable of processing a vast number of products and components offering a cabin-wide view of how different equipment compares against each other;
- Process a complex set of numerous relevant data points representing cabin product features and aspects of various nature into a single figure representing its overall sustainable quality;
- Operate on confined information that may be limited to product materiality (material composition and mass per material) due to data-sharing practices existing in the industry;
- Offer a quick turnaround of the results delivered within resource constraints, which may imply a limitation to one FTE (Full-Time Equivalent) and short project duration (within 3 months);

- Minimise or avoid any access requirements to special tools or bespoke training content for the practitioner who potentially lacks formal LCA expertise.

The intended SSAPTI application is cabin product sustainability assessment to inform further projects, such as RFP specification, product development, or formal LCA studies. Qualitative inputs are suitable for these purposes i.e., products need to be ranked per their sustainable performance with relative preference intensities indicated for each rank position, but no absolute values are necessary. In this sense, SSAPTI uses an attributional approach and not a consequential one as distinguished in [6].

Of the three core sustainability pillars [7], SSAPTI serves to evaluate the environmental aspect and not social nor economic in line with the LCA focus [8]. The environmental pillar is a popular starting point to address before others due to its criticality for global well-being; the other two are assessed by academic research [9] and corporate social responsibility reports from stakeholders.

5.1.3 Intended Capabilities

The functional requirements outlined above were used to drive SSAPTI development in a top-down approach, with each capability implemented as one of its four core function blocks:

- i. Quantitative sustainability assessment block used for processing product materiality data from LCA databases was built first to act as the foundation. Its derivation has followed the standard sequence of a formal LCA process until it was no longer possible to continue due to data gaps.
- ii. Qualitative sustainability assessment block was introduced when the opportunities for using the objective values from LCA databases were exhausted. It builds upon product life cycle stages and represents the environmental viewpoint, but uses qualitative judgement for evaluations.
- iii. The intended SSAPTI applications require extending the scope of its consideration beyond the sole concern about product sustainability. A

- Strategic assessment block was adopted from HCCA to exclusively assess the organisation's business drivers related to cabin product design.
- iv. The Results block aggregates the outputs from the three assessment blocks by combining their outputs into a single score and includes the capability to adjust their relative contributions.

SSAPTI framework also includes several secondary, or supporting blocks that hold settings, functions, or data feeding into one or several core blocks. These aggregate partial results at refined granularity to inform the interpretation of the final outputs through investigating and comparing cascaded impacts.

Multiple simplifications to the formal LCA process were motivated by [10] following a similar approach. Several feasible LCA simplification paths are outlined in [8], each offering a distinct modelling fidelity level. A mixture of directional tools and matrix methods was judged as most appropriate for SSAPTI. These offer sufficient accuracy to indicate the direction of the user's work (e.g., prioritise products for further investigation in detail) while only requiring a fraction of effort as opposed to a full LCA study.

5.1.4 LCA-MCDA Integration

Matrix methods for simplified LCA use a mixture of qualitative and quantitative data expressed on custom numerical scales (nominal scores, percentages) to estimate product performance. MCDA tools enable implementing this owing to their characteristics complimentary with LCA [11]. The observation of the MCDA to LCA matching is presented in Appendix C.3-1 to inform several conclusions:

- The use of LCA tools offering access to relevant LCIA methods and impact databases is inevitable, which incurs some minimum level of practitioner's skill to retrieve the top-level material impacts;
- Informing the user's priorities for further assessment, innovation design, or RFP content cannot be achieved by either of the approaches alone – it has to combine MCDA and LCA in a holistic process;

- The assessment of users' business drivers is solely enabled by MCDA since quantitative assessment based on product materiality data disregards any subjective or case-specific cabin design aspects.

Tailoring the MCDA-LCA integration to a specific context requires substantial development [11], which is addressed by a systemic review of MCDA opportunities for LCA tasks in [Appendix C.3-2](#). The MCDA benefits SSAPTI by enabling a cost-effective interface between LCA and the wider strategic context.

The potential of LCA to achieve reliable results depends on project maturity and data quality, reliability, and granularity. The complexity grows from qualitative to quantitative assessment, and from lower to higher project maturity due to an increasing volume of data involved. Formal LCA methods require a) extensive data and resources, which may not fit the scope of a small-scale, superficial study, or strategic projects; and b) 3rd party validation to legitimise the results claimed. Simplified LCA, in its turn, is intended for use with limited resources at any product design stage or for contexts outside of product development. Hence, SSAPTI adopts a simplified MCDA-LCA approach to maximise its relevance.

5.1.5 Intended Users

The SSAPTI is intended for application by any user concerned about the assessment of passenger cabin interiors. While in most cases that would likely be the Operators, DA, or CEM, its application does not imply constraints on the type of user it serves. Naturally, some stakeholders are less likely to use SSAPTI – such as MRO, whose sustainability credentials depend on the equipment, facilities, and processes they use to maintain the aircraft cabin airworthy, and not on the quality of the cabin product itself. [Section 4](#) and [Appendix B.5](#) list typical cabin stakeholders, which shall inform the consideration of impacts on the wider stakeholder landscape when running a cabin assessment - whichever stakeholder the user represents. [Appendix C.4](#) outlines the perspectives and use cases for some key stakeholders who are likely to participate in a cabin sustainability study or design project more often than others.

5.2 Framework Functionality

This section describes the different blocks constituting SSAPTI – both primary and secondary, and outlines the thinking that brought the conception of implementation of that functionality.

5.2.1 Quantitative Assessment Principles

The development of the SSAPTI quantitative block started by following the formal LCA process up to the point where the available cabin data prevents its further application. It starts with the selection or identification of key settings for the unfolding assessment [8]. The following settings apply to SSAPTI:

i. Functional Unit:

The FU (Functional Unit) often used in the aerospace sector is PSK (passenger-seat kilometre) for direct comparison. SSAPTI uses a simpler kg/years FU to assess full product content in a cabin over a given use period expressed in years. For example, a 10-year horizon aligns with the 10% SAF (Sustainable Aviation Fuels) goal agreed by the WEF (World Economic Forum) [12].

The FU must be comparable at the level of assessment performed on a given project. As a minimum, it must be able to compare the different products being assessed e.g., seats versus overhead bins. Some projects, however, may pursue cross-platform comparison – such as relating the impacts of the same product types made by different suppliers and installed onto the different aircraft types across the fleet. In this case, the FU also needs to be divided by the passenger capacity of the aircraft assessed for each product to allow cross-fleet comparison. This is not applied to the case study presented in [Section 5.3](#) since it assesses a generic aircraft and thus, no fleet-level distinction is required.

ii. Impact allocation:

The only kind of objective data used in SSAPTI is material mass allocation to products. The PAS standard for LCA [8] excludes mass and energy allocation metrics and thus, is rejected for SSAPTI application. ISO 14041 [13] offers 4

impact allocation approaches with allocation by mass as the most suitable one for the SSAPTI context, thus justifying ISO 14041 acceptance as its methodological basis since:

- No data is available except product materials and dimensions, limiting quantitative assessment to materiality only and excluding the consideration of upstream/downstream supply processes;
- The tendency of allocation by mass approach to produce disproportionate results may be an issue for a precise LCA study task but is suitable for a ranking task since MCDA accepts some imprecision.

Next, SSAPTI is aligned with formal LCA process flow by selecting the most appropriate LCIA method, database, and IC (Impact Categories) to be addressed using product materiality data available.

5.2.1.1 LCIA Methods

LCIA methods convert the PS (Product System) flows into environmental effects [14] using custom impact chains, substance coverage, and characterization models [15]. The selection of suitable LCIA methods for SSAPTI implementation is informed by:

- **Assessment Focus:** most LCIA methods are generic, but some are dedicated to specific impacts, industries, or purposes. The construction industry uses BEES (Building for Environmental and Economic Sustainability) [16], whereas WAVE (Water Accounting and Vulnerability Evaluation) [17] focuses on water scarcity. These methods are omitted due to irrelevant focus.
- **Measurement units:** while most LCIA methods use common measurement units, some use custom units to assess a unique IC. The EPS (Environmental Priority Strategies) [18] uses kg, persons/year, and instances among other metrics. The ReCiPe [19] uses unique units with popular IC to harmonise regional impact views at a global scale. Material impacts fed into SSAPTI are nondimensionalised on a relative scale using Weitendorf ratios [20] to make different LCIA method inputs comparable.

- **Normalisation Factors:** despite most LCIA methods offering geography-specific normalisation factors, SSAPTI uses the largest scale available by choosing methods dedicated to different regions.

LCIA method selection is case-specific [8] based on the intended purpose of using the LCA task results. This purpose determines the scope of specific IC to be addressed, which in turn drives the selection of suitable LCIA methods. Each IC is perceived to be better assessed by a specific LCIA method and no single method is recognised as the best one for assessing all IC [15]. For example, PEF [21] recommends the IPCC method [22] for climate change, the ReCiPe for ozone formation, and the ILCD for acidification and resource depletion [23].

The variability of nomenclature prevents a combined application of multiple LCIA methods in formal LCA [24]. The simplicity of SSAPTI allows integrating multiple LCIA methods to broaden the perspectives offered. This is inspired by [23], [14], and [15] comparing several LCIA methods to identify the diversion between their outputs. Nine LCIA methods are used in SSAPTI outputs, as presented in [Section 5.3.2](#). SSAPTI users can select the most suitable one for their task by filtering for the preferred method in its “Results Aggregation” sheet in [1], a screen capture of which is also presented in [Appendix C.1-6](#).

5.2.1.2 Life Cycle Impact Databases

LCIA methods use detailed data stored in the LCA databases characterising the far-reaching impacts of individual materials, processes, or semi-finished products used in modern industries. Each entry is dedicated to a particular material, process, or product and selected for SSAPTI based on [8], [25]:

- **Entry Type:** database entries offering the best representation of cabin materials are used. Processes are omitted for model consistency across products due to varying knowledge depths. For example, the inclusion of metalworking processing with aluminium inventory would misrepresent it against the plastics, for which the specific processes applied within the cabin supply chain are unknown.

- **Cut-Off Points:** endpoint cut-off is used to account for the fullest impact available for each material. Choosing other cut-offs would only import partial impacts, thus neglecting SSAPTI's core purpose.
- **Process Allocation:** all products are selected at market cut-off to represent the inputs into the cabin product integration shopfloor gate. Cut-off point selection must remain consistent across different SSAPTI blocks to offer the most encompassing view of the total product impacts achievable.
- **Geographical Allocation:** global allocation is preferred to avoid region-specific distortions, which is in line with the selection logic for the cut-off points seeking to capture the fullest version of impacts. Furthermore, this represents the highly global nature of extended cabin interior supply chains.
- **Domain Specification:** generic LCA databases are preferred for SSAPTI over industry- or application-specific ones to minimise the risk of material or process omission or misrepresentation.

The commercial Ecoinvent database was selected as the source of impacts for SSAPTI due to its 3 features: easy access using SimaPro 9 software, the most complete collection of materials fulfilled with the most likely values for industry-standard processes, and widely recognised validity of its outputs.

5.2.1.3 Life Cycle Impact Categories

The LCIA methods aggregate granular PS flows into the overall effect accumulated across the process chain [25]. Each flow element contributes to multiple impacts, and each impact is created by multiple flow elements [14] resulting in the final damage types designated as IC.

User preferences are typically reflected in IC importance weights dictating its relative contribution to impact aggregation. IC weighting may be analytical against a monetisation basis or a political target; based on expert consensus or literature review [25]. Expert panel approach is too resource-consuming for simplified LCA, while the literature offers no weighting versions specific to cabins.

Cabin expert surveys have shown that cabin stakeholder opinions diverge regarding the different IC priorities and thus, SSAPTI is equipped with the capability to prioritise among the IC by importance. Estimation of the IC importance weights is based on their popularity across multiple industries. The popularity estimate for each IC is informed by [26] and assessed by the DIVAPIME [27] MCDA method. It was identified as the most suitable MCDA method for the IC weighting task using DP characterisation parameters outlined in [Appendix C.5-1](#) with ProBCA [4]. DIVAPIME uses pairwise comparisons like the ELECTRE method [28] to assess each IC pair on a [0, 1] scale. DIVAPIME, however, was tailored for SSAPTI by replacing the survey-based threshold elicitation procedure with a simpler approach that respects the specifics of the cabin interior assessment context:

- DIVAPIME is used to elicit criteria importance weights where no precise values are pre-defined, whereas SSAPTI benefits from precise criteria ordering obtained from [26];
- A simplified LCA approach implies avoiding any kind of surveys or elaborate expert inputs, although this may change if a detailed LCA study follows SSAPTI application on a real industry project.

The descriptivist approach [27] is adopted for the weighting of relative IC importance in SSAPTI. It presumes a pre-defined nature of the order and values that reflect criteria importance, which remain unchanged during the elicitation process. This differs from the constructivist approach of detailed LCA studies where IC importance would have to be adjusted continuously so it represents the perspective of specific users as the investigation of their unique impacts unfolds.

5.2.2 Circular Economy Integration

The CE (Circular Economy) assessment capability implemented in SSAPTI is shown in [Appendix C.1-3](#). It allows estimating the potential for improvement in cabin design to lower the environmental impact of its materials. This improvement could be achieved by technology, material selection, or legislation. Inspired by

appropriate lifetimes principle [29], SSAPTI CE block uses the MCI (Material Circularity Indicator) methodology [30] tailored to reflect the CE benefit as an effective design life extension using:

5.2.2.1 “R-Value” parameter

The SSAPTI uses a custom “R-value” parameter that embodies an MCDA-CE hybrid. There are 8 options titled “R#” describing the possible fate of cabin material post-dismantling. Two unique “Rx” utility values are assigned to each “R#” fate option of each material, which represent the benefit of each fate option to the environment and the user. Where a fate is impossible or not viable for a material from the current’s user’s point of view, “0” R-value is assigned. These R-values impose utility function shapes after MAUT (Multi-Attribute Utility Theory) principles [31] used e.g., in PROMETHEE methods [28]. The R type values are devised using [5], [22], [32], [33] to cover the full breadth of EOL fates available.

i. Sustainable Benefit (Ra):

The first value (Ra) is generic and represents the environmental benefit produced by the material fate applicable. It is represented by a Gaussian (S-shaped) value function with a negative gradient: the perceived sustainability benefit is non-linear across the fates and falls with subsequent fate types. The lowest environmental utility is 0 since no action implies no effect due to circularity opportunities.

ii. Strategic Benefit (Rb):

The second value (Rb) represents the case-specific benefit e.g., to an airline. Rb utility modelling is inspired by [34], delivered at a lower fidelity level by replacing a continuous value model with 8 discrete scores for each R#. The minimum strategic utility is 1, which prioritises sustainability over strategy in SSAPTI so any option offering a sustainable benefit remains visible even where the strategic benefit is low. Rb is represented by a non-monotonic gaussian utility function to express the divergence between the environmental and business perspectives. For example, R1: Refuse benefits the environment by rejecting the product, but is detrimental to airline business by removing value-generating levers [35].

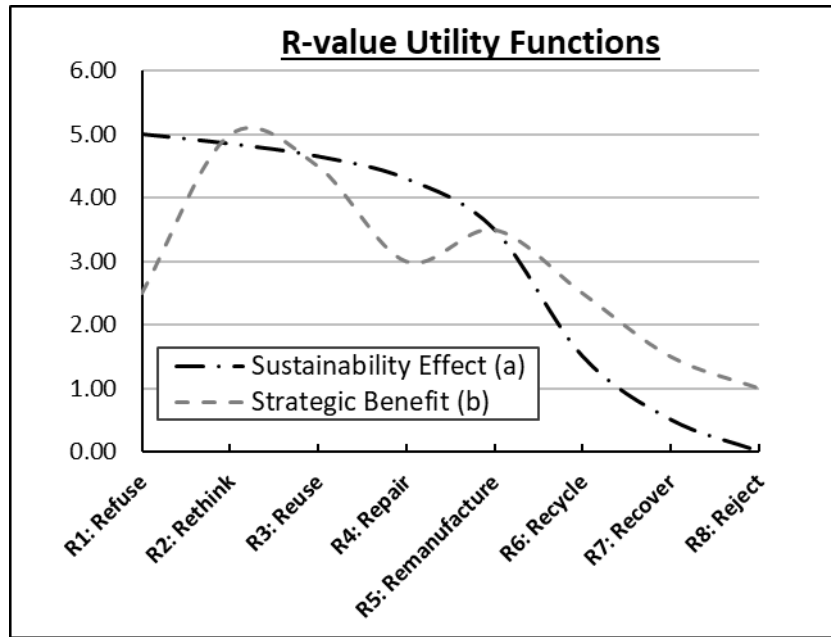


Figure 5-1: R-value utility function shapes for SSAPTI CE

The definition of R# types and the associated Ra & Rb values is presented in [Appendix C.7](#). The utility function shapes resulting from Ra and Rb definition are presented in [Figure 5-1](#) for all R types.

5.2.2.2 “D-Factor” parameter

SSAPTI model invites the consideration of material recycling but does not account for its potential destination. Even if a material can be recycled, the user may be unable to find a buyer and would have to reject the circular strategy for it [6]. The supply-to-demand ratio for recycled materials is normally reflected using the A-factor defined in [21], reversed to make the “D-factor” (demand/supply ratio) in SSAPTI. It assigns a lower life extension effect to oversupplied materials in both open-loop (sell the recycled material elsewhere) and closed-loop (return it into cabin supply chain) circularity models.

i. Recycling Efficiency:

Where relevant, recycling efficiency metric accounts for the proportion of recycled material in the new product made with it. Traditionally, efficiency solely reflects the ratio of inputs to outputs, which would be a misleading way to model the

benefit of recycling cabin interiors since airworthiness regulations require that material properties used for new products meet some minimum performance thresholds. This is typically achieved by mixing raw material with recycled output to restore performance. Different materials require varying volume of raw material to achieve this, which must be accounted for by the efficiency parameter. For example, recycled plastics could lose 10% in performance due to lubricants, adhesives, and other impurities mixed into it. Mixing it with 10% of raw plastic to recover properties results in 81% effective recycling efficiency of the final product and not 90%.

ii. Multiple Routes:

Material quantities are manually entered at each R# level to reflect the proportions entering each recycling route. All material has to be accounted i.e., if 10% product weight is recycled and the rest is landfilled then 10% is assigned to R6 and 90% to R8, making the total accounted composition of 100%. This ensures comparability of life extension effects due to circularity between the different products.

The CE benefits are maximised by reviewing material fates beyond single user's perspective and modelling multiple relevant recycling routes. This is accounted for by the multiples of product mass e.g., 300% mass means that some material feeds into 3 separate routes during its extended life, where each route may be applied multiple times (life loops); an example is provided in [Section 5.3.2.5](#).

Effective product life extension is obtained by pulling Ra and Rb outputs from all 8 R# routes into a single value. The contribution weights are used to reflect the user's strategic preference and may be unique for each product. For example, an airline may see seat recycling strategic impact above that for insulation blankets. The formulae for calculating CE final effect are listed in [Appendix C.7-2](#).

5.2.3 Qualitative Assessment Approach

The quantitative assessment of cabin sustainability is limited to product materiality and does not duly represent the wider context informing cabin stakeholder supply chain and business strategy decisions. In the non-theoretical product design or improvement projects, however, it is imperative to consider the broader business perspective so that technically feasible solutions are also viable strategically. For example, a scoping assessment for a subsequent formal LCA study must rely on the business value of products to justify investment in making them better. In a cabin, for example, this value may include direct exposure to passengers and subsequent effects on their willingness to pay, satisfaction, and loyalty; or product maintainability costs. The capability to consider product impacts beyond materiality is implemented as qualitative assessment blocks in SSAPTI to make it truly holistic, including Qualitative LCA ([Appendix C.1-4](#)) and Strategic Assessment ([Appendix C.1-5](#)) blocks addressing the strategic risks.

5.2.3.1 Qualitative Life Cycle Assessment

While product materiality may be identified by direct observation or measurement, product life cycle has to be assessed using expert-driven qualitative evaluations in a typical cabin assessment study targeted by SSAPTI. A 6-stage cabin product life cycle is tailored from [10] as a repetitive sequence of 5 generic steps, each covering a range of effects and not any single metric like in formal LCA:

- i. **Transport:** product delivery to facilities within the given life cycle phase

Fuel consumption is typically used for assessing the impacts of Transportation, which is dependent on transport mode, distance, routes, and local regulations. In SSAPTI, it also accounts for transportation effects on the product and its components given the fragile nature of some cabin content. For example, aluminium transport receives a score of 1 due to its damage tolerance, while luminescent light tubes score 5 since careless transportation would require up to 100% replacement in case of an accident.

- ii. **Store:** retain the feedstock/components at the facility until it is used

Storage conditions may have a critical impact on material qualities and subsequently product fit for further use. For example, inadequate packaging of seat cushion foams for high-humidity environment storage may cause their properties to deteriorate [36]. It may also increase insulation blanket weight due to water absorption [37], rendering it discarded and leading to extra shipsets ordered. Both these items score 5 for the storage criterion, while the metallic parts resistant in the short-term score 1.

- iii. **Process:** the core activity done on feedstock within given life cycle stage

The specific process steps differ for each phase depending on its unique nature. For example, pre-operations phases are concerned with transforming materials into parts and then a complete product. The core factors affecting the sustainability impact scoring of the phase processing activities include:

- a) **Complexity:** approximate number of actions required to finish a process and the extent of streamlining applied to the sequence of these actions
- b) **Needs:** inputs required to perform the actions involved in process delivery
- c) **Efficiency:** overall feedstock-to-product ratio delivered by a process

The higher resource requirement in leads to a higher score assigned to its impact.

- iv. **Deliver:** produce items, validate fitness for use in the subsequent phase

Product delivery generally reflects the output quality for a product (e.g., seat) or the completion of some activity (e.g., installation of the seats into a cabin). The higher difficulty of delivery receives a greater score e.g., products requiring a complex certification programme or susceptible to multiple scrap and re-do iterations would score higher than those normally delivered first-time right.

- v. **Ethics:** non-technical aspects affecting the actions, processes, outputs

Corporate ethics generally reflect the managerial practices exercised by stakeholder organisations e.g.:

- A location known for low staff morale or inadequate communication is more likely to produce low-quality products and thus, components made by such would receive a score 5 to indicate concern;
- Companies that adhere to best practices will likely be on-track to sustainable action and thus, score 1 is applied to indicate the low probability of environmental issues caused by their internal politics.

Each product is assessed against each life cycle step using the nominal scores defined in [Section 5.2.3.3](#). Importance weights are applied to each life cycle step as defined by pairwise comparison within each LCA phase using SC (Sum of Contributions) MCDA method [38] identified using ProBCA [4]. The calculation was tailored from [35] to reflect the relative weights of life cycle steps.

The baseline version of SSAPTI [1] suggests the baseline comparisons of life cycle steps. These reflect the generic outlook at the LC stages, for example: storage impacts are considered more critical in the pre-operation phases (before the material is used to manufacture a high-quality product) than after it is dismantled. Qualitative assessment of EOL storage impacts, however, is not discarded since it affects the ability to re-sell products into further loops, which is one of the highly effective EOL strategies. The user may change these baseline comparisons to fit with their specific project context or purposes.

The importance weights derived for each life cycle step can be adjusted by thresholds to constrain their differential contribution. Threshold application uses a calculation approach identical to that presented in [Section 4](#) using the formulae borrowed from [35]. LCA scoring aggregation is adjusted by product mass due to its vital effect on life cycle impacts. Without thresholds the extreme weights may differ by a factor of 25, thus rendering some steps negligible. Since all steps defined for Qualitative LCA bear some significance, it is advisable to keep the imbalance of contributions within a 10-fold difference.

5.2.3.2 Strategic Criteria

The assessment of product qualities affecting stakeholder business or operational strategy follows the design drivers defined within the HCCA framework described in Section 4. SSAPTI strategic criteria are directly imported from [35] (except for the Sustainability driver) along with design driver and factor weights and thresholds. Scoring aggregation for the strategic assessment does not use product masses since product importance may be fully independent of its mass. For example, some light-weight products or components may affect passenger experience and cabin perception significantly due to their direct and constant exposure to passengers. Whenever SSAPTI is used, the applicability of the strategic criteria and their importance weights shall always be checked and amended as necessary to represent the context and purpose of a specific assessment task or improvement project appropriately.

5.2.3.3 Qualitative Evaluation Scoring System

Formal LCA methods do not include a qualitative layer of assessment and are strictly objective by definition, with data gathered from across the supply chain for the model. SSAPTI includes a qualitative layer as a way to compensate for the lack of a complete and objective process and supply data, and to add functionality beyond formal LCA methods. Unlike formal LCA, it allows the integration of the user's views, priorities, or limitations without a detailed interaction with product supply chain. It only uses a single source for standard material and process impacts stored in the Ecoinvent database with no further case-specific modelling, which is an acceptable level of accuracy to enable SSAPTI assessment.

SSAPTI qualitative assessment modules use a common scoring scheme to allow the expression of subjective opinions provided by relevant experts in the absence of objective measures reflecting the qualitative performance of cabin products. This scoring scheme is applied by filling the appropriate values into the evaluation tables provided in respective SSAPTI LCA and Strategic assessment sheets.

SSAPTI qualitative scoring scheme features a set of pre-defined nominal values across 3 dimensions: evaluation, bias, and confidence. Higher scores represent a greater level of strategic risk and life cycle resource involved, which drives the focus of potential design or improvement activities when the scores are aggregated. Five discrete scores are defined on a [1, 5] scale adopted from [39].

Qualitative assessment is performed by gathering subjective evaluations from experts involved in the project. These evaluations may be characterised by uncertainties that typically come in two forms:

- **A lack of consensus:** multiple experts may express different opinions on the same issue, resulting in a multitude of evaluations with no further basis to discern which ones better reflect the reality;
- **A lack of knowledge:** when assessing a particular issue, an expert may have a vague idea about its state of affairs but struggle to pinpoint the precise qualitative value with sufficient confidence.

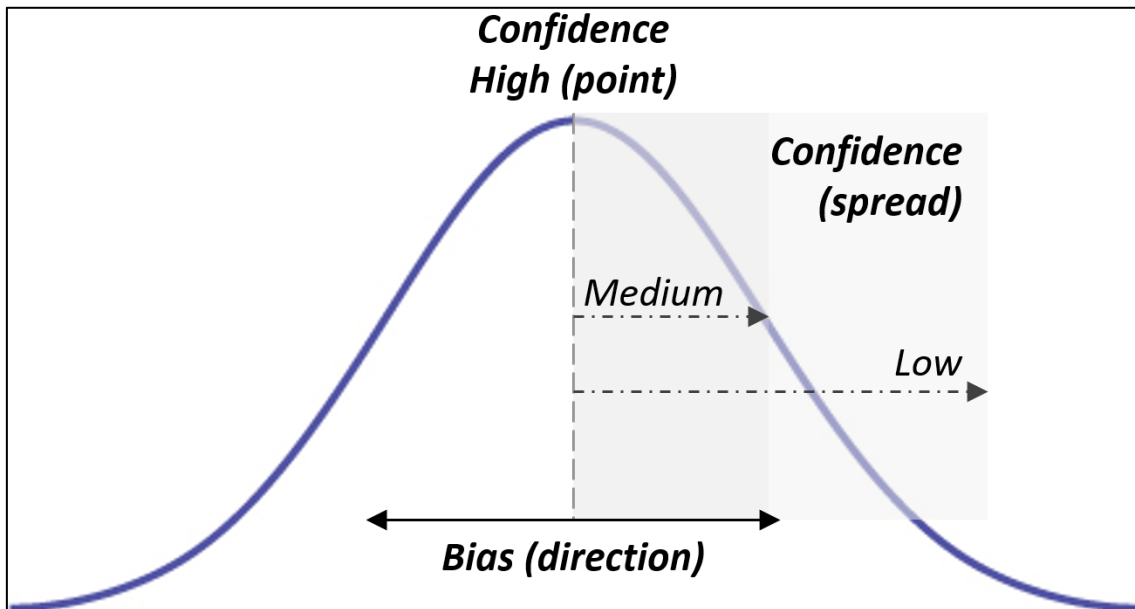
In SSAPTI, the basic 5-point scoring approach is extended with two bespoke adjustment parameters reflecting expert bias and confidence levels. These parameters are used to address the two uncertainty types reflected above, as justified in [25] and presented below with their relevant rating schemes:

- **Bias rating (B):** reflects the respondent's belief about the likely data diversion tendency by driving the adjustment of the evaluation score entered towards a larger or a smaller value:
 - **Low bias** indicates that the actual product performance against the given criterion is likely to be lower than the expert-suggested evaluation score, but not low enough to warrant the assignment of the next smaller evaluation score. For example, an expert may suggest that a solution for luggage storage scores 3 points in affecting the passenger experience criterion and feels it may be slightly lower than that, but not low enough to assign a score of 2.

- **Medium bias** indicates that the actual product performance in the given criterion is likely to match the evaluation given by the expert except for the extreme cases (score 1 or 5). The idea behind the medium bias rating holds that when an expert assigns an extreme score with imperfect confidence, the reality is likely to diverge from their extreme evaluation. The lower the confidence, the stronger the actual product performance is likely to be in balance with the average of all other products being assessed (i.e., closer to score 3).
- **High bias** indicates that the actual product performance in the given criterion is likely to be higher than the score suggested by an expert, but not high enough to assign the next larger evaluation score.
- **No bias** can only coexist with high confidence as described below.
- **Confidence rating:** reflects the certainty level in DM response by expanding the diversion from the suggested evaluation score in presence of bias:
 - **High confidence** allows no diversion from the evaluation score provided by the expert so it contributes to the calculation of the overall product performance with no adjustment.
 - **Medium confidence** rating applies a moderate diversion from the original evaluation score provided by the expert where they express a bias. For example, where an expert assigns an evaluation value of 3 points with medium confidence and suggests that the product may perform better against the given criterion then its resulting contribution will be 3.25 points.
 - **Low confidence** rating suggests that actual product performance may significantly differ from the indicative evaluation score assigned. This may occur in situations where an expert appreciates their insufficient knowledge in relation to the criterion being assessed and only provide their subjective estimate. This may also happen when the opinions from multiple experts exhibit a high level of variability so the assigned

score tends to indicate the opinion of the more senior experts or those whose operational area warrants a higher level of trust.

The basic principles used in SSAPTI qualitative assessment scoring scheme, including the meaning of its adjustment parameters, is illustrated in [Figure 5-2](#).



[Figure 5-2: Qualitative scoring value shape with adjustment parameter effects](#)

The above-presented definition of adjustment parameters is not uniform across the baseline scoring values. Identical combinations of confidence and bias ratings produce adjustment effects of different magnitude depending on the score, with greater effects applied to the extreme scores (1 or 5) and softer effects at the medium score (3). The adjustments are modelled using fuzzy MCDA to allow the conversion of vague or contradictory inputs into precise maximum-likelihood values. ProBCA taxonomy [4] presented in [Section 3](#) was used to identify the MCDA method most suitable for processing biased uncertainties for SSAPTI purposes using the settings listed in [Table C.5-2 \(Appendix C.5\)](#). ARAS-F (Fuzzy Additive Ratio Assessment Method) [40] method was identified to be the most suitable basis for SSAPTI qualitative assessment. It was tailored by only borrowing the fuzzy processing component and omitting the AHP-like matrix element since pairwise comparison of product alternatives against more than 25 criteria would be excessively cumbersome for SSAPTI targeted applications.

Qualitative scores (column S) and adjustment ratings (columns C, B) are assigned for each product against each criterion directly into the respective SSAPTI qualitative assessment sheets. These inputs are processed by the automated functional block in [1] acting as a black box i.e., the user shall not interact with it. It produces the resultant value (column R) using the conditional “if ... then ...” statements, integrating the analytical formulae observed from the ARAS-F method. SSAPTI qualitative scoring scheme implemented in functional block is summarised in [Table 5-1](#) and illustrated graphically in [Appendix C.6](#). Note that column R in qualitative assessment matrices is not related to the R-value definition used in SSAPTI product circularity assessment block.

Table 5-1: Fuzzy scoring scheme used for SSAPTI qualitative assessment

Score = 1				Score = 2				Score = 3				Score = 4				Score = 5			
S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R
1	L	L	1.50	2	L	L	1.75	3	L	L	2.50	4	L	L	3.25	5	L	L	4.00
1	L	M	1.50	2	L	M	2.25	3	L	M	3.00	4	L	M	3.75	5	L	M	4.50
1	L	H	2.00	2	L	H	2.75	3	L	H	3.50	4	L	H	4.25	5	L	H	4.50
1	M	L	1.25	2	M	L	1.75	3	M	L	2.75	4	M	L	3.75	5	M	L	4.50
1	M	M	1.25	2	M	M	2.00	3	M	M	3.00	4	M	M	4.00	5	M	M	4.75
1	M	H	1.50	2	M	H	2.25	3	M	H	3.25	4	M	H	4.25	5	M	H	4.75
1	H	/	1.00	2	H	/	2.00	3	H	/	3.00	4	H	/	4.00	5	H	/	5.00

The resulting qualitative assessment values are aggregated using the WSM (Weighted Sum Method) MCDA tool [41] by processing all qualitative scores for the given product. The WSM was selected using the parameters reflected in [Appendix C.5-3](#) with ProBCA. These parameters result in 8 candidate MCDA tools suggested by ProBCA, of which the most suitable one was selected by expert judgement to offer the best fit with the purposes of qualitative assessment aiming for efficiency. The total ratings resulting from WSM application to qualitative assessments of each product are used for total product rating aggregation and ranking in the Results Aggregation sheet ([Appendix C.1-6](#)).

5.2.4 Scoring Aggregation

The approach to scoring aggregation used in SSAPTI motivated by [42], which uses the SMAA [43] method to aggregate the individual LCIA contributions into single-score impacts. However, simpler MCDA methods are preferred for SSAPTI to align with stakeholder resource constraints existing in the cabin interiors industry, which is also a typical issue affecting the implementation of LCA projects [44]. The MCDA methods relying on direct scoring are applied whenever possible in SSAPTI, with pairwise comparison approaches only applied where necessary. The MCDA methods that involve complex analytical techniques or require otherwise significant resource are rejected for SSAPTI.

Various combinations of MCDA selection parameters were tested in ProBCA [4] to identify the most suitable method for aggregating the scores from the separate SSAPTI blocks. Originally, the layered nature of SSAPTI architecture has driven the consideration of hierarchical method types, which were rejected eventually due to their elevated implementation complexity. The final version of ProBCA settings offering the best reflection of SSAPTI aggregation context are shown in [Appendix C.5-4](#). It has produced a recommendation of 8 basic MCDA approaches as candidates for SSAPTI analytical basis. These methods allow a direct aggregation of numerical scores and include such methods as COPRAS [45] (COMplex PROportional Assessment), ARAS (Additive Ratio Assessment Method), and WSM. The final preference was given to WSM [41] as the oldest and thus, the most proven method. MOORA [20] method was used to validate the results produced by WSM but eventually omitted from the baseline version of SSAPTI to avoid confusion. While the interim values differ between the two methods, their normalised scoring and ranking are identical and do not affect the final aggregation of SSAPTI scores.

5.3 Framework Application

This section presents a detailed example of SSAPTI framework application to demonstrate its operating principles and sample outputs as described in [Section](#)

5.2. Product data and study context are borrowed from the ATI FlyZero project [2] with several considerations relevant to the case presented:

- Products and materials assessed in this case study resemble the partial content of a typical aircraft passenger cabin based on real products that were physically observed during project work or investigated with assistance from aircraft dismantler companies involved with these products;
- This case study does not aim to assess the full extent of all possible cabin content options since the specific product selection is unique to aircraft types, airlines, and cabin versions that may differ between the individual routes an aircraft is operated on or aircraft age;
- This case study is limited to several products where data could be estimated at a sufficient level of accuracy and confidence to inform a hypothetical study to a sufficient level of representativeness;
- This case study does not claim to represent the most accurate results from the whole of the aircraft cabin interiors industry since its purpose is to demonstrate the operational principles, functionality, and expected outputs of the SSAPTI framework using a small selection of real product examples.

The intended users of SSAPTI – cabin interior stakeholders positioned along its value chain – shall apply it to perform full-scale sustainability assessments of their products. To do this, the low-resolution data for product examples used in the hypothetical case study presented below shall be replaced with detailed material and dimensional data obtained for the actual products investigated. For example, the engineering department at a CEM may pull the information in the SSAPTI inventory table from product BOM (Bill Of Materials). Alternatively, an airline may liaise with product suppliers for detailed product data for the inventory or obtain it through the service manuals held by their maintenance department.

5.3.1 Product Inventory

Cabin products exhibiting higher weight or volume are prioritised to maximise the relevance of the study performed. The data available for the case study presented

in this thesis offered a medium level of confidence and thus, required refinement by estimations based on literature review and expert surveys. Product scoping threshold of 1% by cabin weight or volume was applied following the standard LCA practices [46] to constrain the estimation effort. Any component that constitutes $\leq 1\%$ of the whole PS is omitted from further consideration. The retrieved composition of the 6 cabin products assessed is recorded in SSAPTI inventory (Appendix C.1-1), split into 9 sub-assemblies listed in Appendix C.9-1.

5.3.1.1 Database Matching

Product composition was disaggregated into 20 individual materials in SSAPTI inventory to match the Ecoinvent entries as listed in Appendix C.9-2. Some of the materials that are widely used in passenger cabins are not available in Ecoinvent and thus, their nearest equivalents were identified as follows:

- PEKK (Polyetherketoneketone) and PEEK (Polyetheretherketone) are widely used in cabin interiors; these were replaced by PEI (Polyetherimide) based on [47] and [48];
- NOMEX equivalent material composition is retrieved from [49] as: 51% PA and 49% PF;
- Nylon 6-6 (PA 66) was used instead of Aramid for NOMEX in line with [50];
- Synthetic Leather composition was estimated from [51] as: 20% Cotton, 35.5% PC (Polycarbonate), 40% PU-FF (Polyurethane Flexible Foam), 4.5% PBDE (Polybrominated diphenyl ethers);
- Epoxy adhesive is composed of 82% ER (Epoxy Resin) and 18% DMA (Dimethylaniline).

The exact transformation processes and locations vary significantly for cabin products, thus preventing a reliable guess of the detailed impact chain along their life cycle. Ecoinvent interrogation solely served to identify the materials as received at the CEM door, with baseline pre-processing accounted for in Ecoinvent but omitting any specific impacts associated with cabin product supply chain and life cycle.

5.3.2 Quantitative Assessment

Multiple LCIA methods were considered for SSAPTI by a down-selection process informed by [24], [52], and method-specific references presented on SSAPTI LCIA method selection sheet ([Appendix C.2-1](#)). Nine methods were selected: ReCiPe [19], non-baseline CML-IA [53], EF (Environmental Footprint) [54], EP (Environmental Prices) [55], EPS [18], ILCD [56], IMPACT 2002+ (IMPact Assessment of Chemical Toxics) [57], and TRACI (Tool for Reduction and Assessment of Chemicals and other Impacts) [58]. Various methods are selected to allow the widest possible outlook at cabin product impacts from the different viewpoints represented by each method. For example:

- the ReCiPe method represents the most generalised view on product impacts
- non-baseline CML-IA addresses impacts relevant for the European industry
- TRACI provides a North-American perspective on sustainability impacts
- the EP method offers a view on the monetary impacts
- the IPCC method deeply focuses on the global warming effects

It is not necessary to use many LCIA methods for the purposes of SSAPTI application in the industry. However, these are included in the baseline version of SSAPTI to offer a comparative view on the many LCIA method effective to extend the benefit offered by the presented research work. Any user shall be deliberate in selecting the LCIA methods used with SSAPTI e.g., material impacts calculated using the methods focused on water ecosystem impacts shall be used if this aligns with their strategic priorities.

5.3.2.1 Raw Impact Extraction

Raw impact values are pulled from the Ecoinvent database for materials listed in [Appendix C.9-2](#) using the selected LCIA methods and 1 kg unit mass to ensure a comparable baseline. The impacts retrieved are normalised on percent scale using Weitendorf ratios [20] to remove scaling effects imposed by the different IC units. Example outputs list CFRP as having the heaviest Global Warming impact followed by Aluminium at only 13% of the CFR impact. Cotton leads the

Stratospheric Ozone Depletion impact, followed by PU Rigid Foam comparing at 64% of that, CFRP at 47%, and PBDE at 34%. In this thesis:

- Normalisation on a per cent scale using Weitendorf ratios [20] shows the relative position of each material entry from the Ecoinvent database on a scale from 0% to 100%, and their sum is not 100%;
- Normalisation on a cumulative per cent scale shows the contribution of each item (material, product) to the total effect, and the sum of all scores accumulates to 100% exactly.

Impacts produced by the different LCIA methods diverge on a scale between 3 orders of magnitude to a factor of 3 for each IC even where the ranking order is consistent [15]. This may influence the user's strategy and financial decisions driven by the assessment outputs. For example, a significant difference among product scores may motivate prioritising one product and rejecting another as an improvement priority, but a small difference may lead to both products being prioritised for further initiatives even where their ranking order is unchanged between the two scoring versions. Cumulative percent normalisation is applied to impact aggregation in SSAPTI to mitigate this distortion:

- The highest impact in each IC is always 100% (e.g., CFRP for Global Warming IC in ReCiPe)
- The lowest impact in each IC is always 0% (e.g., Steel for Global Warming IC in ReCiPe)
- Extreme values do not imply that e.g., Steel produces no Global Warming impact and solely reflect the position of a material on a relative scale among all materials assessed
- The interim values indicate the exact position of each material on the minimum-maximum range

Normalised values are imported into SSAPTI supporting sheets marked "s4" for each method. ReCiPe data imported and normalised into sheet s4-vii is presented in [Appendix C.2-4](#) to offer an example.

5.3.2.2 Inventory-Based Adjustment

The normalised material impacts imported into SSAPTI from Ecoinvent are adjusted by the inventoried per-product material masses for each IC on the respective LCIA input sheets. This transition from the generic material impacts to the product-specific view enables a direct comparison of impacts between the individual cabin products assessed within each IC. The original Ecoinvent entries are assembled by cabin materials at this step e.g., Cotton, PC, PU-FF and PBDE feed into a single Faux Leather material.

The IC-specific product impacts then are averaged into the total impact of each product across all ICs by averaging the per-IC product impacts, thereby producing the complete product view within each LCIA method. This procedure is different in cases where some ICs are prioritised over others.

5.3.2.3 Impact Category Weights

The definitions of similar ICs differ between the LCIA methods [26] and thus, need to be generalised to enable a direct comparison of different LCIA outputs in SSAPTI. This is performed in [Appendix C.2-2](#) by combining the IC of identical nature. For example, the 3 granular ecotoxicity IC types reflected to a varying extent in the different LCIA methods are combined into a single ecotoxicity category in SSAPTI.

The IC comparison is informed by [26] reporting their differential popularity. The baseline IC order is based on the frequency of each IC identified as “Required” by the respondents. The average values for “Required”, “Nice to know”, “No Opinion”, and “Low Priority” responses per IC were used to identify:

- **Preference threshold (p):** 23.1% delta between the “Required” and “Nice to know” average values
- **Indifference threshold (q):** 12.3% delta between the “Nice to know” and unimportant averages

These thresholds are a part of the DIVAPIME procedure and are used to define the pairwise comparison values for each IC. This procedure was used to derive the importance weights for each generalised IC in SSAPTI, as presented in [Appendix C.2-3](#). The user may activate IC importance weights by selecting an appropriate option on top of the Quantitative Assessment sheet in SSAPTI ([Appendix C.1-2](#)).

5.3.2.4 Per-Method Aggregation

The impacts accumulated by each LCIA method feed into the Quantitative Assessment sheet for each product and each material to allow a deep comparison of impacts across two perspectives. Per-product impacts are presented in the table below the main table on that sheet summarising product contents, and per-material impacts are shown in the table to the right from it. The last row (per-product impacts) / column (per-material impacts) in these tables present the combined scores averaged across all LCIA methods for each product/material. These offer a generalised view when the user has no preference for a particular LCIA method. These scores feed into the first line of results in [Appendix C.1-6](#).

5.3.2.5 Circular Economy Effects

SSAPTI only considers primary material flows and omits the secondary effects like incinerator exhaust capture for delayed carbon flows to fit with the resource constraints of targeted application contexts. This thesis introduces the new methodology embodied by SSAPTI but does not aim to critically review the existing cabin interior design solutions or discuss the specific routes to its potential improvement. Therefore, no cabin material follows R1 or R2 routes in the circularity assessment for the hypothetical case studied in this section. Should the user wish to review circular redesign effects in SSAPTI, product interdependencies have to be accounted for. For example, replacing cabin

insulation blankets with improved linings with a 50% weight penalty must be accounted by either:

- Assign 100% of insulation blanket material as R2: Re-Think positive impact, but add the respective negative impact (e.g., R7: Recover) to Sidewall Panels item equating to 50% of blanket weight; or
- Keep sidewall panels unchanged, but add the new insulation product as a separate item to assess.

The logic for other material routes needs to be decided on a case-by-case basis in a similar manner. The portion of material assigned into each circularity route needs to be sense-checked against the existing reality in the cabin interiors business since the ability to follow a circularity route does not guarantee its successful utilisation. For example, the following considerations informed the assignment of circularity routes for the overhead bins and sidewall panels, with sense-checking comments:

- **R3:** bins and wall linings can be re-sold to other operators without repair (100% of material is assigned to R3: Reuse route). However, there is no demand from other operators.
- **R3, R4:** the undamaged portion of bins can be sold to other operators (50% to R3) and the damaged portion could be repaired and re-sold (50% to R4: Repair). This is a more realistic scenario, but may need tweaking the proportions assigned to R3 and R4 based on the aftermarket study.
- **R5:** the components suitable for remanufacturing could be retrieved from the bins and sidewall panels and returned into the manufacturing loop (unknown content to R5). This approach is not viable due to insignificant benefits returned by challenging repairs of damaged honeycomb.
- **R6:** the material could be attempted to recycle after its first use (100% to R6: Recycle). However, this route is not viable since there are currently no effective recycling routes for NOMEX.
- **R6:** a small amount of aluminium used in the bins and sidewalls for thin brackets could be retrieved for recycling (minor content to R6). This route is

not viable due to insufficient material amount to warrant an attractive business case unless other aluminium parts are recycled with lining brackets.

Based on the considerations and sense-checking presented above, a custom re-use scenario was hypothesised for illustrative purposes by combining several routes into the baseline SSAPTI model:

- Re-sell all items after 1st use, the next operator re-sells undamaged bins (assume 50%) again after use: a total of 150% to R3, assume a rise in demand due to the sustainability push by the operators
- The other half of the items are repaired and re-sold by the 2nd operator after use cycle: 50% to R4
- The whole set of linings gets another life through another repair and re-sell cycle: 100% to R4
- All bins are incinerated by the 3rd operator after a total of 3 life loops: 100% to R7 (Recover)

An environmentally-conscious CEM could specify such far-horizon circular schedule for their products as best practice and design it with features and materials to facilitate the suggested recirculation.

5.3.3 Qualitative Assessment

Once the quantitative assessment of cabin interior sustainability is complete based on product material content, SSAPTI offers its user to take a wider perspective enabled by qualitative assessment blocks:

5.3.3.1 Qualitative LCA

The qualitative LCA scores provided in baseline SSAPTI version reflect author opinions based on the research outputs and expert interviews. The user may revise it by reviewing the operational records of their organisation and consulting its internal departments when assessing each life cycle stage. For example, procurement may inform component supply scores, engineers may assess

production stage scores, maintenance function could assess the installation and dismantling activities, and so on. The scores must be based on case-specific life cycle circularity scenarios e.g., for the seat structure:

- Refurbish and repair to re-sell: rejected since the assessed seat is outdated and unlikely to re-sell
- Remanufacture: rejected due to a prohibition by the current airworthiness regulations
- Recycle raw material for secondary (non-aerospace) use: accepted as the most viable option

The LCA scores in Appendix C.1-4 are built from case-based scenarios with assumptions, for example:

- It is assumed that metallic seat frame elements are remelted into raw materials with updated mechanical properties and sold into other industries.
- Cabin floor panels are also made of aluminium, but standardisation and interchangeability make them easy to re-sell unlike model-specific seat frames. However, there is no reason to dismantle floor panels until the aircraft reaches its design life; the only case when useable floor panels could be re-sold is if the aircraft is scrapped for any reason.
- Composite structure scores 1 with high confidence for EOL Transport since careless transportation imposes no risks on products destined for incineration.
- Overhead bins may be re-sold complete or disassembled and re-sold as spares if there is a buyer. They score 5 on EOL transport with low confidence to reflect the potential criticality of damage.
- Unlike other life cycle aspects, Corporate Ethics is supplier-dependent and not product-dependent. All products score 3 with medium confidence and bias for installation and maintenance phases. It can be performed anywhere in the world by any MRO with unpredictable corporate practices.

All LCA scores are justified by case-based logic, which is not presented in this thesis due to subjectivity. Its justification is outside of the scope of this thesis since the hypothetical case study presented solely serves as a demonstration of SSAPTI capabilities and does not pursue cabin design quality evaluation.

5.3.3.2 Strategic Assessment

The approach to assessing products against the strategic criteria is identical to qualitative LCA, but requires a heavier involvement of the business-critical functions such as sales or business development. Component-specific rationale informing the scores in baseline SSAPTI version reflects subjective author views on the current industry context. An unobvious example is cabin floor panels:

- **Ambience:** score 2. Despite not visible to passengers (score 1 expected), its flatness impacts the overall cabin appeal while bumps or dips affect occupant impression and satisfaction subliminally;
- **Crew Operations:** score 3. An uneven floor would obstruct smooth operation of cabin trolleys and may even cause injuries to the crew if trolleys do not roll as expected in adverse flight conditions.

Strategic scores shown in [Appendix C.1-5](#) reflect the current product standard and do not consider the potential design improvements in the future. For example, there is no current link between the metallic seat frame and communications informing in-flight service provisioning by the crew (scores 1 with high confidence). The future seats, however, may include various sensors measuring passenger weight and dynamics to inform the crew about one's activities and needs, resulting in a different set of scores.

The assessment of current cabin standard sets the benchmark for informing the future NPD or cabin assessment projects. SSAPTI inventory may include baseline product options along with new designs. Strategic scores are justified using case-based logic omitted from this thesis due to scope irrelevance.

5.3.4 Assessment Outputs

Once all three assessment blocks are complete, SSAPTI aggregates the resulting scores in a single table on the "Results Aggregation" sheet ([Appendix C.1-6](#)) using the WSM procedure. A cumulative, easy-to-read table is used to summarise all results from the three analytical blocks. It is supported by a graphical representation of product priorities to drive the investigation of their

detailed contributions and enable drawing the conclusions and actionable insights. [Appendix C.1-6](#) shows this summary sheet resulting from the hypothetical case study describe in this thesis, which uses product data available through the FlyZero project. A numerical extract of SSAPTI results is demonstrated in [Table 5-2](#) with baseline case settings i.e.: linear life cycle, equivalent IC importance, 10-year study horizon, combined LCIA scores.

Table 5-2: SSAPTI scores aggregated for the case study assessed

Aggregated Assessment Results			Seats				Cabin Linings		Bins	Cabin Floor	
LCIA Method selected:	Combined Scores		i. Metallic Structure	ii. Composite Structure	iii. Comfort Interfaces	iv. Miscellaneous Components	v. Sidewall Panel	vi. Insulation Blankets	vii. Overhead bins	viii. Carpet	ix. Floor Panel
1. Quantitative Assessment	Contribution weight A:	60%	9.6%	24.7%	29.7%	4.2%	1.8%	12.7%	11.1%	3.8%	2.5%
3. Qualitative LCA	Contribution weight C:	10%	15.4%	9.1%	26.2%	6.1%	7.8%	10.7%	17.2%	2.7%	4.7%
2. Strategic Assessment	Contribution weight B:	30%	8.8%	15.5%	13.8%	11.4%	11.1%	7.1%	13.9%	10.9%	7.4%
RESULTS	Aggregated Performance		9.9%	20.4%	24.5%	6.6%	5.2%	10.8%	12.5%	5.8%	4.2%
	Component-Level Priorities		5	2	1	6	8	4	3	7	9
	Distance Between Priorities		0.9%	4.2%	N/A	3.3%	0.6%	1.7%	7.9%	0.8%	1.0%
	Product-Level Performance		61.4%				16.0%		12.5%	10.0%	

The visualisation of SSAPTI outputs aggregated through the entire cascade of settings and contributions is presented in [Figure 5-3](#), which simplifies the perception of the resultant product priorities.

The user can adjust block contributions in the results table to match their strategy or task context. In the example shown, quantitative assessment is judged the most important due to heavy environmental focus of the FlyZero project where the data for this case study was pulled from. Qualitative LCA is weighted lowest despite also addressing the environmental issues since it is subjective and better addressed by a formal, objective LCA effort. An LCA-wide study is also outside of the use cases targeted by SSAPTI so deprioritised in the assessment. The Strategic block has medium weight due to its crucial importance to output interpretation and decision-making, despite also subjective. The final scores drive further effort prioritisation based on product ranks and preference intensities. The sensitivity assessment of SSAPTI parameters and potential applications of its outputs are discussed in [Section 5.4](#).

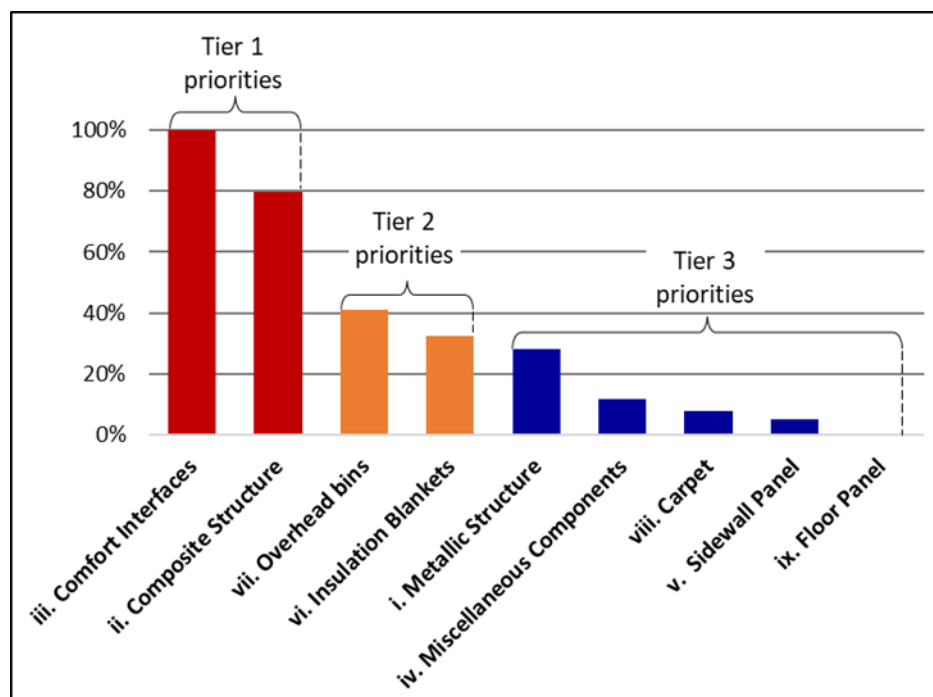


Figure 5-3: product priorities derived in baseline SSAPTI version

5.4 SSAPTI Discussion

The overall investigation cycle of SSAPTI leads to switching the perspective on sustainable quality of the cabin from product-based to impact-based view to improve the search for suitable solutions. Without this transition, granular impacts on part or material level are often overshadowed by engineering bias (prioritising heavier materials) or business drivers (prioritising costly materials) alone at product level. This makes it important that SSAPTI application to real projects involves a diverse range of functional or stakeholder representatives from organisations along product supply chain.

Although SSAPTI application process presented in [Appendix C.8](#) is linear, the broader flow it enables is circular. The use of unrefined cabin product data allows retrieving the relative top-level impacts, which then drives further investigation of the more detailed impact mechanisms and their sources. Formal LCA methods can only perform such studies at maximum depth to be reliable. If the detailed and representative data is not available from across the supply chain, the

difference between the full LCA study and SSAPTI is negligible – with LCA being also unable to offer a set of strategic insights provided by SSAPTI. It remains economically viable to use a simpler approach for many iterations before the user would consider running a full-scale LCA instead. This makes SSAPTI convenient and economical to apply in many sustainability assessment contexts in the industry, keeping its following qualities in mind:

5.4.1 SSAPTI Qualities

The SSAPTI was tested to offer a set of qualities distinguishing it from the formal LCA approaches existing, making it a member of the simplified LCA domain. It retains the link to the standard LCA process by allowing the comparison of cabin assessment outputs produced by the 9 different LCIA methods to inform user's strategy based on what IC are prioritised by their organisation.

5.4.1.1 SSAPTI Capabilities

The core capability enabled by SSAPTI is to identify the core problematic areas across the whole cabin, which are summarised in its results table ([Appendix C.1-6](#)). Two aggregation options are available:

- **Series aggregation:** qualitative scores may be used as multipliers of quantitative values to ensure that strategic importance and life cycle challenges act as factors to quantitative product priorities;
- **Parallel aggregation:** qualitative blocks can be added to quantitative outputs separately to ensure that product materiality does not distort qualitative views, which is used in SSAPTI baseline version.

The value system modelled implies that qualitative perspectives have a lower influence level on the overall result. For example, products that use problematic materials should be prioritised even where they score low in qualitative blocks i.e., pose no life cycle challenges and are not critical to business. This ensures that sustainability angle is prioritised above others in line with SSAPTI motivation.

SSAPTI allows a cost-efficient assessment of cabin sustainability where formal LCA is impractical. It can be used not only to inform prioritisation for subsequent study or improvement, but also for product development activities. For example, it could drive collaborative creation of better products between multiple cabin stakeholders by considering a wide range of relevant qualities beyond weight.

The framework also allows the comparison between existing and potential cabin solutions, including the option of not changing anything or not using a product. This may be a better option depending on the availability of sustainable technologies, business models, or the opportunities to adopt them.

The practical value of SSAPTI is delivered by assisting the in-house experts in gathering the material inventory. Hidden behind the disintegrated interdepartmental communication and confidentiality agreements discussed in [Section 4](#), this data is often unavailable for defining game-changing projects.

5.4.1.2 SSAPTI Limitations

The key value offered in this section is the delivery of a new framework for assessing the sustainability of cabin products and a detailed outline of its application principles. This paper does not attempt to introduce any formal LCIA methods, nor it allows adding new material or process entries into LCIA databases like Ecoinvent. It is, however, observed that LCA databases do not offer a complete material coverage to date, and should be expanded to list the materials used in aircraft cabins e.g., Nomex.

Although SSAPTI is well fit for assessing the cabin content in various transport modes, the case study presented uses the data obtained from outdated or hypothetical product samples that have to be replaced with representative data for any real project. It does not attempt to offer a detailed outline of products and materials used in aircraft cabin interiors nor to indicate their real quantities. This study solely focuses on fixed cabin equipment i.e., that constituting a part of OEW. It excludes expendables (catering, amenities, blankets, etc.) due to a different mentality required to assess the sustainability of such products where

the majority of impact is created by packaging and logistics, or which extend into other industries like agriculture (for catering) or crop growth (for natural textiles or bamboo cutlery).

5.4.2 Sensitivity Analysis

The SSAPTI framework includes several adjustable parameters allowing the user to fine-tune the model in line with the specific case context or the alternative scenarios considered. While the contributions from the three assessment blocks will have the primary effect on SSAPTI outputs, it is important to test how the nuancing of optional parameters affects the aggregation of final results.

Table 5-3: SSAPTI Sensitivity Assessment – Baseline Version Settings

Sheet	Cells	Value	Rationale
Cabin Inventory	All	Baseline	Raw material inventory as obtained or deduced for the individual products during the ATI FlyZero project
Sustainability Assessment	E3	Equivalent	Baseline view accepts equivalent IC importance
	K2	10	Baseline horizon assumes operator's ownership for 10 years
	K3	Linear	Baseline represents a conventional linear product life cycle
Results Aggregation	C3	Combined	Baseline case represents average view from all LCIA methods
	D5	60%	Baseline SSAPTI version is focused on quantitative sustainability impacts, with medium focus on qualitative assessment against the strategic criteria and deprioritised qualitative LCA contribution (<i>rationale in Section 5.2.4</i>)
	D7	10%	
	D9	30%	

The baseline SSAPTI version output is captured in [Appendix C.10-1](#) using the settings outlined in [Table 5-3](#). It provides a common benchmark for comparing the variations of parameter settings produced by the scenarios studied. These settings remain unchanged throughout the study, except for the specific value adjustments that simulate various setting scenarios, as specified in tables below.

5.4.2.1 Differential Block Contributions

The first scenario tested in SSAPTI sensitivity study simulates the differential prioritisation of the three analytical blocks representing the different viewpoints on the products being assessed. The results of the three tests performed are presented on the three graphs presented in [Appendix C.10-2](#).

i. Quantitative impact domination:

The first scenario simulates the case when the user is heavily focused on the objective sustainability impacts created by cabin materials, and has no agenda to involve qualitative assessment in the final decision e.g., when choosing the products to improve. The baseline settings are adjusted as follows:

Table 5-4: SSAPTI Sensitivity Setting – Quantitative focus

Sheet	Cells	Value	Rationale
Results Aggregation	D5	90%	Quantitative-heavy view: <ul style="list-style-type: none">• 90% assigned to Quantitative impact contribution• 5% assigned to LCA and Strategic contributions each
	D7	5%	
	D9	5%	

The purpose of this simulation is to test whether a sustainability-heavy viewpoint will differ from the qualitative-heavy viewpoints. The case simulated here is not significantly different from the baseline settings and thus, no significant changes from baseline are expected.

Indeed, the main difference observed in the quantitative-heavy simulation is the swapping of the rank positions between Overhead Bins and Insulation blankets; sensitivity to quantitative focus is proven.

ii. Qualitative LCA domination:

The next scenario simulates the case when the user wants to focus on qualitative LCA assessment e.g., to have a rough appreciation of what results a full-scale

formal LCA study is likely to produce besides the impact of quantitative sustainability impacts. The baseline settings are adjusted as follows:

Table 5-5: SSAPTI Sensitivity Setting – LCA focus

Sheet	Cells	Value	Rationale
Results Aggregation	D5	5%	LCA-heavy qualitative view: <ul style="list-style-type: none"> • 90% assigned to Qualitative LCA impact contribution • 5% assigned to Quantitative and Strategic contributions
	D7	90%	
	D9	5%	

Comfort interfaces rank 1st due to the large number and high relative complexity of the processes involved in assembling the multi-material seat cushioning and lumbar support elements, as observed in the “Qualitative LCA” sheet. These activities are known to consume the biggest portion of production resources at the CEM and also require particular care in transportation and storage activities to retain component quality in the upstream portion of its supply chain. This ranking informs the drive to choose simpler design solutions that use fewer components and thus, offer more efficient assembly processes.

The other products rank noticeably lower than comfort interfaces, thus refocusing the top priority on a single product and rendering all other products as 2nd and 3rd-tier priorities. The composite structure, which is among the tier 1 priorities in the baseline case, ranks among the tier 3 priorities in the LCA-focused assessment because composite parts are delivered to the CEM in a pre-manufactured state and require limited storage and production resources. These differences indicate noticeable sensitivity of the results to LCA-focused aggregation, thus proving the significance of its weighting.

iii. Strategic Assessment domination:

The last scenario simulates the user’s focus on the strategic product importance e.g., when the most strategically significant products need to be identified:

Table 5-6: SSAPTI Sensitivity Setting – Strategic focus

Sheet	Cells	Value	Rationale
Results Aggregation	D5	5%	Strategic-heavy qualitative view: <ul style="list-style-type: none"> • 90% assigned to Qualitative LCA impact contribution • 5% assigned to Quantitative and Strategic contributions
	D7	5%	
	D9	90%	

Contrary to the LCA-focused view, the Strategic bias now places 3 products as Ties 1 priorities. It aligns with the expectation to see that more products have a critical impact on the user's business strategy about a passenger cabin since most products are located in the passenger's direct sight or subject to direct passenger interaction. Composite structure and comfort interfaces have a direct impact on passenger comfort and perception, two of the most important strategic criteria for cabin success. The overhead bins are only operated over a short time period, but may also affect passenger experience; also, they occupy a large portion of the passenger's view, thus impacting the overall cabin ambience. The sensitivity to strategic contribution is proven by significant re-tiering of priorities.

5.4.2.2 Quantitative Assessment Settings

The next area of the sensitivity study investigates the effects of adjusting the parameters applied to SSAPTI quantitative impact evaluation. The settings from Section 5.3.2.1 – Test A (Block Contributions – Quantitative Domination) are applied to all tests in this sub-section to focus on the contributions from the quantitative impact assessment block (Quantitative block = 90%, qualitative LCA and Strategic blocks = 5% each). The results are presented in Appendix C.10 – Figure C.10-3 subset, which only shows quantitative block contributions but omits those from qualitative blocks as unaffected by IC weighting.

i. IC Importance Weights:

Based on the user's choice, the ICs may be considered equal or differentially weighted by importance. Since the baseline case assumes equal IC importance, the following setting is updated for this test:

Table 5-7: SSAPTI Sensitivity Setting – IC Importance Weights

Sheet	Cells	Value	Rationale
Sustainability Assessment	E3	Weighted	To test the effects of differential IC importance weighting on the aggregation of overall results

The effects of weighted IC importance on aggregation results are shown in Figure C.10-3a. The resultant ranking of products remains unchanged, with several product impacts updated within a few percent. The investigation of IC importance weights, however, indicates a 6-fold difference between the largest and the smallest weights used to assess the IC importance. Although a significant effect on aggregated results is expected, its absence may be explained by the heavy dominance of some components and materials over others where the heaviest components are most impactful in the most important IC.

A brief investigation of the individual LCIA input sheets confirms this hypothesis. For example, comfort interfaces are by far the heaviest sub-product considered in the hypothetical cabin subject to the case study in this thesis (roughly 2-fold). It includes both flexible and rigid PU foam, which scores noticeably high in most LCIA methods and the majority of high-importance ICs. Examples include Photochemical Oxidation and Ozone Layer Depletion in the CML non-baseline method as may be observed in [1].

Nevertheless, changing the IC importance view to a weighted version did affect the final scoring aggregation and may have an even greater effect if a different set of products is assessed. For example, those could feature a more diverse set of materials whose weight contribution to the cabin is distributed differently from the current case study. When investigating the impacts of each IC on the granular results e.g., per product or LCIA method, the “Method Comparisons” sheet shall be consulted in [1]. This is particularly important when the user’s strategy in the assessment is to address the IC that are not currently associated with the highest importance, such as Land Use. In these cases, selecting the right LCIA method is more important than to apply IC importance weights for representing the user’s strategy and the method comparison page becomes a useful source of insights.

ii. Life Cycle Circularity:

The “Sustainability assessment” sheet also allows for comparing the existing linear and the hypothetical circular life cycle of the products assessed. Figure 10.3-b is based on the following settings:

Table 5-8: SSAPTI Sensitivity Setting – Circular life cycle

Sheet	Cells	Value	Rationale
Sustainability Assessment	K3	Circular	To test the effects of a hypothetical circular economy scenario modelled in the sheet “Circular Economy”

The overall balance of product impacts sees some changes with a circular life cycle applied. The 3 top-ranking products are identical to the baseline case with up to 5% change in their relative contribution scores. Among the tier-2 priorities, overhead bins have moved 2 positions down as the result of high metallic and plastic content reducing their overall impact by offering a recirculation potential. Thus, the consideration of circular life cycle scenarios may have a noticeable impact on product priorities depending on the nature of materials assessed and thus, sensitivity to circular economy is proven.

iii. Time Horizon Effect:

The last test checks the effects of product impact aggregation time horizon on quantitative assessment. Its importance is conditioned by the differential expected design life among products. It is originally defined by the manufacturer’s product specification indicating the maximum duration of warranted product use e.g., the metallic part of the seat structure is normally designed to last the lifetime of the aircraft (typically 25 years). The user may further adjust the design life for selected products based on their operational experience. For example, seat cushioning may be designed to last 5 years but up to 50% of it may have to be replaced every 2 years in specific operations locations or with specific carriers. For this test, the time horizon is set to match the design life of a typical aircraft:

Table 5-9: SSAPTI Sensitivity Setting – Assessment horizon

Sheet	Cells	Value	Rationale
Sustainability Assessment	K2	25	Testing a noticeably longer assessment horizon by setting the assessment timeframe to the expected life of an aircraft

The output chart in Figure 10-3c shows no difference from the baseline case. This proves the stability of impact calculations since the assessment horizon is used to derive a common time basis for products whose design lives differ. It is derived by dividing the time horizon by product design life and then using it as a multiplier of material content for each product. This indicates the number of times a product will be replaced in a given period, which depends on its expected life. Bringing the differential life durations of separate products onto a common scale makes their relative contributions unaffected by the time horizon setting value. No sensitivity is concluded for the time horizon parameter; its value is in offering the user a view on the product-specific material quantity that has to be replaced within the timeframe set – which may help e.g., in long-term procurement planning.

5.4.2.3 LCIA Preference

SSAPTI uses 9 LCIA methods to assess product materiality impacts from different angles. It also offers a cumulative view by averaging product impacts from all methods represented by the “Combined Scores” entry on its Sustainability Assessment sheet [1]. This sensitivity test compares the baseline case that uses a cumulative view against four LCIA methods selected based on a significant divergence of their results from the baseline case. The settings made in the “Results aggregation” sheet are presented in Table Table 5-10.

Each of the LCIA methods selected for this test offers its unique viewpoint as presented in the LCIA method selection sheet (Appendix C.2-1). The resulting values representing the relative sustainability impact scores produced by each method for each product are presented in the “Method Comparison” sheet (Appendix C.2-5). It allows a detailed comparison of product impacts among all LCIA methods within each IC used in the SSAPTI framework. Its discussion is

omitted from this thesis due to a highly bespoke nature of tasks that could warrant interrogating a particular LCIA method or an IC – such as the user focusing solely on the ecosystem or social impacts produced by their cabin, omitting other ICs. In some cases, SSAPTI application may require pulling the results from other LCIA methods that are not covered in its baseline version – for example, WAVE method [17] may need to be selected in SimaPro tool to pull Ecoinvent impacts that are specific to water bodies if that’s the sole focus for SSAPTI user.

Table 5-10: SSAPTI Sensitivity Setting – LCIA Preferences

Sheet	Cells	Value	Rationale
Results Aggregation	D3	T1: ReCiPe 2016	Testing the aggregated results from 4 different LCIA methods whose scores differ to a significant extent due to the different perspectives or ICs addressed by each.
		T2: ILCD 2011	
		T3: IPCC 21 100	
		T4: EPS 2015d	

It is evident from the “Method Comparison” sheet in SAPTI that the results produced by the different LCIA methods may vary dramatically between the ICs if the amounts of individual materials are similar. This results from significant disagreement in product scoring and ranking for some LCIA methods within some IC, such as: Energy & Fuel Depletion, Ozone Depletion, Ecotoxicity, Mineral & Metal Depletion. A small diversion in scores may produce noticeable changes in product ranking and thus, it is imperative that the user prioritises relevant IC and selects appropriate LCIA methods based on the study context.

Similar material quantities, however, make an unlikely scenario since most products will have structural materials prevailing over other material types e.g., those serving functional or aesthetic purposes. In a typical passenger cabin, structure prevails as the key enabler to carrier services over function, which plays a secondary role in cabin design despite its criticality for the operator’s commercial success. This logic aligns with the hypothetical cabin studied in this thesis, where several proven structural materials make a larger portion of cabin interior weight due to stringent performance requirements imposed by the

airworthiness regulations that apply to civil aerospace products. A different logic may apply when the user wants to assess the relative sustainability of selected cabin equipment e.g., the different IFE system options, where functional materials have similar or higher criticality than structural framing.

The subset of Figures C.10-4 in [Appendix C.10](#) shows that the quantitative sustainability impacts of the cabin materials assessed exhibit a significant diversion depending on what LCIA method is selected. Up to an 8% difference in product scores is observed with some reshuffling in product rankings, particularly for the EPS method, thus confirming a high sensitivity of the results due to LCIA method selection.

5.4.2.4 Material Quantities

The last sensitivity test explores how different material configurations may affect the final aggregation of product sustainability scores. The following settings are changed from the baseline case for this test. These include an update to block contributions in the “Results Aggregation” sheet to highlight impacts that depend on material content in calculations (Quantitative assessment, Qualitative LCA):

Table 5-11: SSAPTI Sensitivity Setting – Material Inventory

Sheet	Cells	Value	Rationale
Sustainability Assessment	F12:F13	÷10	To test the effects of an alternative, although unlikely material inventory where the weights of some components are either 10-fold magnified (carpets) or reduced (composite seat structure)
	F47:F50	×10	
Results Aggregation	D5	60%	To highlight the contribution of impacts whose calculation relies on product material weights. The Strategic block is deprioritised since the calculation of its scores is weight-agnostic.
	D7	35%	
	D9	5%	

The resulting reprioritisation of products shown in Figure C.10-5 of [Appendix C.10](#) indicates that their cumulative sustainability impacts heavily depend on the material content present in a given cabin. As expected, the Carpets (which are tested at 10x weight in the simulated scenario) Defined by the weight and

composition of each product, the content of individual materials may be driven by both individual, material-heavy products; or distributed across multiple products using the same materials. The former option (material presence dominated by fewer products) is easily evident through SSAPTI as it assesses the relative impacts of separate cabin products. The latter case (higher-impact materials distributed across multiple products) can only be observed if SSAPTI is used to compare several cabin types, each represented as an individual product. This, for example, may be relevant when an airline needs to compare several detailed proposals for a full cabin interior shipset submitted by different vendors. The sensitivity of SSAPTI results to product material content is confirmed, thus proving its effectiveness in guiding product priorities and decision strategy for the potential paths to sustainability improvement.

5.5 SSAPTI Conclusion

This section presents SSAPTI [1], a new simplified LCA framework for assessing the sustainability of transport passenger cabin interiors. It embodies a synergy of LCA principles with MCDA approaches in application to aircraft cabin interiors. SSAPTI is validated by assessing the material content of cabin products retrieved through the ATI FlyZero project [2] to inform a case study. SSAPTI informs the appreciation of cabin product sustainability from multiple perspectives within and beyond the isolated consideration of sustainability impacts created by cabin materials. These include a qualitative view on cabin product life cycle impacts, which substitutes a formal LCA study of a whole cabin where detailed data is difficult to obtain; and a view on the strategic factors relevant to the commercial cabin design context. The quantitative and qualitative assessment modes are implemented by combining measured cabin data, material impacts pulled from the official LCA databases, and subjective expert judgment.

The new framework is fit for use in a holistic cabin development context by any cabin stakeholder but is most likely to be used by the PMOs at the CEMs, their suppliers, or their customers – the airlines. It provides a clear view of the relative sustainability and commercial impacts of cabin products assessed at the various

levels of aggregation, including the views at the material, LCIA method, and IC levels. The wider benefits enabled by SSAPTI lie in its ability to be applied to passenger interiors in other transport modes e.g., railroad, maritime, or automotive sectors and not only aircraft cabins.

5.5.1 Future Work

The baseline version of SSAPTI leaves space for further evolution and extension to offer a better fit for a wider range of applications. The following improvements are recommended:

5.5.1.1 Near-Term Extension

The first priority is to run SSAPTI on a set of real and detailed product data representing the latest cabin sustainability standard. This will benchmark the state-of-the-art cabin interiors to better inform the investigation of potential improvement and innovation opportunities in the cabin interior space. Feeding real product data into SSAPTI will have to be accompanied by a confirmed expression of the IC importance weights from the user (e.g., an operator) and their own version of the strategic scoring.

5.5.1.2 Mid-Term Adaptation

SSAPTI is as applicable to expendable cabin content as it is to fixed equipment to inform a detailed LCA study. Cabin expendables, such as amenities or catering, are diverse and some (like blankets) lead to a significant scope expansion in formal LCA due to multi-level, cross-sector complexities. For example, passenger blankets consist of multiple different fibre types so its assessment requires an in-depth investigation into the plastics, agriculture, and potentially metals industries to deliver a robust output. While SSAPTI simplifies this task by taking a higher-level view of material and LCA impacts, it may need

extensive tailoring to enable expendable product consideration with correct assumptions applied.

5.5.1.3 Long-Term Integration

Eventually, the Strategic block in SSAPTI could expand formal LCA capabilities as a part of it. Process mining can be integrated into LCA to enable continuous assessment of sustainable quality for cabin products during their production [59]. The inherent LCA process barriers limiting the compilation of PS inventory across the life cycle can be addressed by data gathering at a deeper level than required for a formal LCA study. This capability could be implemented in an evolved SSAPTI-based framework that simultaneously integrates technical data with strategic business drivers to deliver a truly holistic LCA.

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6 COMBINED CAPABILITY DISCUSSION

The preceding chapters of this thesis present the background, development process, and practical outputs delivered in the scope of the research task concerned with the early-stage design of aircraft passenger cabin interiors. This section discusses relevance, practicality, and limitations of the delivered research both in relation to the stated research aims and objectives, and outside of it.

This thesis delivers three practical tools that constitute a complete methodology for holistic passenger cabin interior conceptualisation. It offers a complete concept design capability by enabling as follows:

- Section 3 (ProBCA, a synoptic taxonomy of MADM methods): provides an extensive collection of MADM methods and an approach to select the most suitable tool for the specific task at hand;
- Section 4 (HCCA, a guiding framework for cabin concept assessment): offers a comprehensive mapping of cabin design drivers, stakeholders, and typical products with an outlook at differential importance, applicability, and contribution of the individual drivers and parties involved;
- Section 5 (SSAPTI analytical tool for assessing cabin interior sustainability): enables a holistic and strategic assessment of relative sustainability impacts for all products across the cabin at once.

The conception of these tools was informed by a mixture of extensive literature reviews, expert surveys, and project applications consolidated through the administration of analytical judgment. Its effectiveness is proven by application to granular tasks and a full case study in Sections 4 and 5.

6.1 Outputs Overview

The outputs resulting from the research work conducted, while offering a unique benefit in their own right as independent tools, are designed for application to cabin product conception as an assembled methodology. The contribution of each tool to this overarching capability is discussed in this chapter.

6.1.1 ProBCA Taxonomy

ProBCA enables the identification of the most suitable MADM tool for the DP at hand by its appropriate characterisation using the descriptor parameters suggested. It closes the gap among the existing MCDA taxonomies, none of which can effectively discern the methods recorded with sufficient refinement as evidenced by the literature review in [Section 2.1.3](#). The key benefit of ProBCA is the switch of the DM's core problem from the MADM angle (identifying the range of available methods and selecting the most suitable one) to the DP angle. The latter is concerned with describing the DP context precisely for building its representative model. Considered the most critical aspect of MCDA practice, it is achieved by research, analysis, and debate until all parties involved in or affected by the DP are assured that its modelling accounts for their unique perspective to a satisfactory extent. Then, a fitting MADM tool may be selected from ProBCA and analytically implemented by consulting relevant method references.

This benefit delivered by ProBCA is applicable across a wide range of DP contexts and user profiles that are not constrained solely to product design tasks or the aerospace industry remits. It is proposed as a generic capability adding value to the MCDA domain by constituting a compromise between the other MCDA taxonomies, which are either too detailed or superficial for distinguishing among the 300 MADM methods identified to a sufficient refinement.

In the context of cabin interior product conceptualisation, ProBCA enables the capability to prioritise among the large lists of product concept and technology candidates available. These may include the potential materials to use in an existing product, the available products to choose from in the CEM's catalogue, or the emerging technologies to enable novel cabin functions. This constitutes the analytical core of the cabin assessment frameworks proposed to help the user identify what products best respond to their purpose within the given cabin design task. For example, they may need to select a novel technology for cabin implementation that offers the highest potential for passenger satisfaction and loyalty retention. Alternatively, they may be concerned with prioritising the specific products or equipment elements in an existing cabin to address by a full-

scale LCA study before a subsequent sustainability improvement initiative, which is only practical if addressing a limited number of targets.

6.1.2 HCCA Framework Core

The HCCA framework presented in [Section 4](#) provides a guide for cabin interior project organisation for a wide range of contexts. These may include the conception of new configurations for the whole cabin shipset or an isolated product type, the prioritisation of the most potent improvements to selected cabin items, or the comparative assessment of specific product qualities in qualitative or quantitative terms. HCCA enables this by providing a comprehensive list of stakeholders involved in the cabin supply and value chains, mapping their design drivers, and outlining the baseline list of potential products that can be addressed in the cabin (although the latter is open for expansion with novel cabin functions). In doing so, HCCA constitutes a holistic framework that can be directly applied to prioritise cabin design project actors and workstreams. It offers a suitable substitute for the MDO approaches that are not adequate for early-stage cabin conceptualisation and fills an existing capability gap as per [Section 1.1](#).

HCCA also provides the capability to decide which stakeholders to involve first by reflecting on their relative contribution or impact; and assign relative importance weights to top-level design drivers and detailed factors characterising the pertinent qualities of typical cabin interior products. While the scope of cabin qualities considered may expand with the introduction of new technology into cabins, a reflection of the current cabin standard baseline offers the starting point to assess novel product ideas.

HCCA application allows the identification of top-priority development areas to be addressed first by the specific cabin project in relation to its overarching purposes. Its intended function is to order the solution options considered by their adherence to the DP goals. This list sets the progression priorities for subsequent product evolution, such as product detail design and engineering, full-scale LCA, KPI definition for product RFP, or any other elaboration driven by the design

drivers and factors suggested in HCCA. Further product development addressing the design factors prioritised within the given DP scope involves a range of possible activities, such as:

- Cabin product certification (“Safety”, driver 7, factor “d”) requires the validation of product performance limits by analytical and experimental means;
- The ability of new technology to maximise passenger satisfaction (all factors included in HCCA drivers 3 and 4) will likely include a combination of literature review, market research, focus group assessment, and experimentation activities to examine the potential ability of product candidates to satisfy all passenger profiles targeted;
- Cabin sustainability assessment (HCCA driver 8) will require a literature review, technology research, and analysis activities to prioritise among the existing products to improve or order the potential product solutions considered by their sustainable quality.

The last example from the list above i.e., addressing the prioritisation of cabin products based on their sustainable quality, is implemented in the scope of research delivered. It provides a relatable case study into factors “a” and “d” of HCCA driver 8, demonstrating its practical application for the user’s benefit.

6.1.3 SSAPTI Framework

A framework for cabin product sustainability assessment, titled SSAPTI and presented in [Section 5](#), was built in the scope of the research work delivered. Dedicated to comparing the relative sustainability impact of cabin products, it processes their material inventory and life cycle details against the related material impacts. These are obtained from the recognised, industry-standard EcolInvent database and categorised into weighted impact categories. Although relying on the same data sources as formal LCA methods, SSAPTI acts as a suitable framework for simplified cabin LCA where formal methods are less practical, as inferred from the literature review in [Section 2.3.2](#). Its effectiveness

is based on utilising the benefits of combining the LCA approach with MCDA capability, which are laid out in [Section 2.3.3](#).

The credibility of SSAPTI results is subject to the quality of cabin inventory inputs, which may suffer from stakeholder hesitation to share detailed data on their products' exact material composition and weights. Thus, it is imperative that SSAPTI users ensure data availability by securing the related legal and contractual enablers (such as signing the non-disclosure agreements) before the sustainability assessment exercise is initiated. Provided adequate availability of detailed data, SSAPTI is capable of executing relative sustainability assessment across the whole cabin product scope. Formal LCA methods are capable of covering such a vast product scope within a single study in theory. In practice, however, such a use case is not viable due to the exorbitant level of effort, budget, and participation required to produce a reliable and trustworthy result. SSAPTI, on the contrary, is able to assess the sustainability of up to 25 product types or improvement options at a fraction of cost, time, and talent.

SSAPTI application results in ordering the in-scope products or potential solutions by their sustainable impact. The products considered must be defined at the level of materials used i.e., each individual material used in a product and constituting more than 1% of its mass must be specified along with its weight per product. There is no need, however, to define the specific product assemblies or part names that constitute the product – as long as precise material specification and weight are available. Inputs must be defined against a common baseline, for which a single shipset belonging to an aircraft of a particular type and version is proposed as the most convenient choice.

The ordered list of product priorities produced by SSAPTI should be judged in relation to the goals and context of the specific study. For example, the user may have limited control over the selection of technology and materials used in the production of the product showing up as priority #1, but enjoy extensive freedom to dictate the definition of another, lower-ranking product. The aim of SSAPTI output interpretation is to strike a balance between the ability to deliver the promised sustainability improvement, and the value of that potential improvement

offered by the product selected. Therefore, it may be more effective to choose a lower-priority product as the subject for further improvements.

6.1.4 Assembled Conceptualisation Methodology

The overarching conceptualisation methodology embodied by this thesis suggests that the progression of each cabin design driver listed in HCCA follows a set sequence of top-level steps:

- i. Define the exact DP associated with each design driver and factor listed in HCCA, including the scope of stakeholders, products, and context aspects involved in or affected by prioritisation;
- ii. Use ProBCA to identify the MADM method most suitable for modelling each prioritisation task i.e., which is capable of accounting for all relevant DP conditions – such as uncertainties, criteria importance weights, multitude of opinions, immeasurable preference sentiments, etc.;
- iii. Apply the selected method to implement the decision model for each design driver and factor as an analytical tool in analogy with SSAPTI, which represents an example of how driver 8, factors “a” & “d” can be implemented;
- iv. Perform the research, analysis, and debate activities required to fill the assessment scores for each solution option against each criterion, including all DP-specific aspects like uncertainty measures or multiple opinions;
- v. Apply the filled decision model to retrieve a ranking of solution candidates, ordered by their fit with the overall DP goal;
- vi. Interpret the resulting ranking with reference to original decision information and DP context to identify further elaboration priorities in the scope of the design driver or factor selected;
- vii. Combine the retrieved priorities into a holistic view to identify the top-level progress strategy by observing priority suggestions versus design driver and factor importance weights.

This sequence is visualised in [Figure 6-1](#) to offer simplified guidance to its potential users. The proposed methodology accepts a degree of flexibility:

- It accepts a flexible scope of top-level priorities e.g., the user may need to identify a single priority among 100 solution candidates, the 10 top-ranking solution options, or all solution options falling within some ranking bracket (e.g., scoring in the top 10%, which may not constitute 10 options).
- It accepts a flexible scope of design driver and factor importance weights e.g., the CEM stakeholder using it to conceptualise a novel product may pairwise compare the design factors in a manner significantly different from the views of an Airline looking to scope a detailed material LCA study.
- It accepts incomplete consideration of the drivers suggested by HCCA if the user is only concerned with investigating a limited scope of specific cabin product qualities. For example, an airline wishing to assess the viability of existing product options to purchase from various CEMs may not be concerned about the intricacies of product design and certification.

Ultimately, the potential scope of ProBCA and SSAPTI applications extends far beyond the subject of passenger cabins and potentially across industries and products – with some adjustment required. While the combined methodology enabled by HCCA at its core is best suited for the conceptualisation of whole user spaces and their constituent products, it also allows applications outside of the aviation domain. It may aid the early-stage design of any other transport cabins or living spaces, although likely subject to more elaborate adaptation and adjustment (e.g., by updating the design driver definitions).

6.2 Relevance to Research Aim

The development of a complete HCCA methodology, delivered through its 3 constituent frameworks, was driven by the goal of satisfying the overarching research aim presented in [Section 1.1.4](#) as:

“Conceive a modern approach to conceptualising viable passenger cabin interior products”

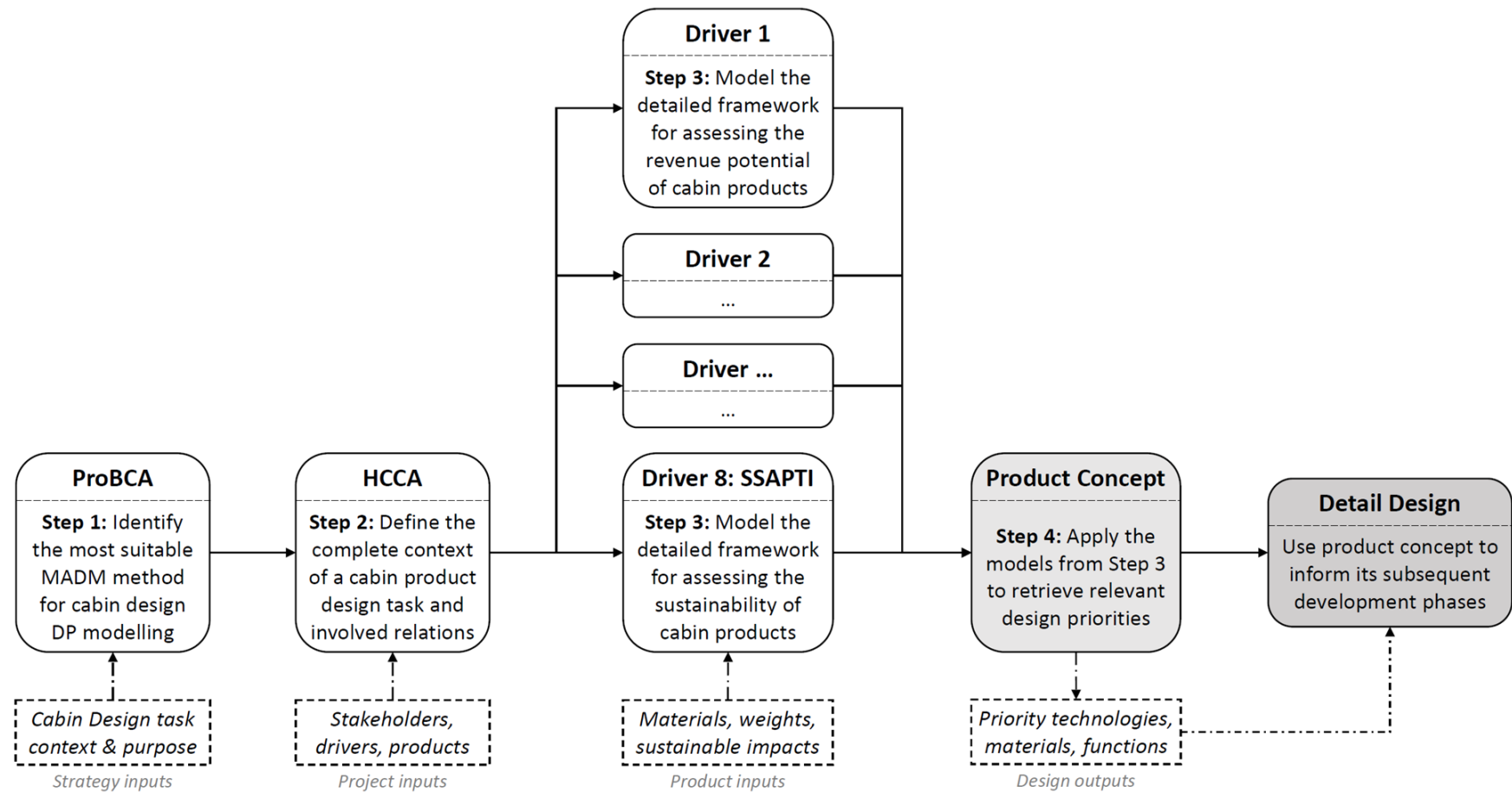


Figure 6-1: Application Process Flow for the Combined Conceptualisation Methodology

This definition of the research aim imposes 6 distinct implications, also presented in [Section 1.1.4](#); and unfolds into 3 contributing objectives, each addressed by a related deliverable as per [Table 6-1](#):

Table 6-1: Matching of HCCA Components to Top-Level Research Objectives

Obj.	Definition	Solution
I	Identify suitable MCDA methods to use as the basis for the new cabin concept design approach	ProBCA (Section 3): “A Synoptic Taxonomy of Discrete MCDA Methods for Ranking”
II	Formulate a holistic methodology for streamlined delivery of cabin interior concepts	HCCA core (Section 4): “A Holistic Concept Design Framework for Passenger Cabin Interior”
III	Apply the proposed methodology by specifying a selected aspect of cabin interior products at a deeper level of refinement to demonstrate its effectiveness	SSAPTI (Section 5): “A Synergistic MCDA-LCA Framework for Cost-Effective Sustainability Assessment of Cabin Interiors”

A fact-based discussion of how each of these objectives is satisfied by their respective deliverables is presented below, laid out with reference to the 6 core implications of the overarching research aim.

6.2.1 Research Deliverables (“Conceive”)

The first implication of the research aim pursued ensues the goal to conceive a novel, structured, and sequenced approach by identifying a suitable analytical basis, building a coherent process, and proving practicality & effectiveness through a case study.

6.2.1.1 Objective I: MCDA core

The identification of a suitable analytical core for the HCCA capability is facilitated by ProBCA. Based on a thorough review of MCDA theory, circa 450 MCDA methods (some discarded as MODM, sorting, or DSS solutions), and 20 pre-existing approaches to method selection. Some of its parameters are adopted or combined from existing taxonomies, and its process flow resembles existing

selection practices. Nevertheless, ProBCA constitutes an original taxonomy conceived, built upon a bespoke logic for characterising its 300 MADM methods.

6.2.1.2 Objective II: Holistic Framework

The core of the HCCA framework features a comprehensive list of stakeholders involved in or affected by cabin design, their most pertinent design drivers, and a breakdown of baseline cabin interior products. Its functional content includes an automated MADM-based capability for deriving the relative stakeholder contribution and criteria importance weights from a simple pairwise comparison procedure, with criteria represented by a hierarchical structure of design drivers and their constituent factors. The HCCA framework was conceived from first principles based on a diverse multitude of sources and with support from senior-level industry experts with no open-source equivalents available.

6.2.1.3 Objective III: Case Application

SSAPTI framework is developed as a demonstration of how its users may elaborate on a priority design driver suggested by HCCA. Its purpose is to illustrate the breadth and depth of work required to reach a conclusive concept design recommendation on any driver presented in the HCCA core. HCCA and SSAPTI together embody the full process flow: it starts with top-level project organisation for a new cabin product and concludes by retrieving a list of priority actions to implement in the subsequent design and engineering stages. In the case of SSAPTI, addressing the sustainability design driver results in ranking cabin products (refined at the level of product assemblies) by their environmental qualities. SSAPTI is developed as a standalone tool by integrating LCA best practices with MCDA functionality and is the first framework for simplified cabin-wide LCA proposed in the remits of cabin interiors industry.

6.2.2 Adequacy Credentials (“Modern”)

The second implication of the research aim suggests that the new methodology shall adhere to current aircraft design best practices. The key features attributed to a relatable aircraft design approach include holism (embracing all perspectives and content options), relevance (fit with the current market context), and efficiency (addressing relevant constraints & considerations cost-efficiently).

6.2.2.1 Objective I: MCDA core

The compilation of ProBCA taxonomy was concerned with two aspects of enabling a MADM selection process: a comprehensive collection of MCDA methods relevant to ProBCA scope (ranking problematic) and a comprehensive set of descriptors to allow unique characterisation of the listed methods. To achieve this, an extended scope of methods and selection approaches were combined into a single, holistic taxonomy representing the current, most relevant best practice. Furthermore, ProBCA is designed with simplicity in mind so it can be applied by a broad spectrum of users with minimum training and resource.

6.2.2.2 Objective II: Holistic Framework

A thorough literature review elaborated in [Section 2](#) and validated by expert surveys described in [Section 4](#) allowed the gathering of a comprehensive collection of relevant cabin design drivers and their lower-level factors. These represent the most up-to-date perspective on what constitutes the task of modern cabin interior design. Matching them against a comprehensive list of stakeholders involved through an automated procedure enables practical application of the HCCA core within typical cabin project resource limits. The experts interviewed aligned in their opinions that HCCA represents the first capability of this kind (particularly employing the MADM process) in the cabin interiors industry.

6.2.2.3 Objective III: Case Application

Sustainability concerns in aviation are primarily concerned with aviation fuels, propulsion systems, and weight-efficient airframe solutions, as discussed in Section 2.3. The state of sustainability awareness and technological maturity is far less advanced in the cabin interiors industry. It is primarily concerned with reducing the weight of cabin products and promoting circularity and better material choices for the replaceable items in the cabin – such as passenger amenities, food containers, and the like. One of the key issues hindering the in-depth sustainability review of the fixed cabin equipment is the extensive list of highly dissimilar products that constitute a modern passenger cabin. Each product is associated with a large number of individual materials and life cycle processes associated with it, which presents a problem of size that cannot be practically tackled by the full-scale, formal LCA approach. This issue is addressed by introducing SSAPTI, which offers a cost-efficient alternative to LCA that is able to assess the entire scope of cabin products. MCDA-based LCA simplifications existed before the introduction of SSAPTI. However, the nature of LCA simplifications is highly bespoke and tailored to a specific problem so none could fit the context of cabin interior sustainability assessment. SSAPTI was confirmed to be the first tool offering cost-efficient sustainability assessment across the whole cabin scope by experts during its early version development and first application on the FlyZero Sustainable Cabin project.

6.2.3 Proven Coherence (“Approach”)

The conception of a holistic approach implies the delivery of a coherent methodology (a collection of methods and analytical instruments) and knowledge informing its application (useful references and considerations), implemented as a toolset accessible for any user disregarding their skill level.

For all 3 objectives driving the core of the research work presented, this implication of the term “approach” in the research aim is addressed by implementing each of the 3 frameworks delivered as MS Excel-based tools

uploaded in an open-access repository. These are available to a broad spectrum of users by exploring the current thesis, which serves as a learning and application manual. It offers a compendium of relevant background literature, reference methods, and key considerations that are imperative for enabling effective use of the tools provided.

The coherence of the proposed approach is proven by case-based application of the complete HCCA methodology. First, ProBCA is used to identify the most suitable MADM tools to constitute the analytical core of HCCA and SSAPTI. Then, HCCA is used to assess a comprehensive set of stakeholder drivers and derive priorities among them. Lastly, SSAPTI is applied to identify a narrow selection of products in a hypothetical baseline cabin that offer the highest potential for effective sustainability improvements through revised product design or new technology implementation.

6.2.4 Enabled Applications (“Conceptualisation”)

The reference to conceptualisation activities in the definition of the research aim suggests that the new methodology shall be applied for early-stage product design. It is concerned with deriving a common view of a prospective cabin product shared by all stakeholders involved through a holistic consideration of their business and operational requirements, and defining the means to satisfy them effectively.

The scope of ProBCA application is generic and thus, is not limited to any specific product, development stage, or even industry. For HCCA and SSAPTI, however, potential applications are most beneficial in early-stage product development activities. Their capability is most effective for guiding the top-level definition of product features to be developed – for example, HCCA prioritises the key product qualities that a cabin project should focus on, and SSAPTI allows identifying the most critical materials to revise in a new cabin product version. This benefit fades when product development enters the detail design and engineering phase due to the need to employ high-precision, target-driven methods at this stage.

6.2.5 Viable: Proven Relevance (“Viable”)

In accordance with its overarching aim, the HCCA shall be able to ensure the technical and commercial success of the product conceptualised through its application. This requires noticing the most palpitant conflicts between stakeholder priorities, identifying or deriving the opportunities to resolve them, and finding ways to implement these as a balanced, holistic compromise maximising multilateral benefits.

6.2.5.1 Objective I: MCDA core

One way to ensure the viability of a multicriteria solution is to use the latest capabilities offered by the MCDA domain. This mindset is incarnated in ProBCA, which offers a diverse selection of methods for discrete ranking DP ranging from classical models first conceived in 1848 to instruments as new as 2022. Such a wide span of methods to select from ensures that cabin design DP modelling allows the flexibility to fine-tune the decision logic through a diverse set of parameters available. These may be used to reflect the level of certainty about the input data, consider a multitude of opinions, or allow choosing the most effective mathematical principle depending on the nature of the output sought. As a result, cabin design DP may be modelled to identify maximum-viability solutions most effectively.

6.2.5.2 Objective II: Holistic Framework

The MADM-based analytical capability is agnostic to the kind of solution options considered for cabin implementation. An existing airline or DA may prioritise among a set of pre-existing, market-ready cabin products (such as different IFE system configurations) or assembly-level equipment options (like seat cover materials) to identify the most viable choice. A progressive CEM or component supplier may use HCCA to compare the potential benefits offered by low-TRL technologies that have no prior history of cabin application, with the FUCAM project acting as an early example of such a task. Achieving this requires deriving

a set of refined assessment frameworks to address each of the drivers listed in HCCA, with SSAPTI serving to address driver 8 (Sustainability). Likewise, a practical MADM-based framework can be introduced by integrating the individual factors from drivers 3 (Passenger Perception) and 4 (Passenger Experience) to compare solutions for maximum passenger satisfaction.

6.2.5.3 Objective III: Case Application

The search for the most commercially viable or otherwise impactful course of action is futile unless the whole design space can be addressed simultaneously. In similarity to the mindset externalised in ProBCA, SSAPTI is dedicated to enabling product sustainability assessment across the whole cabin. Settling for a limited selection of cabin products to review using formal, resource-consuming LCA methods only allows for a narrow scope of potential sustainability improvement paths. While operating at a lower refinement level by only considering product materiality, SSAPTI enables a quick and cost-effective means to identify sustainability improvement priorities among a full cabin interior shipset. An early version of SSAPTI was used to discern the most promising cabin sustainability improvement options by funnelling from the original roster of over 5,000 emerging technology candidates to a final selection of 19 most promising solutions. This process was implemented through a 4-stage down-selection process in scope of the ATI FlyZero Sustainable Cabin Design project.

6.2.6 Product Scope (“Cabin Interior Products”)

The definition of the core research aim requires that the new product conceptualisation approach is primarily focused on passenger cabin interiors. This implies that the product scope addressed must be flexible enough to aid equipment design at various scope levels, from whole cabin configuration and content (e.g., several cabin shipset versions for a specific aircraft type) to individual product elements.

6.2.6.1 Objective I: MCDA core

Along with its wide applicability scope that ranges across multiple product development stages, the generic capability enabled by ProBCA is not limited to any specific product or industry. It may be applied to any discrete prioritisation and selection DP concerned with technology selection for a cabin or any other product type within or outside of the aerospace, interior design, or even product development domains. The ability to identify the most suitable MADM method for modelling a discrete DP is subject-agnostic and thus, can also be used for non-technical tasks like project selection, investment targeting, geography prioritisation, and many more.

6.2.6.2 Objective II: Holistic Framework

The scope of the HCCA application is defined by the specific content it features and thus, is not relevant for purposes outside of the interior design domain. Its primary purpose is to offer a readily available capability to design aircraft passenger cabin concepts or the selected products within it. Nevertheless, HCCA may be applied to early-stage design for other interior spaces with limited adaptation – including other transport cabins or other living spaces. The extent of the required HCCA amendment for these tasks would include a review of pairwise comparison scores to recalculate stakeholder contributions and criteria importance weights. It may need updating the description and naming of stakeholders and their multi-level drivers, and potentially changing the list of stakeholders considered (likely to a lower count by removing some aerospace-specific ones). It would most likely require updating the list of baseline cabin equipment, and driver applicability mapping to a refined list of parties concerned.

6.2.6.3 Objective III: Case Application

In similarity to the nature of the HCCA core, the content covered by SSAPTI also imposes a rigid definition to its application scope, which is solely suitable for cabin sustainability assessment in its original form. The nature of inputs it accepts is

restricted to product material content (by material types and weights) and relative sustainability impact values pulled from LCA databases like EcoInvent accessible through SimaPro software. These inputs are intrinsic to the SSAPTI framework and cannot be changed to keep its assessment functional. For example, Section 5 demonstrates SSAPTI application to prioritise among a set of 5 major cabin products represented by the 12 sub-assemblies and 20 materials they consist of.

SAAPTI does allow, however, some flexibility in the type of products assessed. As long as the subject of assessment is represented by a physical product, it may be applied to assess any kind of multi-material configuration, such as passenger cabins in other transport modes (railroad, maritime, automotive) or other complex products where formal LCA application is impractical at a holistic product level.

This concludes the discussion of benefits and capabilities offered by the complete HCCA framework proposed in relation to the original aim of the research presented and its constituent objectives.

7 CONCLUSION

The structure of this thesis unfolds the presentation of a new holistic methodology for the early-stage design of passenger cabin interiors. It is motivated by the gap between the technological capabilities currently available to meet the expectations of modern passengers and the traditional cabin design standard that has remained largely unchanged in the past decades. The need for a novel design approach is recognised by the top industry players and is addressed by delivering a research task that uncovers the most effective opportunities for evolving the existing approaches to cabin design. The methodology presented consists of 3 distinct frameworks whose derivation was informed by an extensive literature review, which was further extended and validated by anonymised expert surveys.

The resulting set of capabilities, which are represented by each framework proposed in isolation and by their combination, enables a number of beneficial applications within and beyond the original scope. On a top level, it provides any user within the cabin interior supply and value chains in any transport mode with an integrated toolset and process guide for scoping and planning their interior projects:

- The methodology presented offers a sorted collection of analytical tools available for integrating the objective and subjective cabin design criteria at various levels of complexity and certainty,
- It lists these criteria in a pre-defined template to review and tailor to specific design projects, and offers the list of project interfaces to involve with an outlook on their relative contribution;
- The capability is tested by assessing cabin sustainability as the current preference for measuring the viability and quality of new products within conditions governing the industry, which are shaped by environmental concerns and the necessity to future-proof the impact created by cabins.

In addition, it provides the basis for further R&D activities addressing transport cabin design principles. It may also be used as a negotiation guide to set up

healthier communication practices in an industry that suffers from a lack of holistic awareness by the involved parties. Ultimately, the HCCA capability offered shall enable justifying a review or extension of the current certification basis when required to integrate emerging technology into the aircraft cabins. This resolves the current industry's struggles to implement new technology on board due to prolonged and costly qualification and certification efforts, which render the new technology a few years out of date by the time it is ready to take off in a cabin.

Potentially, a discussion with the authorities and international aviation governance bodies will be required to expand and diversify the existing set of requirements to allow a safe but accelerated and flexible addition of new technology into cabins. The application of the methodology presented shall enable justifying the business case for initiating such discussions, prioritising the technologies and products to address, and identifying the specific areas of concern or challenge that need to be resolved.

7.1 Future Work

The presented methodology is not conclusive nor exhaustive; instead, it is deliberately developed in a manner that allows extensive diversification and tailoring in line with the current industry trends. It is likely that the approaches to cabin design will continue to be revised, improved, and adjusted to align with the expanding technological landscape and potentially diversifying certification approaches for it. Hence, further development and application of the methodology proposed shall include at a minimum:

7.1.1 Hands-On Application

The current version of the presented methodology is semi-theoretical, based on a combination of literature review and project work. It requires validation through a hands-on application on an industry or funded R&D project, where stakeholder participation and the robustness of their inputs is assured by the requirement to

deliver against the investment. The potential interest within the industry to use the combined methodology introduced in this manuscript has been confirmed by the representatives from various cabin stakeholders (airframers and operators primarily) during the ATI FlyZero project.

7.1.2 Setting the Standard

The experts and professionals involved in the cabin supply chain are recognised to have the full capacity to perform their individual roles in the development of aircraft interior products. This manuscript does not indicate a lack of expertise or capability as an issue affecting the evolution of cabin design standard. Where the issue exists, however, is in the lack of awareness among the professionals in the industry and academia about the operational conditions, constraints, needs, and enablers of other participants.

The methodology offered shall be used as the basis for standardising talent development and project organisation principles in the cabin interiors industry. This would ensure that the involved professionals have the minimum required awareness about relevant stakeholder landscape and basic design criteria affecting product design for commercial success, technical feasibility, and sustainability. Furthermore, this would enable any organisation to build upon the presented framework components in developing their internal training e.g., enabling the decision-making or project planning capability.

7.1.3 Cross-Sector Expansion

The methodology presented in this manuscript is the first source combining the multiple principles of cabin design, an outlook on the stakeholders involved, and a suggestion of appropriate decision-making tools available in the public domain. Although it represents the case for aircraft cabins, it is applicable to other transport or consumer product design purposes after necessary tailoring to various extents. The key benefit in cross-sector expansion of the presented

capability is case-based popularisation of the MADM methods outside of the academic, information technology, and policy-making domains that are currently the key users of MCDA capabilities. Spreading it to serve various technical and operational purposes shall greatly improve the effectiveness of decision-making approaches practised due to the widespread presence of inevitable subjective aspects in most problems that cannot be addressed by automatic means.

Overall, the HCCA methodology for holistic cabin interior design presented in this thesis benefits the scientific and industrial community by bringing together a diverse set of tools and considerations, all of which were previously known to selected experts but never before assembled as a unified capability.

APPENDICES

Appendix A : Synoptic Taxonomy of Discrete MCDA Ranking Methods (Section 3)

A.1 ProBCA Taxonomy Screenshots

This Appendix presents the screenshots of ProBCA taxonomy sheets. Each screenshot depicts a dedicated sheet of the original ProBCA .xls file uploaded to CORD (Cranfield Online Research Data) repository (Ref. [1] in Section 3).

Table A.1-1: The Complete ProBCA Taxonomy:

The core ProBCA Taxonomy is presented as a matrix characterising the complete list of methods recorded (Table A.1-3) using relevant parameters (Table A.1-2).

Table A.1-2: A Detailed Breakdown of ProBCA Parameters:

The detailed elaboration of all MADM method characterising parameters used in ProBCA laid out in a hierarchical manner from top-level parameter categories to bottom-level descriptor values. The presentation also includes the explanation, comments, justification, and examples for each descriptor value available.

Table A.1-3: Reference list for MADM methods included in ProBCA:

The list of references to the original sources for MADM methods listed in ProBCA. As discussed in Section 3.2.2, the provided list does not constitute an exhaustive and sufficient source for complete understanding of each method. Instead, it presents the single earliest publication describing the application of particular analytical domains or techniques as an MCDA tool for each method listed.

Table A.1-1: The Complete ProBCA Taxonomy

Header:

ProBCA Taxonomy of MADM Methods for Ranking										Ranking										Subjective										Objective										N/A									
Weighting		226	Point Values	164	Option Ratings	52	Option Ratings	48	Light	112	≤ 25	95	Weighted	237	Subjective	104	Point Value	113	Assignment	146	Independent	246	Flat only	235	≤ 25	58	Nominal	28	Point Value	113	Direct Rating	125	Functional	122															
Formulation		17	Distribution	18	Preference Model	42	Criteria Influence	17	Reasonable	103	Unlimited	205	Equivalent	63	Objective	22	Ratio	59	Comparison	52	Interacting	54	Hierarchical	65	Unlimited	194	Measurable	146	Ratio	27	Comparison	67	Separation	44															
Order Statements		7	Intervals	13	Both	42	Both	18	Heavy	85					Pre-determined	111	Distribution	16	Reference	25					N/A	48	Abstract	10	Distribution	16	Reference	24	Programming	116															
Mixed		6		92	N/A	164	N/A	217							N/A	63	Interval	14	Probability	8					Any	116	Interval	20	Probability	21	N/A	18																	
										1. Problem Specification										2. Criteria Definition										3. Preference Aggregation																			
Abbreviation		Full Name		Year		Top-Level Description					Type Count		1.1: Task Facilitated		1.2: Output Format		1.3: Ambiguity Presence		1.4: Relative Thresholds		1.5: Resource Required		2.1: Criteria Count		2.2: Criteria Importance		2.3: Weights Basis		2.4: Weights Format		2.5: Definition Procedure		2.6: Criteria Dependency		2.7: Criteria Hierarchy		3.1: Options Count		3.2: Attribute Nature		3.3: Rating Format		3.4: Rating Procedure		3.5: Method of Aggregation				

Matrix:

Abbreviation	Full Name	Year	Top-Level Description	Type Count	1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
ACUTA	Analytic Center UTA	2010	A UTA-based aggregation-disaggregation type approach: allows to automatically deduce the preference model from a subset of considered alternatives. Employs Linear Programming to solve the value functions, graphically represented as a polyhedron.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
AIM	Aspiration-level Interactive Model	1992	Developed to aid problems that feature 2+ conflicting objectives. Derives the total level of aspiration by combining the aspiration levels of individual criteria to identify the non-dominated alternatives.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Subjective	Point Value	Reference	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Programming
AIR	Aggregation of Individual Rankings	2012	A GDM enrichment to the CBR method that allows aggregation of preferences into non-strict rankings by conjunctive elimination. Several GDM methods are used simultaneously to derive final ranking as an average. Particularly useful to select or recommend among a set of action options.	1	Ranking	Order	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	≤ 25	Any	Order	Comparison	Programming
AIRM	Aggregated Indices Randomization Method	1908	Aggregates probabilistic, incomplete and imprecise data from the various experts to derive the probabilistic ranking for the most important attributes of the involved solution alternatives. Does not use explicit criteria, but distinguishes between information sources using credibility rating.	1	Ranking	Order	Option Ratings	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Ratio	Probability	Programming
AMAST	Advanced Multi-Attribute Scoring Technique	1989	A MAUT-based method dedicated to ranking the solution options based on performances against multiple criteria. Originally introduced as part of the RFP process for Purchasing functions, but can be used on its own. Involves ratio weighing, functional utility scoring, and indifference thresholds. Suitable for dealing with a very large number of variables.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Interacting	Hierarchical	Unlimited	Nominal	Point Value	Direct Rating	Functional
ANP-F (FANP)	Fuzzy ANP	2003	ANP basis with the fuzzy expression of criteria weights.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	≤ 25	Weighted	Objective	Ratio	Options-based	Interacting	Hierarchical	≤ 25	Nominal	Ratio	Comparison	Functional
APIM	Aggregated Preference Indices Method	2008	Extension to AIM using Bayesian randomization models implemented through "immunocomputing" to evaluate the alternatives with non-numeric, uncertain, and incomplete information.	1	Ranking	Distribution	Preference Model	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Programming
ARAMIS	Aggregation and Ranking of Alternatives near the Multi-attribute	2008	A simpler alternative to TOPSIS-like methods. Expert judgements (may be contradictory, diverse, non-compromising) of the solution performances against the criteria are stored in sets, which are then ordered in accordance with similarity to hypothetical best and worst solution.	2	Ranking	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
ARAS	Additive Ratio Assessment	2010	Involves simple operations on the decision matrix where criteria weights are used as scalar multipliers. The matrix values are normalised against a common scale. No pairwise comparison is involved and thus, a large number of criteria and options can be processed.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
ARAS-F (FARAS)	Fuzzy ARAS	2010	An improvement to ARAS using Fuzzy numbers to deal with uncertain decision information due to subjectivity, hesitation, or multiple opinions.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Functional
ARAS-G (GARAS)	Grey ARAS	2010	An improvement to ARAS using Grey numbers approach to deal with uncertain decision information expressed as min/max bounds.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Interval	Assignment	Independent	Flat only	Unlimited	Measurable	Interval	Direct Rating	Functional
ARAS-H	Hierarchical ARAS	2021	An adaptation of the ARAS method for problems involving hierarchical criteria.	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
ARGUS	Achieving Respect for Grades by Using ordinal Scales	1994	Uses ordinality represented qualitative preferences. Uses 5 preference relations to compare the alternatives. Criteria weights are based on a 5-score system. Constructs an outranking-based preference graph. Outperforms other outranking methods by using interval or ratio scales.	1	Ranking	Order	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	Unlimited	Any	Order	Comparison	Programming
ARIADNE	Alternative Ranking Interactive Aid based on DomNance structural Information Elicitation	1984	Uses graph theory algorithms to specify the structural model for a decision situation using relevant information (parameters, scores, etc.) rather than have it spontaneously adjusted by the DM. Allows setting the desired precision for the parameter and outcome (ranking) values in an iterative process.	1	Ranking	Order	Both	Both	Reasonable	≤ 25	Weighted	Subjective	Interval	Assignment	Independent	Hierarchical	Unlimited	Measurable	Interval	Probability	Functional
ASPID	Analysis and Synthesis of Parameters under the Information Deficiency	1996	An ANP-like method developed specifically for policy evaluation, which implies uncertainty. Contrary to ANP (which involves subjective criteria weights), criteria importance is derived mathematically based on the equality or inequality of importance among the criteria.	1	Ranking	Distribution	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Distribution	Probability	Independent	Flat only	Unlimited	Measurable	Ratio	Probability	Functional
ASTRIDA	Advanced STRategic Intelligent Decision Aid	1989	Built upon MAUD & ZAPROS, represents a practical application of the Dominance Search Theory to model the decision process. Facilitates problem structuring and choice between alternatives based on the decision maker's preferences expressed in natural language. Does not require limiting the number of considered alternatives since not all pairwise comparisons have to be made, some may be omitted based on the available information. Also called PARK (foreign transiteration) or PACOM (Pairwise Comparison).	1	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Abstract	Order	Comparison	Programming
BCR	Benefit-to-Cost Ratio	2021	Similar to CBA, but requires that all criteria are already expressed in monetary terms (or other common scale) and includes the process for deriving criteria weights.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Order	Comparison	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Functional
BDA	Bayesian Decision Analysis	1971	Allows ranking the solution alternatives to a particular problem in accordance with its effectiveness w.r.t. some particular criterion e.g. costs.	1	Ranking	Distribution	Option Ratings	N/A	Reasonable	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Ratio	Probability	Programming
BGM	Brown-Gibson Model	1972	Uses the measures of critical, objective, and subjective factors within a compound formula to reflect both objective and subjective evaluations on individual parameters simultaneously.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
CA (II)	Cloud Aggregation	2014	A linguistic assessment scale is used to transform any linguistic term into a cloud of linguistic variables and further into numerical assessment values for Group DM. Includes DM competence weighting.	1	Ranking	Order	Option Ratings	N/A	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Programming
CAM	Consensus Analysis Model	2007	A qualitative ranking method that uses comparative assessments provided by multiple stakeholders in linguistic terms. Measures the degree of consensus between stakeholders.	1	Ranking	Order	Both	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	Unlimited	Nominal	Point Value	Direct Rating	Functional
CBA	Cost-Benefit Analysis	1848	Not formally a MCDA method, but performs an equivalent function by evaluating the alternatives against two attribute dimensions: any negative aspects associated with an alternative are expressed in monetary terms as costs; while its positive aspects represent the utility components and may be expressed in either monetary terms or the original measured units.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Interacting	Flat only	Unlimited	Any	Point Value	Direct Rating	Functional
CBR	Case-Based Reasoning	2008	Uses intelligent analysis of historical data to rank the existing solutions or help to derive the new ones based on the measure of similarity.	1	Ranking	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Ratio	Reference	Functional
CCA	Convex Cone Approach	1984	An interactive method that applies an Optimisation technique (convex cones) to solve discrete selection problems with ill-defined preferences. It is used to derive a suitable preference function by comparing the solution alternatives among each other.	1	Ranking	Order	Option Ratings	Option Ratings	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
CCDM	Capacities-based Criteria Dependence Models	2019	A method for ranking option performances using integral approaches for problems involving a hierarchy of interactive criteria and incomplete preference information from the DM.	1	Ranking	Point Values	Preference Model	N/A	Heavy	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Interacting	Hierarchical	Unlimited	Any	Distribution	Probability	Programming
CM	Conjunctive Method	1964	One of the earliest MCDM methods: alternatives are rejected/deprioritised in accordance with passing the minimum criteria thresholds.	2	Ranking	Order	N/A	Option Ratings	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
CMCDA	Constructivist MCDA	2021	A simple method for ranking a large number of options on many criteria in the presence of multiple stakeholders.	1	Ranking	Point Values	Preference Model	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Hierarchical	Unlimited	Any	Point Value	Direct Rating	Functional
COCOSO	Grey COCOSO	2019	A compromise-seeking method based on a combination of WSM and WPM	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
COCOSO-G	Combined COmpromise Solution	2019	An extension to CoCoSo with Grey Numbers to account for multiple expert opinions on the alternative ranks in a GDM setting.	2	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Interval	Direct Rating	Functional
CODAS	COMbinative Distance-based Assessment	2016	A simple method similar to other well-known distance-based approaches, but allows specifying the Indifference threshold to compare highly dissimilar options.	1	Ranking	Point Values	N/A	Option Ratings	Light	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
COMET	Characteristic Objects METHOD	2015	Uses the distance from the nearest characteristic objects and their value by determining the domain and Fuzzy Sets. Uses triangle fuzzy numbers to represent alternative affiliations to linguistic values of criteria for pairwise comparison.	1	Ranking	Point Values	Option Ratings	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Any	Point Value	Comparison	Separation
COPRAS	Heavy Proportional Assessment	1996	An improvement to SAW method that features the consideration of the maximising and minimising criteria influences to improve applicability and precision.	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
COPRAS-G	Grey-number COPRAS	2008	COPRAS method enhanced with Grey Relations to cater for imprecise data on attribute performances.	2	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Interval	Direct Rating	Functional
COSIMA	CompoSite Model for Assessment	2007	A hybrid method for assessing the Total Rate of Return for the considered alternatives based on a scaled combination of CBA (monetary criteria) and MCDA (for deriving option utilities based on DMs preferences).	1	Ranking	Distribution	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Any	Point Value	Probability	Programming
CP	Compromise Programming	1973	A post-processing method for MCDM tasks once the Pareto set of efficient options is identified. Defines the best solution as the one positioned the shortest distance from an ideal point in the absence of additional criteria. Uses Taylor expansion of utility value in the vicinity of the ideal point.	2	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
CUT	Concave UTILITY	2014	An interactive procedure for choosing form a set of discrete objects when the DM's preferences adhere to a concave value function.	1	Ranking	Order	N/A	N/A	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Nominal	Order	Reference	Programming
DCE	Discrete Choice Experiments	2005	A method for inferring probabilistic criteria weights based on hypothetical outcome scenarios from multiple DMs using non-interactive, pre-defined surveys.	1	Ranking	Order	Preference Model	N/A	Light	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Order	Comparison	Programming
DEA	Data Envelopment Analysis	1987	A nonparametric iterative programming technique for evaluating the relative efficiencies of decision units with common input and output terms using historical data and a hypothetical aggregating criterion. Typically used for retrospective monitoring and control applications, but also offers benefits if applied as an MCDA tool despite not originally coming from the MCDA domain.	1	Ranking	Point Values	N/A	Criteria Influence	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
DELTA	N/A (custom name)	1998	A tool for choosing the available action (represented as solution options) based on the probability (represented as thresholds) of possible consequences (represented as criteria).	1	Ranking	Intervals	Option Ratings	Option Ratings	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Measurable	Interval	Probability	Separation
DEX	Decision Expert	1990	A language-based method that organises qualitative attributes hierarchically. Implemented using dedicated software only.	1	Ranking	Order	Option Ratings	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Hierarchical	Unlimited	Any	Point Value	Direct Rating	Programming
DIER-BCS	Dependence-based Interval-valued Evidential Reasoning combined with Balanced Score Card	2012	Dedicated to analysing the alternatives with dependent criteria of both quantitative and qualitative nature under uncertainty with minimum loss of precision.	1	Ranking	Order	Option Ratings	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Hierarchical	≤ 25	Measurable	Interval	Direct Rating	Programming
DM	Disjunctive Methods	1964	One of the earliest MCDM methods: the better alternatives are those exhibiting the higher scores on any single criterion.	2	Ranking	Order	N/A	Option Ratings	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
DNMA	Double Normalization-based Multiple Aggregation	2019	A comprehensive algorithm to derive the ranking of solutions based on benefit, cost, and target elements of the decision. Accepts both qualitative & quantitative criteria using probabilistic means of assessing linguistic terms. Involves 2 normalisation tools and 3 aggregation techniques.	1	Ranking	Point Values	N/A	N/A	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Point Value	Probability	Separation

Abbreviation	Full Name	Year	Top-Level Description	Type Count	1. Problem Specification					2. Criteria Definition							3. Preference Aggregation				
					1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
DRAPE	Deep Ranking Analysis by Power Eigenvectors	2019	Ranks the alternatives using pre-defined tournament table rules. Offers high-precision ranking in complex setups with incomplete data.	1	Ranking	Order	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Order	Comparison	Functional
DRPM	Double Reference Point Method	2018	A detailed method dedicated to assessing geographical performance indicators (e.g. sustainability) in complex GDM problem settings.	1	Ranking	Intervals	Preference Model	Both	Heavy	Unlimited	Weighted	Subjective	Point Value	Assignment	Interacting	Hierarchical	Unlimited	Measurable	Distribution	Direct Rating	Programming
DST	Dempster Shafer Theory	2011	An analytical discipline that can be used to rank the alternatives in GDM settings using TOPSIS-like process to produce probabilistic ranking value using judgements from multiple DMs. Although a specific method is proposed in the source, no name is assigned so the discipline title is used.	1	Ranking	Distribution	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Separation
EBA	Elimination by Aspects	1972	Eliminates options one by one by outranking against each criterion in the order of probabilistic discrimination power until the single winning option remains.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Probability	Programming
ELECTRE GKMS	ELECTRE extension with ROR	2011	ELECTRE extension with Robust Ordinal Regression that uses ordered reference alternatives as baseline information for deriving preferences. A complex, yet highly flexible, versatile, and precise method for building preference models.	1	Ranking	Order	N/A	Both	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Measurable	Order	Reference	Programming
ELECTRE II	ELECTRE version 2	1971	The first version of a ranking ELECTRE method, adapted from ELECTRE I method used for choice problematic. Uses the concordance and discordance indices to transform a partial order into a complete order. These reflect the portion of criteria in which one alternative is at least as good (within the indifference threshold), or better than (outside of threshold), the other.	1	Ranking	Order	N/A	Both	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Functional
ELECTRE III	ELECTRE version 3	1978	An improvement to ELECTRE II allowing to solve ranking problems with imprecise or imperfect knowledge using pseudo-criteria.	1	Ranking	Order	Option Ratings	Both	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Functional
ELECTRE IV	ELECTRE version 4	1982	A simplification of the ELECTRE III method with unweighted criteria that replaces it with relative coefficients for the performance evaluation credibility.	1	Ranking	Order	Option Ratings	Both	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Functional
ELECTRE SS	ELECTRE III with Stochastic Scoring	2007	ELECTRE III method that accounts for uncertainties in criteria importance weights.	1	Ranking	Order	Both	Both	Reasonable	Unlimited	Weighted	Subjective	Distribution	Probability	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Functional
EPISSURE	N/A (Foreign Transliteration)	2010	Evaluates the relative order of complex alternatives (e.g. projects, companies) in terms of non-financial (i.e. purely qualitative) hierarchical indicators provided in linguistic terms. Involves a hybrid step using ELECTRE TRI method (excluded from this list) to sort the options into performance groups.	1	Ranking	Order	N/A	Both	Heavy	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Programming
ER	Evidential Reasoning	1994	A generic, evidence-based approach to problems with quantitative & qualitative criteria under uncertainties, such as ignorance or randomness.	1	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Probability	Functional
ES	Even Swaps	1998	The clean form of conjoint analysis where the preference intervals are used to make trade-offs when evaluating the alternatives against each other. Uses "bartering" approach i.e. thinking about one criterion in terms of the other criteria.	4	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming
EVAMIX	EVALuation with MIXed data	1983	The algebraic sum of two dominance indexes (one for ordinal evaluations and one for cardinal) represents a single performance value to measure the dominance between each pair of alternatives.	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Objective	Point Value	Probability	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Separation
EXPROM	Extension of the PROMethee	2019	Dedicated to evaluating and ranking the alternatives more accurately than PROMETHEE methods. EXPROM I assesses the entering & leaving flows to produce a partial ranking. EXPROM II yields the net flow in the form of the final value and yields a full ranking of alternatives.	1	Ranking	Order	N/A	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
FANMA	N/A (custom name)	2002	A simple approach to ranking project or action alternatives that have a common basis e.g. a geographical context (e.g. selecting what to do with the available watered from 3 rivers).	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
FDMM	Forced Decision-Making Matrix	2015	The first version of the pairwise comparison matrix where the relative performances between the options are assessed as either 0 or 1, and then calculated in a WSM-like approach. A rough, but easy to implement method.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Order	Comparison	Independent	Flat only	≤ 25	Measurable	Ratio	Comparison	Functional
FITradeoff-R	Flexible and Interactive Tradeoff for Ranking	2019	A software-based method for iterative ordering of alternatives based on incomplete preference information expressed through partial preorder of the hypothetical outcomes.	1	Ranking	Order	Preference Model	Option Ratings	Reasonable	≤ 25	Weighted	Pre-determined	Order	Assignment	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
FMEA	Failure Modes and Effects Analysis	1949	Although not a formal MCDA method itself, it is widely used across the industries to evaluate the risk levels based on both qualitative and quantitative aspects of a product or action. Uses a pre-defined criteria categories (failure modes), Scoring values (severity), and importance weights (likelihood) that are used to describe the system (product, action) for the evaluation.	1	Ranking	Order	N/A	Both	Light	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	Unlimited	Nominal	Point Value	Direct Rating	Functional
FPC	Fuzzy Pairwise Comparison	1989	A fuzzy version of the Pairwise Comparison method dedicated to accounting for uncertainties in defining optimal criteria weights.	1	Ranking	Point Values	Both	N/A	Reasonable	≤ 25	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	≤ 25	Measurable	Ratio	Comparison	Functional
FUCA	Faire Un Choix Adéquat ("Make an adequate choice" from French)	2011	A very simple method for ranking the Pareto front of equivalent alternatives. Each alternative is ranked based on its performance Scoring within each criterion (top rank for best Scoring, bottom rank for weakest performance). Then, weighted sum is calculated for each alternative based on option rank and performance Scoring for all criteria.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Comparison	Functional
FWA	Fuzzy weighted average	2008	A thorough method for dealing with uncertain preference information to derive the fuzzy utility bounds for each alternatives with consideration of the DM's preference for the strictness of criteria weighting.	1	Ranking	Intervals	Both	N/A	Heavy	Unlimited	Weighted	Pre-determined	Interval	Assignment	Independent	Flat only	Unlimited	Measurable	Interval	Direct Rating	Programming
GAIA	Geometrical Analysis for Interactive Aid	2009	A visualisation technique for MCDA problems that provides a graphical view of criteria, data points, and decision axes. Uses PCA method in its operation and represents a sensitivity analysis technique for PROMETHEE outputs, thus providing a clearer view on the resultant ranking.	1	Ranking	Point Values	N/A	Option Ratings	Heavy	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
GMCR	Graph Model for Conflict Resolution	1997	A thorough method for inferring option scoring from subjective preference information expressed in immeasurable linguistic form (e.g. Yes/No answers) against many criteria. Uses mathematical Graph theory approach to infer ranking output.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Interacting	Flat only	Unlimited	Abstract	Order	Comparison	Programming
GRA	Grey Relational Analysis	1998	Employs Grey System Theory to model incomplete or multiple information. Combines the use of other methods (AHP, TOPSIS) and accounts for DM competence by weighting their opinions.	1	Ranking	Point Values	Option Ratings	N/A	Light	≤ 25	Weighted	Subjective	Point Value	Comparison	Independent	Hierarchical	Unlimited	Measurable	Point Value	Reference	Separation
GRIP	Generalized Regression with Intensities of Preference	2009	An efficient (i.e. less effort-consuming) evolution of UTA/GMS allowing the DM to provide preference information on compatible criteria only and not considering all criteria jointly, which leads to the derivation of a partial order.	1	Ranking	Point Values	N/A	Option Ratings	Heavy	Unlimited	Weighted	Subjective	Order	Comparison	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Programming
GTMA	Graph theory and matrix analysis	2007	An analytical discipline dedicated to complex problems with dependence among the criteria. Considers multiple qualitative and quantitative attributes simultaneously. Requires fewer operations than other methods offering similar capability at a cost of omitting uncertainties and probability. Although a specific method is proposed in the source, no name is assigned so the discipline title is used.	1	Ranking	Point Values	N/A	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
HAW	Hierarchical Additive Method	1981	A combination of SAW and AHP for problems characterised with criteria hierarchy.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	≤ 25	Measurable	Ratio	Comparison	Functional
HDT	Hasse Diagram Technique	1952	A partial-ordering method capable of dealing with incomparability among the alternatives (i.e., where some criteria do not apply to all alternatives). A relatively complex method; however, capable of considering a large number of alternatives against many criteria.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Comparison	Programming
HEIM	Hypothetical Equivalents and Inequivalents Method	2005	A precise, mathematically robust, and yet relatively simple method for determining criteria weights using a hypothetical reference of equivalent weights.	1	Ranking	Point Values	N/A	Criteria Influence	Reasonable	≤ 25	Weighted	Objective	Ratio	Options-based	Independent	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
HGDM	Hierarchical Group Decision-Making	2020	A subjective method for ranking projects (described with qualitative & quantitative criteria) in large GDM settings where the group DMs represent a hierarchical structure (e.g. corporate departments). Includes the rating of DM competence.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
HIA	Hierarchical Interactive Approach	1986	A simple approach for dealing with a large number of hierarchical qualitative or quantitative criteria. Each criterion is evaluated individually at the lowest level. This is then used to construct a general correlation matrix describing criteria interdependencies and derive their weights.	1	Ranking	Point Values	N/A	N/A	Heavy	Unlimited	Weighted	Subjective	Point Value	Assignment	Interacting	Hierarchical	Unlimited	Any	Order	Comparison	Separation
HSMAA	Hierarchical Stochastic Multicriteria Acceptability Analysis	2020	An adaptation of SMAA to hierarchical criteria structure; produces probability-based rankings using Monte-Carlo simulation.	1	Ranking	Distribution	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Distribution	Probability	Independent	Hierarchical	≤ 25	Measurable	Distribution	Probability	Programming
HT	Hierarchical Tradeoffs	1981	Makes the alternatives equivalent in all attributes except those interrelated by tradeoffs, then allows to outrank the alternatives against each of the interdependent criteria using a graphical representation.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Order	Assignment	Interacting	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming
IAMS	Integral Aided Material Selection	2013	A combination of QFD to assess the importance of criteria, and VIKOR to perform a robust ranking and selection of options.	1	Ranking	Point Values	Preference Model	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
IDCR	Interactive Design Characteristics Ranking	2002	Used to prioritise the technical characteristics based on the weighted customer design requirements of a product at the early design stages. Dedicated for application after QFD/HQ has been used to elicit design characteristic weights.	1	Ranking	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Abstract	Order	Comparison	Programming
IDRA	Intercriteria Decision Rule Approach	1997	A pairwise comparison method that relies on a mixed utility function to consider criteria weights & compromises. Determines the preferences using decision rule reliability scores.	1	Ranking	Order	Preference Model	N/A	Heavy	Unlimited	Weighted	Subjective	Point Value	Comparison	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
IOWA	Induced Ordered Weighted Average	1999	IOWA extension that orders criteria using a dedicated ordering value instead of using performance rating magnitudes. This allows a more direct implementation of the desired value function shape.	1	Ranking	Point Values	N/A	N/A	Heavy	Unlimited	Weighted	Subjective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
IPS/IPV	Inner Product Space / Inner Product of Vectors	2011	Not a formal MCDA method, originates from engineering/technical applications concerned with characterising data clouds. Is an evolution to PCA, but designed to deal with highly inconsistent data clouds featuring multiple outliers.	1	Ranking	Point Values	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
IROR	Imprecise Robust Ordinal Regression	2012	ROR extension to deal with uncertain alternative Scoring.	1	Ranking	Order	Option Ratings	N/A	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Interval	Direct Rating	Programming
LAM	Linear Assignment Method	1977	Uses attribute weights and attribute-wise ranking of each alternative to derive the overall ranking using a linear compensatory process.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Any	Order	Comparison	Programming
LAM-F (FLAM)	Fuzzy LAM	2013	A fuzzy extension to LAM for dealing with imprecise (interval) information on both criteria weights and Option Ratings.	1	Ranking	Order	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Assignment	Independent	Flat only	≤ 25	Nominal	Point Value	Direct Rating	Programming
LFA	Loss Function Approach	2016	Calculates the total loss value for each alternative by combining the individual attribute losses. Uses linear, quadratic, or cubic functions on a 0-1 scale to allow for adjustable output precision depending on the scale of the option performance values (e.g. a cubic function amplifies small differences).	2	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
UNMAP	Linear programming technique for Multidimensional Analysis of Preferences	1973	A linear programming procedure based on conjoint analysis to rank the ordered information. Assesses the weights and locates the ideal solution to identify the alternative closest to it.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Weighted	Objective	Point Value	Options-based	Independent	Flat only	≤ 25	Any	Order	Comparison	Separation
LM	Lexicographic Method	1993	Compares all options against the most important criterion first based on criteria ordering by importance as part of the input data. Compares and outranks the options against the most important criteria in the order of decreasing importance until only one alternative is left.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	Unlimited	Any	Order	Comparison	Programming
LOWA	Linguistic OWA	1996	IOWA extension that uses convex linguistic tables to define preference values.	2	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Functional
MABAC	Multi-Attribute Border Approximation Area Comparison	2015	The method calculates the values of criteria functions for each alternative and then evaluates the distance between the total criteria value for each alternative and the approximation area border. The ranking is based on this distance, with the farthest option representing the most preferred solution. Proposed as having better precision than more basic distance-based methods.	1	Ranking	Point Values	Both	N/A	Reasonable	≤ 25	Weighted	Objective	Point Value	Options-based	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
MACBETH	Measuring Attractiveness by a categorical Based Evaluation Technique	1990	A simplified method similar to the AHP that uses pairwise comparisons to evaluate both the criteria and options. Linguistically defined qualitative performance evaluations are used to generate 7 possible numerical scores against weighted criteria.	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	≤ 25	Any	Order	Comparison	Functional
MAGIQ	Multi-Attribute Global Inference of Quality	2005	Based on a hierarchical decomposition of comparison attributes and a Scoring assignment using rank order centroids.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	≤ 25	Any	Order	Comparison	Functional
MAPPACC	Multicriteria Analysis of Preferences by Pairwise Actions and Criterion Comparisons	1986	Uses qualitative performance measures translated into numerical representation, and quantitative criteria weighing for pairwise comparison; both normalised on a 0-1 scale.	1	Ranking	Order	N/A	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Order	Comparison	Programming
MARCOS	Measurement Alternatives and Ranking according to COmpromise Solution	2020	Uses distance measurement from the best/worst known solution to construct a utility function. A simple method allowing to operate on a large number of criteria and options.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Comparison	Separation
MARE	Multi-Attribute Range Evaluations	2014	Represents the suitability of solution options as utility ranges against the identified criteria instead of providing precise ranks or specific utility values. Works by performing a global sensitivity analysis, that is considering multiple criteria at a time rather than one by one.	1	Ranking	Distribution	Option Ratings	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Functional
MARICA	MultiAttributive Ideal-Real Comparative Analysis	2021	Derives the performance of each option by measuring the difference between the hypothetical ideal and empirical performance Scoring for each criterion and summing these gaps to inform option rankings. Similar to MARCOS, but only uses 1 reference point.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Objective	Point Value	Options-based	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
MARS	Measuring Attractiveness near Reference Situations	2014	An indirect method combining ZAPROS & MACBETH. Allows the elicitation of DM's preferences using pairwise comparisons of alternatives. Produces numerical scores for each alternative to enable ranking.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Measurable	Ratio	Comparison	Functional
MAUD	Multi-Attribute Utility Decomposition	1982	A VDA approach that applies the minimum difference method to specify the differences & similarities between the alternatives. Expresses the decision criteria as attribute poles.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Point Value	Reference	Independent	Flat only	≤ 25	Nominal	Ratio	Comparison	Functional
MaxiMax	MaxiMax	1968	Based on the strongest link principle: prioritises an alternative that has the highest Scoring of its highest-performing criterion as opposed to other alternatives. Suitable for the situations where solution performance is driven by a single criterion demonstrating the strongest performance.	4	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming
MaxiMin	MaxiMin	1944	Based on the weakest link principle: prioritises an alternative that has the highest Scoring of its lowest-performing criterion as opposed to other alternatives. Suitable for the situations where solution performance is driven by a single criterion demonstrating the weakest performance.	4	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming

Abbreviation	Full Name	Year	Top-Level Description	Type Count	1. Problem Specification					2. Criteria Definition							3. Preference Aggregation				
					1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
MCCPI	Multiple Criteria Correlation Preference Information	2015	A method for ordering the alternatives in situations requiring the evaluation of relative criteria importance (weights) and interaction.	1	Ranking	Intervals	N/A	N/A	Heavy	≤ 25	Weighted	Subjective	Point Value	Comparison	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
MCM	Meaningful Compensation Method	1972	ELECTRE special case based on ill-defined criteria substitution rates (e.g. strongly conflicting DM opinions only allowing the definition of min-max boundaries and no compromise).	1	Ranking	Order	Preference Model	Both	Reasonable	≤ 25	Weighted	Subjective	Interval	Assignment	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Functional
MCQA	Multi-Criteria Q-Analysis	1977	Works by expressing the alternatives on a 2D plane and ranking in accordance with separation from the ideal point. Offers the procedure to translate option Scoring against multiple criteria into 2D expression by outranking.	1	Ranking	Order	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
MELCHIOR	N/A (Foreign Transliteration)	1984	An extension to the ELECTRE IV method using Graph Theory, which sets an ordinal relationship between pseudo-criteria. Preference aggregation is achieved by testing concordance and the lack of discordance.	1	Ranking	Order	N/A	Option Ratings	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Order	Comparison	Programming
MEW	Multiplicative Exponential Weighting	1987	A light method similar to SAW that uses multiplication instead of addition. Allows exaggerating the distinction between alternatives that otherwise rank indistinguishably close to each other.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
MiniMax	MiniMax	1944	The reverse of the MaxiMin method representing the weakest link principle: eliminates alternatives that perform lowest on their highest-performing criteria. Suitable for the situations where solutions are outranked if they perform weak in high-importance criteria.	4	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming
MIVES	Modelo Integrado de Valor para Estructuras Sostenibles	2010	A procedure for structuring complex MCDM problems and assessing options in terms of value that uses both cardinal evaluations and dominance relations. Uses multi-stakeholder workshops to gather input information and translates it into objective problem setup parameters. Allows choosing an appropriate value function to represent DM preference behaviour.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Interval	Direct Rating	Functional
ML-FDM	Multi-Level Fuzzy Decision Maps	2015	An extension to FDM (II) for dealing with multi-level criteria hierarchy that allows deriving the ranking of alternatives.	1	Ranking	Point Values	N/A	Criteria Influence	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Interacting	Hierarchical	≤ 25	Nominal	Ratio	Comparison	Functional
MMASSI	Methodologia Multicriterio para Apoio a Selecao de Sistemas de Informacao	2003	Similar to the AHP but avoids the use of Pairwise Comparisons by using pre-defined set of option performance scores, allowing to cover an exhaustive set of generic factors.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Reference	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Functional
MMCDM	Markovian MCDM	2008	A Group DM algorithm based on a steady-state Markov chain from pairwise comparisons to produce a ranking vector. Offers a relatively quick evaluation of very large amounts of alternatives, with little information requirements. Involves weighting both the criteria and DM competence evaluation.	1	Ranking	Distribution	Both	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Ratio	Assignment	Independent	Flat only	≤ 25	Any	Ratio	Probability	Programming
MOORA	Multi Objective Optimization by Ratio Analysis	2006	A simple method for ranking the alternative options, which is based on the principles borrowed from the Multi-Objective Optimisation (MODM) domain.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
MSIP	Multidimensional Scaling with Ideal Point	1964	DM opinions for preference order on the alternatives are used to represent them as points in space, which are then compared against the ideal solution point. The judgements on criteria are converted into two dimensions reflecting Similarity and Dissimilarity.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Ratio	Comparison	Separation
MULTIMOORA	Multiplicative MOORA	2010	A version of MOORA that uses multiplicative value function mixed with the reference-point approach to offer a higher precision of results.	3	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
MUSA	Multicriteria Satisfaction Analysis	2002	A preference disaggregation method used to assess satisfaction utility functions to retrieve a global satisfaction criterion consistent with customer preferences. Helps to identify the performance of alternatives (e.g. customer) against relevant criteria (e.g. customer satisfaction dimensions).	1	Ranking	Distribution	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Programming
MUSA-INT	Interactive MUSA	2014	An evolution of UTA-GMS-INT that involves dependent criteria to allow the definition of groups using reference user/customer profiles.	1	Ranking	Order	Option Ratings	N/A	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Interacting	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Programming
MZM	Martel & Zaras Method	1990	Dedicated to problems where option performances against each attribute are uncertain and provided in the form of probability distributions. Uses stochastic dominance to derive partial preferences based on concordance and discordance indexes retrieved using the ELECTRE method.	1	Ranking	Order	N/A	Both	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Any	Distribution	Probability	Programming
NAFIM	Non-Additive Fuzzy Integral Method	2008	An implementation of non-additive development of the Sugeno integral for problems involving uncertainties e.g. linguistic variables.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
NAIADE	Novel Approach to Imprecise Assessment and Decision Environments	1995	Establishes pairwise outranking relations on fuzzy alternatives. Offers 6 distinct preference relations to remove the requirement for the DM to define performance thresholds.	1	Ranking	Point Values	Option Ratings	Option Ratings	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Point Value	Comparison	Functional
NAROR	Non-Additive Robust Ordinal Regression	2010	A detailed method for determining the relative order of preference for complex alternatives that are characterised by the interdependent criteria with uncertain weights.	1	Ranking	Order	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Order	Reference	Interacting	Flat only	≤ 25	Any	Order	Reference	Programming
NDEA	Slack-Based Measure DEA	2013	A method for ranking objective (measurable) alternatives w.r.t. DMs preferences expressed by a set of complex, hierarchical, but unweighted criteria.	1	Ranking	Order	Both	N/A	Heavy	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Programming
NEAT	New Easy Approach to Fuzzy PROMETHEE	2021	An efficient (less effort-consuming), user-friendly approach to applying Fuzzy PROMETHEE method.	1	Ranking	Intervals	Both	Option Ratings	Heavy	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Point Value	Direct Rating	Programming
NMUTA (UTA-NM)	Non-monotonic UTA	1995	Derives the order of priority for quantitative alternatives in cases where the preferred performance values are not strictly defined and are instead represented by a range.	1	Ranking	Point Values	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Ratio	Comparison	Programming
NNO	Noncompensatory, Nonlinear Composite Indicators	2009	Derives a ranking order for a set of alternatives characterised by the quantitative (measurable) criteria exhibiting equivalent importance and uncertain performance Scoring.	1	Ranking	Order	Option Ratings	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	≤ 25	Measurable	Ratio	Comparison	Programming
NSFSSS	Non Structural Fuzzy Decision Support System	2002	Applies relative fuzzy set theory using linguistic variables rather than quantitative. Implemented in 3 steps: decomposition, comparative judgment, and synthesis of priorities.	1	Ranking	Point Values	Option Ratings	N/A	Light	≤ 25	Weighted	Subjective	Order	Comparison	Independent	Hierarchical	≤ 25	Any	Order	Comparison	Programming
OPA	Ordinal Priority Approach	2019	A method for ranking a set of discrete solution alternatives in GDM setting, which also considers DM competence differences.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	Unlimited	Any	Order	Comparison	Programming
ORESTE	Organisation, Rangement Et Synthèse De Données Relationnelles	1980	Uses ordinal evaluations of alternatives and importance-based criteria ranking. The distance function is used to derive a complete ranking of alternatives based on preference/preference relations. Allows incomparability by aggregating a global ranking.	1	Ranking	Order	Option Ratings	Option Ratings	Heavy	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Order	Comparison	Separation
ORME	Office Scoring Methodology	2002	A combination of PCA and ELECTRE that requires agglomerating the many criteria into 2 or 3 main ("principal") axes. These axes are independent and are analysed using 2D or 3D PCA, but the criteria within each axis may be dependent on each other.	1	Ranking	Point Values	Option Ratings	Both	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Order	Reference	Functional
OWA	Ordered Weighted Average	1993	A family of aggregation approaches that allows adjusting the shape of the value function by selecting criteria weights appropriately. The criteria weights are ordered in accordance with option Ratings, but specific weight values/ratios are selected by the DM to reflect the desired preference behaviour.	1	Ranking	Point Values	N/A	N/A	Heavy	Unlimited	Weighted	Subjective	Ratio	Options-based	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
OWG	Ordered Weighted Geometric	2001	An evolution of OWA with Fuzzy Sets that uses 3 types of information about option performances from the DM: preference orderings, utility functions, and fuzzy preference relations. The nature of accepted information requires updating the analytical basis to use the Geometric Mean instead of averaging.	1	Ranking	Point Values	Both	N/A	Heavy	Unlimited	Weighted	Subjective	Ratio	Options-based	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
OWGA	Ordered Weighted Geometric Average	2002	An OWG-based aggregation method that uses the max & min performance values of each criterion to set its importance weighting values.	1	Ranking	Point Values	Both	N/A	Heavy	Unlimited	Weighted	Subjective	Ratio	Options-based	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
PAIRS	Preference Assessment by Imprecise Ratio Statements	1992	An interactive method based on the value trees with imprecise preference statements and interval-based criteria weights. Uses Linear Programming to derive dominance relations. Originally implemented as a computer program; requires expertise to implement independently.	1	Ranking	Intervals	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Comparison	Independent	Hierarchical	Unlimited	Measurable	Interval	Direct Rating	Functional
PAMSEM	Procédure d'Aggrégation Multicritère de type Surclassement de Synthèse pour Evaluations Mixtes	1996	A hybrid of ELECTRE III, NIADE I & PROMETHEE I. Uses fuzzy evaluations and concordance/discordance indexes for preference aggregation to determine preference relations between the alternatives. PAMSEM I allows for incomparability of alternatives to form a partial preorder. PAMSEM II resolves incomparability into a total order.	1	Ranking	Point Values	Both	Both	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Programming
PAPRIKA	Potentially All Pairwise Rankings of all possible Alternatives	2008	A survey-based statistical technique for determining the subjective valuation of the different solution attributes based on conjoint analysis. Users express their preferences on the relative importance of criteria/attributes by pairwise comparison of the alternative options.	1	Ranking	Order	N/A	N/A	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Comparison	Programming
PCA	Principal Component Analysis	1988	A multivariate statistical technique demonstrated to be an effective standalone ranking method (not originally a formal MCDA method). Used for complex information pre-processing by breaking it down into criteria (principal decision components).	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Separation
PDM	Pugh Decision Matrix	1981	A qualitative technique capable of ranking the options based on all factors relevant for a particular DP. As opposed to the Decision Matrix tool used in the other methods, serves an effective standalone MCDA method capable of deriving recommendations at low effort.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Any	Order	Comparison	Functional
PHSS	Plithogenic HyperSoft Set	2020	Plithogenic logic is a new mathematical approach representing the generalisation of the four existing approaches for dealing with sets of different accuracy levels: Crisp, Fuzzy, Intuitionistic fuzzy and Neutrosophic. Used in MCDA operations as a universal preference aggregation approach. Offers supreme flexibility for dealing with data at highly varying levels of accuracy.	1	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
PIV	Proximity Index Value	2018	Specifically proposed to minimise the issue of Rank Reversal. Relies on the measure of solution proximity to the best available or ideal possible solution. Introduces the Proximity Index Value and processes it against the value & weight of each criterion considering. The overall Proximity Value for each alternative is then derived and used for ranking.	3	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
PLVF	Piecewise Linear Value Functions	2018	Piecewise linear value functions offer a simpler alternative to non-linear value functions to derive relative utility values to rank the options. The precision of this approach competes with non-linear value functions while requiring a level of effort comparable to using linear ones.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
PPARC	Preference Programming through Approximate Ratio Comparisons	1995	A relatively simple method for dealing with uncertain weighting of hierarchical criteria (e.g. in a GDM setting) that offers progressive development of the result before all pairwise assessments are done, thus reducing the workload burden on the DM.	1	Ranking	Intervals	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Comparison	Independent	Hierarchical	≤ 25	Nominal	Interval	Comparison	Programming
PP-JOI	Preference Programming with Incomplete Ordinal Information	2013	A Preference Programming-type method that uses ordinal information to reflect both the criteria weights and the performance Scoring of alternatives in GDM settings.	1	Ranking	Order	Option Ratings	Both	Heavy	≤ 25	Weighted	Subjective	Order	Reference	Independent	Flat only	Unlimited	Any	Interval	Direct Rating	Programming
PRAGMA	Preference Ranking Global Frequencies in Multicriteria Analysis	1988	The analytical component of the MAPPAC method that derives a global ranking of alternatives based on their "action profiles" (graphically represented commensurable behaviour) against selected criteria (partial profile) or all criteria (full profile), where the behaviour of the different alternatives may differ significantly.	1	Ranking	Order	N/A	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
PREFCALC	PREFerence CALCulator	1990	A UTA extension enabling the DM to directly react on the shape of the Value Functions derived. Includes the classical aggregation phase to estimate model parameters directly, and the disaggregation phase to express DM's holistic judgments.	1	Ranking	Order	N/A	Option Ratings	Heavy	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Separation
PRIAM	Programme utilisant l'Intelligence Artificielle en Multicritère (French)	1986	An interactive, unstructured method based on an AI-like searching tree software to narrow down the set of available alternatives to a feasible subset by series of pairwise comparisons. Represents a ranking method at its core, but extends to a Selection task by the consideration of incomparability between alternatives ("I don't know" user statements).	1	Ranking	Order	Option Ratings	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Measurable	Order	Comparison	Programming
PRIME	Preference Ratios in Multiattribute Evaluations	2001	Used to analyse the incomplete information in multi-attribute weighting models. Involves constructing an imprecise preference model from imprecise ratio judgements. Ranks the options based on the dominance structures and the decision rules using holistic comparisons.	1	Ranking	Order	Option Ratings	Criteria Influence	Heavy	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Hierarchical	Unlimited	Any	Order	Comparison	Programming
PROMETHEE GKS	PROMETHEE ROR extension	2012	A Robust Ordinal Regression -based extension to the classical PROMETHEE methods. Allows using the desired ordering of reference alternatives as the baseline information for deriving preferences.	1	Ranking	Order	N/A	Option Ratings	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Reference	Programming
PROMETHEE I	Preference Ranking Organization Method for Enrichment of Evaluations I	1984	Uses outranking based on 6 preference thresholds and Concordance and Discordance preference indicators. Produces partial ranking of alternatives, which allows for incomparability. Partial ranking implies that additional evaluation effort is required to retrieve a clear view of the prioritised alternatives, but allows to exclude poorly performing options.	2	Ranking	Order	N/A	Option Ratings	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
PROMETHEE I-F	Fuzzy PROMETHEE I	2017	A PROMETHEE I basis with fuzzy representation of uncertain preference information.	2	Ranking	Order	Both	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Interval	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
PROMETHEE II	PROMETHEE II	1985	An extension of PROMETHEE I that offers a complete ordering of alternatives by resolving incomparabilities using the aggregation of entering and leaving flows.	2	Ranking	Order	N/A	Option Ratings	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
PROMETHEE II-F	Fuzzy PROMETHEE II	2017	APROMETHEE II basis with fuzzy representation of uncertain preference information.	2	Ranking	Order	Both	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Interval	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
PROMETHEE III	PROMETHEE III	2002	Produces an interval order of option priorities to emphasize indifference relations and distinguish it from incomparability. This is achieved by allowing for option performance overlaps when deriving an interval order of preferences, which effectively accounts for uncertainty in the evaluation of alternative performances. Accounts for risks in the form of uncertain performance scoring.	1	Ranking	Order	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Comparison	Functional
PSO-SA	Particle Swarm Optimization with Simulated Annealing	2020	Compares all possible ranking orders of the solution options to identify the one offering highest satisfaction with respect to criteria.	2	Ranking	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
QFD / HOQ	Quality Function Deployment / House of Quality	1966	Used to translate product requirements into design specifications. Used to rank product design characteristics by quantifying its relationship product requirements through importance scores. QFD operation is based on the MCDA concepts and akin to prioritising multicriteria options.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Functional
QUALIFLEX	QUALITY by FLEXible multicriteria	1978	Uses concordance analysis through successive permutations to rank the alternatives so they corroborate with ordinal information.	1	Ranking	Order	Both	N/A	Heavy	Unlimited	Weighted	Subjective	Point Value	Comparison	Interacting	Flat only	Unlimited	Any	Interval	Direct Rating	Programming

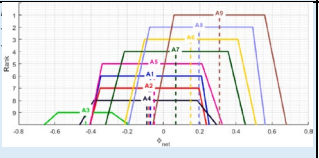
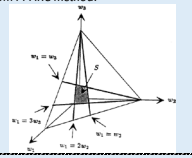
Abbreviation	Full Name	Year	Top-Level Description	Type Count	1. Problem Specification					2. Criteria Definition							3. Preference Aggregation				
					1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
RA	Realization Analysis	2020	Requires representing a complex system of criteria through 2 key parameters, Value & Cost. Serves to uncover the full spectrum of the potential outcomes in the decision situations involving uncertainty and high similarity of the alternatives. Particularly useful for practical decision-making in situations that are traditionally served by complete methods.	1	Ranking	Distribution	Option Ratings	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Hierarchical	Unlimited	Any	Distribution	Probability	Separation
RBOP	Ranking Based on Optimal Points	2018	Finds the best option by measuring the distances of the available alternatives from the optimum and the optimal alternatives. The best alternative sits closest to its optimum points and the optimal points simultaneously. The criteria are not outlined explicitly but defined through hypothetical "optimum" alternatives used to map the available options against them.	1	Ranking	Point Values	Option Ratings	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	≤ 25	Any	Order	Comparison	Functional
REGIME	REGional Multicriteria Elimination	1982	Builds a pairwise comparison matrix using +1 for positive dominance, 0 for equivalent alternatives, and -1 for negative dominance to build weighted pre-order of alternatives.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	≤ 25	Any	Order	Comparison	Programming
REMBRANDT	Preference RANKing Global frequencies in Multicriteria Analysis	1992	A multiplicative version of the AHP that uses pairwise comparison to subjectively perform both criteria weighting and option performance Scoring tasks.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	≤ 25	Nominal	Ratio	Comparison	Programming
RICH	Rank Inclusion in Criteria Hierarchies	2005	A detailed method for determining precise criteria weights based on DM's criteria dominance statements, and geometrical assessment of option rankings based on Interval Scoring. Allows for both known and uncertain information on option performances against various criteria.	1	Ranking	Intervals	Preference Model	Criteria Influence	Heavy	≤ 25	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	≤ 25	Nominal	Interval	Direct Rating	Programming
RIM	Reference Ideal Method	2015	A method that uses reference to ideal and anti-ideal solutions like TOPSIS and VIKOR. However, where other methods define the ideal/anti-ideal solutions with extreme Max/Min values for each criterion, RIM allows for the hypothetical ideal solution to be described by any value and not necessarily the Max/Min possible value for given criterion, which is more realistic.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
RIM-F (FRIM)	Fuzzy Reference Ideal Method	2018	A fuzzy version of the RIM method that deals with imprecise option ratings and reference interval bounds.	1	Ranking	Point Values	Option Ratings	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
RMCDM	Robust MCDM	2017	Combines subjective and objective approaches (EM I, AHP, TOPSIS, and VIKOR methods) to minimise risk and maximise gain by introducing the consideration of DM views into objective analysis.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Objective	Point Value	Comparison	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
RMP	Ranking with Multiple Profiles	2013	A simple ranking method for dealing with various types of criteria that may not be numerical and have to be evaluated subjectively. Uses comparative outranking against hypothetical solution options to model the DMs preference and not a pairwise comparison between the actual alternatives, which allows for a larger number of criteria and options to be considered.	1	Ranking	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Flat only	Unlimited	Any	Order	Reference	Programming
RMP-PE	Preference Elicitation for Ranking with Multiple Profiles	2022	An objective preference elicitation method for pairwise-based ranking methods, originally intended for use with the RMP method. Used to derive option Scoring and preference orders for non-numerical (lexicographic) criteria.	1	Ranking	Order	Both	Both	Heavy	Unlimited	Weighted	Pre-determined	Ratio	Assignment	Independent	Flat only	Unlimited	Measurable	Order	Reference	Programming
RPAP	Reference-based Preferences Aggregation Procedure	2013	A qualitative method for dealing with situations where the importance relations of criteria and preference relations of options are mutually dependent (i.e. one serves as the reference for the other).	1	Ranking	Order	N/A	N/A	Heavy	≤ 25	Weighted	Subjective	Order	Reference	Independent	Flat only	≤ 25	Abstract	Order	Reference	Programming
RRMI	Relative Ranking with Multidimensional Indicators	2018	A thorough method for ordering the alternatives in situations where their performance against the individual criteria is defined by multiple differing scenarios.	1	Ranking	Point Values	Preference Model	N/A	Heavy	≤ 25	Weighted	Pre-determined	Order	Assignment	Independent	Hierarchical	Unlimited	Measurable	Interval	Direct Rating	Programming
RTM	Ranking Theory Method	2019	A family of related methods based on ranking theory to build a special score matrix for a given problem. Simultaneous use of several calculation approaches offers a wider view on results.	1	Ranking	Point Values	N/A	N/A	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Comparison	Functional
RUBIS	N/A (custom name)	2008	A new iterative subtype of outranking approaches that uses bipolar-valued outranking digraph to enable progressive decision-aiding (i.e. options get eliminated along the process).	1	Ranking	Order	N/A	Both	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Ratio	Comparison	Programming
RUTA	Rank-related requirements with UTA	2012	An evolution of GRIP where, instead of using criteria, the DM preferences are expressed as the desired rank of reference alternatives to order non-reference options.	1	Ranking	Order	N/A	Option Ratings	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Ratio	Reference	Programming
SAW	Simple Additive Weighting	1954	Simplified MAVT/special case MAUT with additive value function normalised on a 0-1 scale. Involves direct addition of the alternative performances multiplied by the criteria weights.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
SAW-F (FSAW)	Fuzzy SAW	2013	A SAW basis with fuzzy representation of the criteria weights.	3	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Functional
SBER	Simulation-Based Evidential Reasoning	2015	A simulation-based extension to the original Evidential Reasoning method for dealing with information (multiple conflicting "belief Scoring"). Requires a computer code to execute.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Order	Probability	Programming
SCA (I)	Strategic Choice Approach	1987	An interactive method for dealing with problems involving complex knowledge. Facilitates consensus between stakeholders or assessing the solution options through a joint learning process. Uses pairwise comparison of alternatives to derive a graphical representation of the overall comparison between each pair. Implemented as STRAD software.	1	Ranking	Distribution	Option Ratings	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Order	Probability	Programming
SCA (II)	Spatial Compromise Programming	1997	A combination of CP and GIS methods for prioritising among the geographical solution alternatives where different geographical locations are used as a separate criteria layer.	1	Ranking	Point Values	N/A	Criteria Influence	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Separation
SI	Sugeno Integral	2004	A detailed, precise technique to rate option performances against the Max & Min reference point on interacting criteria.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Interacting	Flat only	≤ 25	Any	Order	Comparison	Programming
SIPRES	Simos' Procedure for Reference Situations	2015	The combined ZAPROS & Simos methods for ranking qualitative alternatives using quantitative information.	1	Ranking	Point Values	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Nominal	Ratio	Reference	Separation
SIR	Superiority and inferiority ranking	2001	An extension of the PROMETHEE method that introduces Superiority & Inferiority concepts instead of Concordance & Discordance. Can be applied to rank the alternatives on its own or in combination with other existing methods for criteria weighting and options ranking.	1	Ranking	Point Values	N/A	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
SIR-F/G/IFG	Fuzzy SIR / Grey SIR	2010	A fuzzy extension to SIR for dealing with uncertainties in option Scoring. A variety of versions exist, including Fuzzy, Grey, and Grey-Intuitionistic representation of option Scoring. Allows working with many criteria in a hierarchical structure, but forces the user to narrow down to 15 flat criteria in the process. Includes the consideration of DM competence.	1	Ranking	Point Values	Both	Option Ratings	Reasonable	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Hierarchical	≤ 25	Nominal	Point Value	Direct Rating	Separation
SMAA	Stochastic Multicriteria Acceptability Analysis	1998	A ranking method based on stochastic simulation of heavy uncertainties. Uses option performances to derive criteria weights by calculating the "rank acceptability index" for each possible rank order of options.	1	Ranking	Order	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Comparison	Independent	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
SMAA-2	SMAA for GDM	1998	SMAA adapted for incomplete preference information presented using value ranges.	1	Ranking	Order	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Comparison	Interacting	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
SMAA-3	SMAA with thresholds	1998	SMAA with thresholds limiting the possible option values, which affects the possible selection of option rankings from which criteria weights are calculated.	1	Ranking	Order	Preference Model	Option Ratings	Heavy	≤ 25	Weighted	Subjective	Interval	Comparison	Interacting	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
SMAA-A	SMAA based on Achievement functions	2002	SMAA that uses subsets of reference points to derive criteria weights that produce the most acceptable ranking order of alternatives.	1	Ranking	Order	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Interval	Reference	Interacting	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
SMART	Simple Multi-Attribute Scoring Technique	1976	Simplified MAVT/special case MAUT: uses an additive model with a linear simplification of the utility/value function. Assumes independence of utility and preference. Independent performances are assigned at a common scale. Includes a simple approach to deriving criteria weights.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Ratio	Reference	Functional
SMARTER	SMART Exploiting Ranks	1994	An improvement to SMARTs offering methodological preference elicitation for the pre-specified attributes. Does not require stakeholder interviews and offers simpler calculations.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Order	Comparison	Independent	Flat only	Unlimited	Measurable	Ratio	Reference	Functional
SMARTS	SMART + Swings	1994	An improvement to SMART method that resolves its insensitivity to ranges/variability of utility values. Uses SWINGS method to derive criteria weights from subjective ordering.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	Ratio	Reference	Functional
SMCDM	Stratified MCDM	2018	Uses stratification concept to consider the possible probabilistic variations in criteria weights while a decision is being made or after it was made.	1	Ranking	Point Values	Preference Model	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Probability	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
SNOD	Scale of Normalized and Ordered Differences	2004	A VDA method involving the efficiency criteria grouped into independent subsets. Performs a pairwise analysis of advantages and disadvantages between the alternatives. VDA procedures imply verbal participation of the DMs i.e. qualitative, verbal responses retrieved through interviews are fed into the analytical model to aggregate numerical preference scores.	1	Ranking	Order	N/A	N/A	Light	≤ 25	Equivalent	N/A	N/A	N/A	Interacting	Flat only	≤ 25	Measurable	Ratio	Comparison	Programming
SORR	Stochastic Ordinal Regression for Ranking	2013	A method built by combining the approaches from SMAA, ROR, & ERA methods. It allows building a very detailed representation of the DMs preferences using scarce data and derive a reliable ranking recommendation based upon several different utility function types.	1	Ranking	Distribution	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Comparison	Programming
SP	Scenario Planning	1995	A planning approach that leverages the full range of possible events and outcomes to select the best course of action. Consideration of the various possible scenarios is corrected for the common cognitive biases (overconfidence, tunnel vision). Combines both qualitative and quantitative planning means (the latter typically related to financials & timeline).	1	Ranking	Distribution	Option Ratings	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Abstract	Order	Comparison	Programming
SPOTIS	Stable Preference Ordering Towards Ideal Solution	2020	A simple method for ranking deterministic options based on how far they fall from the ideal solution available for each criterion.	1	Ranking	Point Values	N/A	Option Ratings	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
SURE	Simulated Uncertainty Range Evaluations	2018	An improvement to MARE method using triangular distribution simulations to reflect the uncertainty in the performance of alternatives. Produces a range of possible values with the most likely values indicated.	1	Ranking	Distribution	Option Ratings	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Nominal	Distribution	Probability	Functional
TACTIC	Treatment of the Alternatives according To the Importance of Criteria	1986	Concordance & discordance-based preference evaluation is used on DM's subjective judgements to yield the most objective order of alternatives based on the relative importance of criteria.	1	Ranking	Order	Option Ratings	Both	Heavy	Unlimited	Weighted	Subjective	Order	Comparison	Independent	Flat only	Unlimited	Measurable	Order	Reference	Programming
TCO	Total Cost of Ownership	2011	A quantitative method for evaluating quantitative & qualitative decision aspects through a common factor expressed in monetary terms. Allows for imperfect quantification of non-monetary aspects. Is not originally part of the MCDA domain, but allows to derive a merit for ranking the alternative solutions. Allows the inclusion of DM competence rating.	1	Ranking	Intervals	Both	N/A	Light	Unlimited	Weighted	Objective	Point Value	Options-based	Interacting	Hierarchical	Unlimited	Measurable	Point Value	Direct Rating	Functional
TODIM	Interactive Multi-Criteria Decision Making (Port.)	1991	Facilitates gathering the insights about DM/Stakeholder subjective preferences. Uses dominance measure to reproduce the gain/loss function of prospect theory.	1	Ranking	Point Values	Option Ratings	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
TODIM-CPT	TODIM based on Cumulative Prospect Theory	2013	An extension of TODIM that takes criteria interactions into account	1	Ranking	Point Values	Both	N/A	Heavy	≤ 25	Weighted	Subjective	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
TODIM-E	Extended TODIM	2019	An extension of TODIM method for dealing with probability intervals.	1	Ranking	Intervals	Option Ratings	N/A	Heavy	≤ 25	Weighted	Subjective	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Interval	Probability	Separation
TODIM-F	Fuzzy TODIM	2012	An extension of the original TODIM method for dealing with imprecise decision information expressed by the DM as interval or linguistic values.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Separation
TODIM-IF	Intuitionistic Fuzzy TODIM	2013	A general extension to TODIM that considers hesitation regarding option performances.	1	Ranking	Point Values	Option Ratings	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	Interval	Direct Rating	Separation
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution	1981	Emphasises the solutions closest to the ideal goal using Euclidean distances by minimising the distance to the ideal solution and maximising the distance to the anti-ideal solution. Requires fewer calculations than VIKOR.	3	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
TOPSIS-F	Fuzzy TOPSIS	2012	A TOPSIS basis with fuzzy triangular representation of criteria weights and options Scoring to represent a discordance of opinions in a GDM setting.	1	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Separation
TOR	Trade-Off Ranking	2016	Allows choosing the best alternative from a set of equivalent Pareto Optimal solutions (as produced by an MODM procedure) by ranking based on minimising trade-off.	1	Ranking	Point Values	N/A	N/A	Light	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
TRUST	Trigger-based aUtomatic Subjective weighting	2009	An efficient method (i.e. avoids pairwise comparisons) for prioritising options using a combination of subjective and objective judgements on specific technical and natural parameters outside of DM's control (e.g. equipment performance values).	1	Ranking	Point Values	N/A	N/A	Reasonable	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Abstract	Point Value	Direct Rating	Functional
ULOWA	Unbalanced Linguistic Ordered Weighted Averaging	2010	An extension to LOWA that uses non-uniform distribution of Fuzzy values assigned to linguistic labels to allow a more precise, case-specific adjustment of the DM's preference behaviour. This helps to deliver a more realistic interpretation of the linguistic terms provided by the DMs with different opinion weights.	2	Ranking	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Functional
UTA	UTILITIES Additives	1982	The core method in a set of "aggregation-disaggregation" approaches originally developed as an alternative to MAUT. Optimally infers additive value function consistent with the global preferences expressed through ranking a set of reference alternatives by the DMs.	3	Ranking	Order	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Point Value	Reference	Programming
UTA-GMS	Extension of UTA with GMS (named by the authors' names)	2008	A version of the UTA method that uses permutation of all possible consistent value functions to identify the most suitable one.	3	Ranking	Order	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Point Value	Reference	Programming
UTA-GMS-INT	UTA GMS for INTERacting criteria	2014	An extension of the UTA-GMS method using Non-Additive Integrals to allow for dependence between criteria.	1	Ranking	Order	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Interacting	Flat only	≤ 25	Any	Point Value	Reference	Programming
UTAMP	UTA Meta-Process	2005	An extension to UTA that highlights the differences between successive reference actions to yield a more pronounced preference model.	3	Ranking	Order	N/A	Option Ratings	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Point Value	Reference	Programming
UTASTAR	UTA with Stability Analysis	1985	A more precise version of UTA that replaces constraint values with error margins for the proposed rankings.	1	Ranking	Point Values	Option Ratings	N/A	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Any	Ratio	Reference	Programming

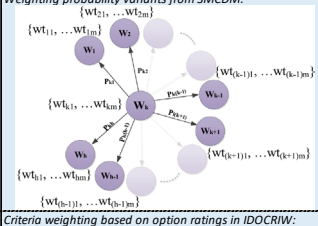
Abbreviation	Full Name	Year	Top-Level Description	Type Count	1. Problem Specification					2. Criteria Definition							3. Preference Aggregation				
					1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
VCIO	Variation of Criteria Importance Order	2011	Objectivity of this method is supported by the fact that it calculates all possible variations of criteria rank orders of importance. This allows to graphically demonstrate the probabilities of a particular criteria to take a particular rank position, where the section area for each criterion on the graph can be used to define the final rank position for that criterion among others.	1	Ranking	Intervals	Both	N/A	Reasonable	≤ 25	Weighted	Subjective	Order	Comparison	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
VIKOR	Multi-Criteria Optimisation & Compromise	2012	A compensatory version of TOPSIS that minimises the distance to ideal solution using linear normalization. Produces a more precise, relevant answer and allows exploring the range of stable criteria weights i.e. such that retain the same ranking as was obtained with original weights.	1	Ranking	Point Values	N/A	Criteria Influence	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Separation
VIKOR-F	Fuzzy VIKOR	2015	A VIKOR basis with fuzzy representation of the DM preferences and option performance Scoring to suit a GDM setting with multiple opinions.	1	Ranking	Point Values	Both	Criteria Influence	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	Separation
VIMDA	Visual MCDA reference Direction Approach	1988	An interactive method for measuring the DM's overall aspiration levels using reference directions. Ranking is derived subjectively using graphical output representation.	1	Ranking	Order	N/A	Option Ratings	Reasonable	≤ 25	Weighted	Objective	Ratio	Options-based	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
VIP	Variable Interdependent Parameters	2000	A method for preference aggregation using additive value functions for problems with imprecise decision information. Involves progressive down-selection of the alternatives using tolerance measures.	1	Ranking	Intervals	Option Ratings	Both	Reasonable	≤ 25	Weighted	Subjective	Ratio	Reference	Interacting	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Programming
WASPAS	Weighted Aggregated Sum Product Assessment	2012	Represents a combination of WPM and WSM with adjustable bias towards one of the aggregation approaches (multiplicative or additive), if preferred.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
WASPAS-G	Grey WASPAS	2015	An extension to the WASPAS method with Grey numbers for dealing with imprecise, underdefined, or immeasurable decision information.	1	Ranking	Point Values	Both	N/A	Light	Unlimited	Weighted	Pre-determined	Interval	Assignment	Independent	Flat only	Unlimited	Nominal	Interval	Direct Rating	Functional
WEBIRA	WEIGHT Balancing Indicator Ranks Accordance	2017	A high-precision method for optimising criteria weights through an iterative procedure until the optimum distribution of weights is identified, based on the initial ranking of alternatives performed with equal criteria weights.	1	Ranking	Point Values	N/A	N/A	Heavy	≤ 25	Weighted	Objective	Order	Options-based	Independent	Flat only	≤ 25	Measurable	Point Value	Direct Rating	Programming
WISDOM	Weightless Incremental Selection, Decision, and Ordering Method	2003	A very simple, spreadsheet-based method for deriving option performance Scoring from pairwise comparison information that uses qualitative gradations. The aggregation function is hidden from the user.	1	Ranking	Order	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	Unlimited	Any	Order	Comparison	Functional
WLCRT	Weighted Linear Combination Ranking Technique	2013	Uses linear combinations of matrix algebra (Eigenvector calculations) to derive criteria weights based on option performances. Produces the decision matrix using nominal scoring against external reference values for each criterion. Relatively simple and flexible.	1	Ranking	Point Values	N/A	Option Ratings	Heavy	Unlimited	Weighted	Objective	Point Value	Options-based	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
WLSM	Weighted Least Square Method	1979	A more robust and precise version of the AHP-like method that involves elaborate computer-based calculations.	1	Ranking	Point Values	N/A	N/A	Reasonable	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	≤ 25	Nominal	Ratio	Comparison	Functional
WOD	Weighted Overlap Dominance	2011	An interactive procedure for ranking the alternatives based on weighted overlap of interval Scoring values, risk attitude, and weighted dominance. Presents a visual output to facilitate the DM's understanding of the relationships between ranked alternatives.	1	Ranking	Intervals	Option Ratings	Option Ratings	Heavy	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	Unlimited	Measurable	Interval	Direct Rating	Separation
WPM	Weighted Product Method	2011	A version of the WSM method that uses multiplicative aggregation instead of addition to amplify performance differences between the options.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
WPM-F (FWPM)	Fuzzy Weighted Product	1996	An extension to WPM method where the α -level sets are used to derive fuzzy utilities	3	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Functional
WSM	Weighted Sum Method	1954	Global performance of each alternative is computed as the algebraic sum of its evaluations multiplied by its weighted criteria.	8	Ranking	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	Functional
WSM-F (FWSM)	Fuzzy Weighted Sum	1996	An extension to WSM method where the α -level sets are used to derive fuzzy utilities	3	Ranking	Point Values	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Measurable	Distribution	Direct Rating	Functional
XOR-AHP	XOR-based AHP	2019	A technique for deriving criteria weights and ranking the alternatives based on multiple judgements in the presence of uncertainty regarding both option scoring and criteria weights. Incorporates optimistic, pessimistic, and neutral DM attitudes to uncertainty by implementing XOR/Exclusive OR logic.	1	Ranking	Point Values	Both	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	≤ 25	Nominal	Ratio	Comparison	Programming
ZAPROS	Foreign Transliteration of an acronym in Russian: Closed Procedures near Reference Situations	1979	A verbal decision analysis method that derives partial order on the set of options using psychologically aligned preference elicitation procedures. Uses ordinal evaluation of alternatives against criteria pairs to build binary relations.	1	Ranking	Order	N/A	N/A	Light	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Abstract	Order	Comparison	Programming
ZAPROS III	Foreign Transliteration of an acronym in Russian: Closed Procedures near Reference Situations, version 3	2001	An extension of ZAPROS method for dealing with ordinal evaluations of alternatives expressed in interval form, which allows for incomparability and partial order.	1	Ranking	Order	N/A	N/A	Reasonable	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Abstract	Order	Reference	Programming
ZMii	N/A (custom name)	2019	A Scoring technique for aggregating interval judgements about option performances in GDM setting, where the degree of agreement between the DMs and the degree of information completeness are measured to give prioritisation.	1	Ranking	Distribution	Preference Model	N/A	Heavy	≤ 25	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Reference	Functional
AHP	Analytic Hierarchy Process	1980	Pairwise comparison of hierarchical criteria based on difference information (additive). Rankings estimated using the maximum eigenvector method. Performance evaluation uses a 9-score system. Suitable for multiple DMs with different voting powers.	2	Weighting	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	N/A	Any	N/A	N/A	Functional
AHP-F (FAHP)	Fuzzy AHP	2011	AHP basis with fuzzy evaluation of criteria weights.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	N/A	Any	N/A	N/A	Functional
AHP-M (MAHP)	Multiplicative AHP	1997	AHP extension where pairwise comparisons are based on ratios, and ranking approximations are based on the logarithmic least squares technique. Allows magnifying the differences between alternative performances to offer a better distinction between the alternatives. Used for the problems where the evaluations of some alternatives fall very close to each other.	2	Weighting	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	N/A	Any	N/A	N/A	Functional
AHP-MG	Consensus Decision-Making	2019	Consensus analysis for GDM MAHP settings based on heuristic consistency control.	1	Weighting	Point Values	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Hierarchical	N/A	Any	N/A	N/A	Programming
AHP-R (RAHP)	Revised AHP	1983	An improved version of AHP featuring a revised rating procedure to resolve rank reversal in iterative applications. It involves normalising option Ratings so their sum always equals 1.	1	Weighting	Point Values	N/A	N/A	Light	≤ 25	Weighted	Objective	Ratio	Comparison	Independent	Hierarchical	Unlimited	Any	N/A	N/A	Functional
AIP	Aggregated Individual Priority	2017	A simple method for criteria weighting based on the geometric mean principle. Offers a rough approximation of the EM results at low effort only using one simple formula.	3	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Functional
ANP	Analytic Network Process	1996	General, non-linear evolution of AHP that uses Markov-chain based aggregation. Clusters the DP elements (criteria, solution alternatives) as a graph structure to investigate the connections.	1	Weighting	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Comparison	Interacting	Hierarchical	N/A	Any	N/A	N/A	Functional
BCM	Base-Criterion Method	2019	A simplification of BWM using a single base-criterion selected, which is pairwise compared against all other criteria to ensure fully consistent criteria weights.	1	Weighting	Point Values	N/A	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Reference	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
BPA	Benefits Prioritization Analysis	2020	Aggregates the preferences ("perceptions") collected from a large number of different stakeholders, offering an additional metric to measure the respondent's expertise and the importance of their opinion in the given project. Dedicated for use with BIM in the building industry, but could be adapted for other contexts.	1	Weighting	Point Values	Preference Model	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
BWM	Best-Worst Method	2015	Based on selecting the best (most important) and the worst (least important) decision criteria followed by systematic pairwise comparison of the remaining criteria against these two. Proposed as a simplification to the AHP pairwise process to enable working with many criteria efficiently.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Reference	Independent	Flat only	N/A	Any	N/A	N/A	Functional
BWM-G	Group BWM	2021	An adaptation of BWM for GDM i.e. a multitude of opinions regarding the Best & Worst criteria	1	Weighting	Point Values	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Reference	Independent	Flat only	N/A	Any	N/A	N/A	Functional
BWS	Best-Worst Scaling	1990	Serves as a cost-effective decision data collection tool. Uses the DM's best/worst preferences for all available options compared in pairs to derive priorities by identifying the maximum difference in option utilities. Although requiring some competence in MCDA theory for the analyst, this method is dedicated to offer a data-gathering process that is simple for the respondents to use.	1	Weighting	Distribution	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Point Value	Reference	Independent	Hierarchical	N/A	Any	N/A	N/A	Functional
CA (I)	Conjoint Analysis	1978	A highly flexible method for estimating high-precision preference structure of multiple DMs (attributes, weights, priorities) from their overall evaluations, which may be vague. Allows building a unique preference model for each individual DM or a unique situation depending on the goal of the task. Combines various analytical methods (reference-based, comparison-based, functional, statistical).	1	Weighting	Distribution	Preference Model	N/A	Reasonable	≤ 25	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
CBS	Count-Balanced Sum	2019	A simple method for criteria weighting that offers a simpler calculation procedure than EM to produce similar results.	3	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Functional
CCSD	Correlation Coefficient and Standard Deviation	2010	A method for objective criteria weight derivation based on the performance of alternatives against each criterion and its individual effect on the overall ranking. Offers the ability to include the DM's subjective preferences for criteria weights (e.g. threshold, bias) on top of an objective weight.	1	Weighting	Point Values	N/A	Criteria Influence	Heavy	Unlimited	Weighted	Objective	Distribution	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Programming
CFPR	Consistent Fuzzy Preference Relations	2004	A Group DM method for defining criteria weights from multiple vague opinions using pairwise comparisons. Translates linguistic terms into fuzzy numbers.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Abstract	N/A	N/A	Functional
CGT	Cooperative Game Theory	2019	An analytical approach to discrete MCDA used to consider preferential dependence existing in complex problems as a consequence of interaction among the options or criteria. Although a specific method is proposed in the source, no name is assigned so the discipline title is used.	1	Weighting	Point Values	N/A	N/A	Heavy	≤ 25	Weighted	Objective	Point Value	Comparison	Interacting	Hierarchical	Unlimited	Any	N/A	N/A	Programming
CI	Choquet Integral	2004	A method for objective derivation of weights for the criteria that exhibit dependencies between each other. Based on partial preorder of a reference set of criteria.	1	Weighting	Order	Preference Model	Criteria Influence	Heavy	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Interacting	Flat only	N/A	Any	N/A	N/A	Programming
CILOS	Criterion Impact Loss	1987	A simple procedure for objective criteria weighting based on measuring relative criteria impacts using entropy methods applied to Option Ratings.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Objective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Functional
CILOS-F	Fuzzy CILOS	2020	Extension of CILOS method to deal with vague criteria loss representations using triangle fuzzy numbers.	1	Weighting	Point Values	Option Ratings	N/A	Reasonable	Unlimited	Weighted	Objective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Functional
CRITIC	CRiteria Importance Through Intercriteria Correlation	1995	Defines the criteria weights using an approach opposite to the EM method. Tests the correlation between criteria using the information contained in the Decision Matrix.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Objective	Distribution	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Functional
CROC	Cardinal Rank Ordering of Criteria	2012	A method for cardinal criteria weighting based on criteria rank to represent ordinal importance information. Calculates criteria weights based on the identification of the most and the least important criteria. Allows grouping criteria weights that are more or less similar in importance. Implemented as software.	1	Weighting	Point Values	Preference Model	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Separation
DANP	DEMATEL-based ANP	2011	An extension of ANP with the DEMATEL method for assigning criteria weights with high precision and solving dependence and feedback problem.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Point Value	Assignment	Interacting	Hierarchical	N/A	Any	N/A	N/A	Functional
DEMATEL	Decision making trial and evaluation laboratory Determination of interrelations	1974	An adaptation of the original DEMATEL method for finding the cause-and-effect relationships between objects to MCDA tasks. May be used either to rank the alternatives with implicit consideration of the criteria; or to derive criteria weights. Represents a special case FCM.	2	Weighting	Point Values	N/A	Criteria Influence	Light	≤ 25	Weighted	Subjective	Ratio	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
DIVAPIME	Variation pour les Parametres d'Importance des Methodes Electre (Kronack)	1995	An interview-based method for criteria weighting that uses a more detailed version of preference relations to model complex DM attitudes; includes hesitation and intransitive relations.	1	Weighting	Point Values	N/A	Criteria Influence	Reasonable	≤ 25	Weighted	Subjective	Order	Reference	Independent	Flat only	N/A	Any	N/A	N/A	Separation
ELICIT	N/A (custom name)	2016	A semi-objective criteria weighting method that uses the order of criteria importance provided by the DM to infer the most probable criteria weights using a statistical approach.	1	Weighting	Point Values	Preference Model	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
EM	Eigenvector Method	1977	Used to retrieve criteria weights using matrix operations on the nominal criteria importance Scoring from multiple DMs.	1	Weighting	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Functional
EWM	Entropy Weights Method	1992	Facilitates the definition of objective criteria weights from option performances where the DM has no information on criteria importance. Prone to resulting in criteria weights that may be 100s of times greater than for other criteria.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Objective	Point Value	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Functional
FARE	Factor RElationshIp	2011	A detailed method for determining the weights of criteria that exhibit measurable interdependence based on subjective scaling of the criteria importance by the DM.	1	Weighting	Point Values	N/A	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
FCM	Fuzzy Cognitive Maps	1986	The application of Cognitive Maps method to depict the relationships between interdependent criteria.	1	Weighting	Order	Preference Model	Criteria Influence	Heavy	≤ 25	Weighted	Subjective	Order	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Programming
FDEMATEL	Fuzzy DEMATEL	2011	DEMATEL modification intended for working with uncertainties in the decision input data.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Probability	Independent	Flat only	N/A	Any	N/A	N/A	Functional
FDM	Fuzzy Decision Maps	2006	An evolution of FCM dedicated to dealing with the feedback effect due to criteria dependencies.	2	Weighting	Point Values	N/A	Criteria Influence	Light	≤ 25	Weighted	Subjective	Ratio	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
FUCOM	Full Consistency Method	2018	An elaborate method for deriving precise criteria weights based on simplified pairwise comparison procedure offering a more robust process.	1	Weighting	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Programming
HRE	Heuristic Scoring Estimation	2013	An iterative process to retrieve the unknown criteria weights based on the known weights for the reference set of criteria. The unknown weights are determined as an arithmetic mean of the values and ratios determined from the known weights.	1	Weighting	Point Values	Preference Model	N/A	Heavy	≤ 25	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Programming
IDOCRIW	Integrated Determination of Objective CRiteria Weights	2016	An integrated compensatory method that employs CILOS decision matrices and Entropy Method to measure relative criteria weights.	1	Weighting	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Objective	Ratio	Reference	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Functional
ISM	Interpretive Structural Modelling	1975	A software-based method that uses DMs knowledge about the considered criteria to infer intercriteria influences and inform criteria structure by creating a binary relations matrix.	1	Weighting	Order	N/A	N/A	Reasonable	Unlimited	Weighted	Subjective	Order	Comparison	Interacting	Hierarchical	N/A	Any	N/A	N/A	N/A

Abbreviation	Full Name	Year	Top-Level Description	Type Count	1. Problem Specification					2. Criteria Definition							3. Preference Aggregation				
					1.1: Task Facilitated	1.2: Output Format	1.3: Ambiguity Presence	1.4: Relative Thresholds	1.5: Resource Required	2.1: Criteria Count	2.2: Criteria Importance	2.3: Weights Basis	2.4: Weights Format	2.5: Definition Procedure	2.6: Criteria Dependency	2.7: Criteria Hierarchy	3.1: Options Count	3.2: Attribute Nature	3.3: Rating Format	3.4: Rating Procedure	3.5: Method of Aggregation
KANO	N/A (by Author's name)	1984	A qualitative method dedicated to ordering product attributes in accordance with their importance for the task at hand. Used as a precursor to calculating criteria weights using other methods.	1	Weighting	Order	N/A	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Programming
KANO-F (F-KANO)	Fuzzy KANO	2009	An adaptation of the KANO method to allow for uncertainty or variability in the user/expert opinions, which may be expressed using more than 1 score, or withheld altogether.	1	Weighting	Order	Preference Model	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Programming
KEMIRA	KEmeny Median Indicator Ranks Accordance	2014	Originally dedicated to Choice problematic and does not offer a ranking capability. Allows deriving criteria weights for problems involving 2 sets of different criteria e.g. qualitative and quantitative, positive and negative, etc. where sets do not exhibit equal importance. Options can be subsequently ranked using optimisation on both sets of criteria.	1	Weighting	Point Values	Preference Model	N/A	Heavy	Unlimited	Weighted	Objective	Order	Comparison	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Programming
KEMIRA-E	Entropy KEMIRA	2017	An extension of the KEMIRA method with entropy tools to incorporate the consideration of 3 or more groups of criteria when deriving weights.	1	Weighting	Point Values	Preference Model	Criteria Influence	Heavy	Unlimited	Weighted	Objective	Order	Reference	Independent	Hierarchical	Unlimited	Measurable	N/A	N/A	Programming
LFDN	Linguistic Fuzzy Decision Networks	2013	An extension to FDM (II) for dealing with uncertain definitions in the relative criteria importance.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Functional
MEREC	MEthod based on the Removal Effects of Criteria	2021	A simple method for objective criteria weight elicitation that uses a logarithmic function and a permutation of the possible scenarios.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Objective	Point Value	Probability	Independent	Flat only	Unlimited	Measurable	N/A	N/A	Programming
PACMAN	Passive and Active Compensability Multicriteria Analysis	1998	Distinguishes between the active & passive criteria to demonstrate compensation asymmetry. Binary indexes are used to identify preference relations.	1	Weighting	Point Values	Preference Model	Criteria Influence	Heavy	≤ 25	Weighted	Subjective	Order	Comparison	Interacting	Flat only	N/A	Any	N/A	N/A	Programming
PIPRECIA	Pivot Pair-wise Relative Criteria Importance Assessment	2017	A method for defining criteria weights in large GDM settings with highly diverse opinions.	1	Weighting	Point Values	Preference Model	N/A	Light	Unlimited	Weighted	Subjective	Order	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Functional
RE	Rank Exponent	1981	A method for semi-objective criteria weighting. Similar to RR, but its formula involves an additional parameter for the number of ranking dimensions. Allows working with problems involving a mix of both ordered and equal weights.	4	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
RI	Relative Importance	1999	A method for criteria weighting that uses a non-iterative analytical procedure to offer the result nearly identical to EM. Used to replace the EM method if the computational resource is limited or to validate EM outputs. Offers better alignment of relative results than AIP or CBS methods.	3	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Functional
ROC	Rank Order Centroid	1992	A method for objective criteria weighting based on subjective ranking of criteria as a reflection of its ordinal importance. Based on the mathematical principle of centroid, but suffers from unconstrained range of the possible criteria weights resulting - which can differ far enough to appear that some criteria have negligible influence on the decision compared to others.	4	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
ROD	Rank Order Distribution	2002	A method for semi-objective criteria weighting that offers an improved, reliable performance over ROC method by using a more objective probabilistic assumption. Unrestricted weights are assumed to have uniform distribution and calculated using probability density functions. Produced criteria weights are similar to RS method and more objective than ROC method.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
RR	Rank Reciprocal	1981	A method for semi-objective criteria weighting. Calculates the non-normalised weights in 0-1 range through division by rank reciprocals (1/n).	4	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
RS	Ranking Sum	1981	A method for semi-objective criteria weighting. Calculates normalised weights in the 0-1 range through the division of criteria ranks by the rank-sum. Suggested for use in place of ROD method in problems featuring too many criteria (≥25).	4	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
SAST	Strategic Assumptions Surfacing and Testing	1979	The procedure for deriving criteria importance weights based on two key metrics: importance and uncertainty	1	Weighting	Point Values	N/A	N/A	Reasonable	Unlimited	Weighted	Subjective	Ratio	Comparison	Interacting	Flat only	N/A	Abstract	N/A	N/A	Programming
SIMOS	N/A (by Author's name)	1990	A method for objective derivation of the criteria weights using a bespoke set of coloured cards. Simplifies the elicitation of relative criteria importance evaluations in a play-like process.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Programming
SRF	Simos-Roy-Figueira (Revised SIMOS)	2002	An improved version of the SIMOS method for criteria weights derivation based on reference points rather than mutual comparison between criteria.	1	Weighting	Point Values	N/A	Criteria Influence	Light	Unlimited	Weighted	Subjective	Ratio	Comparison	Independent	Flat only	N/A	Any	N/A	N/A	Programming
SS	Light Scoring	2018	One of the simplest methods for ranking the alternatives. Relies on transforming a complex set of values and requirements into a clear (mutually exclusive, exhaustive, and relevant) criteria. Particularly effective in Group DM settings. Separate options are scored directly by voting and ranked using the sum or the average of the provided scores.	1	Weighting	Point Values	N/A	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Hierarchical	N/A	Any	N/A	N/A	Programming
SWARA	Step-wise Weight Assessment Ratio Analysis	2010	A method for criteria weighting in Group DM settings based on the frequency of criteria mentions in respondent opinions. Requires the involved stakeholders to express their opinions regarding criteria importance, which are then combined to yield the resultant relative criteria weights.	1	Weighting	Point Values	Preference Model	N/A	Light	≤ 25	Weighted	Pre-determined	Order	Assignment	Independent	Flat only	N/A	Any	N/A	N/A	Functional
SWING	Derived from the concept of swinging between extremes	1986	A multistage method for deriving criteria weights based on the total range of possible option ratings. Uses dedicated functions (linear, non-linear) to allow different preference shapes between the extremes.	1	Weighting	Point Values	N/A	N/A	Light	≤ 25	Weighted	Subjective	Ratio	Reference	Independent	Flat only	N/A	Measurable	N/A	N/A	Functional
SWING-I (ISWING)	Imprecise SWING	2017	SWING criteria weighting method adapted for partial preference inputs.	1	Weighting	Point Values	Preference Model	N/A	Reasonable	≤ 25	Weighted	Subjective	Ratio	Reference	Independent	Flat only	N/A	Measurable	N/A	N/A	Functional
BSC	Balanced ScoreCard	1995	Originally a "pros-and-cons" type tool and not a formal MCDA method. A qualitative business analysis framework for aligning the decisions with organisational strategy. Uses 4 dimensions: Financial, Customer, Internal, Growth. Allows deriving the criteria and solution alternatives to apply with MCDA criteria weighting and aggregation.	1	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Order	Comparison	N/A
CM (II)	Cognitive Mapping	1988	A group method to map the DM's perception about the problem as a value tree (node & arrow diagram) representing the various connections and relationships between criteria. Useful for structuring complex problems with multi-level quantitative and qualitative criteria that are difficult to comprehend in precise terms. Used as a precursor to criteria weighting methods.	1	Formulation	Statements	Preference Model	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Interacting	Hierarchical	N/A	Any	N/A	N/A	N/A
DELPHI	N/A (Assigned name and not an acronym)	1962	A structured group interaction method to define, select, and structure the evaluation criteria and solution options for MCDA problems using statistical methods.	1	Formulation	Mixed	Both	N/A	Light	Unlimited	Weighted	Subjective	Distribution	Probability	Independent	Flat only	Unlimited	Any	Distribution	Probability	N/A
DPSIR	Drivers, Pressures, States, Impacts, Responses	1993	A qualitative "pros-and-cons" type approach to structuring MCDA criteria. Describes interactions between the systems through cause-effect relationships expressed through the associated criteria and solution alternatives. Developed to simplify the representation of complex problems (e.g. environmental) for use before the application of an aggregation approach.	1	Formulation	Mixed	N/A	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Independent	Hierarchical	Unlimited	Any	Point Value	Direct Rating	N/A
DPSWR	Driver, Pressure, State, Welfare, Response	2013	A DPSIR basis ("pros-and-cons" type approach) modified to identify measurement objects within a problem, which represents criteria interactions.	1	Formulation	Mixed	N/A	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Assignment	Interacting	Hierarchical	Unlimited	Any	Point Value	Direct Rating	N/A
EEP	Expert Elicitation Process	2011	A qualitative method for retrieving decision information from multiple experts before formulating an MCDA task. The information retrieved allows to formulate the objectives of the task (used as criteria in an MCDA task), prioritisation of the objectives (to inform criteria weights), and define action alternatives (used as options).	2	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Independent	Hierarchical	Unlimited	Any	N/A	N/A	N/A
GCM	Group Cognitive Maps	1994	Cognitive Mapping ("CM II") method adapted for Group DM.	1	Formulation	Mixed	Both	N/A	Reasonable	Unlimited	Weighted	Subjective	Distribution	Assignment	Interacting	Hierarchical	Unlimited	Any	Distribution	Direct Rating	N/A
MADM-OPT	OPTimum MADM	2016	A method for defining the criteria, identifying the options and the ideal alternative, and deriving option performances based on a range of available documentation e.g. legislative or technical. No aggregation procedure is involved.	1	Formulation	Point Values	N/A	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Reference	N/A
MCIA	Multi-Criteria Intelligence Aid	2017	An AI-based approach for structuring complex problems with uncertain linguistic inputs, which also considers the DM's risk-taking attitude (represented as criteria influence thresholds).	1	Formulation	Mixed	Both	N/A	Light	Unlimited	Weighted	Subjective	Distribution	Assignment	Independent	Flat only	Unlimited	Nominal	Point Value	Direct Rating	N/A
NGT	Nominal Group Technique	1970	A structured method for identifying ratios of subjective outcome likelihoods. Facilitates equal contribution from stakeholders and quick agreement on the final ranking.	1	Formulation	Mixed	Option Ratings	N/A	Light	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Nominal	Ratio	Probability	N/A
PMADM	Propective MADM	2016	A GDM approach to derive option Scoring based on future event probabilities and the limitations to possible Option Ratings.	1	Formulation	Point Values	Option Ratings	N/A	Light	Unlimited	Weighted	Pre-determined	Point Value	Assignment	Independent	Flat only	Unlimited	Measurable	Point Value	Direct Rating	N/A
PRUF	Possibilistic Relational Universal Fuzzy	1978	A method for translating verbal (linguistic) assessments of option performances into probabilistic values with application of fuzzy logic to account for vagueness in verbal meanings.	1	Formulation	Distribution	Option Ratings	N/A	Heavy	Unlimited	Equivalent	N/A	N/A	N/A	Independent	Flat only	Unlimited	Any	Internal	Probability	N/A
SA	Stakeholder Analysis	1997	Not a formal MCDA method originally. Offers decision-aiding function by helping the DM to identify the key actors / stakeholders in a project, and assess their respective interests and influences. The evaluations from different stakeholders are used to define the criteria. The possible actions affected by the evaluation define the options.	1	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Interacting	Flat only	N/A	Any	N/A	N/A	N/A
SODA	Strategic Options Development and Analysis	2010	A qualitative method that uses a form of Cognitive Mapping process to build a value map, which in MADM problems can be used as a mean to define the criteria and their hierarchy. Dedicated to undefined problems of both quantitative and qualitative nature. Centred around the subjectivity of stakeholder views in organisational decision-making tasks.	2	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Independent	Hierarchical	Unlimited	Any	N/A	N/A	N/A
SSM	Soft Systems Methodology	1990	A method for defining objectives/criteria for complex, poorly defined or vague decision problems through an interactive interview/questionnaire process. Offers a strong qualitative capability and involves comparing the considered problem against the existing or past real-world examples. Results in sets of criteria that can be further used in MCDA process.	1	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Interacting	Hierarchical	Unlimited	Any	N/A	N/A	N/A
SUSAIP	Sustainability appraisal in infrastructure projects	2006	A method for translating strategic objectives into finite criteria in large group settings (e.g. public polls) to pre-process objectives for MCDM activities before using an aggregation method (e.g. WSM).	1	Formulation	Point Values	Both	N/A	Light	Unlimited	Weighted	Subjective	Point Value	Comparison	Interacting	Hierarchical	Unlimited	Any	Distribution	Direct Rating	N/A
SWOT	Strengths, Weaknesses, Opportunities, and Threats	1998	Originally a "pros-and-cons" type tool and not a formal MCDA method. Can be used to inform the system of criteria for strategic decision problems. A qualitative tool for defining the parameters/RPIs considering the specifics of the surrounding business environment. Evaluates the situation and potential actions against 4 dimensions: Strengths, Weaknesses, Opportunities, and Threats.	1	Formulation	Statements	N/A	N/A	Light	Unlimited	Equivalent	N/A	N/A	Assignment	Independent	Flat only	Unlimited	Any	N/A	N/A	N/A

Table A.1-2: A Detailed Breakdown of ProBCA Parameters

Section	ID	Parameter	Parameter Explanation	Comments	Available Values	Problem-Based Value Implication	Uses & Justification	Example	Comments																								
1. Problem Specification	1.1	Task Facilitated	The specific task or sub-task that a DP is focused on, with reference to a generic MCDA process flow: - Options Formulation - Criteria Definition - Preference Aggregation	Ranking methods may or may not include sub-processes for options definition and criteria weighting. Where these sub-processes are included, they are marked as "Ranking" nevertheless, because their ultimate function is to aggregate the decision information into the global performance values.	Ranking	The option facilitates the DP addressing two sets of decision information, normally the solution options and the criteria. The process involves: - Step 1 (mandatory): evaluation of option performances against the criteria - Step 2 (optional - used in some methods): evaluation of criteria weights - Step 3 (mandatory): aggregation of global results informing the decision	These methods are used to identify the specific position of each option in the ranking of all options. Some options may rank close to each other, but it is very rare that 2 or more options have identical global performances and occupy the same ranking position. The results may be cardinal or ordinal depending on the decision information used.	<i>Point value ranking from ARAS method:</i> <table><tr><th></th><th>Alt.</th><th>K</th><th>Rank</th></tr><tr><td>A</td><td>0.6707</td><td>4</td><td></td></tr><tr><td>B</td><td>0.6564</td><td>6</td><td></td></tr><tr><td>C</td><td>0.7727</td><td>2</td><td></td></tr><tr><td>D</td><td>0.7734</td><td>1</td><td></td></tr><tr><td>...</td><td>...</td><td>...</td><td>...</td></tr></table>		Alt.	K	Rank	A	0.6707	4		B	0.6564	6		C	0.7727	2		D	0.7734	1		...	...	...	...	Minimum information required for a ranking operation: - Criteria-wise option performance ratings - Specific method for aggregating the data into global performance for each option (may use analytical or logical tools) Optional information for ranking: - Criteria weights (some methods do not use it)
						Alt.	K	Rank																									
					A	0.6707	4																										
B	0.6564	6																															
C	0.7727	2																															
D	0.7734	1																															
...	...	...	...																														
Weighting	The option facilitates the DP addressing just one set of decision information that can either consist of the solution options (compared in the absence of criteria) or the criteria (assessed to derive their importance weights). The process involves two mandatory steps: - Step 1: evaluation of option or criteria preferences against each other - Step 2: aggregation of the final results, which can either be: → option performance scores/ranking order → criteria weights	These methods are used when options have to be compared against each other directly in the absence of the secondary set of decision information. From this point of view, criteria weighting and direct option comparison tasks are equivalent in nature. The only exemption from this rule are objective criteria weighting methods that use existing (measurable, objective) option performances to derive criteria weights. Since option performances are pre-defined, their scoring is a calculation task and not a decision one and thus, whereas the decision component of the task aims to retrieve criteria weighting information that can be further used for a full ranking task that involves two sets of data.	<i>Criteria weights in SWING method:</i> <table><tr><th>Criteria</th><th>INC</th><th>ETC</th><th>WAC</th><th>FTG</th><th>TPD</th><th>ICO</th></tr><tr><td>Weights</td><td>0.10</td><td>0.29</td><td>0.14</td><td>0.24</td><td>0.05</td><td>0.19</td></tr></table>	Criteria	INC	ETC	WAC	FTG	TPD	ICO	Weights	0.10	0.29	0.14	0.24	0.05	0.19	In case of criteria weighting DP, this option prohibits the use of "Equivalent" criteria weights and any parameters related to the assessment of option performances. Any options assessed using Weighting methods are treated as "Criteria" and not "Options" to allow the space to enter option parameters (e.g. Unlimited count, Measurable nature) for objective methods or those otherwise reliant on the nature of options described by the criteria being assessed. Any weighting methods used to directly assess the solution option in the absence of criteria should be assessed as "Criteria" in Section 2 (Criteria Definition).															
Criteria	INC	ETC	WAC	FTG	TPD	ICO																											
Weights	0.10	0.29	0.14	0.24	0.05	0.19																											
Formulation	Sub-activities used exclusively to conceive suitable solution options or structure the criteria using vague knowledge about DP context and DM opinions. The primary definition is produced in linguistic terms, and in some cases may include numerical information derived qualitatively but with no aggregation procedure involved.	Used to identify suitable solution options; and/or define the description and measurement scale for its attributes. Informs the assignment of solution ratings where the ways to measure it are not readily known.	<i>Definition of options description in EEP method:</i> <table><tr><th>Group</th><th>Measures</th></tr><tr><td>A →</td><td>measures for which authority already exists. Such measures would involve minimal costs, increase awareness of key VECs, focus on impact prevention, and could be implemented quickly.</td><td>• Mark critical locations to prevent mooring near mussel beds or special shoreline areas. • Mark shallow mussel beds to reduce direct impacts of tow traffic. • Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources.</td></tr></table>	Group	Measures	A →	measures for which authority already exists. Such measures would involve minimal costs, increase awareness of key VECs, focus on impact prevention, and could be implemented quickly.	• Mark critical locations to prevent mooring near mussel beds or special shoreline areas. • Mark shallow mussel beds to reduce direct impacts of tow traffic. • Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources.	Value naming is inspired by the terms used in ARIADNE method source.																								
Group	Measures																																
A →	measures for which authority already exists. Such measures would involve minimal costs, increase awareness of key VECs, focus on impact prevention, and could be implemented quickly.	• Mark critical locations to prevent mooring near mussel beds or special shoreline areas. • Mark shallow mussel beds to reduce direct impacts of tow traffic. • Provide the navigation industry with charts showing locations of sensitive resources and include rationale for avoiding such resources.																															
1.2	Output Format	The format of output values used to rank the options in accordance with DP requirements, context, constraints, or preferences.	Allows specifying the desired output format in line with DP requirements. E.g. for some DP, interval output is acceptable to create partial order, while precise figures and complete orders are required for other DPs.	Point Values	The DP requires output values to take the form of numerical values.	A ranking derived using point values allows the measurement of preference intensity for each option.	See above for "Ranking" example from ARAS method.	Point values may take any scale, e.g. whole numbers or normalised within [0, 1] range.																									
				Distribution	The DP requires that output values are distributed in a non-flat pattern over a range with clear boundaries and maximum likelihood point.	Distribution is used to represent statistical outputs or probabilities.	<i>Distribution-type output in HSMAA method:</i>	A distribution may be statistical (bell curve) or fuzzy linear (triangle) depending on the calculation method.																									
				Intervals	The DP requires that output values are evenly distributed over a range with clear boundaries but no indication of likely maximum.	Intervals are used to represent numerical outputs associated with uncertainty or a range of possibilities.	<i>Interval outranking flows from NEAT method:</i>	Ranking is typically retrieved using averaging over a range in combination with context-based judgement.																									
				Order	The required output format represents ordinal positions without reflecting preference intensity. The order may be constructed using arbitrary point values, a sequenced list of solution references, or a mathematical graph structure acting as a visual representation of the solutions' ranking.	Allows distinguishing the more preferred alternative among any two compared, but prevents identifying the relative measure of how much more preferable one solution is to another. Mathematical graph structure offers visual presentation of results and uses relevant analytical tools to analyse the relative position of each alternative. Traditionally, the order-based ranking is produced directly by an outranking procedure. However, a large portion of methods produces an arbitrary point value to construct solution order. These values are detached from the original performance ratings of options and thus, are unable to reflect the intensity of relative option utilities in a measurable way.	<i>Resulting order of alternatives from ARIADNE method:</i>	Where incomparability exists among the alternatives, it is technically more appropriate to use Order as an immeasurable format, rather than any measurable type. While some methods may allow producing arbitrary values, these will always have an element of imprecision and unreliability because incomparable alternatives have at least one criterion that is not common, preventing a true absolute comparison.																									
				Statements	The output has to be presented in the form of descriptive statements based on natural language.	Used for Criteria Definition methods that are concerned with the definition of criteria wording (which may or may not be concerned with criteria weighting), and Options Formulation methods concerned with derivation of Options Description (which may or may not be concerned with Option Performance Rating).	See above for "Formulation" example from EEP method.	Statements are not sufficient for a complete Ranking task and only occur in constituent stages preceding the analytical part of the MCDA task.																									
				Mixed	The output is presented in a mixture of formats from the list above.	Only produced by Options Formulation-type methods that are simultaneously concerned with defining options from a range of subjective opinions and evaluating its performances against criteria.	<i>Mixed output types in NGT method:</i> <table><tr><th colspan="4">Participants' ratings of five favourite ideas to promote health in our community</th></tr><tr><th>Good Ideas Generated</th><th>Participant Number</th><th>1</th><th>2</th></tr><tr><td>Provide free information – free cooking class, recipes</td><td>1 4 4 1 5</td><td>1</td><td>16</td></tr><tr><td>Healthy school lunches (healthy lunchbox competition)</td><td>3</td><td>5</td><td>12</td></tr><tr><td>Advocacy materials – develop brochure/pamphlets and distribute to library, schools, churches, hospital, shops</td><td>5</td><td>3</td><td>8</td></tr><tr><td>Health awareness Community groups/similar to neighbourhood watch (Health Watchers)</td><td>3</td><td>11</td><td>3</td></tr><tr><td>Competitions among various communities</td><td>2 2 2</td><td>2</td><td>8</td></tr></table>	Participants' ratings of five favourite ideas to promote health in our community				Good Ideas Generated	Participant Number	1	2	Provide free information – free cooking class, recipes	1 4 4 1 5	1	16	Healthy school lunches (healthy lunchbox competition)	3	5	12	Advocacy materials – develop brochure/pamphlets and distribute to library, schools, churches, hospital, shops	5	3	8	Health awareness Community groups/similar to neighbourhood watch (Health Watchers)	3	11	3	Competitions among various communities	2 2 2
Participants' ratings of five favourite ideas to promote health in our community																																	
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Health awareness Community groups/similar to neighbourhood watch (Health Watchers)	3	11	3																														
Competitions among various communities	2 2 2	2	8																														
1.3	Ambiguity Presence	Indicates the presence of ambiguity i.e. when some of the quantitative decision information (criteria weights or option ratings) is unknown. This relates to cases where: - A value may exist in several different versions expressed by different DMs (multiple opinions on specific values); - Precise boundaries or some values are unknown (unknown data limits); - Some values may be absent in a range (i.e. incomplete data between limits)	Multiple distinct values corresponding to any option rating (dimension 1) or criteria weight (dimension 2) from multiple DMs (dimension 3) is a 3D DP, as opposed to 2D DP where only a single DM is involved. No other parameter reflects method applicability to GDM case. Some methods do not attempt to pin down ambiguous information to specific values and produce an output in interval or distribution format. Other methods, which provide a Point Value output, include instruments to pre-process imprecise ratings into crisp format before Preference Aggregation takes place. This is performed using dedicated techniques specified as a part of the method.	Option Ratings	Ambiguity exists within the knowledge related to option performance ratings.	Various forms of ambiguity representation allow dealing with a lack of precision or knowledge in the decision information. Grey numbers are considered more objective because they only indicate the max/min boundaries, which may be easier to obtain by objective judgement of possible system states. Fuzzy numbers are presumed less objective since specifying the "likely" point tends to involve subjectivity.	<i>Trapezoidal Fuzzy Number from ULOWA:</i>	As a general rule: - Triangular Fuzzy numbers are recognised as a distribution (min/max bounds with a vertex, which also allows a bias); - Trapezoidal Fuzzy numbers are recognised as an interval (min/max bounds, but vertex is stretched into a flat segment); - Grey numbers are recognised as interval (min/max bounds only) See the accompanying publication on ProBCA for more discussion.																									
				Preference Model	Ambiguity exists within the knowledge related to criteria weights, aspiration levels, and/or definition.	The same selection of formats as above (distributions, intervals) allows dealing with ambiguity in relation to criteria weights and interaction intensities (reflected by Criteria Dependency parameter).	<i>Triangular Fuzzy Number from ULOWA:</i>	The notion of ambiguity as presented in Column E (Comments) does not match the general implication of uncertainty i.e. the absence of guarantee for the expected values to be true. The use of this parameter drives the DM to specify any "uncertain" values to reach certainty regarding their possible boundaries, multiple variants, and knowledge gaps.																									
				Both	Ambiguity exists within the knowledge related to both option performance ratings and criteria parameters.	A simultaneous combination of the above two types of ambiguity.	See above for individual ambiguity examples from "ULOWA" method.	N/A																									
				N/A	No ambiguity is present in the decision information.	Used for DP cases associated with complete clarity of information.	See above for "Ranking" example from ARAS method.	N/A																									

Section	ID	Parameter	Parameter Explanation	Comments	Available Values	Problem-Based Value Implication	Uses & Justification	Example	Comments																																											
1. Problem Specification	1.4	Use of Thresholds	Indicates whether thresholds are used i.e. pre-defined bounds limiting the overall or relative influence of quantitative decision information (option ratings, criteria weights) within a DP context.	Thresholds serve to segregate influences, either between options (preference, indifference) or criteria (veto levels limiting maximum influence of any criterion). This is different from Bounds delimiting the acceptable rating values to eliminate under- or over-performing options in a Selection task. Since ProBCA concentrates on Ranking, the elimination tools are left outside of its scope. All options participate in a ranking assessment, unless pre-excluded by the DM.	Option Ratings	Pre-defined value brackets controlling the relative effect of varied option performance ratings. Consider the difference in option performances against a particular criterion ("delta"): - If delta falls within the indifference bracket, options are considered equivalent and occupy same ordinal position; - If delta falls beyond the indifference value but within preference bracket, higher-performing option is given a higher ordinal position, which may be a measurable or an immeasurable ordinal difference depending on the method; - If delta exceeds preference threshold, the rating of higher-performing option is replaced by the preference threshold value in any aggregation calculations to limit its total effect.	Used to define an ordinal relationship in a pairwise comparison of any two alternatives against a given criterion by delimiting the acceptable difference between their performances. Defines the "indifference" and "preference" intervals for option rating deltas. Naturally imposes a maximum "veto" limit beyond which the contribution of a particular rating in any single criterion, even an outlier, remains constant and does not affect the aggregated performance of an option too heavily.		Applicable to purely ordinal tasks that use measurable ratings to derive an order of options; and to part-ordinal tasks where individual option ratings contribute to quantifying aggregated performance after pre-ordering the options using ordinal relations imposed by the thresholds. Thresholds may be defined using some objective basis, but also offer a mechanism to impose the DM's subjective delimiters on objective data for both weights and ratings.																																											
					Criteria Influence	Pre-defined weight brackets or fixed nominal values to choose from delimiting the influence of any single criterion on the total performance aggregation. Weight thresholds are defined as fixed values ("weights fall within [0.2; 0.8] range"), standard deviation, feasible region of a 3D graph, or in any other way.	Constrains criteria importance in cases when any single criterion weight is distinctively higher/lower than that of other criteria: - if too high, that one criterion drives the entire aggregation while other criteria have no noticeable role in producing the final ranking, which is nearly equivalent to running a single-criterion problem; - if too low, that one criterion effectively does not participate in forming the final ranking, which is equivalent to omitting it.	Extracted from PPARC method: 	Weight thresholds limit the impact of diverse criteria weights if they are heavily imbalanced. This may occur if criteria weighting is sourced by subjective opinions expressed through direct assignment or pairwise comparisons. "Veto" term may indicate both criteria influence bounds and differential preference relations, causing confusion.																																											
					Both	Pre-defined brackets for both the criteria weights and the differences in pairwise option performance comparisons are applied simultaneously.	Used in cases when the DP context is prone to disbalance, which is the likely case when the decision information is heavily subjective or ambiguous (see Ambiguity parameter above).	See above for "Option Ratings" and "Criteria Influence" examples.	Rating thresholds are inapplicable when the DP only involves abstract ratings; weight thresholds are inapplicable when all criteria exhibit equivalent importance levels.																																											
					N/A	No limitations are imposed onto decision information.	Typically the case for simpler DP types that use pre-defined decision information e.g. based on objective measurements.	N/A	N/A																																											
	1.5	Resource Required	The relative measure of effort, time, finance, computational power, expertise, and other resource that needs to be spent for an efficient and effective method application.	Not an objectively measured value; but serves as a useful tool for planning the timeframe, selecting an appropriate DM (e.g. identifying an internal capability or hiring an external facilitator), and budgeting an MCDA project. Also reflects the quality of available literature e.g., the nature of a method may be average, but information delivery in the existing references make it difficult to understand its application intricacies.	Light	Low-complexity DP that allows independent method application by a single, non-expert DM with no advanced math skills, who uses hand calculations or a simple digital setup (e.g. MS Excel tool) utilising no advanced capabilities.	The described conditions imply the use by someone who may not have extensive analytical experience and possess no prior MCDA awareness without any additional supervision, e.g. a graduate.	N/A	Methods using mathematical functions are in most cases Light or Reasonable.																																											
					Reasonable	DP complexity level implies the use of MCDA method that requires computer-based capability and a DM with some knowledge of MCDA and maths (e.g. an engineer); and oversight by another professional of at least equivalent level for quality assurance and error proofing.	The described conditions imply that method application is excessively complex for pen-and-paper implementation, but allows a DM who possesses non-expert MCDA awareness.	N/A	N/A																																											
					Heavy	The DP requires the application of a more elaborate MCDA method involving at least one MCDA expert who is highly capable in mathematical and logical concepts, and oversight by another expert of comparable level for quality assurance and error proofing.	The described conditions may be split among a team of people e.g. an OR scientist acting as the MCDA expert, while a Data Scientist acting as an expert in mathematical logic. Automated implementation likely requires developing a dedicated software, or complex analytical models e.g. MS Excel-based tools that use advanced features. The conditions allow for a non-expert to perform the task while developing expertise under the guidance of appropriate experts and secondary proofing by another set of equivalent experts.	N/A	- Methods that involve processing logical statements tend to be assessed as Heavy due to non-trivial analysis involved. - In some cases, "Heavy" type intrinsically indicates the quality of available source: while the method itself may require "Reasonable" effort, understanding it correctly due to the specific terminology and presentation style used in the source requires sufficient MCDA expertise. For example, a method may not offer a specific example of using its results for ranking. - In many cases "Heavy" methods offer a higher level of output refinement (detail, precision, adjustability), which correlates with heavier resource requirement.																																											
	2. Criteria Definition	2.1	Criteria Count	The most appropriate DP size that a method should be used for, expressed as a number of criteria involved.	Does not impose a hard limitation on method applicability, but serves as a useful indication of whether it is more suitable for tackling smaller or larger problems (in terms of criteria count).	≤ 25	The DP involves a smaller number of criteria associated with intricate information structure and operations, but may need a higher level of result refinement and modelling detail. Reflects whether a DP can be modelled in 1 working day as a generic indicator of complexity. Typical examples: - DPs that use separate, unique formulae for each criterion; - DPs that involve measurable pairwise comparison to derive criteria weights (25 x 25 criteria = 625 comparisons, -25 diagonal elements = 600/2 due to matrix symmetry = 300 entries)	The definition uses a rough time estimate required to operate the number of options involved in a DP against all criteria. An arbitrary temporal baseline of 1 working day is chosen as the delimiter, based on the following optimistic assumptions: - 1 working day = 8 hours = 5 hours work + 3 hours setup/admin - 5 hours work = 300 minutes = 300 x 1-minute operations - Retrieving & entering a data point from known set = 1 min - Modelling an intricate operation for 1 criterion = 10+ min Thus, "25 maximum" methods are suitable for tasks involving <300 data entries and/or <30 criteria requiring complex modelling. The delimiter is set to 25 because pairwise comparison (popular in MCDA) of more than 25 criteria exceeds 300-minute effort baseline.	Pairwise criteria importance comparison from AHP: <table><tr><th></th><th>EEE</th><th>ECE</th><th>ICE</th><th>CSE</th><th>MECH</th><th>priority vector</th></tr><tr><th>EEE</th><td>1</td><td>1</td><td>3</td><td>1</td><td>1</td><td>0.2284</td></tr><tr><th>ECE</th><td>1</td><td>1</td><td>3</td><td>1</td><td>3</td><td>0.2846</td></tr><tr><th>ICE</th><td>0.33</td><td>0.33</td><td>1</td><td>0.33</td><td>0.33</td><td>0.0755</td></tr><tr><th>CSE</th><td>1</td><td>1</td><td>3</td><td>1</td><td>1</td><td>0.2284</td></tr><tr><th>MECH</th><td>1</td><td>0.33</td><td>3</td><td>1</td><td>1</td><td>0.183</td></tr></table>		EEE	ECE	ICE	CSE	MECH	priority vector	EEE	1	1	3	1	1	0.2284	ECE	1	1	3	1	3	0.2846	ICE	0.33	0.33	1	0.33	0.33	0.0755	CSE	1	1	3	1	1	0.2284	MECH	1	0.33	3	1	1	0.183	Criteria & Options Count parameters are not fully separated: - Where operations affected by criteria definition require less effort, it is marked "Unlimited" even if option-related operations are cumbersome (then, Options Count would be limited to 25). - However, some methods explicitly state suitability for "large volume of options" despite including extensive option-related operations and simpler criteria structure. These are marked as "25 max" in criteria count to allow for unlimited options count. Applying this type of methods to large DPs involving Over 25 criteria is possible, but will require the amount of time and effort that grows exponentially with increasing criteria count.
						EEE	ECE	ICE	CSE	MECH	priority vector																																									
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Unlimited	The DP involves a large number of criteria (over 25), where criteria-related formulation does not include complex structuring or intricate calculations. Typical examples include: - DP that involves equal criteria importance weights; - DP involving immeasurable pairwise comparison to derive importance-based criteria ordering.	Following the rationale for defining 25 criteria as the delimiter, "over 25 criteria" methods are not expected to consume a significant time of additional effort when a DP involves more than 25 criteria (which may reach hundreds).	See the number of criteria defined in the original reference for DIER-BCS method (example is too large in size to insert a visualisation).	Some "over-25 criteria" methods involve pairwise comparison. These are cases when criteria comparisons are objective and may be automated, so the DM does not have to assess each criteria pair individually. E.g. these may calculate some available values instead of using DM judgement. Applying this type to small problems (25 criteria or less) is simple and requires no extra effort, but may not offer the level of refinement and depth of "25 max" methods.																																																
2.2	Criteria Importance	Indicates whether a DP involves differential criteria importance values or only allows the use of equivalent criteria weighting.	Criteria weighting procedures attempt to make subjective weighting more objective. It always starts with the expression of DMs preferences, which then is rationalised using analytical techniques.	Weighted	The DP accepts differential values for criteria importance weighting.	In many real DP, criteria are viewed as having different weights of relative importance. This needs to be accounted for in the analytical procedure used by the method used to aid the decision.	Option performance aggregation that uses criteria weights, from CCSD method: $d_i = \sum_{j=1}^m z_{ij} w_j, \quad i = 1, \dots, n$	Where a ranking method suggests a specific approach for calculating criteria weights, it is also described as an integral part of that method in the original reference.																																												
				Equivalent	The DP does not consider dissimilar criteria importance. This option prohibits the use of the subsequent three parameters related to criteria weighting definition (2.3, 2.4, 2.5). This option also applies when the criteria weights are unknown and are not to be derived as a part of the decision procedure, e.g. when the options are compared subjectively on an ordinal scale.	Some DP treat all criteria with equal importance and do not need a dedicated analytical part for dealing with criteria weights.	A generic example from (Hwang, Yoon, 1981): <table><tr><th></th><th>x_1</th><th>x_2</th><th>x_3</th><th>x_4</th><th>x_5</th><th>x_6</th><th></th></tr><tr><td>$b =$</td><td>2.5</td><td>2100</td><td>18000</td><td>6.5</td><td>low</td><td>average</td><td>x_1</td></tr><tr><td></td><td>1.8</td><td>2000</td><td>21000</td><td>4.5</td><td>high</td><td>high</td><td>x_2</td></tr><tr><td></td><td>2.2</td><td>1800</td><td>20000</td><td>5.0</td><td>average</td><td>average</td><td>x_3</td></tr></table>		x_1	x_2	x_3	x_4	x_5	x_6		$b =$	2.5	2100	18000	6.5	low	average	x_1		1.8	2000	21000	4.5	high	high	x_2		2.2	1800	20000	5.0	average	average	x_3	On the notion of "compensatory" methods - Criteria importance does not reflect whether a method is compensatory or not: - Compensatory methods imply that criteria tradeoffs are allowed i.e. the criteria are weighted; - Non-compensatory methods imply no trade-offs, which means equivalent importance weights and an option is eliminated if its performance does not meet the minimum aspiration.												
	x_1	x_2	x_3	x_4	x_5	x_6																																														
$b =$	2.5	2100	18000	6.5	low	average	x_1																																													
	1.8	2000	21000	4.5	high	high	x_2																																													
	2.2	1800	20000	5.0	average	average	x_3																																													
2.3	Weights Basis	The basis for criteria importance weighting applicable within given DP context.	Criteria weighting can be subjective, objective, or integrated in accordance with the source reference for MERE method. Independent from the choice of weights derivation tools (pairwise comparison, geometric centroid, etc.) - these are indicated by the following parameters for Criteria Weighting.	Subjective	Subjective opinion is used as the basis for criteria weights derivation in given DP context i.e. the user assigns preference based on their judgement with no objective/measured evaluation basis available.	Used to indicate that the DM is expected to use own, subjective judgement when providing inputs for criteria weighting.	Criteria order as extracted from ROD method: $w_1 \geq w_2 \geq \dots \geq w_n > 0$	Subjective weighting does not solely imply that weights are subjectively assigned; it may apply to methods that use objective analytical tools on some subjective input e.g. order of importance.																																												
				Objective	Objective, independent, and in many cases measurable data is used to derive criteria weights e.g. based on measured option performances or physical parameters attributed to the options considered.	Mostly used when there is a requirement to exclude as much subjectivity as possible from the DP. However, such an approach is argued to diminish the benefits offered by the MCDA methods.	Criteria weighting formula from CCSD method: $w_j = \frac{\sigma_j \sqrt{1 - R_j}}{\sum_{k=1}^m \sigma_k \sqrt{1 - R_k}}, \quad j = 1, \dots, m$	The only importance derivation approach that is truly objective is when option performances measured by technical means are used as direct input into criteria weighting. However, this analytical approach solely based on option performances does not offer any means to reflect DM's preferences.																																												
				Pre-determined	Criteria importance weights are used, but are not derived within given DP scope and thus, no particular approach to deriving weight values is indicated.	Used for DPs where criteria importance weights are readily available or the DM has their own preference for weighting method.	Extracted from ARAS method: <table><tr><th colspan="7">Criteria</th></tr><tr><th>The amount of air per head</th><th>Relative air humidity</th><th>Air temperature</th><th>Illumination during work hours (8-17)</th><th>Rate of air flow</th><th>Dew point</th><th></th></tr><tr><th>x_1</th><th>x_2</th><th>x_3</th><th>x_4</th><th>x_5</th><th>x_6</th><th></th></tr><tr><td>Weight of criteria - w</td><td>0.21</td><td>0.16</td><td>0.26</td><td>0.17</td><td>0.12</td><td>0.08</td></tr></table>	Criteria							The amount of air per head	Relative air humidity	Air temperature	Illumination during work hours (8-17)	Rate of air flow	Dew point		x_1	x_2	x_3	x_4	x_5	x_6		Weight of criteria - w	0.21	0.16	0.26	0.17	0.12	0.08	Criteria importance weights are readily provided for method application; weighting source is not questioned by the method.																
				Criteria																																																
The amount of air per head	Relative air humidity	Air temperature	Illumination during work hours (8-17)	Rate of air flow	Dew point																																															
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N/A	The DP that does not consider variable criteria importance.	Not used - refer to Criteria Importance - Equivalent.	See above for "Equivalent" example from (Hwang, Yoon, 1981).	N/A																																																

Section	ID	Parameter	Parameter Explanation	Comments	Available Values	Problem-Based Value Implication	Uses & Justification	Example	Comments																										
2. Criteria Definition	2.4	Weights Format	Weighting value format, reflects the format of input informing criteria importance weight definition that best suites the context of a given DP.	The preferred format may depend on the desired outcome, available decision information, or the intended use of criteria weight values further in method operation.	Point	Criteria weighting input is provided as a precise, crisp value.	Used as the simplest representation of criteria weights. Typically used with Pre-Determined criteria, or requires good DP awareness in subjective weighting approaches.		"Subjective - Point" combination implies the likely use of linguistic preference values whose quantification may be performed using the provided rules or altered by the DM to introduce a bias.																										
					Ratio	Criteria weighting input is expressed in measurable relative terms (quantifiable comparison), which may be normalised to [0, 1] range.	Normally retrieved by performing a quantified comparison of one criteria to another e.g. "A is 3x more important than B".		Ratio weights naturally impose implicit veto thresholds for criteria importance since comparison excludes disbalance e.g. "1/1000".																										
					Distribution	Criteria weighting input is provided as a non-flat range characterised by the vertex of maximum likelihood for the possible weight value and the less likely weight values spread out to range extremes.	Typically used in the following DP contexts: - GDM setting with a large number of individual DMs whose opinions on criteria weighting creates a distribution curve; - Ambiguous settings where the DM provides a linguistic estimation of criteria weights to process using triangular fuzzy numbers; - Iterative techniques characterised by the uncertainty in the overall balance of weights (i.e. no weights are fixed), where sifting through the possible weight values creates a distribution of results; - Weights expressed as a mean with standard deviation values where objective criteria weights are derived using option ratings.	Very low (VL) (0,0,1,0,3) Low (L) (0,1,0,3,0,5) Medium (M) (0,3,0,5,0,7) High (H) (0,5,0,7,0,9) Very high (VH) (0,7,0,9,1,0)	There are no methods reflecting a case where a DM would provide a subjective distribution of likely weights directly and it does not resemble a logical thinking context; however, this is not impossible and may occur in future methods. Distribution-based analysis produces values that are easier to understand since they are linked to maximum likelihood vertex. However, its realism is questionable since it is not entirely conclusive to condense a multitude of opinions and possibilities.																										
					Interval	Criteria weights can take any value along a flat range (i.e. no maximum likelihood) between some bounds.	Typically used in the following DP contexts: - The DM is not certain about a precise weight, but is able to delimit what the weights are not; - Used to reflect trapezoidal fuzzy numbers in ambiguous settings - Used to translate subjective comparison of relative importance of criteria in cases where there is no ambiguity about these relations	Interval weights example from FWA method: $u_{w_1}(w_1) = \begin{cases} w_1/0,3 & 0 \leq w_1 \leq 0,3 \\ (0,9 - w_1)/0,6 & 0,3 \leq w_1 \leq 0,9 \end{cases}$ $u_{w_2}(w_2) = \begin{cases} (w_2 - 0,4)/0,3 & 0,4 \leq w_2 \leq 0,7 \\ (1 - w_2)/0,3 & 0,7 \leq w_2 \leq 1 \end{cases}$	Interval-based analysis is not as clear to understand as a distribution because there is no indication of the more likely value within a range; however, it is more realistic since it gives equal consideration to all possible values within a range.																										
					Order	Criteria weighting input is provided in the form of immeasurable order of criteria reflecting their dissimilar importance. Immeasurable order reflects the position of each criterion within the order, but does not quantify the relationship between positions: one cannot say by how much rank 1 is more important than rank 2.	Used for subjective pairwise comparisons or direct ordering of criteria where the DM cannot pin down the specific values or reflect on the magnitude of importance, but can arrange the criteria from the most important to the least important in an order.	See example above for Weights Basis parameter - "Subjective" value from ROD method.	DP contexts where the DM can only provide importance order of criteria may benefit from criteria weighting thresholds, especially if many criteria are used. This would allow preventing the cases where criteria weights resemble a geometrical progression.																										
					N/A	Indicates a DP that does not consider variable criteria importance.	Not used - refer to Criteria Importance - Equivalent.	See above for "Equivalent" example.	N/A																										
					2.5	Definition Method	The approach (method or specific process) to retrieving input information for criteria wording and/or importance weights.	The most suitable method for providing inputs for criteria definition (wording, scales, weights, interaction) depends on DP context, such as: knowledge available to the DM, intended application of decision-aiding results, required DP model precision. Criteria Definition is mostly associated with eliciting quantitative criteria information: importance weights and interactions. It also describes criteria wording and scaling definition, but only uses "Assignment" value.	Assignment	Criteria definition input is directly assigned without resorting to the use of any elicitation tools or procedures, disregarding input format (i.e. can assign criteria weight values, rank positions/order, etc.).	The simplest procedure for providing criteria definition inputs. Typically used with Pre-Determined criteria, or requires good DP awareness in subjective definition approaches.	Direct assignment of criteria weights in DNMA method: Step 4. Suppose that the experts assign the weights of criteria as: $\omega_1 = 0,29$, $\omega_2 = 0,26$, $\omega_3 = 0,16$, $\omega_4 = 0,12$, $\omega_5 = 0,09$	Assignment procedure does not imply questioning the source of information or attempting to amend or update it. It is also the only value that reflects qualitative criteria definition (wording, scaling).																						
	Comparison	Criteria parameters are derived using subjective comparison among criteria pairs.	Used to derive criteria weights from DM's subjective judgements. Whatever output format is used, pairwise comparison is used.	See AHP example from Criteria Count parameter - "Up to 25" value for a measured pairwise comparison.					Comparison produces an order of values, which may be measured (criterion rank position and influence intensity) or immeasurable (rank position that does not indicate influence intensity).																										
	Reference	Criteria parameters are derived using subjective comparison against some real or hypothetical reference e.g. sample criteria weights, partial order of importance, or min/max scaling range boundaries.	Used in cases when some information is available to help criteria definition other than the set of criteria itself. This could be min/max value boundaries, aspiration levels, partial weighting example etc.	Benchmark-based SWING weighting: Benchmark 3 0 2 1 4 0 7 0 INC 5 0 2 1 4 0 5 33.33 ETC 3 5 2 1 4 0 1 100 WAC 3 0 5 1 4 0 4 50 FTG 3 0 2 5 4 0 2 83.33 TPD 3 0 2 1 5 0 6 16.67 ICO 3 0 2 1 4 3 3 66.67					There are no possible external references for guiding the definition of criteria; reference can only exist within criteria set since all criteria participate in defining the parameters.																										
	Probability	Criteria parameters are derived using probability estimations, which may be subjective or objective data (e.g. measured statistics).	Sometimes the DM possesses sufficient information to estimate or objectively derive the probability of possible criteria parameters.	Weighting probability variants from SIMCDM: 					Retrieving the probabilities of possible weights requires good awareness of the DP context or access to objective information. Probability-based weights are uncertainty-friendly due to allowing the consideration of different opinions with respective reflection of how likely they are to be true.																										
	Options-based	The definition of criteria weights is in some way based on option performance ratings and do not need DM's subjective judgements.	Useful in DP situations where maximum objectivity is required, which drives the exclusion of any subjective influence.	Criteria weighting based on option ratings in IDOCRiW: <table><tr><th></th><th>A₁</th><th>A₂</th><th>A₃</th><th>A₄</th><th>A₅</th><th>r_{max}/r_{min}</th><th>Weight</th></tr><tr><td>R₁</td><td>0.4</td><td>0.15</td><td>0.15</td><td>0.15</td><td>0.15</td><td>2.7</td><td>0.2151</td></tr><tr><td>R₂</td><td>0.6</td><td>0.1</td><td>0.1</td><td>0.1</td><td>0.1</td><td>6</td><td>0.7849</td></tr></table>						A ₁	A ₂	A ₃	A ₄	A ₅	r _{max} /r _{min}	Weight	R ₁	0.4	0.15	0.15	0.15	0.15	2.7	0.2151	R ₂	0.6	0.1	0.1	0.1	0.1	6	0.7849	Exclusion of subjectivity may diminish the benefits of MCDA methods in some DPs, whereas multi-attribute measurement is typically addressed by optimisation techniques e.g. MDO.		
		A ₁	A ₂	A ₃					A ₄	A ₅	r _{max} /r _{min}	Weight																							
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	N/A	Indicates a DP that does not consider variable criteria importance.	Not used - refer to Criteria Importance - Equivalent.	See above for "Equivalent" example.	N/A																														
	2.6	Criteria Dependence	Reflects the presence of a measurable interdependence between criteria.	Represents individual substitution rates of selected criteria i.e. adjustable dependency where the rating in one criterion may allow for measured loss in another one. May be defined for all criteria pairs or the select few.	Independent	There is no interaction observed or defined among the criteria.	Ratings in any criterion do not affect the ratings in other criteria.	See above for Criteria Importance parameter - "Equivalent" value example from (Hwang, Yoon, 1981).	The majority of methods serve DPs with independent criteria. "Interacting" really means "interdependent". The former term is used as the available value in ProBCA since "interdependent" and "independent" look similar and thus, inflicts confusion.																										
					Interacting	Allows (although does not necessitate) dependencies between some or all criteria, which may be measured or immeasurable (affecting the thought process, but not necessarily expressed quantitatively).	While criteria weights reflect their influence on every aggregated score, Dependence reflects substitution effect among the select criteria pairs. Imposed using pre-defined interaction constants provided in addition to criteria weights.	Intercriteria interaction values from IDRA method: Intercriteria information <table><tr><th>Criteria</th><th>Tradeoff</th><th>Credibility</th><th>Importance</th></tr><tr><td>Speed/H.P.</td><td></td><td></td><td>=</td></tr><tr><td>Speed/Aesthetics</td><td>?</td><td>1</td><td>2</td></tr><tr><td>Speed/Price</td><td>500</td><td>1</td><td>2</td></tr><tr><td>Speed/Consumption</td><td></td><td></td><td>=</td></tr><tr><td>Speed/Comfort</td><td></td><td></td><td>=</td></tr><tr><td>H.P./Aesthetics</td><td></td><td></td><td>=</td></tr><tr><td>H.P./Price</td><td>400</td><td>1</td><td>=</td></tr></table>		Criteria	Tradeoff	Credibility	Importance	Speed/H.P.			=	Speed/Aesthetics	?	1	2	Speed/Price	500	1	2	Speed/Consumption			=	Speed/Comfort			=	H.P./Aesthetics	
Criteria	Tradeoff	Credibility	Importance																																
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Speed/Comfort			=																																
H.P./Aesthetics			=																																
H.P./Price	400	1	=																																
2.7	Criteria Hierarchy	Indicates where a DP context requires structuring the criteria in a multilevel hierarchy.	Hierarchical DP settings may be solved using non-hierarchical methods if criteria values are aggregated at the top level of the hierarchy; however, some methods offer dedicated tools as their integral component.	Flat only	Criteria hierarchy is not considered within DP context.	The simplest DP types evaluate a flat list of criteria against a set of solution options.	See above for Criteria Importance parameter - "Equivalent" value example from (Hwang, Yoon, 1981).	If a "flat structure" method is applied to a hierarchical DP, effects imposed by hierarchy must be resolved as a precursor activity outside of method application scope using preferred approach.																											
				Hierarchical	The DP features a multi-level criteria structure, with relevant MCDA methods offering dedicated tools for dealing with multi-level aggregation effects.	Typical for the more complex DP types involving multiple criteria categories, e.g. technical, financial, perceptual, etc.	See multi-level criteria structure defined in the original reference for DIER-BCS method (example is too large in size to insert a visualisation).	Hierarchical methods allow multilevel criteria, but do not require it and they may be applied to flat-criteria DP. Tailoring it to a flat case carries error risk due to needing to omit some calculations.																											

Section	ID	Parameter	Parameter Explanation	Comments	Available Values	Problem-Based Value Implication	Uses & Justification	Example	Comments																																																	
3. Preference Aggregation	3.1	Options Count	The most appropriate DP size that a method should be used for, expressed as a number of entries to define performance ratings for all involves solution options.	Does not impose hard limitation on method applicability, but a useful indication of whether it is more suitable for tackling smaller or larger problems (in terms of option attribute count) based on how many values need to be filled into pre-determined data fields e.g. a decision matrix.	≤ 25	The DP involves a smaller number of solution options, but requires intricate operations to assess it. Reflects whether a DP can be modelled in 1 working day as a generic indicator of complexity. Typical example: a DP involving measurable pairwise comparison to rate 25 options (25 x 25 options = 625 comparisons, -25 diagonal elements = 600/2 due to matrix symmetry = 300 rating entries)	Defined using a similar logic to Criteria Count with reference to an arbitrary temporal basis of 1 working day allowing for 300 off 1-minute operations. An "operation" implies an activity (calculation, comparison, intricate logical procedure) and not simple entry of pre-determined data. The limit is set to 25 alternatives following a similar logic to Criteria Count parameter: pairwise comparison (popular in MCDA) of more than 25 options against given criterion exceeds 300-minute effort baseline.		Options & Criteria Count parameters are not fully separated: - Where option-related operations are cumbersome, Options Count is limited to 25 disregarding of criteria complexity (e.g. criteria definition may require less effort so set to "Unlimited") - Some methods feature simpler criteria operations (should be Unlimited), but explicitly state suitability for a "large volume of options" while featuring extensive rating operations. These are marked "25 max" in Criteria Count, but "unlimited" options. Applying "25 max" methods to large DPs involving Over 25 alternatives is possible, but will require the amount of time and effort that grows exponentially with increasing options count.																																																	
					Unlimited	The DP involves a large number of options (over 25 and may reach hundreds), which are rated by simple data entry and require no complex operations.	A matrix can comfortably serve 25+ options if rating calculations do not need individual processing and may be automated e.g.: - Option ratings are pre-determined e.g. obtained by simple measurement or database retrieval; - A simple order of options is produced by immeasurable pairwise comparison that uses pre-determined, programmable logic. Following the rationale for defining 25 criteria as the delimiter, methods serving "over 25" options are not expected to consume significant additional time of effort when options count grows.	Direct data entry adopted from ARAS method: <table><tr><th></th><th colspan="6">Criteria</th></tr><tr><th>Options</th><th>X₁</th><th>X₂</th><th>X₃</th><th>X₄</th><th>X₅[*]</th><th>X₆[*]</th></tr><tr><td>A</td><td>7.6</td><td>46</td><td>18</td><td>390</td><td>0.1</td><td>5</td></tr><tr><td>B</td><td>5.5</td><td>32</td><td>21</td><td>360</td><td>0.05</td><td>8</td></tr><tr><td>C</td><td>5.3</td><td>32</td><td>21</td><td>290</td><td>0.05</td><td>11</td></tr><tr><td>D</td><td>5.7</td><td>37</td><td>19</td><td>270</td><td>0.05</td><td>9</td></tr><tr><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td><td>...</td></tr></table>		Criteria						Options	X ₁	X ₂	X ₃	X ₄	X ₅ [*]	X ₆ [*]	A	7.6	46	18	390	0.1	5	B	5.5	32	21	360	0.05	8	C	5.3	32	21	290	0.05	11	D	5.7	37	19	270	0.05	9	...	...	...	...	...	...	...	Applying this type (unlimited options) to small problems (25 options or less) is simple and requires no extra effort, but may not offer the level of refinement and depth of "25 options max" methods.
						Criteria																																																				
	Options	X ₁	X ₂	X ₃	X ₄	X ₅ [*]	X ₆ [*]																																																			
A	7.6	46	18	390	0.1	5																																																				
B	5.5	32	21	360	0.05	8																																																				
C	5.3	32	21	290	0.05	11																																																				
D	5.7	37	19	270	0.05	9																																																				
...	...	...	...	...	...	...																																																				
N/A	The DP does not involve any consideration of solution options.	The DP is solely concerned with criteria definition in separation from the part of MCDA task that considers solution options.	See example above for Criteria Count parameter - "25 Max" value from AHP method.	N/A																																																						
	3.2	Attribute Nature	The intrinsic nature of involved option attributes affecting the approach to analysing the associated decision information.	The nature of attributes affects the approach to rating the performance of options against specific criteria. For example, where no quantitative measurements are available about an option it will have to be rated using some qualitative approach, which could be measured (nominal) or immeasurable (abstract). In this definition: - Attribute = an intrinsic quality of a solution alternative that reflects its performance in the sense of a specific characteristic/aspect; - Criterion = a measure defined by the DP within given DP context, which is used as the framework to assess a particular aspect of option performance.	Nominal	A measurable type of subjective ratings used to indicate relative option performances against any given criterion - graded order. Uses pre-defined sets of possible values with no real/material meaning, and thus are mapped on a context-dependent scale e.g.: - Sequential scaling values (e.g. 1 to 5 scores, or 0 - 100 percentage); - Fixed values designed to amplify the scale of preference or reflect the achievement of specific meaning/conditions (e.g. 1, 3, 7, 10); - Linguistic values designed for use in subjective surveys, which may use pre-defined meanings (e.g. Low = 1, high = 5) or assessed within given set of results without prior definition of linguistic meanings.	Subjective ratings depend on the DM and may change from one respondent to another. Used to grade differential performance on attributes that are immaterial (e.g. perception, experience) or whose performance cannot be measured objectively within given DP context (e.g. comfort, suitability) by translating qualitative data into quantitative format. Implicitly reflect DM's preferences where the specific value functions are not explicitly known. Implications: for one DM or within one DP, particular features of a product (e.g. screen type, menu structure) will score higher on some criteria (e.g. comfort, ease of use); whereas for another DM/DP, same features may score lower on the same criteria (comfort, ease of use) or other criteria (e.g. carrying convenience, software complexity).	<table><tr><th>Rating</th><th>Description</th><th>Probability of error</th></tr><tr><td>10</td><td>Very frequent</td><td>Error happening at least once a month</td></tr><tr><td>8</td><td>Frequent</td><td>Error happening between five and ten times in a year</td></tr><tr><td>6</td><td>Infrequent</td><td>Error happening between once and five times in a year</td></tr><tr><td>4</td><td>Low</td><td>Error happening once a year</td></tr><tr><td>2</td><td>Almost remote</td><td>Error happening once every 5 years</td></tr><tr><td>1</td><td>Remote</td><td>Error happening sometimes every 5-30 years</td></tr></table>	Rating	Description	Probability of error	10	Very frequent	Error happening at least once a month	8	Frequent	Error happening between five and ten times in a year	6	Infrequent	Error happening between once and five times in a year	4	Low	Error happening once a year	2	Almost remote	Error happening once every 5 years	1	Remote	Error happening sometimes every 5-30 years	Nominal rating is not known in advance and is defined at the time of preparing the inputs for an MCDA tool. The DM assesses option attributes based on own judgement or using surveys to assign nominal scores in the most suitable format for the DP. Nominal ratings diminish minor differences between option performances if these are smaller than scoring scale, imposing some level of imprecision when assigning a particular grade. For example, two options may perform at 45 and 55% respectively in percentage scale, but will both receive a 5 on a 1-10 score scale.																												
Rating	Description	Probability of error																																																								
10	Very frequent	Error happening at least once a month																																																								
8	Frequent	Error happening between five and ten times in a year																																																								
6	Infrequent	Error happening between once and five times in a year																																																								
4	Low	Error happening once a year																																																								
2	Almost remote	Error happening once every 5 years																																																								
1	Remote	Error happening sometimes every 5-30 years																																																								
				Measurable	Applies to DPs that involve both Nominal (relative measure) and Cardinal (absolute measure) attributes i.e. any performance that can be characterised with numerical ratings disregarding whether its basis is subjective or objective. Cardinal measurements are a measurable type of objective option ratings that reflect option performances that are independently observed or measured using technical means. These use original measurement units and indicate the intensity of real option performance, like: dimensions (meters); weight (kg); cost (USD).	Measurable attributes are used in DPs that combine both subjective and objective judgements to retrieve measured ratings of option performances. A frequent case for DPs dealing with physical objects and products e.g. ranking products, equipment, transport options. May or may not require normalisation depending on the method used. Most methods require converting quantitative data to the same scale to enable running aggregation formulae on it. See the accompanying paper on ProBCA for more on Normalisation. On Cardinal ratings: independent observation implies that rating will not change from one observer/DM to another. These do not require rounding to the nearest score as is the case with Nominal ratings, and thus are more precise. Cardinal rating is pre-determined as an intrinsic quality of a considered option and may be retrieved using available data sources (e.g. item specification) or technical means (measurement, observation). This may be done by the DM or by anyone providing information to the DM.	See above for Criteria Importance parameter - "Equivalent" value example from (Hwang, Yoon, 1981).	For objective attributes e.g. cost, the separation of Nominal vs. Cardinal attribute type depends on DMs knowledge. For example, cost may be assessed as a nominal attribute at early project phases when the knowledge is limited and estimations are scale-based, but can be measured precisely in terms of financial values during later project phases. Percentages may be Nominal or Cardinal depending on attribute: - Where % assessment is defined by the DM based on their subjective judgement, it is a Nominal value; - Where % units reflect some objective state of an alternative (e.g. the amount of material in a reservoir, it is a Cardinal measure. Some MCDA methods are presented as if only suitable for dealing with Cardinal measurements (e.g. MADM-OPT). However, the nature of its operation does not restrict the use of Nominal scores. Generally, whenever a method can operate on measurable values, it is considered as equally suited for accepting both Cardinal and Nominal rating values.																																																		
				Abstract	An immeasurable type of subjective ratings used to express relative position of options with respect to each other. A qualitative order indicating which option meets the DP goals better in a pair. Cannot be evaluated in terms of any numerical value of intensity. May be based on either subjective or objective qualities e.g.: - Objective abstract: Colour (independently observed; one may be seen better than other for given DP context e.g. user group) - Objective abstract: Direction (independently observed; one may be better than another e.g. for a construction project) - Subjective abstract: Beliefs (subjectively perceived; one population group may be judged by the DM as having particular views about some subject e.g. a new policy that are better than the views of another group, as perceived by the DM).	Subjective by nature i.e. none are objectively better, whereas their order of performance depends on the specific DP context and DM goals. Abstract ratings have directions distinguishing what is better and what is worse, but offer no basis to reflect preference intensity i.e. does not allow to indicate "better by how much?". Typically use pairwise comparisons among each other or against some reference.	Objective units used for measurable attribute ratings in ARAS method (note: ARAS is suitable for any rating of Measurable nature, but offers an illustrative example): <table><tr><th></th><th colspan="6">Criteria</th></tr><tr><th></th><th>The amount of air per head</th><th>Relative air humidity</th><th>Air temperature during work hours (8-17)</th><th>Illumination</th><th>Rate of air flow</th><th>Dew point</th></tr><tr><th></th><th>X₁</th><th>X₂</th><th>X₃</th><th>X₄</th><th>X₅[*]</th><th>X₆[*]</th></tr><tr><td>Measurement units</td><td>m³/h</td><td>%</td><td>°C</td><td>lx</td><td>m/s</td><td>°C</td></tr></table>		Criteria							The amount of air per head	Relative air humidity	Air temperature during work hours (8-17)	Illumination	Rate of air flow	Dew point		X ₁	X ₂	X ₃	X ₄	X ₅ [*]	X ₆ [*]	Measurement units	m ³ /h	%	°C	lx	m/s	°C	Whether a qualitative attribute is immeasurable (Abstract) or measurable (Nominal) depends in part on the attribute itself, and in part on the DM's attitude within given DP context. For example: - Colour may be Abstract if different values (Red, Blue, Green) are compared by the DM in pairs as a better or a worse option for the DP, but cannot be graded by "how much better" each option is. - Colour may be a Nominal attribute if its values along the same scale (Yellow, Orange, Red, Brown) can be measured as better or worse among each other e.g. Orange is 2x better than Yellow, Red is 3x better, Brown is 4x better. This also allows the DM to adjust the scaling e.g. Orange is 1.2x better and Red is 2.5x better. Abstract attributes reflected with binary values (Yes/No type) can be categorised as either Abstract or Measurable depending on the DP context and DM's convenience: - In Abstract sense, these offer a clear indication of which one is better than the other (e.g. Yes = better, No = worse); - In Measurable sense, these may be rated using a binary set of values e.g. Yes = 1 or 100%, No = 0.																						
	Criteria																																																									
	The amount of air per head	Relative air humidity	Air temperature during work hours (8-17)	Illumination	Rate of air flow	Dew point																																																				
	X ₁	X ₂	X ₃	X ₄	X ₅ [*]	X ₆ [*]																																																				
Measurement units	m ³ /h	%	°C	lx	m/s	°C																																																				
				Any	Identifies MCDA procedures whose operation is not directly linked to the format of attribute ratings and as such, can accept any type of attributes. For example, these procedures may assign a particular nominal value to the better and the worse option in a pair (e.g. 0.0 if worse, 0.5 if indifferent, 1.0 if better) following the same scale disregarding of how option performance is assessed to inform comparison (e.g. may be subjective immeasurable order, subjective nominal scoring, or an objective parameter measurement).	Used in versatile DPs characterised by no direct link between option qualities (observed independently or subjectively) and attribute-wise ratings (derived in relation to DP context). Such DPs typically involve various attributes representing the needs of many stakeholders. Each stakeholder typically pursues own goal, which may be characterised by the most suitable/convenient approach to assessing option performances against the attributes relevant to stakeholders' businesses.	Assignment of pre-defined nominal values to reflect ordinal relationship between option pairs in DRAPE: $r_{ij}^w = \sum_{k=1}^p w_k \cdot \delta_{ij,k} \quad \text{where} \quad \delta_{ij,k} = \begin{cases} 1 & \text{if } x_{ik} \triangleright x_{jk} \\ 0.5 & \text{if } x_{ik} \triangle x_{jk} \\ 0 & \text{if } x_{ik} \triangleleft x_{jk} \end{cases}$	N/A																																																		

Table A.1-3: Reference list for MADM methods included in ProBCA

ProBCA MADM Method References	
Method	Reference
ACUTA	Bous, G., Fortemps, P., Glineur, F., Pirlot, M. (2010) "ACUTA: a novel method for eliciting additive value functions on the basis of holistic preference statements". Eur. J. Oper. Res. 206(2), 435–444. doi: 10.1016/j.ejor.2010.03.009
AHP	Saaty TL (1980) The analytic hierarchy process. McGraw Hill, New York
AHP-F (FAHP)	Tzeng G.H., Huang J.J. (2011). Multiple Attribute Decision Making: Methods and Applications, CRC Press, Taylor & Francis Group. ISBN 9781439861578
AHP-M (MAHP)	Lootsma, Freerk A. (1997). [Applied Optimization] Fuzzy Logic for Planning and Decision Making, Volume 8: The Additive and the Multiplicative AHP, pp. 109-147 (Chapter 5). doi: 10.1007/978-1-4757-2618-3_5
AHP-MG	Wu, Zhibin & Jin, Bingmin & Fujita, Hamido & Xu, Jiuping. (2019). Consensus analysis for AHP multiplicative preference relations based on consistency control: A heuristic approach. Knowledge-Based Systems, vol. 191. doi: 10.1016/j.knsys.2019.105317.
AHP-R (RAHP)	Belton, V. and Gear, T. (1983) On a Short-Coming of Saaty's Method of Analytic Hierarchies. Omega, 11, 228-230. doi: 10.1016/0305-0483(83)90047-6
AIM	V. Lofti, T. Stewart and S. Zionts. (1992) An aspiration-level interactive model for multiple criteria decision making, Computers and Operations Research 19 (7), pp. 671–681; doi: 10.1016/0305-0548(92)90036-5
AIP	T. J. Aragon. (2017) "Deriving criteria weights for health decision making: A brief tutorial," UC Berkeley: School of Public Health, Berkeley. [Online]. Available: https://escholarship.org/uc/item/52755837 [10 November 2022]
AIR	Yurin, A. Y. (2012). An approach for definition of recommendations for prevention of repeated failures with the aid of case-based reasoning and group decision-making methods. Expert Systems with Applications, 39(10), pp. 9282–9287. doi: 10.1016/j.eswa.2012.02.076
AIRM	Dotsenko, S., Makshanov, A. and Popovich, T. (2014) 'Application of aggregated indices randomization method for prognosing the consumer demand on features of mobile navigation applications. In REAL CORP 2014–PLAN IT SMART! Clever Solutions for Smart Cities', Proceedings of 19th International Conference on Urban Planning, Regional Development and Information Society, May, pp.803–806, CORP–Competence Center of Urban and Regional Planning.
AMAST	Mandell, S. F., Duke, J. R., & Taliaferro, D. (1989). Advanced Multi-Attribute Scoring Technique (AMAST): A model scoring methodology for the Request for Proposal (RFP). Journal of Medical Systems, 13(3), 163–175. doi: 10.1007/bf00995887
ANP	Saaty, T. L. (1996). Decision making with dependence and feedback: the analytic network process: The organization and prioritization of Heavyvity. Pittsburg: Rws Publications.
ANP-F (FANP)	Mikhailov, L., and M.G. Singh. (2003). Fuzzy analytic network process and its application to the development of decision support systems. IEEE Transactions on Systems, Man, and Cybernetics 33 (1): 33–41. doi: 10.1109/TSMCC.2003.809354
APIM	Popovich, V.; Hovanov, N.; Hovanov, K.; Schrenk, M.; Prokaev, A.; Smirnova, A. (2008). Situation Assessment in Everyday Life.
ARAMIS	Petrovsky A. Group verbal decision analysis. In: Adam F and Humphreys P (eds) Encyclopedia of decision making and decision support technologies. Hershey: IGI Global, 2008, pp.418–425. ISBN13: 9781599048437, doi: 10.4018/978-1-59904-843-7
ARAS	Edmundas Kazimieras Zavadskas & Zenonas Turskis (2010) A new additive ratio assessment (ARAS) method in multicriteria decision-making, Technological and Economic Development of Economy, 16:2, 159-172. doi: 10.3846/tede.2010.10
ARAS-F (FARAS)	Turskis, Z.; Zavadskas, E. K. 2010a. A new fuzzy additive ratio assessment method (ARAS-F). Case study: The analysis of fuzzy multiple criteria in order to select the logistic centers location, Transport 25(4): 423–432. doi: 10.3846/transport.2010.52
ARAS-G (GARAS)	Turskis, Zenonas and E. Zavadskas. "A Novel Method for Multiple Criteria Analysis: Grey Additive Ratio Assessment (ARAS-G) Method." Informatica 21 (2010): 597-610. doi: 10.15388/informatica.2010.307
ARAS-H	Ghran, M., Moalla Frikhahela, H. ARAS-H: A ranking-based decision aiding method for hierarchically structured criteria. RAIRO-Oper. Res. 55 (3) 2035-2054 (2021). doi: 10.1051/ro/2021083
ARGUS	De Keyser WSM , Peeters PHM. Argus — a new multiple criteria method based on the general idea of outranking. In: Paruccini M, editor. Applying multiple criteria aid for decision to environmental management, 3. Dordrecht: Springer Netherlands; 1994. p. 263–78 . doi: 10.1007/978-94-017-0767-1_17
ARIADNE	A. P. Sage and C. C. White. "ARIADNE: A knowledge-based interactive system for planning and decision support," in IEEE Transactions on Systems, Man, and Cybernetics, vol. SMC-14, no. 1, pp. 35-47, Jan.-Feb. 1984, doi: 10.1109/TSMC.1984.6131327.
ASPID	Hovanov, N., 1996. ASPID-METHOD: Analysis and Synthesis of Parameters under Information Deficiency. St. Petersburg State University Press. St. Petersburg (in Russian).
ASTRIDA	Berkeley, D., Humphreys, P.C., Larichev, O.I. and Moshkovich, H.M, 1989b. ASTRIDA: Advanced Strategic Intelligent Decision Aid: Global Design. ST/ICERD Doc. ASTRIDA-GD-001. London: LSE.
BCM	Gholamreza Haseli, Reza Sheikh & Shb Sankar Sana (2020) Base-criterion on multi-criteria decision-making method and its applications, International Journal of Management Science and Engineering Management, 15:2, 79-88, doi: 10.1080/17509653.2019.1633964
BCR	Frej, Eduarda Asfora; Ekel, Petr; de Almeida, Adiel Teixeira (2021). A benefit-to-cost ratio based approach for portfolio selection under multiple criteria with incomplete preference information. Information Sciences, 545, 487–498. doi: 10.1016/j.ins.2020.08.119
BDA	Newman, J. W., (1971). Management Applications of Decision Theory. New York: Harper & Row.
BGM	Brown, P.A.; Gibson, D.F. A Quantified Model for Facility Site Selection - Application to a Multiplant Location Problem. AIIE Trans. 1972, 4, 1–10. doi: 10.1080/0569557208974822
BPA	Chen Z, Agapiou A and Li H (2020) A Benefits Prioritization Analysis on Adopting BIM Systems Against Major Challenges in Megaproject Delivery. Front. Built Environ. 6:26. doi: 10.3389/fbuil.2020.00026
BSC	Kaplan, R.S. and Norton, D.P. (1995) 'Putting the balanced scorecard to work', Performance Measurement, Management, and Appraisal Sourcebook, Vol. 6, No. 1, p.66.
BWM	Rezaei, J. (2015). Best-worst multi-criteria decision-making method. Omega, 53, 49–57. doi: 10.1016/j.omega.2014.11.009
BWM-G	Haseli, G.; Sheikh, R.; Wang, J.; Tomaskova, H.; Tirkolaee, E.B. A Novel Approach for Group Decision Making Based on the Best–Worst Method (G-BWM): Application to Supply Chain Management. Mathematics 2021, 9, 1881. doi: 10.3390/math9161881
BWS	Louviere, J.J., & Woodworth, G. G. (1990). Best-Worst Scaling: A Model for Largest Difference Judgments. University of Alberta: Working Paper, Faculty of Business.
CA (I)	Green, P. and Srinivasan, V. (1978) Conjoint analysis in consumer research: Issues and outlook, Journal of Consumer Research, vol 5, September 1978, pp 103–123. doi: 10.1086/208721
CA (II)	Wang, Jianqiang & Peng, Lu & Zhang, H.-Y & Chen, Xiao-hong. (2014). Method of multi-criteria group decision-making based on cloud aggregation operators with linguistic information. Information Sciences. 274. 177–191. doi: 10.1016/j.ins.2014.02.130.
CAM	Ming-Lung Hung, Hwong-wen Ma, Wan-Fa Yang. A novel sustainable decision making model for municipal solid waste management, Waste Management, Volume 27, Issue 2, 2007, Pages 209-219, ISSN 0956-053X. doi: 10.1016/j.wasman.2006.01.008
CBA	Talvitie, Antti (2018). Jules Dupuit and benefit-cost analysis: Making past to be the present. Transport Policy, S0967070X18300684. doi: 10.1016/j.tranpol.2018.01.013
CBR	Li, H. and Sun, J. (2008). Ranking-order case-based reasoning for financial distress prediction. Knowledge-Based Systems, 21(8): 868-878. doi: 10.1016/j.knsys.2008.03.047
CBS	G. ODU, "Weighting Methods for Multi-Criteria Decision Making Technique," Journal of Applied Sciences and Environmental Management, vol. 23, no. 8, pp. 1449-1457, 2019. doi: 10.4314/jasem.v23i8.7
CCA	P. Korhonen, J. Wallenius and S. Zionts, Solving the discrete multiple criteria problem using convex cones, Management Science 80, 1336-1345 (1984). [Online]. Available: https://www.jstor.org/stable/2631568 [Accessed on 10 November 2022]
CCDM	Beliaikov, Gleb, Boswell, Sharon, Cao, Thang, Dazeley, Richard, Mak-Hau, Vicky, Nguyen, Minh-Tuan, Wilkin, Tim and Yearwood, John 2019, Aggregation of dependent criteria in multicriteria decision making problems by means of capacities, in MODSIM2019 : Supporting evidence-based decision making: the role of modelling and simulation : Proceedings of the 23rd International Congress on Modelling and Simulation, MODSIM, [Canberra, A.C.T.], pp. 228-234. doi: 10.36334/modsim2019.B3.beliaikov.
CCSD	Wang, Ying-Ming & Luo, Ying. (2010). Integration of correlations with standard deviations for determining attribute weights in multiple attribute decision making. Mathematical and Computer Modelling. 51. 1-12. doi: 10.1016/j.mcm.2009.07.016.
CFPR	Herrera-Viedma, E., Herrera, F., Chiclana, F., & Luque, M. (2004). Some issues on consistency of fuzzy preference relations. European Journal of Operational Research, 154 (1), 98–109. doi: 10.1016/S0377-2217(02)00725-7
CGT	Ridaoui, M.; Grabisch, M.; Labreuche, C. Interaction indices for multichoice games. Fuzzy Sets and Systems, vol. 383, pp.1-26 (2020). doi: 10.1016/j.fss.2019.04.008
CI	Grabisch, M., Labreuche, C. (2005). Fuzzy Measures and Integrals in MCDA. In: Multiple Criteria Decision Analysis: State of the Art Surveys. International Series in Operations Research & Management Science, vol 78. Springer, New York, NY. doi: 10.1007/0-387-23081-5_14
CILOS	E. K. Zavadskas, Integrated Resource Assessment and Selection Decisions in Construction (Mokslas, Vilnius, 1987), p. 210. (In Russian).
CILOS-F	Valentinas, P., Kazimieras, Z., & Askoladas, P. (2020). An Extension of the New Objective Weight Assessment Methods CLOS and IDOCRIW to Fuzzy MCDM. ECONOMIC COMPUTATION AND ECONOMIC CYBERNETICS STUDIES AND RESEARCH. doi: 10.24818/18423264/54.2.20.04
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CM (II)	Collin Eden (1988). Cognitive mapping. , 36(1), 1–13. doi: 10.1016/0377-2217(88)90002-1
CMCDA	Cunha, Daniel & Andrade, Michelle & Prado, Lucius & Santana, Leonardo & Silv, Marcos. (2021). RISK assessment in airport maintenance runway condition using MCDA-C. Journal of Air Transport Management. 90. 101948. doi: 10.1016/j.jairtraman.2020.101948.
COCOSO	Yazdani, M., Zarate, P., Kazimieras Zavadskas, E. and Turskis, Z. (2019), "A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems", Management Decision, Vol. 57 No. 9, pp. 2501-2519. doi: 10.1108/MD-05-2017-0458
COCOSO-G	Yazdani, M., Wen, Z., Liao, H., Banaitis, A., & Turskis, Z. (2019). A grey combined compromise solution (CoCoSo-G) method for supplier selection in construction management. Journal of Civil Engineering and Management, 25(8), 858-874. doi: 10.3846/jcem.2019.11309
CODAS	Keshavarz-Ghorabae, Mehdi & Zavadskas, Edmundas & Turskis, Zenonas & Antucheviciene, Jurgita. (2016). A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. Economic computation and economic cybernetics studies and research / Academy of Economic Studies, 50, 25-44.
COMET	Salabun, W. (2015) 'The characteristic objects method: a new distance-based approach to multi-criteria decision-making problems', Journal of Multi-Criteria Decision Analysis, Vol. 22, Nos. 1–2, pp.37–50. doi: 10.1002/mcda.1525
COPRAS	Zavadskas, E. and Kaklauskas, A. (1996) 'Determination of an efficient contractor by using the new method of multi-criteria assessment', Paper presented at the International Symposium for 'The Organization and Management of Construction', Shaping Theory and Practice.
COPRAS-G	Zavadskas, Edmundas & Kaklauskas, Arturas & Turskis, Zenonas & Tamosaitiene, Jolanta. (2008). Selection of the effective dwelling house walls by applying attributes values determined at intervals. Journal of Civil Engineering and Management. 14. 85-93. doi: 10.3846/1392-3730.2008.14.3
COSIMA	Kim Bang Salling, Steen Leleur, Anders Vestergaard Jensen, Modelling decision support and uncertainty for large transport infrastructure projects: The CLG-DSS model of the Øresund Fixed Link, Decision Support Systems, Volume 43, Issue 4, 2007, Pages 1539-1547, ISSN 0167-9236. doi: 10.1016/j.dss.2006.06.009.
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CRITIC	Diakoulaki D, Mavrotas G, & Papayannakis L. Determining objective weights in multiple criteria problems: The critic method. Computers & Operations Research (1995), Vol. 22, No. 7, pp. 763-770. doi: 10.1016/0305-0548(94)00059-h
CROC	Riabacke, M., Danielsson, M., Larsson, A., & Love, E. (2012). Employing Cardinal Rank Ordering of Criteria in Multi-Criteria Decision Analysis. In Uncertainty Modeling in Knowledge Engineering and Decision Making : Proceedings of the 10th International FUNS Conference. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:sdu:diva-75395
CUT	Argyris, N.; Morton, A.; Figueira, J. R. CUT: A Multicriteria Approach for Concavifiable Preferences. Operations Research (2014) 62:3, 633-642. doi: 10.1287/opre.2014.1274
DANP	Chen, Fu-Hsiang & Hsu, Tsung-Shin & Tzeng, Gwo-Hsiung. (2011). A balanced scorecard approach to establish a performance evaluation and relationship model for hot spring hotels based on a hybrid MCDM model combining DEMATEL and ANP. International Journal of Hospitality Management - INT J HOSP MANAG. 30. 908-932. doi: 10.1016/j.ijhm.2011.02.001.
DCE	Kjær T. A review of the discrete choice experiment – with emphasis on its application in health care. Syddansk Universitet, Odense, Denmark (2005).
DEA	A. Charnes, W. W. Cooper, E. Rhodes, Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2 (1978) 429–444. http://dx.doi.org/10.1016/0377-2217(78)90138-8
DELPHI	Norman Dalkey, Olaf Helmer, (1963) An Experimental Application of the DELPHI Method to the Use of Experts. Management Science 9(3):458-467. doi: 10.1287/mnsc.9.3.458
DELTA	Mats Danielson, Love Ekenberg. A framework for analysing decisions under risk, European Journal of Operational Research, Volume 104, Issue 3, 1998, Pages 474-484, ISSN 0377-2217. doi: 10.1016/S0377-2217(97)00022-2.
DEMATEL	Fontela E, Gabus A (1974) DEMATEL, Innovative methods, Report No. 2, Structural analysis of the world problematique, Battle Institute, Geneva Research Centre
DEX	Bohanec, Marko & Rajkovic, Vladislav. (1990). DEX: An Expert System Shell for Decision Support. Sistemica. 1. 145-157.
DIER-BCS	Chao Fu, Shanlin Yang. The combination of dependence-based interval-valued evidential reasoning approach with balanced scorecard for performance assessment, Expert Systems with Applications, Volume 39, Issue 3, 2012, Pages 3717-3730, ISSN 0957-4174. doi: 10.1016/j.eswa.2011.09.069.
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DM	Dawes, R. M. (1964). Social selection based on multidimensional criteria. The Journal of Abnormal and Social Psychology, 68(1), 104–109. doi: 10.1037/h0047832
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DPSIR	OECD. (1993). Core set of indicators for environmental performance reviews: a synthesis report by the group on the state of the environment. Environment mono- graphs . Paris: Organisation for Economic Co-operation and Development .
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EVAMIX	Voogd H. Multicriteria evaluation with mixed qualitative and quantitative data. Environment and Planning B: Urban Analytics and City Science (1982); 9:221-36. doi: 10.1068/b090
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FDEMATEL	Dalalalh, D., Hayajneh, M., & Batieha, F. (2011). A fuzzy multi-criteria decision making model for supplier selection. Expert Systems with Applications, 38, 8384–8391. doi: 10.1016/j.eswa.2011.01.031
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GCM	Steven D. Sheetz, David P. Tegarden, Kenneth A. Kozar & Ilze Zigurs (1994) A Group Support Systems Approach to Cognitive Mapping. Journal of Management Information Systems, 11:1, 31-57, doi: 10.1080/07421222.1994.11518029
GMCR	Keith W. Hipel, D. Marc Kilgour, Liping Fang, Xiaoyong (John) Peng, The decision support system GMCR in environmental conflict management, Applied Mathematics and Computation, Volume 83, Issues 2–3, 1997, Pages 117–152, ISSN 0096–3003, doi: 10.1016/S0096-3003(96)00170-1
GRA	Deng Ju-Long, Control problems of grey systems, Systems & Control Letters, Volume 1, Issue 5, 1982, Pages 288–294, ISSN 0167-6911. doi: 10.1016/S0167-6911(82)80025-X
GRIP	Figueira, J. R., Greco, S., & Słowiński, R. (2009). Building a set of additive value functions representing a reference preorder and intensities of preference: GRIP method. European Journal of Operational Research, 195, 460–486. doi: 10.1016/j.ejor.2008.02.006
GTMA	Venkata Rao, Ravipudi. (2007). Decision Making in the Manufacturing Environment: Using Graph Theory and Fuzzy Multiple Attribute Decision Making Methods. doi: 10.1007/978-1-84628-819-7
HAW	C.-L. Hwang, K. Youn, Multiple Attribute Decision Making - Methods and Application: A State of the Art Survey. Springer Berlin, Heidelberg (1981). eBook ISBN: 978-3-642-48318-9; doi: 10.1007/978-3-642-48318-9
HDT	Hasse, H. Über die Klassenzahl abelscher Zahlkörper, Akademie Verlag: Berlin, Germany, 1952.
HEIM	See, T., Gurnani, A., and Lewis, K. (February 14, 2005). "Multi-Attribute Decision Making Using Hypothetical Equivalents and Inequivalents ." ASME. J. Mech. Des. November 2004; 126(6): 950–958. doi: 10.1115/1.1814389
HGDM	Sahin Zorluoglu, Ozge & Kabak, Ozgur. (2020). Hierarchical group decision-making approach for information technology project evaluation and prioritization. Journal of Multi-Criteria Decision Analysis. 27. doi: 10.1002/mcda.1723
HIA	P. Korhonen, A hierarchical interactive method for ranking alternatives with multiple qualitative criteria, European Journal of Operational Research 24, 265–276 (1986). doi: 10.1016/0377-2217(86)90049-4
HRE	Kulakowski, K.: A heuristic Scoring estimation algorithm for the pairwise comparisons method, Central European Journal of Operations Research, 2013, 1–17, ISSN 1435-246X. doi: 10.1007/s10100-013-0311-x
HSMAA	Resce, Giuliano & Schiltz, Fritz. (2020). Sustainable Development in Europe: A Multicriteria Decision Analysis. Review of Income and Wealth. 67. doi: 10.1111/roiw.12475
HT	C.-L. Hwang, K. Youn, Multiple Attribute Decision Making - Methods and Application: A State of the Art Survey. Springer Berlin, Heidelberg (1981). eBook ISBN: 978-3-642-48318-9; doi: 10.1007/978-3-642-48318-9
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IDOCRIW	E. K. Zavadskas, V. Podvezko, Integrated Determination of Objective Criteria Weights in MCDM, International Journal of Information Technology & Decision Making, 15(02), pp. 267–283 (2016), doi: 10.1142/S0219622016500036
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IOWA	R. R. Yager and D. P. Filev, "Induced ordered weighted averaging operators," in IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics), vol. 29, no. 2, pp. 141–150, April 1999, doi: 10.1109/3477.752789
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IROR	Corrente, Salvatore & Greco, Salvatore & Roman, Slowinski. (2012). Robust Ordinal Regression in case of Imprecise Evaluations.
ISM	Malone, D. (1975). An introduction to the application of interpretive structural modeling. Proceedings of the IEEE, 63(3), 397–404. doi: 10.1109/PROC.1975.9765
KANO	Kano, N., Seraku, N., Takahashi, F. and Tsuji, S. (1984) Attractive Quality and Must-Be Quality. Journal of the Japanese Society for Quality Control, 41, 39–48.
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KEMIRA-E	KRYLOVAS, ALEKSANDRAS & Dadelo, Stanislav & Kosareva, Natalja & Zavadskas, Edmundas. (2017). Entropy-KEMIRA Approach for MCDM Problem Solution in Human Resources Selection Task. International Journal of Information Technology & Decision Making. 16. doi: 10.1142/S0219622017500274
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LFA	Vommi, Vijaya Babu & Kakollu, Sravya. (2016). A light approach to multiple attribute decision making using loss functions. Journal of Industrial Engineering International. 13. doi: 10.1007/s40092-016-0174-6
LFND	B. M. Elomda, H. A. Hefny and H. A. Hassan (2013). "An extension of fuzzy decision maps for multi-criteria decision-making". Egyptian Informatics Journal, Vol. 12, iss. 2, pp. 147–155. doi: 10.1016/j.ej.2013.05.001
LINMAP	Srinivasan, V., Shocker, A.D. Linear programming techniques for multidimensional analysis of preferences. Psychometrika 38, 337–369 (1973). doi: 10.1007/BF02291658
LM	B. Roy, D. Bouyssou, Aide Multicritere a la Decision: Methodes et Cas, Economica, Paris, 1993.
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MAGIQ	McCaffrey, J. (2005) 'Multi-attribute global inference of quality (MAGIQ)', Software Test and Performance Magazine, Vol. 2, No. 7, pp.28–32.
MAPPACC	Matarazzo B. Multicriterion analysis of preferences by means of pair-wise actions and criterion comparisons (MAPPACC). Applied Mathematics and Computation, 1986; 18:119–41. doi: 10.1016/0096-3003(86)90020-2
MARCOS	Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to Compromise solution (MARCOS). Computers & Industrial Engineering, 140, 106231. doi: 10.1016/j.cie.2019.106231
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MARS	Górecka, Dorota & Roszkowska, Ewa & Wachowicz, Tomasz. (2014). MARS – a hybrid of ZAPROS and MACBETH for verbal evaluation of the negotiation template.
MAUD	HUMPHREYS, P. C. and S. WOOLER, Development of MAUD through a feasibility study on the use of decision aiding software in vocational guidance, Technical report 81-4, Decision Analysis Unit, London School of Economics, London, 1981.
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MCCPI	Wu, J.-Z., S. Yang, Q. Zhang, and S. Ding (2015). 2-additive capacity identification methods from multicriteria correlation preference information. IEEE Transactions on Fuzzy Systems 23(6), 2094–2106. doi: 10.3390/math7030300
MCIA	Frini, A. (2017). A Multicriteria Intelligence Aid Methodology Using MCDA, Artificial Intelligence, and Fuzzy Sets Theory. Mathematical Problems in Engineering, 2017, 1–10. doi: 10.1155/2017/9281321
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MEW	Zavadskas, E. K. (1987). Multiple criteria evaluation of technological decisions of construction. Dissertation of Dr. Sc., Moscow Civil Engineering Institute, Moscow (in Russian).
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MOORA	Chelviet, Rene & Dammasch, Knoll, Claudia & Rauch-Gebbenleben, Benjamin. (2008). B: A Markov Model for Multi-Criteria Multi-Person Decision Making. 262 - 266. doi: 10.1109/INNOVATIONS.2008.4781672
MOORA	Brauers, Willem Karel M. and Edmundas Kazimieras Zavadskas. "The MOORA method and its application to privatization in a transition economy." Control and Cybernetics 35 (2006): 445–469.
MSIP	Kruskal, J.B. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29, 1–27 (1964). doi: 10.1007/BF02289565
MULTIMOORA	Brauers, Willem & Zavadskas, Edmundas. (2010). Project management by MULTIMOORA as an instrument for transition economies. Technological and Economic Development of Economy - TECHNOL ECON DEV ECON. 16. 5–24. doi: 10.3846/tede.2010.01
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MZM	Martel, J.-M., & Zaras, K. (1995). Stochastic dominance in multicriterion analysis under risk. Theory and Decision, 39(1), 31–49. doi: 10.1007/BF01078868
NAFIM	Wang, C.-H.; Lu, I.-Y.; Chen, C.-B. "Evaluating firm technological innovation capability under uncertainty", Technovation 28 (2008), pp. 349–363; doi: 10.1016/j.technovation.2007.10.007
NAIADE	Munda, Giuseppe. "Multicriteria Evaluation in a Fuzzy Environment: Theory and Applications in Ecological Economics." (1995). Springer, Berlin, 1995. ISBN: 9783790808926
NAROR	Silvia Angeliella; Salvatore Greco; Benedetto Matarazzo (2010). Non-additive robust ordinal regression: A multiple criteria decision model based on the Choquet integral. , 2011(1), 277–288. doi: 10.1016/j.ejor.2009.02.023
NDEA	Mirhedayatian, S.M., et al., A novel network data envelopment analysis model for evaluating green supply chain management. International Journal of Production Economics (2013), http://dx.doi.org/10.1016/j.ijpe.2013.02.009
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NMUTA (UTA-NM)	Despotis, D.K., Zopounidis, C. (1995). Building Additive Utilities in the Presence of Non-Monotonic Preferences. In: Pardalos, P.M., Siskos, Y., Zopounidis, C. (eds) Advances in Multicriteria Analysis. Nonconvex Optimization and Its Applications, vol 5. Springer, Boston, MA. doi: 10.1007/978-1-4757-2383-0_7
NNCI	Munda, Giuseppe & Nardo, Michela. (2009). Non-Compensatory/Non-Linear Composite Indicators for Ranking Countries: A Defensible Setting. Applied Economics. 41. 1513–1523. doi: 10.1080/00036840601019364
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OWA	R. R. Yager, "Families of OWA operators," Fuzzy Sets Syst., vol. 59, pp. 125–148, 1993. doi: 10.1016/0165-0114(93)90194-M
OWG	F. Chiclana, F. Herrera, E. Herrera-Viedma. Integrating multiplicative preference relations in a multipurpose decision-making model based on fuzzy preference relations. Fuzzy Sets and Systems, Volume 122, Issue 2 (2001), Pages 277–291, ISSN 0165–0114. doi: 10.1016/S0165-0114(00)00004-X
OWGA	Xu, Z.S. and Da, Q.L. (2002). The ordered weighted geometric averaging operators. Int. J. Intel. Syst., 17: 709–716. doi: 10.1002/int.10045
PACMAN	Girolotta A. Passive and Active Compensability Multicriteria ANalysis (PAC- MAN). J Multi-Criteria Decis Anal 1998; 7:204–16. doi: 10.1002/(SICI)1099-1360(199807)7:4<204::AID-MCDA192>3.0.CO;2-5
PAIRS	Salo, A.A. and Hämäläinen, R.P., 1992. Preference assessment by imprecise ratio statements. Operations Research, 40(6), pp.1053–1061. doi: 10.1287/opre.40.6.1053
PAMSSEM	Martel, J-M, Kiss, L N., and Rousseau, M. A. 1996. PAMSSEM : Une procédure d'aggrégation multicritère de type surclassement de synthèse pour évaluations mixtes. FSA Working Document, Department Opérations et Systèmes de Décision, Université Laval, Quebec.
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PCA	Bertrand Mareschal, Jean-Pierre Brans, Neometrical representations for MCDA, European Journal of Operational Research, Volume 34, Issue 1, 1988, Pages 69–77, ISSN 0377-2217, doi: 10.1016/0377-2217(88)90456-0
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PRAGMA	Matarazzo B. Preference ranking global frequencies in multicriterion analysis (Pragma). European Journal of Operational Research 1988; 36: 36–49. doi: 10.1016/0377-2217(88)90005-7
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QUALIFLEX	Paelinck, J. H. P., 1978. "Qualiflex: A flexible multiple-criteria method," Economics Letters, Elsevier, vol. 1(3), pages 193-197.
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RIM	Cables Pérez, Elio & Lamata, Maria & Verdegay, Jose. (2015). RIM-Reference Ideal Method in Multicriteria Decision Making. Information Sciences. 337. doi: 10.1016/j.ins.2015.12.011
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ROD	Roberts, R., Goodwin, P., "Weight approximations in multi-attribute decision models". J. Multi-Crit. Decis. Anal. 11:291–303 (2002). doi: 10.1002/mcda.320
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ZAPROS	LARICHEV, O. I., J. A. ZUEV and L. S. GNEDENKO, Method Zapros (closed procedures near reference situations) for solving ill-structured problems of choice with many criteria, VNIISI, Moscow, 1979.
ZAPROS III	Larichev, Oleg. (2001). Ranking multicriteria alternatives: the method ZAPROS III. European Journal of Operational Research. 131. 550-558. doi: 10.1016/S0377-2217(00)00096-5
ZMII	Franceschini, Firenze & Maisano, Domenico. (2019). Fusing incomplete preference rankings in design for manufacturing applications through the ZM II -technique. The International Journal of Advanced Manufacturing Technology. 103. doi: 10.1007/s00170-019-03675-5

A.2 ProBCA Taxonomy Structure

Figure A.2-1: ProBCA Taxonomy Structure (Parameter Category 1)

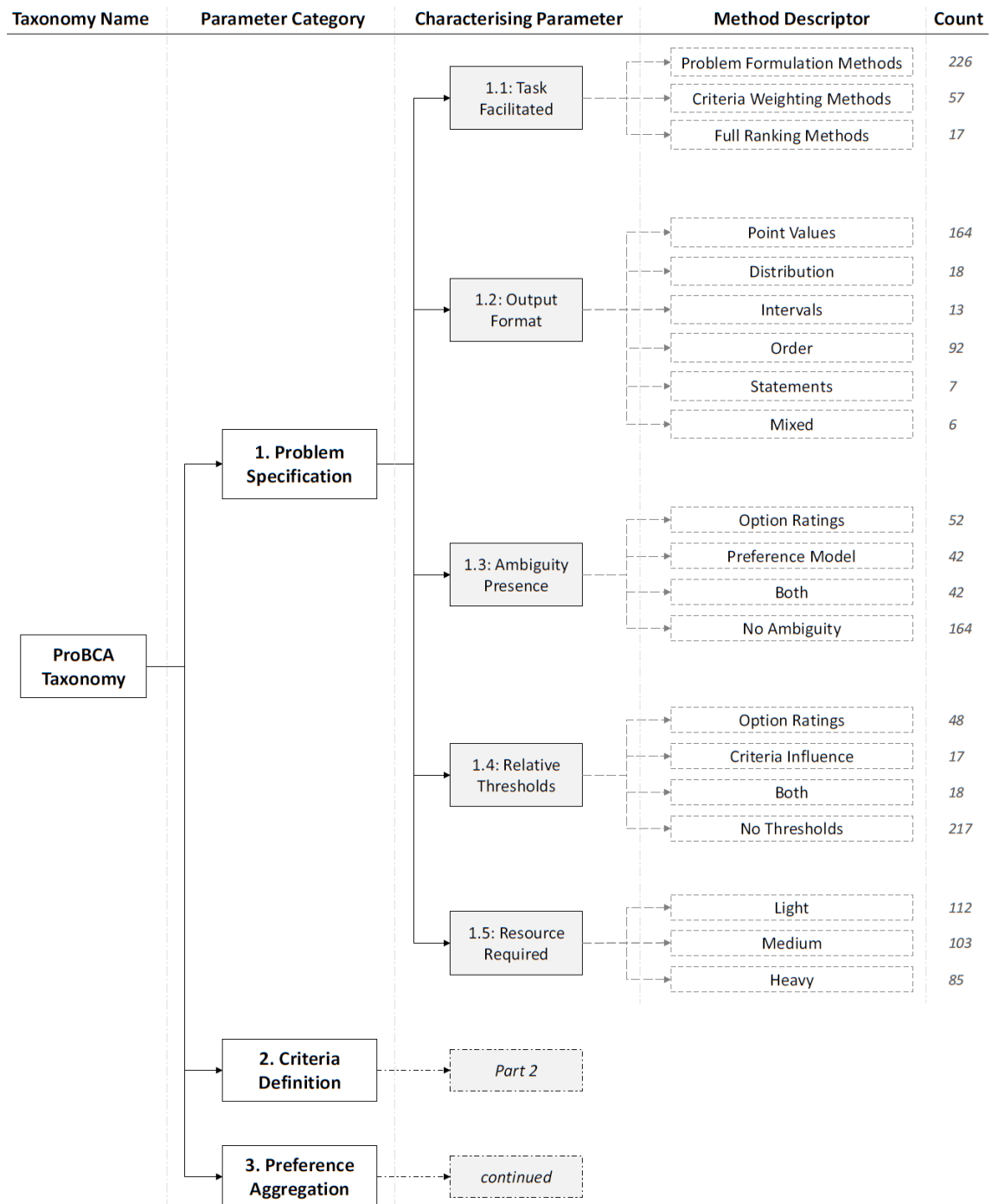


Figure A.2-2: ProBCA Taxonomy Structure (Parameter Category 2)

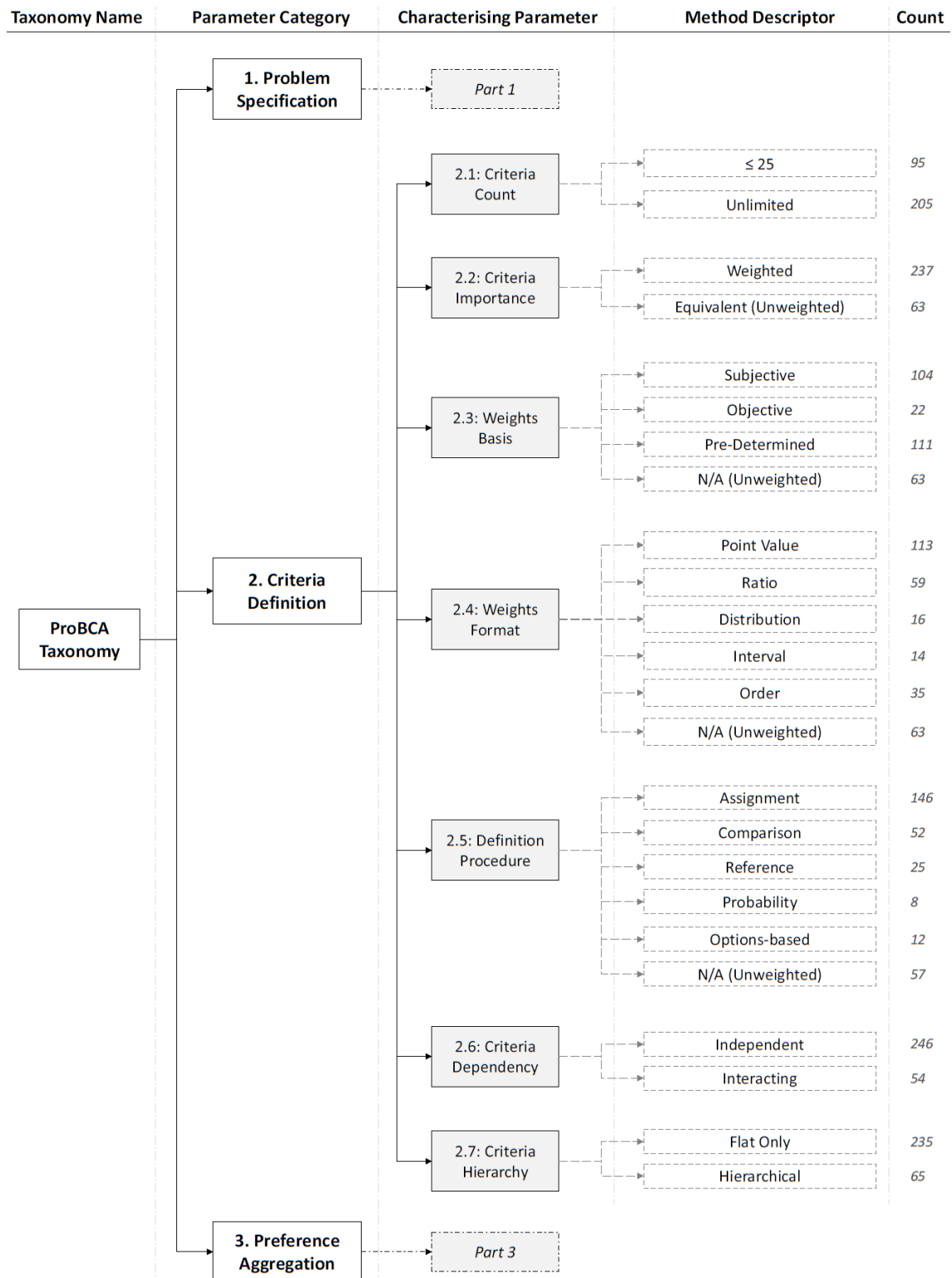
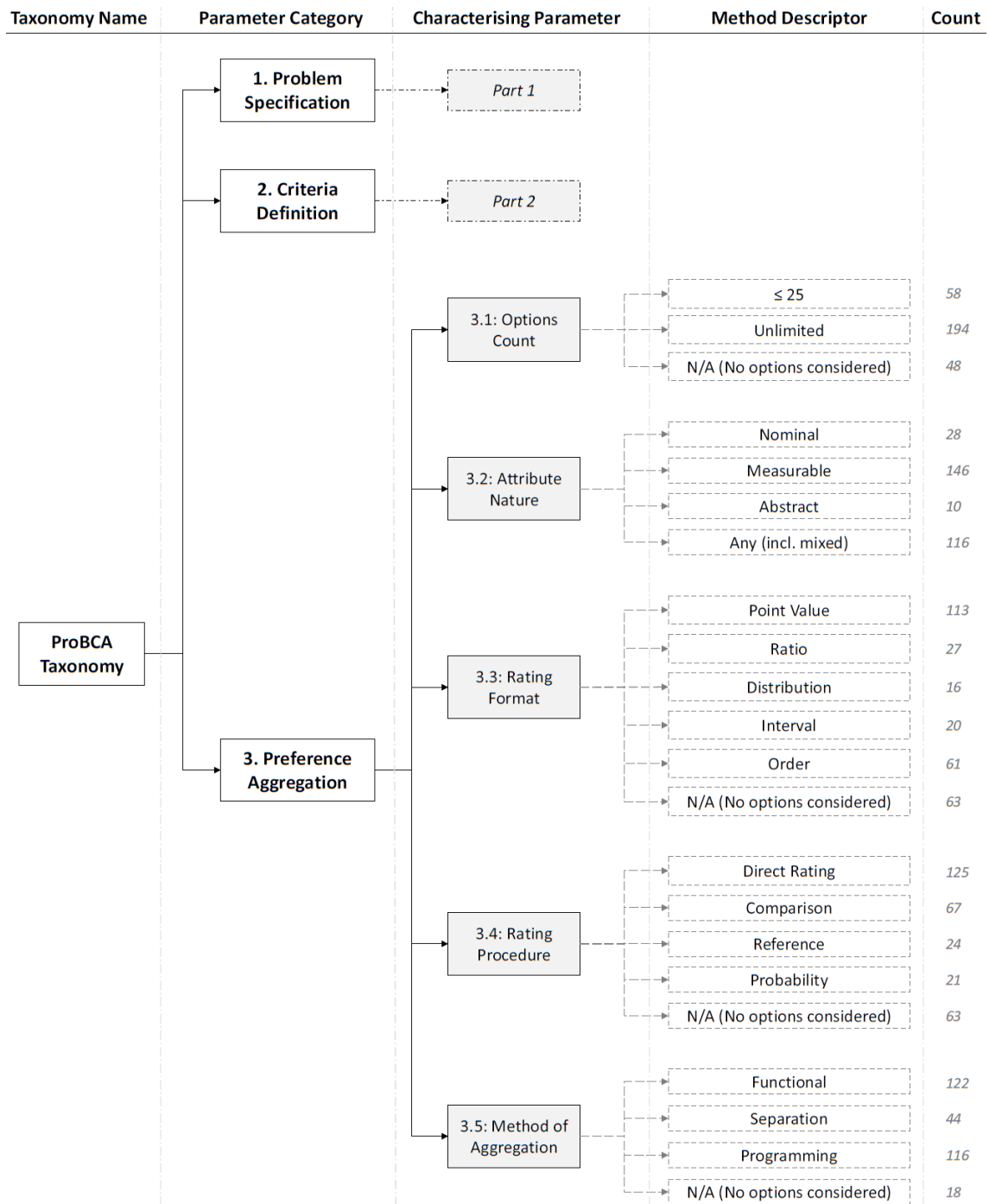


Figure A.2-3: ProBCA Taxonomy Structure (Parameter Category 3)



A.3 MCDA Abbreviations

Table A.3: “M”-based 3- to 5-letter abbreviations used in MCDA domain

Abbrev.	Meaning	Explanation
MADA/ MADM	Multi-Attribute Decision Analysis / Making	Discrete sub-domain of MCDA
MAUA	Multi-Attribute Utility Analysis	The application of MAUT (equivalent)
MAUM	Multi-Attribute Utility Measurement	A MADM method, predecessor to MAUT
MAUT	Multi-Attribute Utility Theory	A distinct MADM method
MAVF	Multi-Attribute Value Function	An element of MAVT
MAVT	Multi-Attribute Value Theory	A distinct MADM method
MCAP* / MCP / MCCP	Multi-Criteria Classification / Assignment Problems	A type of problems solved by MCDA
MCAP**	Multi-Criteria Aggregation Procedure	An element of MCDA process
MCDA / MCA / MCDM	Multi-Criteria Decision Analysis / Making	Common title for the whole domain
MCDP	Multi-Criteria Design Problem	A type of activity served by MCDA
MCIA	Multi-Criteria Intelligence Aid	A sub-domain of MCDA (AI + Fuzzy Sets)
MCOC	Multi-Criteria Ordinal Classification	A subset of MCCP
MCP*	Multi-Criteria Programming	An approach used in some MCA methods
MCPD	Multi-Criteria Polyhedral Dynamics	A theoretical basis of MCQA
MCQA	Multi-Criteria Q-Analysis	A distinct MADM method
MCVM	Multi-Criteria Value Modelling	Uses optimization tools for discrete tasks
MDO*	Multidisciplinary Design Optimization	A type of activity served by MCDA
MDO**	Multi-Objective Design Optimization	A type of activity served by MCDA
MGDM	Multicriteria Group Decision-Making	MCDA methods dedicated to groups
MPDM	Multi-Person Decision-Making	An alternative acronym to GDM
MILP	Mixed Integer Linear Programming	An approach used in some MCA methods
MLFP	Multicriteria Linear Fractional Program	A distinct MODM method

MOCO	Multiple Objective Combinatorial Optimization	A type of problems solved by MODM
MOD	Multi-Objective Design	A type of activity served by MCDA
MODA	Multi-Objective Decision Analysis	The application of MODM
MODM	Multi-Objective Decision-Making	Continuous sub-domain of MCDA
MOEA	Multi-Objective Evolutionary Algorithm	A subset of MODM methods
MOGA	Multi-Objective Genetic Algorithm	A distinct MODM method
MOLP	Multi-Objective Linear Programming	A subset of MOMP
MOM	Multi-Objective Management	A type of activity served by MCDA
MOMP / MMP	Multi-Objective Mathematical Programming	An approach used in some MOO methods
MONLP	Multi-Objective Non-Linear Programming	A subset of MOMP
MOO	Multi-Objective Optimization	A subset of MODM methods
MOP	Multi-Objective Programming	An approach used in some MCA methods
MOPO	Multi-Objective Preference Optimization	The frontier between MCDA & MOP
MOPS	Multi-Objective Problem Solving	A type of activity served by MCDA
MOQA	Multi-Objective Q-Analysis	A separate MCDA method
MOSLP	Multi-Objective Stochastic Linear Programming	A subset of MOMP
MRDM	Multiple Rule Decision-Making	A separate, AI-based MCDA method
MVA	Multi-Variate Analysis	The mathematical approach at the basis of MDO & MCDA
MVO	Multi-Variate Optimisation	MVA version dedicated to optimisation tasks
MVS	Multi-Variate Selection	Part of MVA served by MCDA

A.4 Method Characterisation Example

Table A.4: ARIADNE [Ref A] Method Characterisation Example

ID	Parameter	Value	Justification
1.1	Task Facilitated	Ranking	<u>p. 2 [Ref B], Chap. II, Para. 4:</u> “mathematical programming approaches are used to determine dominance structures for alternative prioritization that are based on parameter information elicited from the decisionmaker”
1.2	Output Format	Order	<u>p. 3 [Ref C], Chap. III, Sec. C, point 4a:</u> “ <i>Display domination digraph</i> ”, which conceals preference intensity.
1.3	Ambiguity Presence	Both	<u>p. 3 [Ref C], Chap. II continued, Para. 8:</u> “ <i>inverse and direct < ... > specification of imprecise values, weights, and probabilities enhances the usefulness of ARIADNE</i> ” <u>p. 3 [Ref C], Chap. III, Sec. B, point 7:</u> “ Encode uncertainty elements in the form of event outcome probabilities, or bounds on these, to the extent possible.” <u>p. 8 [Ref D], Chap. IV, last para. before Chap. V:</u> “ ARIADNE allows parameter imprecision ... ”
1.4	Relative Thresholds	Both	<u>Ratings, p. 2 [Ref B], Chap. II, Para. 4:</u> “Parameters are elicited from the decisionmaker in the form of equalities and inequality bounds. ” <u>Also p. 3 [Ref C], Chap. III, Sec. B, point 7:</u> “ Encode uncertainty elements in the form of event outcome probabilities, or bounds on these, to the extent possible. ” <u>Weights: p. 2 [Ref B], Chap. II, Para. 6: bounds on attribute weights < ... > may be determined by linear programming</u> <u>Also p. 3 [Ref C], Chap. III, Sec. B, point 10:</u> “ Identify attribute weights, or bounds on these functions ”
1.5	Resource Needed	Reasonable	<u>From process presented in Chap. V on p. 8 [Ref D] onwards, deep MCDA expertise is not required to comprehend and apply the method. However, it involves mathematical programming so not suitable for pen-and-paper format and needs an independent quality check.</u> <u>p. 9 [Ref E], Chap. V, Sec. A, para. 4 after Formula 5: “these linear programs are extraordinarily simple to solve”</u>

2.1	Criteria Count	≤ 25	<p>p. 2 [Ref B], Chap. II, Para. 6: “An inverse aiding feature is currently being incorporated into the < ... > system.” Then, p. 3 [Ref C], Chap. II, Para. 7 (start of page): “For a large number of prioritizations, the inverse aiding approach may become cumbersome computationally ...”</p> <p>p. 9 [Ref E], Chap. V, Sec. A, para. 4 after Formula 5: “If A alternatives exist, we will need to solve no more than $A(A - 1)$ LP's to resolve [equation] (3).” For e.g. 25 alternatives, 600 (= $25 * 24$) LPs need to be modelled for each criterion. This requires setting up a model featuring 15000 individual calculations made of 600 automated operations for each criterion. Modelling a separate set of 600 automated calculations for each of the 25 criteria reaches the reasonable effort level in a single working day.</p>
2.2	Criteria Importance	Weighted	<p>p. 3 [Ref C], Chap. II, Para. 8 (last): “specification of < ... > weights < ... > enhances the usefulness of ARIADNE”</p> <p>p. 3 [Ref C], Chapter III, Section B, point 10: “Identify attribute weights, or bounds on these functions”</p>
2.3	Weight Basis	Subjective	<p>p. 9 [Ref E], Chap. V, Sec. A, para. 5 after Formula 5: “We assume that the DM < ... > is able to estimate the weights”</p> <p>p. 10 [Ref F], Chap. V, Sec. A, para. 9 after Table III: “Suppose that the DM says $w_1^1 \leq w_2^1$”</p>
2.4	Weight Format	Interval	<p>p. 8 [Ref D], Chap. IV, last para. before Chap. V: “we allow < ... > expressions for < ... > weights associated with attribute (i) in the form $0.2 \leq w_i \leq 0.4$”</p>
2.5	Definition Procedure	Assignment	<p>p. 9 [Ref E], Chap. V, Sec. A, para. 5 after Formula 5: “We assume that the DM specified < ... > attribute tree and is able to estimate the weights”</p>
2.6	Criteria Dependence	Independent	<p>p. 9 [Ref E], Chap. V, Sec. A, para. 3 after Formula 2: “For the realistic case where weights and attribute scores for each attribute are functionally independent ...”</p>
2.7	Criteria Hierarchy	Hierarchical	<p>p. 2 [Ref B], Chap. II, Para. 3: “A single-level structure or a multiple-level hierarchical structure of attributes may be used < ... > at the discretion of the decisionmaker.”</p> <p>p. 8 [Ref D], Chap. V, Section A, para. 1: “It is possible to use either a hierarchical tree structure < ... > of attributes”</p>

3.1	Options Count	Unlimited	p. 9 [Ref E], Chap. V, Sec. A, para. 4 after Formula 5: “If A alternatives exist, we will need to solve no more than $A(A - 1)$ LP's to resolve [equation] (3).” E.g. for 25 alternatives, 600 LPs need to be solved . This would impose a limit on options count if operations were manual; but the process can be automated for all alternative pairs.
3.2	Attribute Nature	Measurable	p. 8 [Ref D], Chap. IV, last para. before Chap. V: “We encourage the decisionmaker to specify precise values or numerical ranges for facts and values .”
3.3	Rating Format	Interval	p. 8 [Ref D], Chap. IV, last para. before Chap. V: “ we allow expressions for alternative scores on attributes in the form $0.2 \leq v_i(a) \leq 0.5$ ”
3.4	Rating Procedure	Probability	p. 3 [Ref C], Chap. II continued, Para. 8: “inverse and direct < ... > specification of imprecise values, weights, and probabilities enhances the usefulness of ARIADNE ” p. 3 [Ref C], Chap. III, Section B, point 7: “Encode uncertainty elements in the form of event outcome probabilities , or bounds on these” p. 8 [Ref D], Chap. IV, last para. before Chap. V: “ we allow < ... > expressions for <...> probabilities of event (i) resulting from alternative (a) in the form $0.3 \leq P_i(A) \leq 0.45$ ”
3.5	Aggregation Method	Functional	p. 9 [Ref E], Chap. V, Sec. A, Formula (1): the core formula of the method is a mathematical function for positive aggregation . $v(a_i) = \sum_{k=1}^N \rho_k v_k(a_i)$

Ref A: A. Sage and C. White, “ARIADNE: A knowledge based interactive system for planning and decision support,” IEEE Transactions on Systems, Man, and Cybernetics, Vols. SMC-14, no. 1, pp. 35-47, 1984. DOI: 10.1109/TSMC.1984.6313267

Ref B: “English Dictionary,” Cambridge University Press, 2022. [Online]. Available: <https://dictionary.cambridge.org/dictionary/english>. [Accessed 25 August 2023].

Ref C: H. A. Simon, The new science of management decision, New York: Harper and Row, 1960. DOI: 10.1037/13978-000

Ref D: E. Zavadskas, Z. Turskis, J. Tamosaitiene, “Selection of construction enterprises management strategy based on the SWOT and multi-criteria analysis,” Archives of civil & mech. engineering, 11(4), 1063-1082, 2011. DOI: 10.1016/S1644-9665(12)60096-X

Ref E: D. Berkeley, P. Humphreys, O. Larichev and H. Moshkovich, “Modelling and supporting the process of choice between alternatives: the focus of ASTRIDA,” in IFIP (International Federation for Information Processing), North-Holland, 1991

Ref F: G. Colson, “The OR's prize winner and the software ARGOS: how a multijudge and multicriteria ranking GDSS helps a jury to attribute a scientific award,” Computers & Operations Research, vol. 27, no. no. 7-8, pp. 741-755, 2000

Appendix B : A Holistic Concept Design Framework for Passenger Cabin Interiors (Section 4)

B.1 HCCA Framework Screenshots

This Appendix presents the screenshots of the various HCCA framework sheets. Each screenshot depicts a dedicated sheet of the original HCCA .xls file uploaded in CORD repository (see Ref. [4] in Section 4).

Table B.1-1: Aircraft Cabin Interior Products vs Drivers Matrix:

The baseline breakdown of the state-of-the-art passenger cabin interior products. Presented as a Product-Driver matrix to provide the user with a template to map the design factors applicable to in-scope products.

Table B.1-2: Cabin Design Drivers defined in HCCA:

A comprehensive list of cabin design drivers and its lower-level factors. These are presented using the core definition, comments, examples, and relevant references for each factor. The table serves as the guide for the user/PMO to judge what factors are relevant on a given project and use these to develop the detailed project planning and statement of work documentation.

Table B.1-3: HCCA Design Factor Importance Weighting Matrices:

The compendium of Pairwise Comparison matrices used to derive the importance weights for cabin design drivers and their constituent design factors. The automated capability to derive importance weights from the comparison scores entered is offered by the original HCCA MS Excel file available for external users upon request to Dr Craig Lawson (Cranfield University SATM) or the author.

Table B.1-4: Stakeholder Contribution Comparison Matrices:

Pairwise Comparison matrices used to assess relative stakeholder involvement in cabin design projects. The involvement is assessed by mapping stakeholder positioning along the influence and interest dimensions. The positioning vector is derived by feeding the pairwise comparison scores entered into R code template provided on “R input” sheet of the original HCCA file in CORD.

Table B.1-5: Stakeholder Applicability Mapping of Design Drivers:

The matrix mapping the relevance of cabin design drivers (Table B.1-2) to cabin project stakeholders. Applicable factors are mapped using tick marks against each stakeholder column in the matrix. The generic map is presented in baseline HCCA version as illustrated, and may have to be updated for any specific project.

Table B.1-6: Relevant References for HCCA Design Drivers & Factors:

The list of relevant references to help the user better understand the examples and specific requirements associated with each HCCA top-level design driver and bottom-level factor. The list does not constitute an exhaustive scope of sources relevant for each driver or factor. The definition of tasks in the statement of work document for a given cabin interior project shall account for the research effort of appropriate extent to facilitate sufficient understanding of each driver or factor.

Table B.1-1: Aircraft Cabin Interior Products vs Drivers Matrix

[illegible]

Table B.1-2: Cabin Design Drivers defined in HCCA

D#	Driver	Description	Comments	F#	Factors	Definition	Comments	Example Criteria	References
	<u>Top-level motivation</u> Based on Profitability equation at the root	<u>Explanation</u> Implication of each top-level driver	<u>Important additional information</u> Relevant considerations when processing the drivers		<u>Mid-Level implications</u> Lower-level factors associated with each driver: - some factors are interdependent - may represent mixed technology effects	<u>Mid-level effects</u> Definitions are generic; the specific implication of the constituent factors depends on the point of view: the same factor will embody different qualities if considered by a passenger, an airline, an equipment manufacturer, etc.	<u>Important additional information</u> Important considerations and additional information useful for applying the defined factors to a cabin project or adapting for a revised NPDI method. Note: Cabin Solution = cabin product, service, technology, design feature, or any other distinct item being analysed.	<u>Bottom-level design considerations (with KPI per unit time)</u> Detailed examples of the design criteria or specific requirements that may be derived to implement the presented factors. Criteria weights to be assigned based on the higher-level design factor weights (equal criteria weights within each factor), or assigned by the user based on their internal preferences and needs for the project.	<u>Where is it from</u> Example sources discussing the proposed criteria
1	Revenue Potential	Revenue parameters controlled by the respective stakeholder and driven by sales volume	Revenue potential directly fed by the sales and provision of goods to users	a	Brand Image	The effect of a cabin solution on the public perception of stakeholder's brand value and reputation.	The subjective reflection of stakeholders' brand value and reputation in public perception. Affected by the user's ability to leave service/product reviews and its differentiation. Affects stakeholder's share price. More reliable in relative terms (compared against competitors or past performance) rather than as an absolute assessment (with no comparison basis).	- User reviews in social media or other information sources (# reviews and rating pattern) - Impact on demand potential (Δ% seats) - The ability to dictate pricing (Δ% seats due to price adjustments)	[05], [30], [39], [40], [53], [73], [77], [78], [80] - [84], [87] - [89], [100] [104], [105]
				b	Promotion Channels	Stakeholder's capability to realise effective promotion of their own products or services using the cabin solutions implemented.	The ability of a cabin solution to facilitate, expand, diversify, and enhance the effectiveness of Stakeholders' opportunities to market their own products/services. Affects Brand Image, differentiation.	- Promotion channels available (number of individual channels) - Promotion channel effectiveness (Δ% revenue/seats sold due to given channel) - Utilisation effects: increased cabin capacity fulfilment due to new cabin solutions (avg. Δ% revenue/seats)	
				c	Upfront Pricing	Facilitation of effective approaches to setting the price levels for accessing the baseline products/services offered with the flight booking.	Operator's endowment to leverage baseline product/service pricing without losing demand, as enabled by a cabin solution. Reflects inherent significance of new equipment for the user.	- Baseline price effects created by new equipment (e.g. Δ% ticket revenue) - Targeted demand: attraction of the target user persona (perennial: Δ% seats sold) - Collateral demand: attraction of the non-targeted user persona created by new cabin solutions (same KPI) - Utilisation effects: increased cabin capacity fulfilment due to new cabin solutions (avg. Δ% revenue/seats)	
				d	Access Pricing	Facilitation of effective approaches to define on-demand product/service pricing schemes that are realised after the passenger has booked their flight.	Operator's opportunity to impose or adjust on-demand or usage-based pricing schemes after ticket sale, e.g. upgrade service level in-flight. Reflects instantaneous cabin equipment value for money to the users.	- Ancillary revenues enabled by selling on-demand cabin access to products or services available in-flight (Δ% ancillary revenue) - Targeted demand: attraction of the target user persona (transient: Δ% ancillary revenue) - Collateral demand: attraction of the non-targeted user persona created by new cabin solutions (same KPI)	
				e	Growth Potential	The potential for keeping the demand for the same product/service stable or increasing above the original levels in the near/mid-term future.	The state of market dynamics when near- and mid-term demand for a specific product/service in its original form will remain compatible with user trends without the need for significant development or upgrading.	- Sales dynamics for product version or its minor evolutions (Δ% sales as revenue or volume)	
				f	Innovation Capacity	Long-term potential for viable product/service evolution beyond the original baseline.	Long-term market ability to absorb future product/service development profitably. Offers the scope for product innovation by updating, upgrading, expanding, or otherwise changing it to align with changing user trends.	- The presence of product characteristics enabling its evolution (yes/no) - The promise of viable demand for an updated product (expected sales)	
2	Collaborative Potential	Revenue parameters dependent on other stakeholders and requiring collaboration	Revenue potential enabled by collaboration among the service and goods providers	a	Distribution Channels	Product/service distribution channels enabled by the implemented cabin solutions.	Impact that a cabin solution has on the diversity of primary stakeholder opportunities to distribute their products. Does not include in-flight retail of consumer goods from secondary stakeholders.	- Added stakeholder revenues due to newly enabled distribution channels (Δ% revenue)	[73], [100], [105]
				b	Advertising Channels	Stakeholders' ability to effectively advertise products/services offered by the other stakeholders enabled by the implemented cabin solutions.	The ability of a cabin solution to facilitate, expand, diversify, and enhance the effectiveness of Stakeholders' opportunities to advertise products/services on behalf of other stakeholders. Affects collaborative impacts due to B2B and B2C promotion.	- Added revenues from partner advertising through new cabin solutions (Δ% revenue)	
				c	Co-Branding Potential	Facilitation of productive collaboration between several cabin interior stakeholders realised through joint delivery of cabin solutions.	Stakeholder partnership opportunities for mutual amplification of capabilities and reinforcement of synergistic benefits enabled by jointly offered products/services.	- Added revenue from collaborative product/service development (Δ% revenue) - Cost-saving due to collaboration on product/service development (Δ% cost)	
				d	Retail Channels	Facilitation of the operator's capability to effectively sell products or services offered by other stakeholders to passengers in-flight.	Impact of cabin solutions on the diversity of stakeholder opportunities to distribute products on behalf of partner stakeholders. Includes in-flight retail of consumer goods from secondary stakeholders.	- Added revenues from newly enabled partner retail channels (Δ% revenue)	
3	Passenger Perception	Intrinsic qualities of the cabin elements affecting passive passenger perception.	Revenue streams and motivators for raising profit margins conditioned by the passengers' willingness to pay, which arises from their subjective perception of the cabin and flight experience enabled by it, and may be conscious or implicit, physical or mental	a	Physical Comfort	The alignment of cabin elements with user anthropometry affecting the perception of bodily comfort.	The sensations created across the contact area at the physical body-seat interface affected by the structures, surfaces, covers, padding, etc. Primarily relates to the extended physiological reactions created by the involved contact forces and support moments while seated, but also covers other activities. Affected by the physical features of cabin elements (texture, hardness, elasticity, temperature, etc.) and its alignment with user anthropometry (body position, angles, proportions). Affects user's physical wellbeing.	- The distribution and intensity of mechanical force points across body-seat contact surface (Pascals) - Physiological effects due to prolonged sitting (tension, compression, pains, etc.)	[05], [06], [08], [75], [77], [79] - [88], [90], [101], [105]
				b	Cabin Purity	Passenger's perception of explicit cabin cleanliness and implicit hygienic quality. Reflects cabin qualities that prevent health risks due to e.g. surface contamination. Applies to all cabin elements e.g. seating, lavatories, galleys.	Consists of: - explicit purity = cleanliness: a lack of waste; - implicit purity = hygiene: intrinsic product qualities enabling good health. Reflects cabin qualities that prevent health risks due to e.g. surface contamination. Applies to all cabin elements e.g. seating, lavatories, galleys.	- Subjective questionnaires addressing the perception of cleanliness - Embedded sensors (pressure, temperature, etc.) - Post-flight medical examination (where appropriate and relevant e.g. as a part of an R&D project provided passengers' consent)	
				c	Aesthetics	Passengers' subjective perception of visual cabin qualities at both overall and local levels.	Visual cabin qualities creating a harmoniously ordered overall appeal. Manifested at both global (overall cabin architecture) and local (surface finish qualities affecting colour and shading distribution) scale. Affects mental wellbeing of the passengers. Includes personalisation of cabin space to individual passenger preferences and needs with no effects on other occupants.	- Subjective questionnaires addressing the perception of aesthetics - Embedded sensors (light, colour, etc.)	
				d	Autonomy	The effects created by cabin solutions on passenger's subjective perception of own independence, and their separation from the others and their activities.	Cabin qualities enabling privacy (seclusion from others) and autonomy (operational independence). Exhibited across all cabin spaces used by passengers and not constrained solely to the seating space; affects user's wellbeing.	- Subjective questionnaires addressing the user's perception of own autonomy and privacy	[20], [80], [82] - [85], [87], [105]
				e	Ambience	Objective effects created by the cabin solutions on the passengers' mental and emotional state.	Cabin element and environment qualities affecting passenger mood (emotional state). Includes aural and visual environment, which differs from Aesthetics by relying on objective, neuroscience-based effects. Also includes pre-designed cabin space effects enabling mental adjustment e.g. jetlag compensation, relaxation, concentration. Affects user's mental wellbeing.	- Subjective questionnaires addressing the user's mood and emotions in-flight and post-travel - Semi-objective assessment of cabin space views against existing baseline from other industries e.g. interior design	[05], [06], [31], [75], [80] - [84], [89], [90], [105]
				f	Trendiness	Passenger's subjective perception of how well the cabin aligns with popular trends.	Affects the user's self-image and subsequently mental wellbeing. Does not reflect brand image.	- Subjective questionnaires inquiring into the user's perception of: novelty, fashion, exclusivity, etc.	

D#	Driver	Description	Comments	F#	Factors	Definition	Comments	Example Criteria	References
4	Passenger Experience	Explicit qualities of the cabin elements affecting active passenger experience.	<i>Revenue streams and motivators for raising profit margins conditioned by the passengers' willingness to pay arising from their factual, objective experiences with cabin, both physical and mental</i>	a	Ergonomics	The alignment of cabin elements with user biomechanics affecting the perception of convenience and ergonomics.	Convenience is affected by the space/room available for the user to move and operate cabin elements; reachability of cabin interfaces e.g. buttons and vents; operability of cabin elements e.g. comfortable reaction forces and pressure. Reflects the efficiency of cabin space and the architecture of structural and mechanical user interfaces. Includes ergonomics (passenger convenience) and human factors (servicing convenience), excludes boarding procedures. Affects user's physical wellbeing.	- Subjective questionnaires addressing the perception of convenience - Embedded sensors (body shapes in motion, reaction forces, etc.)	[05], [06], [08], [75], [77], [79] - [88], [90], [101], [105]
				b	Cabin Environment	The quality of gaseous environment filling the open volume inside cabin.	Cabin air quality measured through composition, pressure, humidity, temperature, purity, olfactory content. Includes bacteriological and viral safety; and personalisation of the environmental settings to individual passenger preferences and needs with no effects on other occupants.	- Cabin sensors measuring cabin composition, contamination, viral content, and other parameters for subsequent comparison against baseline - Subjective questionnaires addressing the effects of cabin environment on passenger's physiological comfort	[05], [75], [77], [79], [81] - [83], [85], [102], [103], [105]
				c	Experiences	The variety and quality of individual experiences available to passengers on-board an aircraft.	Manifested through 5 experience dimensions: - Quality: affects user satisfaction, - Variety: reflects the richness and diversity of the available experiences, - Type: mental, physical, or combined; - Mode: active (requires user's input) or passive (output to the user only, purely observational); - Theme: reflects the user's experience area e.g. sleep, rest, work, entertainment, learning, family, etc. Includes personalisation of cabin space and functionality to individual needs and preferences related to passenger experiences with no effects on other occupants. Affects the operator's revenues, cabin differentiation, and user's wellbeing.	Assessed across the 5 dimensions listed by a combination of subjective and objective means. E.g. for the variety of IFE experiences and their effectiveness in fulfilling passenger satisfaction: - assessed through subjective indicators (joy, mental rest, relaxation) - measured using a customised set of values (a 10-point scoring scale)	[05], [06], [31], [34], [75], [77], [79] - [86], [88] - [90], [105]
				d	Useability	Cabin solution qualities affecting passengers' ability and convenience to operate it.	Includes two purposes: - Accessibility of cabin-user interaction for the special needs users; - Useability of cabin equipment for the diverse range of user literacy levels and their capabilities in using technology. Includes personalisation of cabin space and functionality to individual passenger preferences and needs with no effects on other occupants.	Assessed by evaluating how simple it is to understand and operate cabin equipment, the presence of intuitive qualities for new technology, and other subjective qualities based on some nominal (e.g. 10-point) scale. E.g. for the IFE systems: - Useability for the special needs users (e.g. visually impaired) - Intuitivity of the operational interface (e.g. the ability to understand menu navigation disregarding of the language skills) - Sufficient capability for using the equipment in a variety of conditions (lights off, turbulence, noise)	[09], [31]
				e	Interfaces	The operational qualities of active cabin equipment interfaces.	Functionality and operability of active cabin interfaces: mechanical, electrical, and electronic. Includes PED integration and interfaces. Affects user's ability to use cabin equipment, subsequently impacting operator's revenues and user's mental wellbeing.	Functionality can be assessed using a combination of subjective scoring and sensor-enabled measurements e.g., per type: - Mechanical: surface texture affecting the grip, button pressure/reaction forces affecting its operation; - Electrical: power level and stability, button or other interface responsiveness; - Electronic: response delay, input processing speed, control precision.	[06], [80], [81], [83], [85], [90], [105]
5	Outside Interfaces	Qualities of cabin interfaces with the outside world	<i>Revenue streams and motivators for raising profit margins conditioned by the passengers' ability to connect to the world outside in a one-way or two-way mode</i>	a	Outside View	The impacts created by cabin solutions on passenger experiences related to viewing outside of the aircraft.	Facilitating the exploration of the views outside the cabin through baseline viewing means (cabin windows) and by integrating novel solutions (e.g. extended reality, outside cameras, added functionality). Affects users' mental wellbeing.	- The quality and variety of experiences involving outside views - Subjective evaluation of user satisfaction e.g. using a custom scale	[105]
				b	In-Flight Information	The impacts created by cabin solutions on passenger experiences that involve one-way information flow.	Solely focuses on unilateral information flow used for passenger information services e.g.: flight information, airport wayfinding, operator's route and transfer planning, transport at the destination. Not constrained to any specific means of delivering information (audio, video, and other CDS). Affects journey continuity and subsequently, passenger's mental and physical wellbeing.	Assessed by measuring the quality and content richness of the inward information flow from the ANSP, Airport, DMO, weather services, urban transport infrastructure, etc.	[05], [75], [85]
				c	In-Flight Communication	The impacts created by cabin solutions on passenger experiences that involve two-way communication exchanges.	Focuses on bilateral information flow used for passenger communication services and enabling passenger's engagement with the outside world during flight e.g.: internet browsing, ground communication (text, voice, video), shopping for ground-based goods and services, leaving reviews on-the-go. Affected by the communications technology more than CDS. Includes personalisation of cabin communication functionality to individual passenger preferences and needs with no effects on other occupants.	Assessed by measuring content quality and richness, and the effectiveness of technical means enabling the communication flow between cabin occupants and a variety of ground-based service and content providers.	[06], [81], [105]
				d	Journey Continuity	The impacts created by cabin solutions on facilitating a seamless journey for the passengers.	Consists of the physical, information (mostly digital), and mental continuity. Facilitates the Aerotropolis model by streamlining passenger activities and processes across the aircraft as a part of the wider airport, inter-city, and urban transport infrastructure. Affected by turnaround processes; affects passenger's wellbeing as well as brand image and revenues for most stakeholders.	- Average journey time reduction (minutes/city pair) - Added stakeholder revenues enabled by the collaboration across the user's journey steps	[75], [78], [83], [86], [105]
6	Operational Cabin Qualities	Cabin solution qualities that affect cabin operations and the related revenues	<i>Flexible cabin qualities independent of the passengers' perspective that affect operational revenues and costs; include passenger services delivered or enabled by the Flight and Ground Crews.</i>	a	Passenger Capacity	The impacts created by cabin solutions on the number of passengers that a given cabin can fit inside it.	The effects that a cabin solution has on the overall passenger capacity.	- The difference in the number of seats available as counted before and after implementing a cabin solution.	[78]
				b	Configuration	The impacts created by cabin solutions on the diversity of possible passenger accommodation layouts (LOPA) attainable within given cabin.	The available variety of possible versions for the overall cabin layout (holistic scale) and constituent equipment configuration (localised scale e.g. passenger equipment versions and options) that a cabin solution enables.	- The efficiency of cabin traffic flow (passengers and crew walking around the cabin, e.g. the average travel time between cabin locations) - The alignment with passenger categories and their needs. For example, if a cabin is split into several classes (traditional - by service level, or innovative - by activity/function type) then a "good" configuration would have all cabin classes/zones equally filled with high occupancy rate.	[105]
				c	Luggage Storage	The impacts created by cabin solutions on the diversity of possible passenger luggage storage attainable within given cabin.	Facilitation of sufficient storage for passenger belongings (checked-in and carry-on), its effective and efficient management from cabin. Includes storage capacity and convenience; also includes non-passenger cargo capacity.	- Available luggage weight and items per passenger (checked-in and carry-on) - Total available luggage weight per flight - Passenger satisfaction specific to carry-on luggage storage and retrieval procedures	[05], [06], [77], [80] - [85], [88], [90], [105]
				d	Turnaround Efficiency	The impacts created by cabin solutions on the efficiency of passenger ingress/egress procedures both to/from the individual seat and the whole cabin.	The effect of a cabin solution on the procedures between flights: - convenience: clear and simple process, - ergonomics: adjusted to human biomechanics, - efficiency: the speed and smoothness of the process Includes GHP activities to replace the consumables and clean the cabin between flights; and cabin evacuation in emergencies.	- Turnaround time effects (Δ minutes) - Emergency evacuation time (Δ seconds) - Inter-flight cabin servicing (number of GHP staff per cabin)	[05], [75], [78], [80], [81], [84] - [86], [89], [90], [105]
				e	Service Capabilities	The impacts created by cabin solutions on cabin crew capabilities to offer passenger services.	The quality and variety of the in-flight services enabled by cabin equipment. Includes the capabilities to deliver goods to passengers, and to resolve passenger difficulties and in-flight issues.	- the number of specific services and service types available	[06], [07], [82], [86] - [88]
				f	Crew Information	The impacts created by cabin solutions on the quality and effectiveness of passenger services delivery by the cabin crew.	The exhibition of interpersonal qualities by the cabin crew as enabled by a cabin solution. Relies on the available capabilities to: - equip the crew with the knowledge of passengers' implicit and explicit needs, preferences, and perceptions; - align the crew's attitude, understanding, and intentions with passenger expectations of appropriate custom (cultural fit). May include cabin crew appearance and behaviours, wearable technology, passenger data access, language and translation capabilities.	- Changes in ticket demand and ancillary revenues as a reflection of cabin service quality; - Using a variety of sensors and processing capabilities to measure passenger's response e.g., by the application of emotional technologies to scan facial expressions and process physiological response before, during, and after cabin service requesting and provisioning.	[05], [75], [77], [78], [80], [82] - [88]
				g	Crew Operations	Cabin solution qualities that help streamlining, optimising, and improving the efficiency of crew operations.	The convenience and ergonomics offered by a cabin service solution to the cabin crew. Affects crew workload, working intensity, conditions, motivation, productivity, efficiency etc. when delivering passenger services. Includes autonomous operational capabilities i.e. independent from the crew and not requiring their involvement, which primarily relates to automation of whole or part of the cabin services.	- Time savings per cabin service operation for a particular service type - The number of passenger requests served per flight - Productivity per cabin service operation: the ratio of valuable output produced (profitability, passenger satisfaction) to supplied inputs (labour, expenditure, consumable materials, etc.)	[05], [06], [77], [80] - [82], [84], [86] - [89]

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7	Integrated Cabin Quality	Qualities of a fixed design solution that remain constant across all flights of the cabin product embodying it	<i>Fixed cabin qualities that are independent of the passengers' perspective, which affect both operational revenues and costs</i>	a	Fuel Burn	Fixed physical qualities of the cabin equipment directly affecting the overall fuel burn.	Represents the fuel burn effects incurred by the presence of a specific product in the cabin at all times (i.e. disregarding of whether it is operated and for how long). Manifested as cumulative fuel burn effect due to equipment weight (primary) and electrical power consumption (secondary).	<ul style="list-style-type: none"> - The fixed weight of cabin equipment and variable weight of its replaceable and consumable materials (kg) - Cabin equipment power consumption (kWh) - Total fuel burn impact (kg/PSK, kg/nm, or other technical units) 	[100], [110]
				b	Adaptability	The level of cabin equipment adaptability for different needs.	The ability of a cabin solution to be adjusted to fit with project specification and requirements (excludes the Certification Requirements), operator's needs (corporate culture, preferred cabin layout and equipment configuration, route specifics); cabin sectoring (classing by function or service level). Excludes customisation to passenger's needs (reflected in other factors).	<ul style="list-style-type: none"> - Effort required to adapt a cabin solution to a specific need / requirement / constraint (measured in monetary terms as cost or FTE; number of people/teams involved, etc.) 	[20]
				c	Applicability	The inherent ability of the cabin equipment to be standardised across the different configurations.	The ability of a cabin solution to be standardised across the CEM's interior projects, cabin products, classes, and aircraft platforms. May transpire at various product levels: individual technologies and/or components, product assemblies.	<ul style="list-style-type: none"> Effort required across all stakeholders to adopt a solution to different projects or platforms; less = better: - FTE or cost impacts due to work performed and other related activities e.g. testing, inspection, documentation updates; - Differences in component count, material volume, related procedures e.g. installation time, maintenance time, number of activities 	[105]
				d	Safety	The inherent qualities of cabin equipment that enable the prevention, aversion, or mitigation of various risks and hazards.	<p>Cabin solution effects across 4 pairs of dimensions related to flight safety and security:</p> <p>1A - Safety: protection from abnormal events or its consequences</p> <p>1B - Security: protection from malicious intent</p> <p>2A - External: caused by the hazards outside the cabin e.g. crashworthiness safety, cyberattack security</p> <p>2B - Internal: caused by the hazards inside the cabin e.g. equipment malfunction proofing, protection from deliberate equipment misuse</p> <p>3A - Passive protection: the inherent ability of cabin equipment to protect its occupants from the potential risk or danger e.g. non-toxicity</p> <p>3B - Active protection: cabin equipment capabilities to withstand, deter, or safely absorb extraordinary circumstances as they unfold and afterwards e.g. impact resistance, FST performance.</p> <p>4A - Perceived Safety: cabin qualities creating the feeling of safety and security in the mind of passengers, affects mental wellbeing</p> <p>4B - Factual Safety: actual cabin safety features, which may not be visible to passengers to have a direct effect on their perception.</p>	<p>Protection areas included but not limited to: viral and bacteriological, physical e.g. crashworthiness, passenger data, electric, electronic, radiomagnetic interference. Also reflects the potential for improvement or expansion of the safety and security measures.</p> <p>A large variety of approaches may be applied to measure safety and security, which will depend on the specific equipment and its capabilities. The majority of this will be covered by the Airworthiness Certification requirements from e.g. EASA CS-25, SAE ARP documents, FST and RoHS guidelines, industry-specific safety regulations and best practices outside of the aerospace domain (e.g. electronic equipment),</p>	[05], [06], [77], [81], [83], [86] - [89], [106], [108]
8	Sustain-ability	Sustainable quality of cabin equipment	<i>Large-scale, indirect cabin solution effects that do not directly impact profitability but may affect passenger perception, loyalty, or legal fees. Some stakeholders are facilitators, others assure quality.</i>	a	Environmental	Cabin solution qualities associated with the environmental impacts.	The cumulative environmental impact of a cabin solution on the wider environment throughout its entire life cycle.	<p>Evaluation approaches and metrics are defined by the accepted Life Cycle Assessment methods of sustainability impacts, for example:</p> <ul style="list-style-type: none"> - ReCiPe (e.g. particulate matter emissions, ozone formation effects, ecotoxicity) - Global Warming Potential (cumulative radiative forcing) 	[51], [57], [58], [81], [100], [109], [110], [111], [113]
				b	Economic	The impact of cabin solutions on the local state of economy and its development.	<p>Cabin solution impacts on the local economic growth by engaging the airport, transport, and other urban infrastructure:</p> <ul style="list-style-type: none"> - Direct impacts: effects directly produced by the cabin solution e.g. operator's revenue, government tax; - Indirect impacts: effects produced in the wider economic landscape in some way due to the implementation of the considered cabin solution e.g. increased passenger spending at the airport. 	<p>May be expressed through:</p> <ul style="list-style-type: none"> - Financial efficiency (revenue to investment ratio in monetary terms) - Financial effectiveness (absolute revenue or profit to stakeholders in monetary terms) <p>on a variety of stakeholders or economic segments e.g.:</p> <ul style="list-style-type: none"> - Infrastructure (e.g. airport) - Government (e.g. budget influx) - Local vendors e.g. technology, education 	[111]
				c	Social	Localised social and governance impacts created by the cabin solutions.	Cabin solution effects against the CSR metrics, primarily its Community Involvement & Development principle at the local and global levels, internal stakeholder staff and the external community. Involves the impacts on culture, talent development and human resource, working environment and opportunities, human rights, justice and equality, education, human rights, globalization, etc.	<p>The specific assessment may use a wide range of CSR metrics selected based on importance to involved stakeholders e.g.:</p> <ul style="list-style-type: none"> - Ethical sourcing of cabin components and materials - Forecasted expansion of specific talent/skill per industry/domain (number of people with a particular skill) 	
				d	Circularity	The recycling potential of the physical and digital cabin equipment.	<p>The possibility of the cabin equipment constituents to be recycled for repeated use:</p> <ul style="list-style-type: none"> - Internal: recycling the materials or components for repeating the same function within the cabin interiors industry (e.g. aluminium seat frame into another seat frame), requires comparable material properties; - External: relinquishing the materials or components for repeated use in other industries (e.g. aluminium seat frame into automotive parts), may accept materials with properties altered by the recycling processes. 	<ul style="list-style-type: none"> - Recyclability (percent) - Recycled quality (composition, properties) 	[58] [100] [113]

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				b	Adaptability	The level of cabin equipment adaptability for different needs.	The ability of a cabin solution to be adjusted to fit with project specification and requirements (excludes the Certification Requirements), operator's needs (corporate culture, preferred cabin layout and equipment configuration, route specifics); cabin sectoring (classing by function or service level). Excludes customisation to passenger's needs (reflected in other factors).	<ul style="list-style-type: none"> - Effort required to adapt a cabin solution to a specific need / requirement / constraint (measured in monetary terms as cost or FTE; number of people/teams involved, etc.) 	[20]
				c	Applicability	The inherent ability of the cabin equipment to be standardised across the different configurations.	The ability of a cabin solution to be standardised across the CEM's interior projects, cabin products, classes, and aircraft platforms. May transpire at various product levels: individual technologies and/or components, product assemblies.	<ul style="list-style-type: none"> Effort required across all stakeholders to adopt a solution to different projects or platforms; less = better: - FTE or cost impacts due to work performed and other related activities e.g. testing, inspection, documentation updates; - Differences in component count, material volume, related procedures e.g. installation time, maintenance time, number of activities 	[105]
				d	Safety	The inherent qualities of cabin equipment that enable the prevention, aversion, or mitigation of various risks and hazards.	Cabin solution effects across 4 pairs of dimensions related to flight safety and security: 1A - Safety: protection from abnormal events or its consequences 1B - Security: protection from malicious intent 2A - External: caused by the hazards outside the cabin e.g. crashworthiness safety, cyberattack security 2B - Internal: caused by the hazards inside the cabin e.g. equipment malfunction proofing, protection from deliberate equipment misuse 3A - Passive protection: the inherent ability of cabin equipment to protect its occupants from the potential risk or danger e.g. non-toxicity 3B - Active protection: cabin equipment capabilities to withstand, deter, or safely absorb extraordinary circumstances as they unfold and afterwards e.g. impact resistance, FST performance. 4A - Perceived Safety: cabin qualities creating the feeling of safety and security in the mind of passengers, affects mental wellbeing 4B - Factual Safety: actual cabin safety features, which may not be visible to passengers to have a direct effect on their perception.	Protection areas included but not limited to: viral and bacteriological, physical e.g. crashworthiness, passenger data, electric, electronic, radiomagnetic interference. Also reflects the potential for improvement or expansion of the safety and security measures. A large variety of approaches may be applied to measure safety and security, which will depend on the specific equipment and its capabilities. The majority of this will be covered by the Airworthiness Certification requirements from e.g. EASA CS-25, SAE ARP documents, FST and RoHS guidelines, industry-specific safety regulations and best practices outside of the aerospace domain (e.g. electronic equipment),	[05], [06], [77], [81], [83], [86] - [89], [106], [108]
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				b	Economic	The impact of cabin solutions on the local state of economy and its development.	Cabin solution impacts on the local economic growth by engaging the airport, transport, and other urban infrastructure: - Direct impacts: effects directly produced by the cabin solution e.g. operator's revenue, government tax; - Indirect impacts: effects produced in the wider economic landscape in some way due to the implementation of the considered cabin solution e.g. increased passenger spending at the airport.	May be expressed through: - Financial efficiency (revenue to investment ratio in monetary terms) - Financial effectiveness (absolute revenue or profit to stakeholders in monetary terms) on a variety of stakeholders or economic segments e.g.: - Infrastructure (e.g. airport) - Government (e.g. budget influx) - Local vendors e.g. technology, education	[111]
				c	Social	Localised social and governance impacts created by the cabin solutions.	Cabin solution effects against the CSR metrics, primarily its Community Involvement & Development principle at the local and global levels, internal stakeholder staff and the external community. Involves the impacts on culture, talent development and human resource, working environment and opportunities, human rights, justice and equality, education, human rights, globalization, etc.	The specific assessment may use a wide range of CSR metrics selected based on importance to involved stakeholders e.g.: - Ethical sourcing of cabin components and materials - Forecasted expansion of specific talent/skill per industry/domain (number of people with a particular skill)	
				d	Circularity	The recycling potential of the physical and digital cabin equipment.	The possibility of the cabin equipment constituents to be recycled for repeated use: - Internal: recycling the materials or components for repeating the same function within the cabin interiors industry (e.g. aluminium seat frame into another seat frame), requires comparable material properties; - External: relinquishing the materials or components for repeated use in other industries (e.g. aluminium seat frame into automotive parts), may accept materials with properties altered by the recycling processes.	<ul style="list-style-type: none"> - Recyclability (percent) - Recycled quality (composition, properties) 	[58] [100] [113]
9	Implement-ation NRC	The NRC required to implement the new technology into a cabin project	<i>Each factor includes an associated testing programme. Applied on a per-project basis: includes all shipsets that have a given cabin version installed.</i>	a	Availability	The level of technology readiness to be applied as a part of a cabin solution.	The effort required to develop the core technology enabling a particular cabin solution from its current maturity level to integration readiness. Involves the activities that are typically performed jointly by the interested parties (cabin supply chain) and the original technology source (R&D institutions, private companies, etc.): - Market research - Technology R&D - Definition of a functional cabin solution and application scenario planning - Derivation of the development strategy, roadmapping	Assessed using a pre-defined 9-point scale to reflect the top-level Technology Readiness Level within key parameter categories e.g.: - Engineering & Integration - Industrialisation & Manufacturing - Operational Performance - Value & Risk Detailed bottom-level assessment is performed using the metrics most appropriate to a particular parameter. The required effort is measured for all involved stakeholders using e.g.: FTE costs for the involved staff to scope, prepare, conduct, and post-process qualification testing, etc.	[105]
				b	Designability	The ability of the considered technology to be adopted as a part of a cabin design solution.	The effort required within cabin interior supply chain to design a concept cabin solution that uses the core technology considered (e.g. a piece of cabin equipment using a novel technology for disruptive IFE experience). Includes the following activities: - develop conceptual designs and virtual/digital mock-ups, - market alignment through concept testing (focus groups, user & customer surveys), - identify and engage with preferred partner stakeholders (in line with Design Factors Map sheet) and collaborative design agreements ("co-creation"), etc. - Derive product requirement specification	<ul style="list-style-type: none"> - Design effort required from across the stakeholders (FTE costs) - Resource required (software licenses, patent fees, etc.) - Concept testing e.g. focus groups, user surveys etc. (FTE costs) 	[29]
				c	Integrability	The ability of the considered technology-based design solution to be integrated into the targeted cabin envelope.	The effort required within cabin interior supply chain to develop the concept technology-based cabin solution into an integrated product. Involves the following activities (not an exhaustive list): - Engineer the related piece of cabin equipment (includes CAD, FEM) - Engineer the integration of cabin equipment into the aircraft cabin envelope (e.g. may require amending the airframe structure or systems, add interfaces, etc.) - Engage the interfacing stakeholders e.g. the Airframer, Certification Authorities, etc. - Produce/update product documentation (e.g. bill of materials, stress sheets, service & operation manuals, configuration and version tracking, etc.), drawings & LOPA - Manage product requirements, verify product design against the specification, identify the applicable Certification Requirements and prepare a testing programme - Prepare visual demonstrator mock-ups and samples for customer inspection, alignment, and usability testing	<ul style="list-style-type: none"> - Engineering effort required from across the stakeholders (FTE costs) - Resource required (software licenses, patent fees) - Customer inspection (FTE costs, materials) - Costs of product changes (e.g. post-inspection update to product requirements) 	[20]

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9	Implemen-tation NRC	The NRC required to implement the new technology into a cabin project	Each factor includes an associated testing programme. Applied on a per-project basis: includes all shipsets that have a given cabin version installed.	d	Manufacturability	The ability of the considered technology-based cabin design solution to be produced or integrated into existing equipment.	The effort required to implement a concept design solution into a cabin product, which involves: - industrialisation: develop the manufacturing processes to build the product - supplier engagement: liaise with suppliers to align the conceptual manufacturing setup - trial: test out the conceptual production approaches and update as required to optimise, de-risk, and resolve inconsistencies - launch: install the physical production equipment (jigs and tools) and launch the production process - Future-proofing: gathering and formalising the lessons learnt, best practices, and other suggestive records	The time (FTE) and cost of internal industrial development work (labour, tools, materials, utilities, facilities, training, etc.) to produce new equipment: - Documentation: preparation and amendment of production manuals, technical publications, configuration tracking, etc. - Licensing: training and access to software and process - Manufacturing: Physical production/software programming of the approved product - Materials: constituents and consumables, facility expenses and utilities - Scrap: the cost of repeated production due to manufacturing errors, supplier quality issues, production process or tooling updates following client-driven design changes, production QA inspection, etc. - Envelope fit: updating airframe production tools/processes to support the integration of agreed out-of-envelope cabin elements	[105]
				e	Certifiability	The ability to attain airworthiness certification for new cabin equipment.	The ability to validate a cabin product (physical, digital, or mixed) against product specification as delivered by the cabin supply chain and integrated by the CEM. Involves various testing activities: - Tests to confirm compliance with airworthiness requirements: structural integrity, fatigue and damage tolerance, operational & FST performance, Particular Risk Analysis validation (e.g. lightning strike protection, engine failure effects), etc. - Tests to confirm compliance with product requirements expressed by the customer, CEM, airframer, or other parties as captured in RS: functional and usability testing, product quality and cabin integration testing (clashes and tolerances), etc. May involve the administrative work and physical testing required to extend the certification basis with new requirements and AMC e.g. for the technologies that use newly discovered physical principles to offer functionality that has not been considered for airworthiness certification before. Does not include technology or material qualification testing, which are covered at the earlier maturity stages.	The impacts due to product certification effort are conveniently assessed using time (FTE) and monetary cost metrics driven by testing scope and complexity: - testing equipment and supplies - labour involved in conducting the testing programme (e.g. contracting external testing service providers) - labour involved in controlling product specification compliance (e.g. fulfilling or updating compliance tracking in the RS with the help of internal or contracted monitoring staff) - CA fees (e.g. contracting CA ambassadors to observe testing and approve compliance)	Same as Protection factor references
10	Implementation RC	The RC incurred by implementing the new technology into a cabin project	Per-shipset basis: RC are calculated per given aircraft or fleet	a	Procurement	Cabin equipment component sourcing arrangements available.	Sourcing arrangements for cabin product constituents - software and hardware, both conventional and belonging to novel cabin solution features.	The costs involved in provisioning novel cabin equipment, such as: - Supplier engagement contracts to deliver the required technology/components - User's price to buy the components/products (Operator, CEM, Airframer), includes the fees to add new SFE or purchase/rent BFE, pricing schemes, economies of scale effects e.g. discounts - The cost of logistics: both to deliver components to the integrator, and the assembled product to the customer. Depends on geography and transport modes, includes the possible effects of product logistics on its quality and reliability (e.g. scrap % due to transportation damage)	[30], [39], [40], [57] [112]
				b	Installation	The effort required to implement the delivered cabin equipment onto an aircraft.	The effort going into shipset installation onto the customer's aircraft. Affected by the level of product complexity and serviceability (e.g. tools reach), and the extent/scale of installation (partial or entire cabin).	The cost of product installation onto the customer aircraft in monetary terms: - Labour required and the effects of product design on it (e.g. complexity, modularity, serviceability), which affects installation speed and the required skillset, ultimately driving the FTE and other human resource costs - Non-human resource involved in the installation process: equipment, consumables, utilities - Service provider (normally the MRO) fees to install the new shipset (above pure labour costs) - Refitability: the ability/effort (FTE cost) to refit/retrofit a cabin product into an existing aircraft - Checking compliance of the installed shipset to confirm project delivery - Inspection expenditure due to novel equipment requiring extended testing and checking	[30], [39], [105]
				c	Phasing Out	The end-of-life scenarios available for cabin equipment.	Effects of cabin equipment end-of-life processes due to both linear and circular scenario.	The cost of equipment phasing-out or recycling at its end-of-life: - the cost of labour, consumables, tools and equipment, and utilities involved in cabin product utilisation or recycling (typically paid to the Dismantler) - the legal/government fees associated with product utilisation (landfill, incineration, etc.) - costs recovered due to recycling suitable components/materials e.g. from subsequent profitable reselling	[58], [100], [113]
				d	Depreciation	The loss of cabin equipment value over its use period.	The loss of investment incurred over cabin equipment life due to NPV and ageing-induced devaluation. Product value decreases constantly towards its end-of-life if it receives no updates or upgrades. The residual value after phasing out differs depending on the specific product characteristics. The devaluation may be slowed down by better resistance to wear & tear to some extent, but cannot be prevented altogether in most cases.	The depreciation effects are measured by the direct and indirect means: - Direct: the absolute reduction in cabin product value expressed as the difference between its purchase price and the price of onward selling of the product to the next user or its components after dismantling. - Indirect: the effects due to alignment between cabin equipment design life and cabin interior life, e.g. a product with a 3-year design life will have a lower relative value than a 7-year design life product when assessed as part of a cabin used for 5 years.	[30], [39]
11	In-Service RC	The RC incurred by operating the new technology	Per-shipset basis: RC are calculated per given aircraft or fleet	a	Operational Needs	The cost of consumable or replaceable materials involved in operating cabin solutions.	Operator's expenditure incurred by providing for cabin equipment operations. Governed by the cost and volume of supplies required e.g.: fluids, food, replaceable components, etc.	- The purchase or rental/lease cost of consumable materials: toiletries and galley materials, some cabin amenities e.g. headsets used with the new equipment, etc. - Servicing costs between flights e.g. cabin cleaning and visual checks by the GHP - Operational costs e.g. crew training and licenses (if required to operate a novel cabin product); insurance, taxes, and legal fees if incurred by the operation of a specific cabin product	[30], [39], [40], [51], [72]
				b	Maintenance	The cost of ordinary cabin equipment servicing imposed by the maintenance schedule.	Relates to regular MRO activities and not between flights e.g.: NDT, cleaning, replacing short-life components, etc.. Typically can be forecasted in advance based on the service manual scope and MRO agreements. May be affected by cabin product design quality (e.g. lower complexity resulting in the reduction of maintenance operations scope).	- Added MRO fees for regular servicing activities of new equipment to keep it operational - Servicing labour costs: direct FTE costs to disassemble, deep clean, test, restore, tighten bolts etc.; training and license costs if required by the new equipment. - Service enablement costs: the provisioning of tools, consumable materials, utilities etc. - Cost effects due to enablement or automation of some servicing functions e.g.: disinfection	
				c	Data Management	The cost of managing the data flow related to a specific cabin solution.	The cost of enabling data-driven cabin experience enabled by the new cabin equipment and informing the associated RM strategies e.g. to optimise its access pricing schemes, track passenger preference patterns, or monitor the condition of equipment or passengers. Excludes data security (a separate driver).	- The cost of data flow management: collection, storage, processing, and interpretation of passenger, crew, equipment, and other relevant in-flight data - The cost of fixed data management: any processes related to fixed cabin data e.g. product material passport, configuration traceability, electronic marking hardware and software - The cost of hiring a vendor to manage and process the involved data, or renting the equipment to process it internally - The cost effects enabled by engaging with the MRO in advance of the maintenance slot by providing product data to inform maintenance activities - The cost of data post-processing in line with relevant regulation s(e.g. GDPR) e.g. secure storage and deletion of data. (Differs from Data Security, which reflects the inherent data breach protection provided)	[105]
12	In-Service NRC	The NRC incurred by operating the new technology	Per-project basis: includes all shipsets that have a given cabin version installed	a	Reliability	Susceptibility of cabin equipment to damage incurred by its use over time.	Reflects cabin product quality affecting repair possibility, frequency, and the required resource. Affected by the design life, structural integrity, architectural complexity (number of components and optimised build), operational complexity (ease of use).	For a given cabin product, may assess the average or total: - probability and criticality of the possible equipment failure events - number of repairs per time unit (e.g. repairs/year) - number of components typically repaired - cost of repair per component - number of components repaired of each type (to inform service planning and upgrading)	[05], [20], [72], [77], [82], [83], [87], [88]
				b	Repairability	The susceptibility of cabin equipment to being repaired in extraordinary events.	Reflects irregular repairs due to equipment damage, malfunction, wear & tear, etc. Forecasted statistically but cannot be reliably foreseen. Irregular repairs are not defined by the standard maintenance schedule, but could be identified during a scheduled inspection. Affected by Reliability. Different from Maintenance (regular servicing). Revenue effects will differ between stakeholders e.g. a loss to the Operator (repair fees) may be the Revenue for the CEM (spares sales, in-service repairs). Note: serious damage to cabin equipment is resolved by replacement and not repairs.	The effort going into arranging a repair where it is possible: - Labour (FTE costs, licensing, etc.) involved in repairing cabin equipment. Note that the time required for a repair will differ for different products and repair/replacement scopes. - Repair materials: new parts/components, fixes require non-regular time or material. - Restoring/checking aircraft airworthiness in cases when it is void - Revenue effects due to unforeseen AOG duration - If the Airframe repair is involved due to cabin equipment damage/malfunction: engineering repairs to cabin envelope, provisioning airframe spare parts, providing guidance and oversight	[51], [72], [107]
				c	Modifications	The cost of cabin equipment modification activities.	The impact of updating or upgrading cabin equipment to a new standard e.g. modernising the existing cabin content with newer versions for a given customer due to its outdated status in relation to passenger needs, competitor trends, differentiation strategy, safety and airworthiness (e.g. a constituent material becoming banned), etc. Affected by the modification extent, complexity of its installation, equipment cost.	The fees and costs related to: - Cabin modification supply, delivery, installation, and inspection - aircraft airworthiness status renewal - updating service manuals, processes, and other relevant documentation	
				d	Opportunity Losses	The potential loss of revenue due to giving up alternative cabin solutions in favour of the ones selected for installation/implementation.	A loss of hypothetical revenue due to not using cabin equipment that would have been used instead of the solutions selected. Includes both: - full opportunity loss: replacing one solution with another completely, and - partial opportunity loss: reducing the capabilities of one cabin solution due to implementing another one (e.g. luggage space loss due to IFE modules installed in the overhead structure)	- Revenue/cost balance e.g. new equipment may save significant fuel costs but incur a loss of passenger revenue - Potential contractual losses e.g. due to ceasing discounted servicing offers	[30], [39], [40]

Table B.1-3: HCCA Design Factor Importance Weighting Matrices

0. Top-Level Design Drivers	Eigenvector											
	1. Revenue Potential	0.50	1.00	0.50	0.75	1.00	0.75	0.50	0.75	1.00	0.75	0.15357983
	2. Collaborative Potential	0.00	0.50	0.00	0.25	0.50	0.25	0.00	0.50	0.75	0.50	0.05275469
	3. Passenger Perception	0.50	1.00	0.50	0.50	0.75	0.75	0.25	0.50	1.00	1.00	0.13490131
	4. Passenger Experience	0.25	0.75	0.50	0.50	0.75	0.25	0.25	0.75	1.00	0.75	0.11027470
	5. Outside Interfaces	0.00	0.50	0.25	0.25	0.50	0.25	0.00	0.25	0.75	0.25	0.05119717
	6. Operational Cabin Qualities	0.25	0.75	0.25	0.75	0.75	0.50	0.50	0.75	1.00	0.50	0.11888889
	7. Integrated Cabin Quality	0.50	1.00	0.75	0.75	1.00	0.50	0.50	1.00	1.00	0.75	0.15934179
	8. Sustain-ability	0.25	0.50	0.50	0.25	0.75	0.25	0.00	0.50	1.00	0.75	0.08576478
	9. Implemen-tation NRC	0.00	0.25	0.00	0.00	0.25	0.00	0.00	0.00	0.50	0.25	0.01572568
	10. Implementation RC	0.00	0.25	0.00	0.00	0.25	0.00	0.00	0.00	0.75	0.50	0.01612494
	11. In-Service RC	0.25	0.50	0.00	0.25	0.75	0.50	0.25	0.25	0.75	0.50	0.07664791
	12. In-Service NRC	0.00	0.25	0.00	0.00	0.25	0.25	0.00	0.25	0.50	0.00	0.02479831

Score	Definition
0.00	i has trivial importance comparing to j
0.25	i is less important than j
0.50	i and j are equivalent / interdependent
0.75	i is more important than j
1.00	j has trivial importance comparing to i

4. Passenger Experience	Importance Weights	
	Summed Weights	
	Interfaces	1.708
	Ergonomics	0.50
	Cabin Environment	0.50
	Experiences	0.50
	Useability	0.50
	Useability	0.25
	Useability	0.00
	Interfaces	0.00

7. Integrated Cabin Quality	Importance Weights	
	Summed Weights	
	Safety	1.400
	Applicability	0.00
	Adaptability	0.00
	Fuel Burn	0.50
	Safety	0.75
	Safety	1.933

10. Implementation RC	Importance Weights	
	Summed Weights	
	Deprecation	0.50
	Phasing Out	0.75
	Installation	0.25

1. Revenue Potential	Importance Weights	
	Summed Weights	
	Innovation Capacity	0.75
	Growth Potential	0.50
	Access Pricing	0.50
	Upfront Pricing	0.50
	Access Pricing	0.50
	Growth Potential	0.50
	Brand Image	0.50
	Promotion Channels	0.50

5. Outside Interfaces	Importance Weights	
	Summed Weights	
	Journey Continuity	0.321
	In-Flight Communication	0.00
	In-Flight Information	0.50
	Outside View	0.50
	Outside View	0.25

8. Sustain-ability	Importance Weights	
	Summed Weights	
	Circularity	1.408
	Social	0.75
	Economic	0.75
	Environmental	0.50
	Environmental	0.25

11. In-Service RC	Importance Weights	
	Summed Weights	
	Data Management	1.375
	Maintenance	0.75

2. Collaborative Potential	Importance Weights	
	Summed Weights	
	Retail Channels	0.775
	Co-Branding Potential	0.50
	Advertising Channels	0.50

6. Operational Cabin Qualities	Importance Weights	
	Summed Weights	
	Crew Operations	2.553
	Crew Information	1.00
	Service Capabilities	0.00
	Turnaround Efficiency	0.50
	Luggage Storage	0.50
	Configuration	0.50
	Passenger Capacity	0.50
	Configuration	0.00
	Luggage Storage	0.00
	Turnaround Efficiency	0.00

9. Implemen-tation NRC	Importance Weights	
	Summed Weights	
	Certifiability	1.126
	Manufacturability	0.50
	Integrability	0.50
	Designability	0.50
	Availability	0.50

12. In-Service NRC	Importance Weights	
	Summed Weights	
	Opportunity losses	1.633
	Modifications	0.75
	Reliability	0.50

3. Passenger Perception	Importance Weights	
	Summed Weights	
	Trendiness	1.553
	Ambience	1.00
	Autonomy	0.75
	Aesthetics	0.50
	Cabin Purity	0.50
	Physical Comfort	0.50

Table B.1-4a: Stakeholder Contribution Comparison Matrices (Influence Matrix)

Score: Authority of i vs j when introducing new technology from i POV:
 0.00 i has no authority/effect over j | i must comply with j
 0.25 i has weak authority over j | i needs may be considered by j
 0.50 i and j have equivalent authority | no effect on each other
 0.75 i has strong authority over j | i drives j but considers j's needs
 1.00 i has full authority over j | j has no effect on i | i dictates to j

Influence																																					
		Passenger	Operator	Design Agency	Integrators & CEM	Airframer	Tier-n Suppliers	Authorities	MRO	Trade Organisations	GHP	Logistics Organisations	DMO	AC Lessor / Owner	Airport	Dismantlers	Government Units	Consumer Retailers	ANSP	Count-Balanced Sum	Normalised Simple	Rank Simple	Sum of Contributions	Normalised Sum	Rank by Contributions	AIP	Normalised AIP	Rank AIP	Eigenvector (from R)	Normalised Eigenvector	Rank Eigen						
i	Passenger	0.50	0.25	0.75	0.75	0.75	0.75	0.25	0.75	1.00	1.00	1.00	1.00	0.75	1.00	0.75	0.75	1.00	1.00	0.78	0.83	3	1.591	0.72	3	0.220	0.86	2	0.09209016	0.7342	3						
	Operator	0.75	0.50	1.00	1.00	0.75	1.00	0.25	0.75	1.00	1.00	0.75	0.75	0.50	1.00	1.00	0.75	0.75	0.75	0.79	0.85	2	1.736	0.8	2	0.220	0.86	2	0.10169951	0.8286	2						
	Design Agency	0.25	0.00	0.50	0.50	0.75	0.75	0.00	0.75	1.00	0.75	1.00	0.75	0.50	1.00	0.75	0.75	1.00	0.65	0.65	5	1.142	0.46	5	0.214	0.7	5	0.07081786	0.5254	5							
	Integrators & CEM	0.25	0.00	0.50	0.50	0.75	1.00	0.00	0.75	1.00	1.00	1.00	1.00	0.75	1.00	0.75	0.75	1.00	0.75	0.71	0.73	4	1.247	0.52	4	0.217	0.77	4	0.07749568	0.5909	4						
	Airframer	0.25	0.25	0.25	0.25	0.50	0.25	0.00	0.50	0.25	0.75	1.00	0.75	0.75	1.00	0.75	0.75	0.75	0.75	0.54	0.5	8	0.936	0.35	8	0.208	0.54	8	0.05830919	0.4025	8						
	Tier-n Suppliers	0.25	0.00	0.25	0.00	0.75	0.50	0.00	0.75	1.00	0.75	0.75	0.75	0.75	1.00	0.75	0.75	0.75	0.75	0.58	0.56	6	0.962	0.36	6	0.211	0.6	6	0.06097474	0.4287	6						
	Authorities	0.75	0.75	1.00	1.00	1.00	1.00	0.50	1.00	0.75	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	0.75	0.9	1	1	2.099	1	1	0.224	1	1	0.11915368	1.0000	1						
	MRO	0.25	0.25	0.25	0.25	0.50	0.25	0.00	0.50	0.75	0.75	0.75	1.00	0.50	0.75	0.75	0.75	0.75	1.00	0.56	0.52	7	0.954	0.36	7	0.209	0.56	7	0.0593161	0.4124	7						
	Trade Organisations	0.00	0.00	0.00	0.00	0.75	0.00	0.25	0.25	0.50	0.25	0.50	0.50	0.25	0.75	0.25	0.50	0.75	1.00	0.36	0.25	12	0.669	0.2	12	0.200	0.3	12	0.03561661	0.1797	12						
	GHP	0.00	0.00	0.25	0.00	0.25	0.25	0.00	0.25	0.75	0.50	0.75	0.50	0.50	0.50	0.25	0.50	0.50	0.75	0.36	0.25	12	0.573	0.14	15	0.200	0.3	12	0.03468019	0.1705	14						
	Logistics Organisations	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.25	0.50	0.25	0.50	0.25	0.50	0.75	0.00	0.50	0.50	1.00	0.31	0.17	16	0.519	0.11	16	0.198	0.23	16	0.02883019	0.1131	16						
	DMO	0.00	0.25	0.25	0.00	0.25	0.25	0.00	0.00	0.50	0.50	0.75	0.50	0.50	0.75	0.25	0.25	0.50	0.75	0.35	0.23	14	0.580	0.15	13	0.199	0.27	14	0.03386835	0.1625	15						
	AC Lessor / Owner	0.25	0.50	0.50	0.25	0.25	0.25	0.00	0.50	0.75	0.50	0.50	0.50	0.50	0.75	0.50	0.50	0.50	0.75	0.46	0.38	10	0.885	0.32	10	0.205	0.43	10	0.05334196	0.3537	9						
	Airport	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.50	0.25	0.25	0.25	0.50	0.00	0.25	0.50	0.75	0.21	0.04	17	0.315	0	18	0.192	0.05	17	0.01731755	0.0000	18						
	Dismantlers	0.25	0.00	0.25	0.25	0.25	0.25	0.00	0.25	0.75	0.75	1.00	0.75	0.50	1.00	0.50	0.75	0.75	1.00	0.51	0.46	9	0.842	0.3	11	0.208	0.52	9	0.05045109	0.3254	10						
	Government Units	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.50	0.50	0.75	0.50	0.75	0.25	0.50	0.50	0.75	0.42	0.33	11	0.889	0.32	9	0.203	0.39	11	0.04766556	0.2980	11						
	Consumer Retailers	0.00	0.25	0.25	0.00	0.25	0.25	0.00	0.25	0.25	0.50	0.50	0.50	0.50	0.50	0.25	0.50	0.50	0.75	0.33	0.21	15	0.576	0.15	14	0.199	0.25	15	0.03473652	0.1710	13						
	ANSP	0.00	0.25	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.25	0.00	0.25	0.25	0.25	0.00	0.25	0.25	0.50	0.18	0	18	0.486	0.1	17	0.190	0	18	0.02363505	0.0620	17						

Table B.1-4b: Stakeholder Contribution Comparison Matrices (Interest Matrix)

Score: Who needs to be satisfied when introducing new technology:
 0.00 i is not impacted by j's use of technology
 0.25 i is impacted by how j uses technology and needs to be informed
 0.50 both i and j have comparable / potentially conflicting interest
 0.75 i informs j | j has some impacts from how i uses technology
 1.00 j fully serves i's interest | i dominates interest in using the tech

Interest		j																	k												
		Passenger	Operator	Design Agency	Integrators & CEM	Airframer	Tier-n Suppliers	Authorities	MRO	Trade Organisations	GHP	Logistics Organisations	DMO	AC Lessor / Owner	Airport	Dismantlers	Government Units	Consumer Retailers	ANSP	Count-Balanced Sum	Normalised Simple	Rank Simple	Sum of Contributions	Normalised Sum	Rank by Contributions	AIP	Normalised AIP	Rank AIP	Eigen vector (from R)	Normalised Eigen vector	Rank Eigen
i	Passenger	0.50	0.50	0.75	0.75	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.75	1.00	1.00	0.9	1	1	2.029	1	1	0.224	1	1	0.11628693	1.0000	1
	Operator	0.50	0.50	0.75	0.75	0.75	1.00	0.75	0.75	0.75	0.75	0.50	0.75	1.00	1.00	1.00	0.75	0.50	0.75	0.75	0.8	2	1.711	0.83	2	0.218	0.83	2	0.09633023	0.8081	2
	Design Agency	0.25	0.25	0.50	0.25	0.75	0.75	1.00	0.75	0.75	1.00	1.00	0.50	1.00	0.75	1.00	0.75	0.50	1.00	0.71	0.74	3	1.400	0.66	4	0.216	0.78	3	0.08113523	0.6620	4
	Integrators & CEM	0.25	0.25	0.75	0.50	0.50	0.75	1.00	0.75	0.75	0.75	0.75	1.00	1.00	1.00	0.75	0.25	0.75	0.69	0.72	4	1.423	0.67	3	0.215	0.76	4	0.0825535	0.6756	3	
	Airframer	0.00	0.25	0.25	0.50	0.50	0.50	0.75	0.25	0.75	0.75	0.75	0.25	0.75	0.50	0.75	0.25	0.75	0.51	0.48	9	0.932	0.4	9	0.207	0.54	9	0.05692056	0.4292	9	
	Tier-n Suppliers	0.00	0.00	0.25	0.25	0.50	0.50	1.00	0.75	0.75	0.75	0.75	0.50	1.00	0.75	0.75	0.75	0.75	0.6	0.59	7	1.060	0.47	7	0.211	0.65	6	0.06472543	0.5042	7	
	Authorities	0.00	0.00	0.00	0.00	0.25	0.00	0.50	0.25	0.00	0.00	0.25	0.00	0.25	0.25	0.50	0.25	0.00	0.25	0.15	0	18	0.200	0	18	0.186	0	18	0.01228908	0.0000	18
	MRO	0.00	0.25	0.25	0.25	0.75	0.25	0.75	0.50	0.75	0.50	0.75	0.50	0.75	0.75	0.75	0.50	1.00	0.56	0.54	8	1.001	0.44	8	0.209	0.6	8	0.06139657	0.4722	8	
	Trade Organisations	0.00	0.25	0.25	0.25	0.25	0.25	1.00	0.25	0.50	0.75	0.50	0.50	0.75	0.25	1.00	0.50	0.75	1.00	0.5	0.46	10	0.866	0.36	10	0.206	0.51	10	0.05272852	0.3888	10
	GHP	0.00	0.25	0.00	0.25	0.25	0.25	1.00	0.50	0.25	0.50	0.50	0.25	1.00	0.50	1.00	0.75	0.25	0.75	0.46	0.41	11	0.736	0.29	12	0.203	0.45	11	0.0443403	0.3082	12
	Logistics Organisations	0.00	0.25	0.00	0.25	0.25	0.25	0.75	0.25	0.50	0.50	0.50	0.25	1.00	0.50	0.50	0.50	0.50	0.50	0.4	0.33	13	0.710	0.28	13	0.202	0.41	13	0.04218476	0.2875	13
	DMO	0.00	0.50	0.50	0.25	0.75	0.50	1.00	0.50	0.50	0.75	0.75	0.50	1.00	0.75	0.75	0.75	0.50	1.00	0.63	0.63	5	1.170	0.53	5	0.213	0.69	5	0.07051577	0.5599	5
	AC Lessor / Owner	0.00	0.25	0.00	0.00	0.25	0.00	0.75	0.25	0.25	0.00	0.00	0.00	0.50	0.25	0.50	0.25	0.00	0.50	0.21	0.07	17	0.312	0.06	17	0.190	0.1	17	0.01774599	0.0525	17
	Airport	0.00	0.00	0.25	0.00	0.50	0.25	0.75	0.25	0.75	0.50	0.50	0.25	0.75	0.25	0.50	0.50	0.50	0.75	0.4	0.33	13	0.689	0.27	14	0.202	0.41	13	0.04128073	0.2788	14
	Dismantlers	0.00	0.00	0.00	0.00	0.25	0.25	0.50	0.25	0.00	0.00	0.50	0.25	0.50	0.50	0.50	0.25	0.00	0.75	0.25	0.13	15	0.372	0.09	16	0.193	0.17	15	0.02191141	0.0925	15
	Government Units	0.25	0.25	0.25	0.25	0.25	0.25	0.75	0.25	0.50	0.25	0.50	0.25	0.75	0.50	0.75	0.50	0.25	1.00	0.43	0.37	12	0.857	0.36	11	0.203	0.43	12	0.04664878	0.3304	11
	Consumer Retailers	0.00	0.50	0.50	0.75	0.75	0.25	1.00	0.50	0.25	0.75	0.50	0.50	1.00	0.50	1.00	0.75	0.50	1.00	0.61	0.61	6	1.151	0.52	6	0.211	0.65	6	0.0700353	0.5553	6
	ANSP	0.00	0.25	0.00	0.25	0.25	0.25	0.75	0.00	0.00	0.25	0.50	0.00	0.50	0.25	0.25	0.00	0.00	0.50	0.22	0.09	16	0.381	0.1	15	0.192	0.14	16	0.0209709	0.0835	16

Table B.1-5: Stakeholder Applicability Mapping of Design Drivers

Cabin Interior Design Driver Map										Primary Stakeholders								Secondary Stakeholders								
Top-Level Design Drivers	Driver Importance Weights - Normalised	Constituent Design Factors	Total Count	Factor Eigenvalues (amend as required)	Factor Importance (adjusted by thresholds)	Intra-Driver Thresholds (adjusted by Driver weight)	Factor Importance (normalised across all factors)	Factor Ranks (by Importance)	Authorities	Operator	Passenger	CEM	Design Agency	Tier-n Suppliers	Airframer	Dismantlers	MRO	Government Units	DMO	Trade Organisations	Logistics Organisations	GHP	Consumer Retailers	AC Leaser / Owner	ANSP	Airport
Effective Count	90%			90%					24	52	33	53	44	56	41	13	21	13	34	56	21	16	15	19	3	18
Contribution (raw)	Max ↑ Min ↓	Eigenvector from Stakeholder Analysis		Max ↑ Min ↓					0.120	0.140	0.148	0.113	0.108	0.089	0.081	0.055	0.085	0.067	0.078	0.064	0.051	0.056	0.078	0.056	0.032	0.045
Contribution Weight	10%	Eigenvector normalised to $\sum w = 1.00$		10%					0.082	0.096	0.101	0.077	0.073	0.061	0.056	0.038	0.058	0.045	0.053	0.043	0.035	0.038	0.053	0.038	0.022	0.031
1. Revenue Potential	0.111	a. Brand Image	10	0.206	0.265	0.029	0.0230	12		✓		✓	✓	✓	✓			✓	✓	✓			✓			✓
		b. Promotion Channels	13	0.199	0.259	0.029	0.0226	13		✓		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓			✓
		c. Upfront Pricing	6	0.208	0.266	0.030	0.0232	11		✓	✓			✓					✓	✓			✓			✓
		d. Access Pricing	7	0.189	0.251	0.028	0.0219	15		✓	✓			✓					✓	✓			✓			✓
		e. Growth Potential	11	0.135	0.208	0.023	0.0181	22		✓		✓	✓	✓	✓		✓	✓	✓	✓	✓			✓		✓
		f. Innovation Capacity	9	0.063	0.150	0.017	0.0131	42		✓	✓	✓	✓	✓	✓	✓		✓		✓			✓			
2. Collaborative Potential	0.071	a. Distribution Channels	11	0.194	0.255	0.018	0.0142	38		✓	✓	✓	✓	✓	✓				✓	✓		✓	✓			✓
		b. Advertising Channels	10	0.277	0.322	0.023	0.0179	24		✓		✓	✓	✓	✓				✓	✓			✓	✓		✓
		c. Co-Branding Potential	14	0.131	0.205	0.015	0.0114	48		✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓		✓
		d. Retail Channels	9	0.398	0.418	0.030	0.0233	10		✓	✓		✓	✓					✓	✓		✓				✓
3. Passenger Perception	0.104	a. Physical Comfort	7	0.259	0.307	0.032	0.0250	8		✓	✓	✓	✓	✓				✓	✓	✓						
		b. Cabin Purity	11	0.235	0.288	0.030	0.0234	9	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓				
		c. Aesthetics	8	0.164	0.231	0.024	0.0188	20		✓	✓	✓	✓	✓	✓				✓	✓		✓				
		d. Autonomy	7	0.163	0.231	0.024	0.0187	21		✓	✓	✓	✓	✓	✓				✓	✓						
		e. Ambience	7	0.110	0.188	0.020	0.0153	32		✓	✓	✓	✓	✓	✓				✓	✓						
		f. Trendiness	7	0.069	0.155	0.016	0.0126	43		✓	✓	✓	✓	✓	✓				✓	✓						
4. Passenger Experience	0.094	a. Ergonomics	10	0.342	0.373	0.035	0.0275	6	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓				
		b. Cabin Environment	8	0.358	0.387	0.036	0.0284	5	✓	✓	✓	✓		✓	✓				✓	✓						
		c. Experiences	8	0.142	0.213	0.020	0.0157	31		✓	✓	✓	✓	✓	✓	✓				✓	✓					
		d. Useability	9	0.057	0.146	0.014	0.0107	51	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓					
		e. Interfaces	9	0.102	0.181	0.017	0.0133	41		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓					
5. Outside Interfaces	0.070	a. Outside View	7	0.080	0.164	0.012	0.0090	54		✓	✓	✓		✓	✓				✓	✓						
		b. In-Flight Information	11	0.332	0.365	0.026	0.0201	16	✓	✓	✓	✓	✓	✓	✓				✓	✓			✓		✓	
		c. In-Flight Communication	9	0.273	0.319	0.022	0.0176	25		✓	✓	✓	✓	✓	✓				✓	✓			✓			
		d. Journey Continuity	13	0.315	0.352	0.025	0.0194	19		✓	✓	✓	✓	✓	✓	✓		✓		✓	✓		✓		✓	✓
6. Operational Cabin Qualities	0.098	a. Passenger Capacity	9	0.365	0.392	0.038	0.0299	3		✓		✓	✓	✓	✓	✓			✓	✓				✓		✓
		b. Configuration	8	0.078	0.162	0.016	0.0124	44		✓		✓	✓	✓	✓	✓				✓	✓			✓		
		c. Luggage Storage	8	0.125	0.200	0.019	0.0152	33		✓	✓	✓	✓	✓	✓	✓				✓	✓					
		d. Turnaround Efficiency	11	0.116	0.193	0.019	0.0147	36	✓	✓	✓	✓	✓	✓	✓	✓					✓			✓		✓
		e. Service Capabilities	9	0.142	0.214	0.021	0.0163	29	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓						
		f. Crew Information	7	0.060	0.148	0.014	0.0113	49		✓	✓	✓	✓	✓	✓	✓				✓	✓					
		g. Crew Operations	8	0.115	0.192	0.019	0.0146	37	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓					
7. Integrated Cabin Quality	0.114	a. Fuel Burn	9	0.350	0.380	0.043	0.0338	2		✓		✓	✓	✓	✓	✓	✓			✓	✓			✓		✓
		b. Adaptability	11	0.083	0.167	0.019	0.0148	34		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		
		c. Applicability	11	0.083	0.167	0.019	0.0148	34	✓			✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓		
		d. Safety	14	0.483	0.487	0.055	0.0433	1	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
8. Sustain-ability	0.084	a. Environmental	16	0.352	0.382	0.032	0.0252	7	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
		b. Economic	12	0.243	0.294	0.025	0.0194	18	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓		
		c. Social	12	0.187	0.249	0.021	0.0164	28	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓		✓		
		d. Circularity	16	0.218	0.274	0.023	0.0181	23	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
9. Implemen-tation NRC	0.056	a. Availability	7	0.225	0.280	0.016	0.0123	46	✓			✓		✓	✓			✓		✓	✓					
		b. Designability	7	0.120	0.196	0.011	0.0086	56		✓		✓	✓	✓	✓	✓			✓		✓					
		c. Integrability	7	0.266	0.313	0.018	0.0138	39				✓	✓	✓	✓	✓		✓		✓						
		d. Manufacturability	11	0.174	0.240	0.013	0.0105	52	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓				
		e. Certifiability	9	0.215	0.272	0.015	0.0120	47	✓	✓		✓		✓	✓	✓		✓		✓				✓		
10. Implementation RC	0.056	a. Procurement	8	0.366	0.393	0.022	0.0173	27				✓	✓	✓	✓		✓			✓	✓		✓			✓
		b. Installation	9	0.225	0.280	0.016	0.0123	45	✓	✓		✓		✓	✓	✓	✓			✓		✓				
		c. Phasing Out	10	0.155	0.224	0.013	0.0099	53	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓				✓		
		d. Depreciation	7	0.255	0.304	0.017	0.0134	40		✓		✓		✓						✓	✓			✓		
11. In-Service RC	0.081	a. Operational Needs	8	0.458	0.467	0.038	0.0294	4		✓		✓		✓	✓					✓	✓	✓				✓
		b. Maintenance	8	0.319	0.356	0.029	0.0224	14	✓	✓			✓		✓		✓	✓		✓	✓	✓				
		c. Data Management	13	0.222	0.278	0.022	0.0175	26	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	✓		✓		✓
12. In-Service NRC	0.060	a. Reliability	11	0.408	0.427	0.026	0.0200	17	✓	✓	✓	✓		✓		✓				✓	✓	✓		✓		
		b. Repairability	7	0.308	0.347	0.021	0.0162	30	✓	✓			✓		✓			✓		✓	✓			✓		
		c. Modifications	10	0.175	0.240	0.014	0.0112	50	✓	✓		✓	✓	✓	✓	✓		✓		✓	✓			✓		
		d. Opportunity Losses	8	0.108	0.187	0.011	0.0087	55		✓		✓	✓	✓	✓				✓	✓	✓		✓			

Table B.1-6: Relevant References for HCCA Design Drivers & Factors

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B.2 Survey Fulfilment Approaches for Cabin Interior Stakeholder

Table B.2: Cabin interior stakeholders and the related information gathering approaches

Type	Stakeholder	Experts Surveyed / Workshop Attendees
<i>Direct Stakeholders</i>	Passenger	<ul style="list-style-type: none"> • Project Outputs: FUCAM project work package 2 outputs delivered by an academic research institution • Workshop attendees: multiple representatives from CEM, DA, and Tier 2 Supplier organisations
	Operator	<ul style="list-style-type: none"> • Project Outputs: FUCAM project work package 2 delivered by 2 academic research institutions • Surveyed experts: 5 Senior Manager-level experts from 3 major airlines from different global regions
	Cabin Equipment Manufacturer	<ul style="list-style-type: none"> • Surveyed experts: former CFO and Engineering VP from 2 major integrated cabin interior manufacturers • Project Outputs: FUCAM project work package 3 outputs delivered by a major integrated cabin interior manufacturer • Workshop attendees: <ul style="list-style-type: none"> ○ Senior R&T Engineer from a major integrated cabin interior manufacturer ○ Engineering Process Consultant from the aircraft interiors manufacturing sector
	Design Agency	<ul style="list-style-type: none"> • Surveyed experts: Managing Director from a specialist cabin interior design consultancy • Project Outputs: FUCAM project work package 3 delivered by a cabin interior design agency • Workshop attendees: <ul style="list-style-type: none"> ○ an expert from a full-service cabin design and engineering consultancy ○ 4 experts and executives from 4 different cabin interior design consultancy service providers ○ Managing Director from a strategy consultancy specialising in aerospace & aviation sectors
	Lessor	No direct exposure; HCCA content informed via literature and workshops / surveys attended by other stakeholders
	Tier 2+ Suppliers	<ul style="list-style-type: none"> • Project Outputs: FUCAM project work package 5 outputs delivered by a cabin equipment and component supplier • Surveyed Experts: R&T Manager from a cabin interior components supplier • Workshop Attendees: <ul style="list-style-type: none"> ○ Operations Director from the provider of customized manufactured components ○ Director from a Tier 2 supplier of intelligent aircraft seat monitoring systems ○ Expert from Tier 2 supplier of integrated cabin monuments and full-service engineering consultancy
	Dismantler	<ul style="list-style-type: none"> • Surveyed experts: 3 executives (2 x Managing Director, 1 x CEO) from 3 different aircraft dismantling organisations

	Maintenance and Repair Organisation	Workshop Attendees: <ul style="list-style-type: none"> Expert from a cabin interiors MRO organisation Opinions from other attendees contributing
	Airframer	<ul style="list-style-type: none"> Project Outputs: FUCAM project work package 3 outputs oversighted by a major aircraft manufacturer Surveyed experts: Expert VP Cabin from a major aircraft manufacturer
	Certification Authority	<ul style="list-style-type: none"> Project Outputs: FUCAM project work package 2 outputs delivered by an academic institution
<i>Indirect Stakeholders</i>	Destination Management Organisation	<ul style="list-style-type: none"> Surveyed experts: Manager Sales from a global travel and ticketing agency
	Consumer Retailers	No direct exposure; HCCA content informed via literature and workshops / surveys attended by other stakeholders
	Trade Organisations	<ul style="list-style-type: none"> Workshop Attendee: Business Development manager from the aircraft interiors focus group at a UK-based aerospace trade organisation
	Government Units	<ul style="list-style-type: none"> Surveyed experts: 4 senior academic experts from 2 academic institutions Workshop Attendee: Strategy Manager from a UK-based aerospace technology strategy institution
	Ground Handling Providers	No direct exposure; HCCA content informed via literature and workshops / surveys attended by other stakeholders
	Logistics Provider	<ul style="list-style-type: none"> Workshop Attendee: Operations Director from the provider of customized supply chain management services
	Airport	No direct exposure; HCCA content informed via literature and workshops / surveys attended by other stakeholders
	Air Navigation Service Provider	No direct exposure; HCCA content informed via literature and workshops / surveys attended by other stakeholders

B.3 Expert Opinion Survey Questions

Table B.3: A Compendium of Questions asked during Expert Workshops and Surveys

Topic	Survey/Workshop Questions
Aircraft Interiors Business and Projects	<ul style="list-style-type: none"> • Do Market research/BD and Engineering/Design functions operate separately in a cascade and not iteratively in parallel? • Does this sequential operation make it difficult to receive product development feedback regularly in an "agile" manner? • Is differentiation an imperative driver for the operator's competitive advantage to win PAX? • What are the timescales for passenger cabin interior product development? • What defines or affects the timeframe for cabin development (focus on the business environment, if relevant)? • What aspects of the interiors business and industry affect the delivery of cabin interior projects? • How does real project execution align with the "ideal" design process e.g., ICAO Cabin Retrofit Guide or ARP? • How often do design iterations / repetitions occur in a typical cabin interior project and why? • How is customer feedback integrated into cabin design, and how frequent are its iterations? • How is cabin product specification managed throughout the cabin development process? • How and why product specification can change during the cabin project? How often this happens, why, and at what scale? • How the project parties react to cabin product specification changes, what are the subsequent cabin project effects? • What solutions and compromises are normally implemented to resolve the existing project issues / challenges / caveats? • Who drives the decision-making in cabin interior design projects? • What is the BFE/SFE setup on a typical cabin interior project and what setups are considered atypical? • How do different stakeholders and their internal functions collaborate and mutually consider each other's needs? • What is the sequence and content of stakeholder involvement in a typical cabin project, and the associated inefficiencies? • What could be the potential improvements for streamlining stakeholder contribution to a project and meet their goals?
Cabin Design Drivers	<ul style="list-style-type: none"> • What are the primary (influencing cabin design) and secondary (affected by cabin design) stakeholders served by cabin interior design decisions, disregarding the extent / depth of their involvement? • What are the key design factors important for/affecting each of these stakeholders/users? • Differences between the needs, preferences, interests and limitations of the airlines and the leasing companies? • How are product offerings defined/conceptualised and what affects new product specification (e.g., target market, cabin classing, project budget)? • How important is the consideration of cabin interior maintainability and serviceability versus other design drivers (like passenger satisfaction, supply availability, designability, etc.)? • How important is the consideration of cabin crew operations (workload, convenience, efficiency, etc.) versus other drivers?

Cabin Innovation	<ul style="list-style-type: none"> • How well a typical new cabin product meets the original specification/expectations? What is the frequency and scale or exceeding or falling short of the expected/contracted performance? (Consider both objective and subjective angles) • How frequent is the occurrence of innovation in passenger cabins? • What is the scale of cabin innovation initiatives / projects occurring at different frequencies? • What are the ratios of cabin production, evolution, and innovation efforts/investment spent by cabin interior supply chain? • What factors (favourable and detrimental) affect the ability of the cabin supply chain to innovate? • How is cabin innovation typically achieved (e.g., in-house or contracted, internal R&T or academic research sources, etc.)? What processes are applied to oversee, drive, and implement it? • What innovation/NPDI processes are used to design new cabins? Consider evolution, innovation, and bespoke projects. • What is the distributing of innovation focus/investment among the different cabin product types? • How important is the consideration of product commonality and compatibility with existing products for cabin innovation? • Who drives innovation in cabin interiors, and who should drive it in the ideal, efficient and effective collaboration?
Cabin Products and Materials	<ul style="list-style-type: none"> • Composition (materials and mass) of cabin components most prevalent in terms of weight, volume, or end-of-life issues • What is the total weight of the most critical components, including both direct and related weight (e.g., IFE screen itself and also brackets, wiring etc.)? • Unit and total weight of the overhead bins and related components • Unit and total weight of the insulation blankets • Unit and total weight of cabin linings and flooring • Total weight of the IFE system and the involved components • How much wiring is there in total per cabin as part of the cabin interiors (not counting the wiring that is not related to cabin interiors)? What systems does it feed? • What are the different types of cabin equipment and interfaces titled in common industry terms/definitions?
Business Impacts due to Cabin Content	<ul style="list-style-type: none"> • What is the cost impact per kg weight per aircraft per year on SA and Turboprop, both in fuel volume and currency? • What materials/components involve heavier upstream supply chain (energy expenditure, SC size in terms of distance and process steps count)? • What aspects of cabin interior components are important to you and your business (material marking, repairability, recyclability, etc.)? • What is the cost impact of select cabin equipment per year - maintenance, operation? • How are cargo containers used - e.g., do they fly always? Can we put all bags there? • What drives the decisions on what to do with the material/component (refurbish, recycle, etc.)? • Who pays for what in Reuse - Refurbish - Recycle - Recover - Dispose?

Integrated Cabin Design Methods	<ul style="list-style-type: none"> • What is your general opinion about a technology selection tool and an integrated method that allows embedding technological innovation into existing cabin interior design processes? • Would you prefer for it to be applied for each market individually with case-based adjustment capability (not one-size-fits-all) to meet differing market preferences and needs, or introduced as a generic, commonly applicable tool? • What assessment system would you see more feasible in the proposed holistic cabin design method (e.g., direct rating defined by objective product/material data, subjective scoring allowing the freedom to express stakeholder views, etc.)?
Cabin Interiors End-of-Life	<ul style="list-style-type: none"> • How cabin components/materials are reused, refurbished, recycled, recovered, or disposed of (specific processes & equipment used)? • Which of the present materials (may not be the most prevalent) pose the toughest challenge to not dispose of (i.e., re-sell, refurbish, recycle, recover), and why? • Who do you interact with when recycling or disposing of cabin interiors, and how (involved stakeholders)? • Which of the present materials (may not be the most prevalent) have the worst impacts when disposing of (toxicity, energy requirement, emissions, etc.)? • What types of waste are prevalent in cabin dismantling, and where it comes from? • How do your upstream & downstream supply chains look when recycling or disposing of cabin interiors? (E.g., receiving an aircraft from an airline, taking off seats and re-selling to another airline) • If not recycled for original use, what other recycling scenarios are typically practiced or offer viable potential (aerospace & non-aerospace)? • How many times, and for how many years, the identified key components get re-sold and re-used until finally having to dispose of it?

B.4 MCDA Tool Selection Parameters

Table B.4: Parameter Settings to select an appropriate MCDA method

ProBCA Set.	Task	Justification
1.1: Task	Criteria	Stakeholders are assigned relative weights in similarity to assigning criteria importance; no options are involved.
1.2: Output format	Point Values	Need to retrieve precise values to use in NPDI assessments
1.3: Ambiguity	N/A	Sufficient data and well-defined opinions are available to express comparative judgements
1.4: Relative Thresholds	N/A	Naturally unbalanced stakeholder involvement (e.g. Airline vs ANSP influence is >95% / <5%) so no need to constrain
1.5: Resource Needed	Light, Reasonable	Task scale does not warrant the use of "Heavy" type, which would normally be used for highly complex task contexts
2.1: Criteria Count	No selection	Less than 25 stakeholders are involved, but the options are left open to relax the freedom of choice for MCDA methods
2.2: Criteria Importance	Weighted	The task is concerned with assigning stakeholder weights along two separate axes
2.3: Weights Basis	Subjective	Stakeholders are compared based on inferences from the literature, project workshops, and expert inputs
2.4: Weights Format	Ratio	Comparison must use measurable scores to be useful
2.5: Definition Procedure	Comparison	Stakeholders need to be compared among each other in pairs to achieve the most refined mapping
2.6: Criteria Dependence	Independent	The rules for stakeholder scoring are independent among each other
2.7: Criteria Hierarchy	Flat	Stakeholders are defined as top-level business entities
3.1: Options Count	N/A	Options not involved – counting options is inapplicable
3.2: Attribute Nature	No selection	Options not involved – attribute selection is inapplicable
3.3: Rating Format	N/A	Option not involved – no ratings to consider
3.4: Rating Procedure	N/A	Option not involved – no ratings to consider
3.5: Aggregation	No selection	Left open to return more options

B.5 Aircraft Passenger Cabin Design Stakeholders

Table B.5-1: Direct Aircraft Passenger Cabin Interior Stakeholders*

	Stakeholder	Abbrev.	Cabin-related purpose/nature	Functional Role on a Cabin Interiors Project
<i>Direct influence on cabin design</i>	Passengers	PAX	Travel between destinations for a variety of reasons.	Source of value in the industry (paying for tickets, services, ancillaries etc.); WTP impacted by overall impression
	Operators	N/A	Operate the aircraft cabin, charging passengers to collect and distribute revenue across the value chain.	Responsible for industry revenue generation through sales of differentiated services and products to passengers.
	Cabin Equipment Manufacturers	CEM	Provide equipment to the operator by product engineering, industrialising, manufacturing, and integrating with the supplied sub-components. Often operate in multi-supplier setup; includes cabin integrators who only manufacture individual products.	Deliver the means for cabin value generation to the operator. Enables profitability by attracting sales volume with a competitive (high quality, differentiation) product.
	Design Agencies	DA	Translate customer's (Operator, CEM, Airframer) vision for a product into its conceptual design.	Invent the means for value generation by delivering competitive product concepts to the CEM and Suppliers.
	Lessors	N/A	Provide the aircraft platform in its ownership. Includes anyone holding formal ownership of the physical aircraft e.g., companies specialising on aircraft lease, airframers, operators, private or commercial aircraft owners, financial institutions funding lease transactions.	Carry the legal responsibilities related to managing the value generation platform. Overall interest is generally aligned with that of an Operator. The role implies "dry lease" situations; in wet lease cases, the two functions (leasing and operating) are two separate stakeholders.
	Tier 2+ Suppliers	N/A	Contribute to the delivery of a complete cabin by sourcing, developing, and delivering raw materials, individual parts, sub-/components, sub-/assemblies, specialist modules (including technology-based solutions) that are beyond CEM's capabilities.	Provide the technological basis to facilitate the delivery and functioning of cabin value generation mechanisms.
	Dismantlers	N/A	Perform cabin product dismantling and utilisation at its end of life, or selling of it to the vendors interested.	Impose product design requirements to minimise the sustainability impacts across its linear or circular life cycle.
	Maintenance and Repair Organisations	MRO	Enable the airline to continuously run an airworthy cabin by keeping it in appropriate operational state.	Deliver efficient servicing of cabin components to ensure continuity of operation for value generation mechanisms.

	Airframers	N/A	Provide the design envelope for cabin products and advises the CEM to ensure structures & systems fit.	Provide the housing platform for cabin value generation.
	Certification Authorities	CA	Ensure appropriate adherence of cabin products and processes delivered by the cabin interior supply chain to airworthiness and safety standards and regulations.	Ensure that cabin value is generated in a safe manner; motivate the supply chain to optimise their product design.

Table B.5-2: Indirect Aircraft Passenger Cabin Interior Stakeholders*

	Stakeholder	Abb.	Cabin-related purpose/nature	Functional Role on a Cabin Interiors Project
<i>Indirect influence on cabin design</i>	Destination Management Organisations	DMO	Develop feasible travel destinations and services; act as sales agents of cabin products and services to PAX; provide the channel for their voice (desires, feedback).	Reinforce value-generating demand for air travel by combining cabin offer with adjacent industries (tourism, business travel, etc.).
	Consumer Retailers	CR	Supply the commercial service and product content for in-flight or adjacent sales.	Enrich cabin content available through value-generating mechanisms; further reinforce the demand for air travel.
	Trade Organisations	TO	Bring the cabin supply chain together to share their needs, desires, practices, and deals with each other.	Consolidate holistic operation of the industry to make cabin value generation more efficient and effective.
	Government Units	GU	Drive the development of cabin interiors industry to ensure viability of its technological advancement.	Facilitate collaboration between academia and industry to enable future prosperity and talent for the industry.
	Ground Handling Providers	GHP	Enable the operators to fulfil cabin service needs between flights by replacing consumable supplies.	Support routine operation of value generation mechanisms by maintaining its readiness and content.
	Logistics Providers	LP	Facilitate the delivery of materials, components, products, and supplies between cabin stakeholders; ensure traceability and harmonised product flow.	Streamline the provisioning and delivery of operational and value generating contents at optimised costs.
	Airports	N/A	Provide the facilities for managing and maintaining passenger flow and cabin operation between flights.	Provide the environment for realising value generation and an interface to adjacent stakeholders and industries.
	Air Navigation Service Providers	ANSP	Collect, distribute, and use information related to air traffic management.	Manage the environment where value generation occurs; provide content for flight information capability.

* ordered by the interest score from SA in [8] within each group (Primary and Secondary)

B.6 HCCA Application Process Flow

Figure B.6-1: Process flow for the HCCA project application (Phase I)

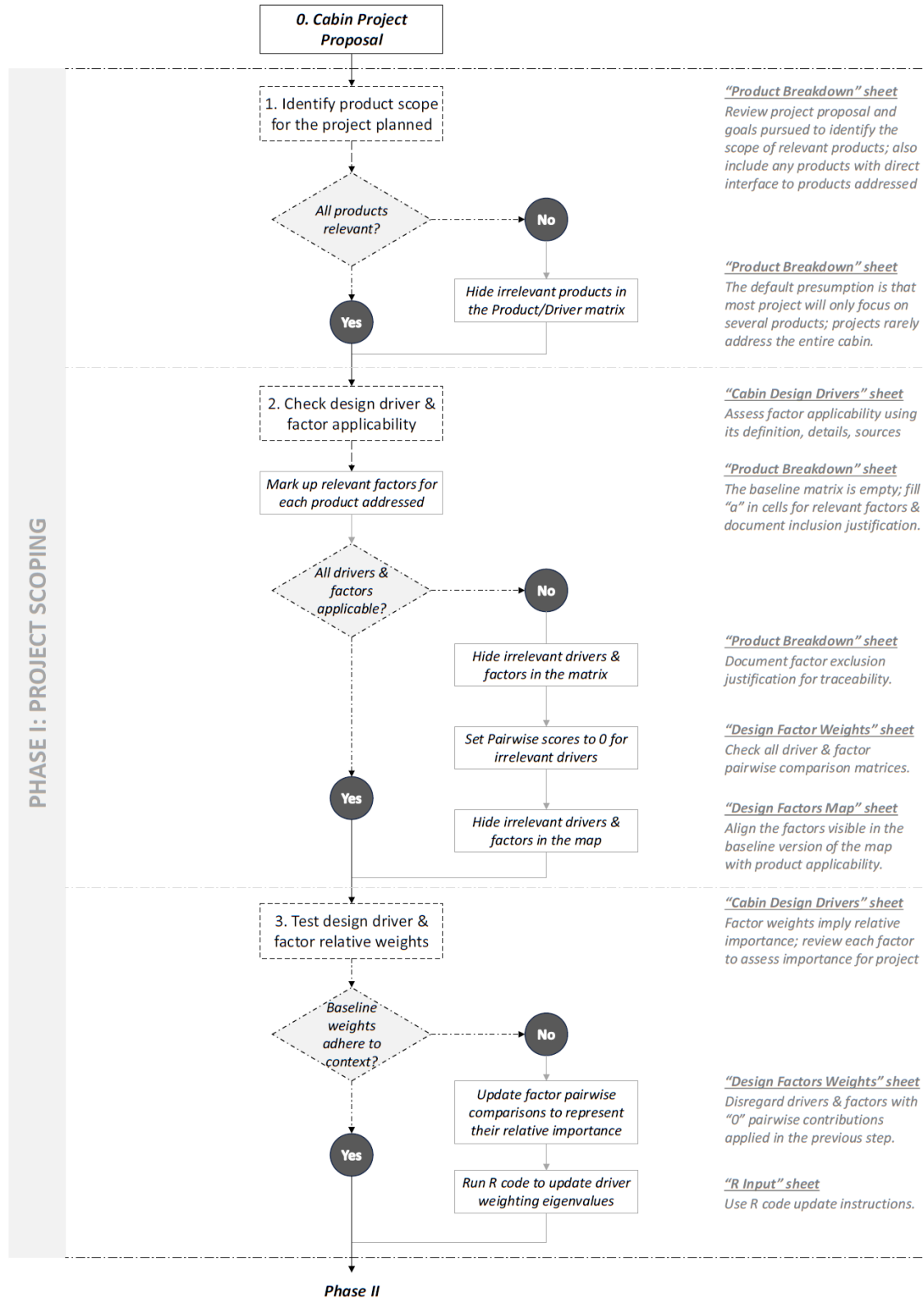
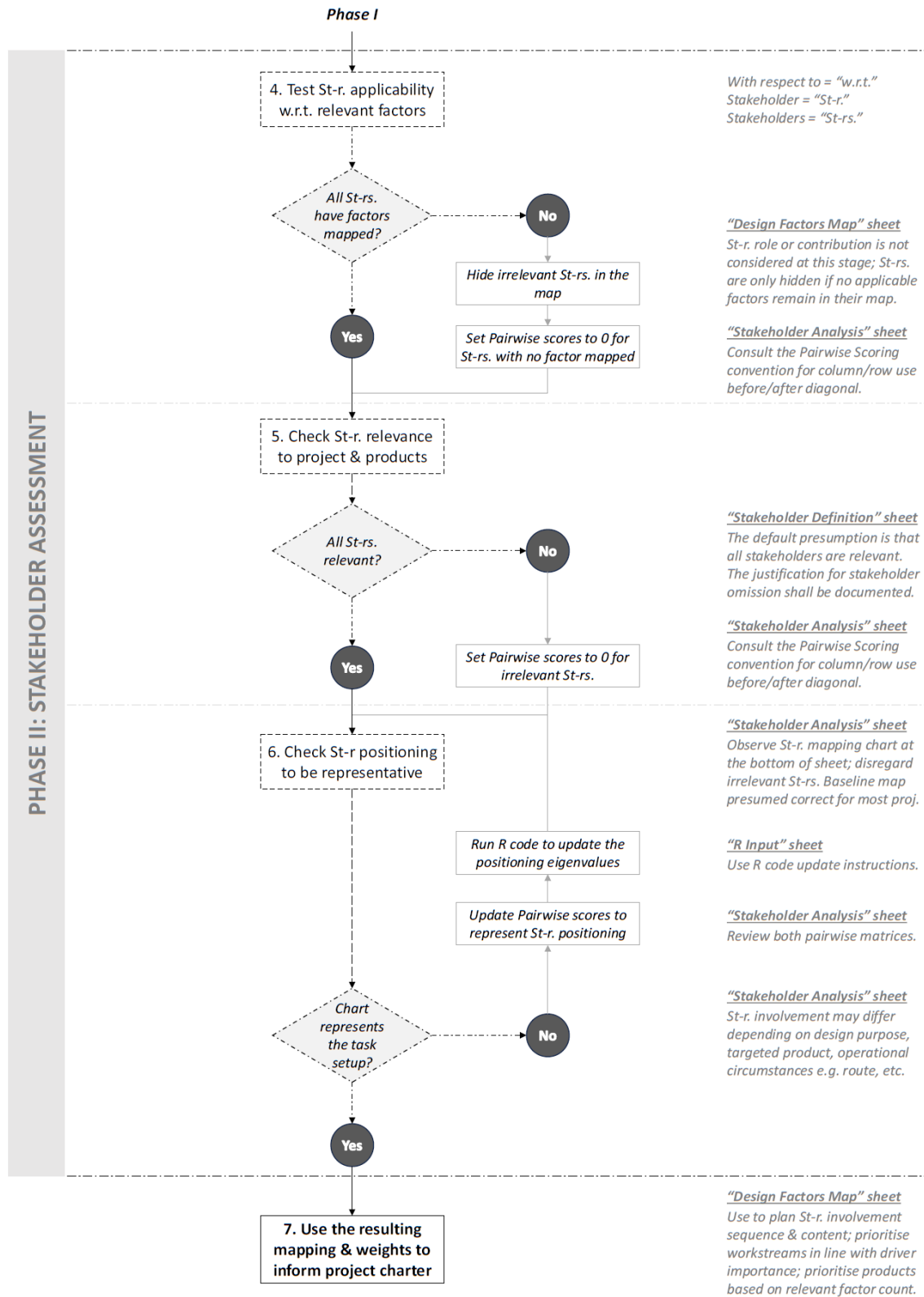


Figure B.6-2: Process flow for the HCCA project application (Phase II)



Appendix C : Synergistic MCDA-LCA Sustainability Assessment of Passenger Transport Interiors (Section 5)

C.1 SSAPTI Framework Screenshots – Core Blocks

This Appendix contains the screenshots for the 6 core blocks used in the SSAPTI framework. Each screenshot depicts a dedicated MS Excel sheet of the original SSAPTI file uploaded in CORD (see Ref. [1] in Section 5).

Table C.1-1: SSAPTI Core Sheet 1 – Cabin Material Inventory:

SSAPTI core sheet 1/6: cabin product and material inventory used in subsequent assessment steps. This sheet provides the user with space to list the individual materials and their weights as contained in each cabin product.

Table C.1-2: SSAPTI Core Sheet 2 – Quantitative Assessment:

SSAPTI core sheet 2/6: pulls the information from various other sheets (Product Inventory, LCIA Method Outputs, IC weights, Circular Economy). Provides the space to enter the timeframe, life cycle, and criteria weighting preferences. These inputs are fed into the automated function to produce the resulting sustainability impact scores in 3 dimensions: per-material, per-product, and per-LCIA method.

Table C.1-3: SSAPTI Core Sheet 3 – Circular Economy Assessment:

SSAPTI core sheet 3/6: provides the space for circular life cycle parameters. The sheet does not distinguish materials and thus, components exhibiting similar circularity potential shall be grouped into a single entry per material (e.g., parts made of certain plastic that can be recycled together would make a single entry).

Table C.1-4: SSAPTI Core Sheet 4 – Qualitative LCA Evaluation:

SSAPTI core sheet 4/6: provides the space to enter qualitative assessment scores for wider product life cycle impacts beyond materiality where quantitative data is not available in use cases targeted by SSAPTI. After gathering the scores with a reflection of the user's confidence and bias, the sheet produces the final output in columns "R" using qualitative function block (supporting sheet 7).

Table C.1-5: SSAPTI Core Sheet 5 – Strategic Assessment:

SSAPTI core sheet 5/6: provides the space to enter strategic assessment scores for cabin products reflecting product importance for the business. The evaluation scores are collected with a reflection of the user's confidence and bias to produce the final output in columns "R" using the function block (supporting sheet 7).

Table C.1-6: SSAPTI Core Sheet 6 – Results Aggregation:

SSAPTI core sheet 6/6: pulls the outputs from the 3 core blocks (Quantitative, Qualitative, Strategic) into the single total score. Also provides the space to adjust the relative contribution of each block. The final scores are used to rank the products assessed by their overall sustainability impacts.

Table C.1-1: SSAPTI Core Sheet 1 – Cabin Material Inventory

Top-Level Assembly	Sub-Assembly	Material	W/unit (kg)	W/aircraft (kg)	W(tot)/cabin (kg)	Product	Size	unit
Aircraft Economy Seat - Triple Assembly 2004 A sample donated by the ASI, [1] Original = triple seat assembly Unit = single seat	Armrests	Aluminium	0.307	55.2	262	Seats [4]	180	units
		PC	0.312	56.1		Windows	80	units
		PU Rigid Foam	0.483	87.0		Cabin Length [4]	27.51	m
		PVC Film	0.010	1.8		Wall & Ceiling arches	3.862	m
		Stainless Steel	0.343	61.8		Cabin Lining area	106.2	m2
	Seat Structure - Metallic	Aluminium	3.797	683.4	696	Insulation blanket arch	7.00	m
		Brass	0.070	12.6		Insulation blanket area	192.57	m2
	Seat Structure - Composite	CFRP	1.823	328.2	337	Floor Area [5]	100.00	m2
		PA	0.050	9.0				
		Synthetic Leather	0.800	144.0				
	Seat Comfort Interfaces	PA	0.080	14.4	490			
		PC	1.163	209.4				
		PET Film	0.050	9.0				
		PU Flexible Foam	0.630	113.4				
		Synthetic Leather	0.320	57.6				
	Back Comfort Interfaces	PA	0.080	14.4	263			
		PET Film	0.050	9.0				
		PU Flexible Foam	1.010	181.8				
		Aluminium	0.083	14.9				
	Miscellaneous	Brass	0.085	15.3	268			
		Cu wiring	0.003	0.6				
		PA	0.118	21.3				
		Paint	0.023	4.2				
		PC	0.007	1.2				
		PET Film	0.192	34.5				
		PU Rigid Foam	0.037	6.6				
		PVC Film	0.010	1.8				
		Silicone Rubber	0.007	1.2				
		Stainless Steel	0.924	166.4				
	Sidewall Panel	NOMEX HC	0.410	43.6	212			
		GFRP	1.220	129.6				
		PVC Film	0.370	39.3				
		PEI	1.744	48.0				
	Window Framing	PEI	0.322	25.8	89			
		Silicone Rubber	0.041	3.3				
		PMMA	0.743	59.5				
	Cabin Insulation Blankets	PET Film	0.050	9.6	438			
		GFRP	2.225	428.5				
	Overhead Bin	NOMEX HC	2.027	62.8	682			
		GFRP	6.031	187.0				
		PVC Film	1.829	56.7				
		Aluminium	12.113	375.5				
Cabin Floor Assembly	Carpet	PA	0.700	70.0	140			
		PET Film	0.280	28.0				
		Cotton	0.140	14.0				
		Latex	0.280	28.0				
	Floor Panel	Aluminium	1.852	185.2	187			
		Epoxy Adhesive	0.014	1.4				

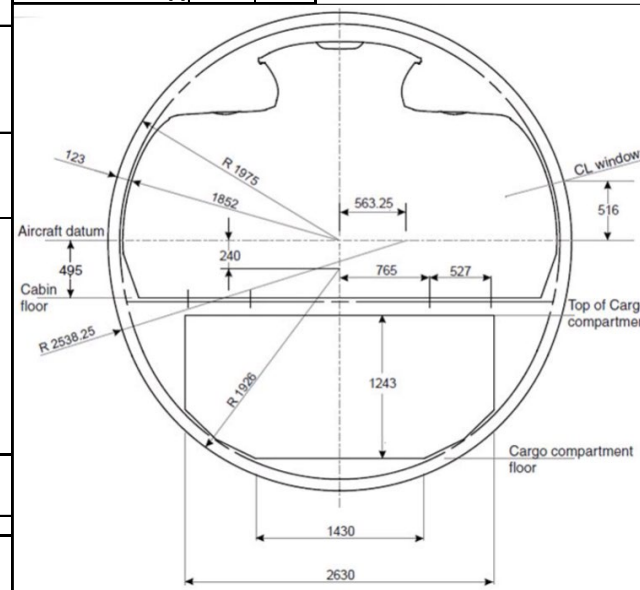


Figure 1: A320 fuselage cross-section with cabin dimensions

Table C.1-2: SSAPTI Core Sheet 2 – Quantitative Assessment

Cabin Interior Material Inventory		Time period analysed:	10	years
Impact Criteria Importance:	Equivalent	Life Cycle Type:	Linear	

All values in kg units	Seats				Cabin Linings		Bins	Cabin Floor		Total
Component	i. Metallic Structure	ii. Composite Structure	iii. Comfort Interfaces	iv. Miscellaneous Components	v. Sidewall Panel	vi. Insulation Blankets	vii. Overhead bins	viii. Carpet	ix. Floor Panel	
Initial Design Life (years)	25	25	5	10	25	5	15	5	25	kg
Aluminium	273.36		110.40	14.85			250.33		74.10	723.0
Brass	5.04			15.30						20.3
Cu wiring				0.60						0.6
Stainless Steel			123.60	166.35						290.0
Cotton								28.00		28.0
Synthetic Leather			403.20							403.2
Silicone Rubber				1.20	1.31					2.5
CFRP		131.28								131.3
GFRP					51.85	856.94	124.65			1033.4
Epoxy Adhesive									0.56	0.6
Latex								56.00		56.0
NOMEX HC					17.42		41.89			59.3
PA		3.60	57.60	21.30				140.00		222.5
PC			531.00	1.20						532.2
PEI					29.50					29.5
PET Film			36.00	34.50		19.26		56.00		145.8
PMMA					23.79					23.8
PU Flexible Foam			590.40							590.4
PU Rigid Foam			174.00	6.60						180.6
PVC Film			3.60	1.80	15.72		37.80			58.9

Material	Per-Material Comparison: Scores									
	DB: EI / M: CML(nb)	DB: EI / M: EF 3	DB: EI / M: EP 2015	DB: EI / M: ILCD 2011	DB: EI / M: IMP 2002+	DB: EI / M: IPCC 21 100	DB: EI / M: ReCiPe 2016	DB: EI / M: TRACI 2	DB: EI / M: EPS 2015d	Combined
	%	%	%	%	%	%	%	%	%	%
Aluminium	21.7%	22.6%	19.8%	30.4%	22.5%	22.9%	22.2%	31.8%	20.1%	23.8%
Brass	2.9%	2.3%	2.5%	2.3%	2.4%	0.2%	2.1%	2.1%	0.7%	2.0%
Cu wiring	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.0%	0.1%
Stainless Steel	2.0%	2.0%	1.4%	3.7%	1.6%	1.9%	2.2%	4.2%	4.4%	2.6%
Cotton	1.5%	2.2%	2.4%	2.1%	1.4%	0.2%	2.4%	0.7%	0.6%	1.5%
Synthetic Leather	7.4%	9.9%	11.8%	8.8%	7.8%	4.6%	10.4%	5.4%	7.7%	8.2%
Silicone Rubber	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
CFRP	28.1%	25.5%	25.5%	26.0%	29.7%	30.4%	20.5%	23.0%	12.7%	24.6%
GFRP	14.0%	13.7%	12.6%	11.9%	13.3%	18.7%	18.9%	13.9%	20.4%	15.3%
Epoxy Adhesive	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Latex	0.1%	0.2%	0.2%	0.1%	0.4%	0.0%	0.3%	0.3%	0.8%	0.3%
NOMEX HC	1.0%	0.6%	0.5%	0.4%	0.7%	0.7%	0.7%	0.5%	1.0%	0.7%
PA	1.5%	2.2%	1.7%	1.6%	2.4%	4.3%	3.8%	2.4%	4.1%	2.7%
PC	3.3%	4.8%	12.0%	3.6%	5.0%	8.6%	5.2%	5.2%	9.8%	6.4%
PEI	0.2%	0.3%	0.7%	0.2%	0.3%	0.5%	0.3%	0.3%	0.5%	0.4%
PET Film	1.6%	0.7%	0.8%	0.7%	0.9%	0.2%	0.6%	0.8%	2.2%	0.9%
PMMA	0.3%	0.3%	0.2%	0.2%	0.5%	0.3%	0.3%	0.3%	0.4%	0.3%
PU Flexible Foam	3.3%	5.1%	3.6%	3.6%	5.6%	4.5%	5.6%	4.9%	9.6%	5.1%
PU Rigid Foam	9.1%	6.9%	3.5%	3.5%	4.7%	1.9%	4.0%	3.3%	3.8%	4.5%
PVC Film	1.8%	0.6%	0.7%	0.7%	0.7%	0.0%	0.2%	0.7%	1.0%	0.7%

Per-Product Comparison: Scores										
DB: EI / M: CML(nb)	8.9%	28.2%	27.9%	4.8%	2.0%	11.8%	11.1%	3.1%	2.2%	
DB: EI / M: EF 3	9.1%	25.6%	31.5%	4.0%	1.6%	11.5%	10.3%	4.1%	2.3%	
DB: EI / M: EP 2015	8.1%	25.6%	35.1%	3.7%	1.8%	10.5%	9.2%	3.9%	2.0%	
DB: EI / M: ILCD 2011	12.1%	26.1%	26.2%	5.1%	1.3%	10.0%	12.7%	3.5%	3.1%	
DB: EI / M: IMP 2002+	9.1%	29.7%	27.8%	3.9%	1.9%	11.2%	10.4%	3.7%	2.3%	
DB: EI / M: IPCC 21 100	8.7%	30.4%	25.0%	2.3%	2.0%	15.5%	10.7%	3.0%	2.3%	
DB: EI / M: ReCiPe 2016	8.9%	20.6%	30.6%	4.1%	1.8%	15.8%	10.6%	5.4%	2.3%	
DB: EI / M: TRACI 2	12.6%	23.0%	26.2%	5.4%	1.6%	11.7%	13.5%	2.8%	3.3%	
DB: EI / M: EPS 2015d	7.8%	12.8%	37.3%	4.6%	2.6%	17.2%	10.8%	4.8%	2.1%	
Combined Scores	9.5%	24.7%	29.7%	4.2%	1.8%	12.8%	11.0%	3.8%	2.4%	
Per-Product Comparison: Ranks										
DB: EI / M: CML(nb)	5	1	2	6	9	3	4	7	8	
DB: EI / M: EF 3	5	2	1	7	9	3	4	6	8	
DB: EI / M: EP 2015	5	2	1	7	9	3	4	6	8	
DB: EI / M: ILCD 2011	4	2	1	6	9	5	3	7	8	
DB: EI / M: IMP 2002+	5	1	2	6	9	3	4	7	8	
DB: EI / M: IPCC 21 100	5	1	2	8	9	3	4	6	7	
DB: EI / M: ReCiPe 2016	5	2	1	7	9	3	4	6	8	
DB: EI / M: TRACI 2	4	2	1	6	9	5	3	8	7	
DB: EI / M: EPS 2015d	5	3	1	7	8	2	4	6	9	
Combined Ranks	4.8	1.8	1.3	6.7	8.9	3.3	3.8	6.6	7.9	

Per-Material Comparison: Ranks										
Aluminium	2	2	2	1	2	2	1	1	2	1.67
Brass	8	8	8	9	8	14	11	10	14	10.00
Cu wiring	18	18	18	18	18	17	18	18	19	18.00
Stainless Steel	9	11	11	5	10	9	10	7	7	8.78
Cotton	13	9	9	10	11	15	9	12	15	11.44
Synthetic Leather	5	4	5	4	4	5	4	4	6	4.56
Silicone Rubber	19	19	19	19	19	18	19	19	18	18.78
CFRP	1	1	1	2	1	1	2	2	3	1.56
GFRP	3	3	3	3	3	3	3	3	1	2.78
Epoxy Adhesive	20	20	20	20	20	19	20	20	20	19.89
Latex	17	17	17	17	16	16	15	15	13	15.89
NOMEX HC	14	14	15	14	14	10	12	14	12	13.22
PA	12	10	10	11	9	7	8	9	8	9.33
PC	6	7	4	7	6	4	6	5	4	5.44
PEI	16	15	14	16	17	11	14	17	16	15.11
PET Film	11	12	12	13	12	13	13	11	10	11.89
PMMA	15	16	16	16	15	15	12	16	17	15.33
PU Flexible Foam	7	6	6	6	5	6	5	6	5	5.78
PU Rigid Foam	4	5	7	8	7	8	7	8	9	7.00
PVC Film	10	13	13	12	13	20	17	13	11	13.56

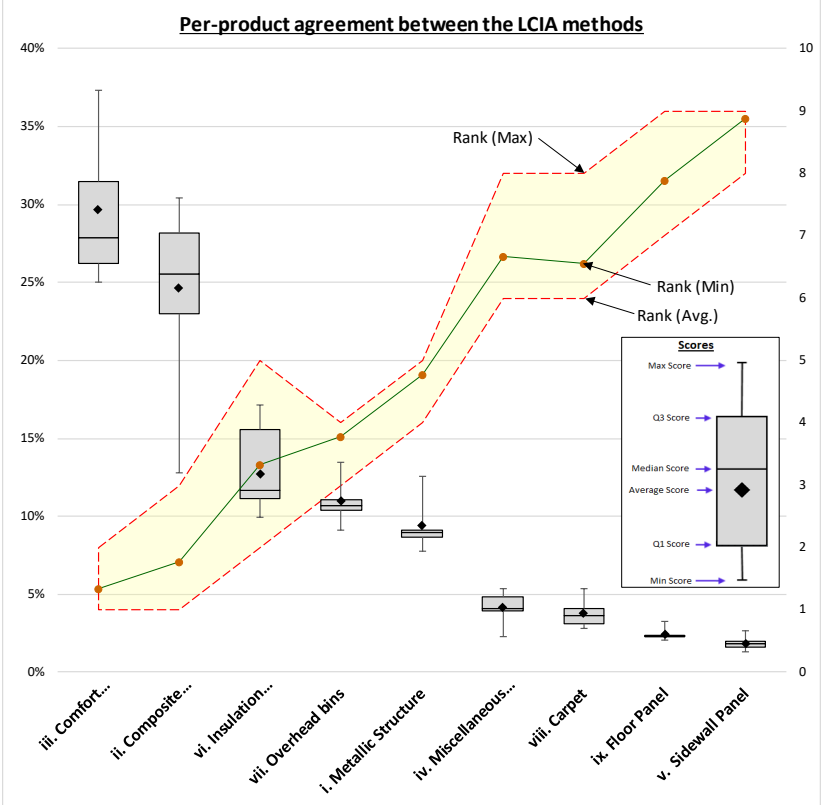
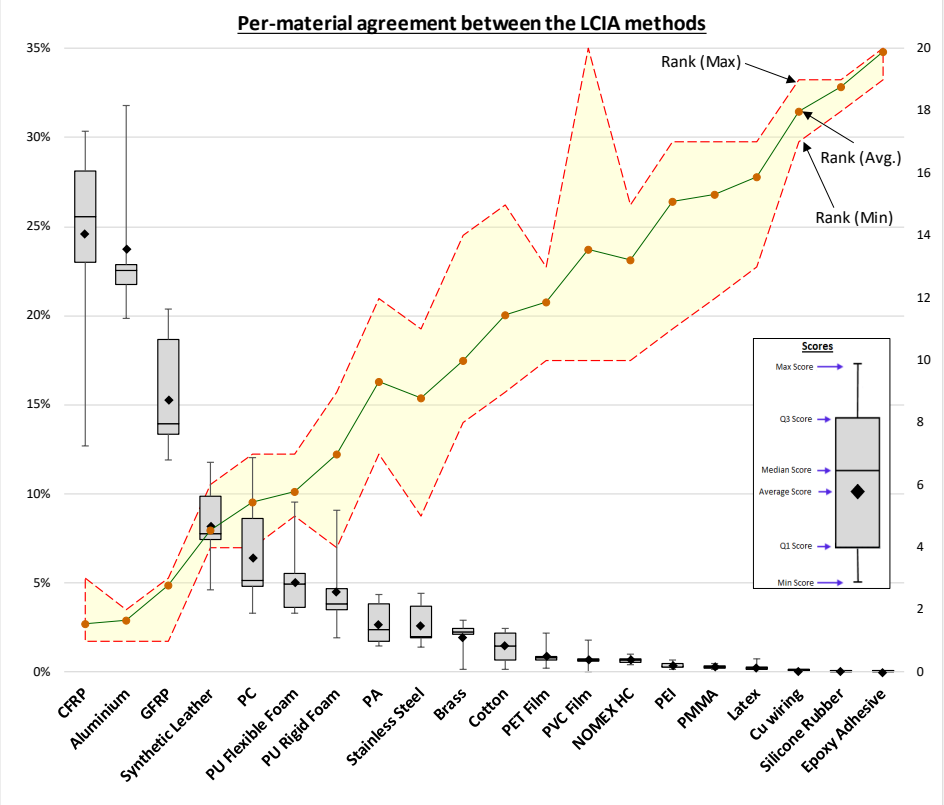


Table C.1-3: SSAPTI Core Sheet 3 – Circular Economy Assessment

Circular Economy Effects			Seats				Cabin Linings		Bins	Cabin Floor	
R Value	Parameter	Units	i. Metallic Structure	ii. Composite Structure	iii. Comfort Interfaces	iv. Miscellaneous Components	v. Sidewall Panel	vi. Insulation Blankets	vii. Overhead bins	viii. Carpet	ix. Floor Panel
R1: Refuse	Product weight proportion addressed	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Product lifetimes avoided	loops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R2: Rethink	Product weight addressed	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Product lifetimes combined	loops	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R3: Reuse	Product weight proportion addressed	%	0%	0%	33%	0%	100%	0%	100%	0%	100%
	D-Factor	score	0	0	5	0	6	0	6	0	8
	Product lifetimes restarted	loops	0.0	0.0	1.0	0.0	1.5	0.0	1.5	0.0	3.0
R4: Repair	Product weight proportion addressed	%	0%	100%	0%	0%	100%	0%	100%	0%	0%
	Repair efficiency	score	0	4	0	0	8	0	8	0	0
	D-factor	score	0	3	0	0	4	0	4	0	0
	Product lifetimes restarted	loops	0.0	1.0	0.0	0.0	1.5	0.0	1.5	0.0	0.0
R5: Remanufacture	Product weight proportion addressed	%	0%	0%	34%	0%	0%	0%	0%	0%	0%
	Remanufacture efficiency	score	0	0	6	0	0	0	0	0	0
	D-factor	score	0	0	8	0	0	0	0	0	0
R6: Recycle	Product lifetimes restarted	loops	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
	Product weight proportion addressed	%	100%	0%	0%	98%	18%	0%	0%	100%	0%
	Recycling efficiency	score	10	0	0	5	8	0	0	4	0
	D-factor	score	10	0	0	6	10	0	0	6	0
R7: Recover	Product lifetimes restarted	loops	3.0	0.0	0.0	1.0	2.0	0.0	0.0	1.0	0.0
	Product weight proportion addressed	%	0%	100%	33%	2%	82%	100%	100%	0%	0%
R8: Reject	Product proportion unable to recycle	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cumulative DL Effect	Total weight used (correctness check)	100%	100%	200%	100%	100%	300%	100%	300%	100%	100%
	Importance of Sustainability effects	%	50%	80%	80%	20%	60%	80%	60%	80%	40%
	Importance of Strategy considerations	%	50%	20%	20%	80%	40%	20%	40%	20%	60%
	Total Product DL Effect due to CE	+ loops	1.20	0.43	0.60	0.15	2.15	0.14	2.08	0.12	2.41

R type	Meaning (The best available option)	Sustainability Effect (a)	Justification	Strategic Benefit (b)	Justification
R1: Refuse	Reject the need	5.00	Reduced impact w.r.t. baseline	2.50	Cost cutting vs. revenue opportunity
R2: Rethink	Revise the application	4.85	Several impacts reduced into one	5.00	Retain revenue sources at reduced co
R3: Reuse	Return directly into primary use	4.65	Original impact unchanged	4.50	Retain revenue sources at small adde
R4: Repair	Update and return into primary use	4.30	Minor impact due to maintenance	3.00	Large cost recovery vs. large repair co
R5: Remanufacture	Retrieve components for reproduction	3.50	Shortened resupply chain impact	3.50	Medium cost recovery vs. small disass
R6: Recycle	Secondary use of purified raw materials	1.50	Extended resupply chain impact	2.50	Small cost recovery from recyclers and
R7: Recover	Recover material energy content	0.50	Minimum impact recovery	1.50	No cost recovery from incinerators
R8: Reject	Dispose without circular action	0.00	No impact recovery	1.00	Cost impact due to waste managemen

Material	Recycling Route (available and viable for cabin interiors)
Aluminium	Raw material recovery (secondary)
Brass	Raw material recovery (secondary)
Cu wiring	Raw material recovery (secondary)
Stainless Steel	Raw material recovery (secondary)
Cotton	Incineration (partial energy recovery)
Synthetic Leather	Incineration (partial energy recovery)
Silicone Rubber	Raw material recovery (secondary)
CFRP	Incineration (partial energy recovery)
GFRP	Incineration (partial energy recovery)
Epoxy Adhesive	Chemical Removal
Latex	Raw material recovery (secondary)
NOMEX HC	Incineration (partial energy recovery)
PA	Raw material recovery (secondary)
PC	Raw material recovery (secondary)
PEI	Raw material recovery (secondary)
PET Film	Raw material recovery (secondary)
PMMA	Raw material recovery (secondary)
PU Flexible Foam	Incineration (partial energy recovery)
PU Rigid Foam	Incineration (partial energy recovery)
PVC Film	Raw material recovery (secondary)

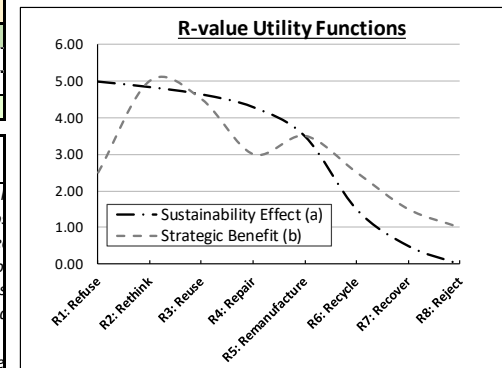


Table C.1-4: SSAPTI Core Sheet 4 – Qualitative LCA Evaluation

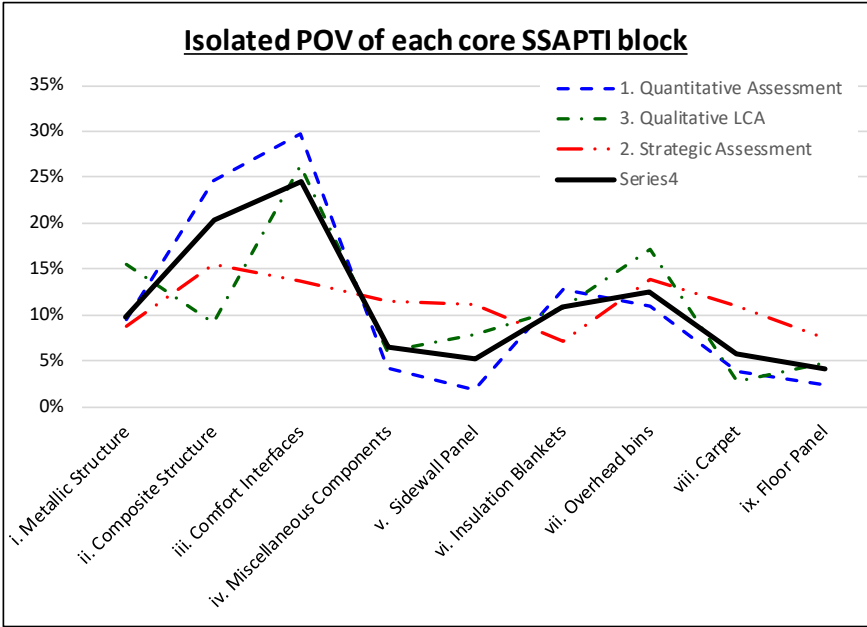
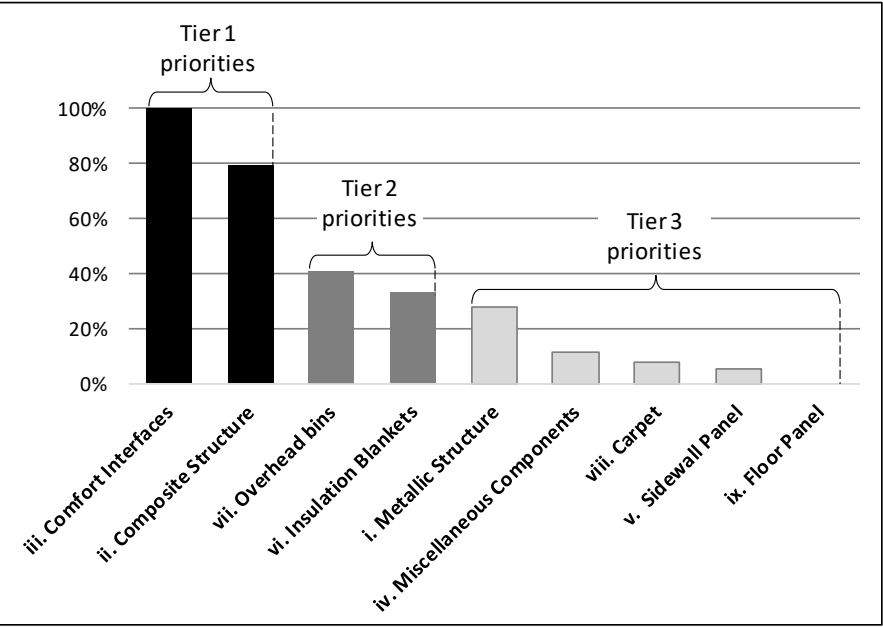
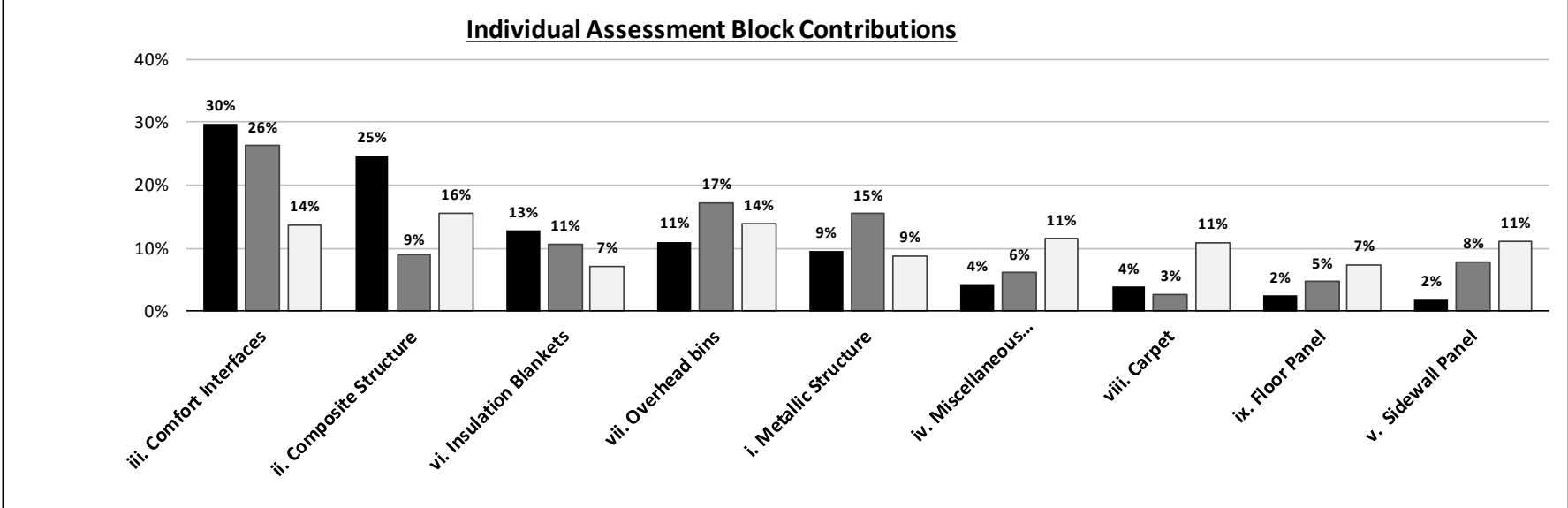
Qualitative Life Cycle Assessment										Seats												Cabin Linings						Bins			Cabin Floor																
Life Cycle Stage	Activity/Event	Stage Impact	Activity/Event Description	LCA Step Importance (point wise matrix pull)	Adjusted for LCA Stage contribution	Adjustment to Min/Max weights thresholds	LCA Step Weights (Final)	i. Metallic Structure				ii. Composite Structure				iii. Comfort Interfaces				iv. Miscellaneous Components				v. Sidewall Panel			vi. Insulation Blankets			vii. Overhead bins			viii. Carpet			ix. Floor Panel											
			Product Weight (kg/aircraft)	90%			Max	696				337				1015				268				349			438			682			140			187											
			Designations: S = Impact Score C = Confidence B = Bias	10%			Min	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R								
1. Component Supply	Material Transport	22.7%	Delivery of the raw material from the source to component supplier	0.090	0.0204	0.1163	2.64%	1	H		1.00	2	M	H	2.25	2	M	H	2.25	1	M	L	1.25	3	M	H	3.25	1	L	M	1.50	3	M	H	3.25	1	M	L	1.25	2	M	H	2.25				
	Storage Impacts		Challenges associated with pre-production storage (e.g. shelf life, temperature)	0.090	0.0204	0.1163	2.64%	1	H		1.00	2	M	H	2.25	2	M	L	1.75	2	L	M	2.25	3	M	L	2.75	5	H		5.00	3	M	L	2.75	1	M	L	1.25	3	M	H	3.25				
	Production Complexity		Component production effort (duration, process chain length, technology)	0.223	0.0506	0.1405	3.19%	2	M	M	2.00	5	H		5.00	3	M	H	3.25	3	M	L	2.75	3	M	L	2.75	2	M	L	1.75	3	M	L	2.75	2	M	H	2.25	5	M	M	4.75				
	Production Needs		Environmental impact of indirect component production inputs (e.g. consumables)	0.163	0.0370	0.1296	2.94%	4	M	L	3.75	5	H		5.00	1	M	H	1.50	1	M	H	1.50	2	M	H	2.25	1	M	L	1.25	2	M	H	2.25	2	M	L	1.75	4	M	H	4.25				
	Production Efficiency		Proportion of material & power input directly converted into components to waste	0.183	0.0416	0.1333	3.03%	4	L	H	4.25	5	H		5.00	2	M	M	2.00	2	L	H	2.75	1	M	H	1.50	2	M	L	1.75	1	M	H	1.50	3	M	L	2.75	5	M	M	4.75				
	Component Quality		The proportion of component scrap/rework cases by both supplier and integrator	0.163	0.0370	0.1296	2.94%	2	M	L	1.75	5	L	L	4.00	2	M	L	1.75	2	M	H	2.25	3	L	L	2.50	1	M	L	1.25	3	L	L	2.50	2	M	H	2.25	4	L	H	4.25				
2. Product Integration	Corporate Ethics	20.8%	Non-technical aspects affecting material/component supply (e.g. fair practices)	0.087	0.0198	0.1158	2.63%	5	L	H	4.50	1	M	H	1.50	2	L	H	2.75	3	M	L	2.75	1	M	L	1.25	3	L	L	2.50	1	M	L	1.25	1	L	L	1.50	5	L	M	4.50				
	Component Transport		Delivery of the individual components from the supplier to product integrator	0.090	0.0188	0.1150	2.61%	2	M	L	1.75	4	M	H	4.25	2	M	L	1.75	1	M	H	1.50	4	M	L	3.75	2	M	H	2.25	5	M	L	4.50	1	H	H	1.00	4	M	H	4.25				
	Storage Impacts		Challenges associated with pre-integration storage (e.g. shelf life, temperature)	0.090	0.0188	0.1150	2.61%	1	H		1.00	3	M	H	3.25	3	L	M	3.00	2	L	M	2.25	2	M	H	2.25	5	M	H	4.75	3	M	H	3.25	2	L	H	2.75	2	L	H	2.75				
	Integration Complexity		Effort involved in product integration (duration, process chain length, technology)	0.221	0.0459	0.1367	3.11%	3	M	H	3.25	4	M	H	4.25	4	M	H	4.25	3	L	H	3.50	2	L	H	2.75	3	L	L	2.50	4	M	H	4.25	2	L	L	1.75	3	M	L	2.75				
	Integration Needs		Environmental impact of indirect product integration inputs (e.g. industrialisation)	0.161	0.0336	0.1269	2.88%	4	M	L	3.75	5	M	H	4.75	4	M	H	4.25	3	L	M	3.00	2	M	L	2.25	3	L	H	3.50	4	M	H	4.25	1	L	M	1.50	2	L	L	1.75				
	Integration Efficiency		The extent of waste (material & energy) resulting from the integration process	0.174	0.0362	0.1290	2.93%	4	H		4.00	4	H		4.00	4	H		4.00	4	H		4.00	2	L	M	2.25	1	M	H	1.50	2	L	L	1.75	2	M	L	1.75	2	M	L	1.75				
3. Product Installation	Product Quality	7.4%	The proportion of final product scrap/rework cases by both integrator and installer	0.153	0.0319	0.1256	2.85%	1	L	M	1.50	3	M	H	3.25	4	M	H	4.25	3	L	L	2.50	2	M	L	1.75	3	L	H	3.50	3	M	H	3.25	2	M	L	1.75	2	M	L	1.75				
	Corporate Ethics		Non-technical aspects affecting product integration (e.g. working shifts)	0.110	0.0229	0.1183	2.69%	1	H		1.00	1	H		1.00	1	H		1.00	1	H		1.00	1	H		1.00	2	H		2.00	1	H		1.00	1	H		1.00								
	Product Transport		Delivery of the complete product from product integrator to the installer (MRO)	0.090	0.0067	0.1054	2.39%	5	M	L	4.50	5	H		5.00	4	M	H	4.25	2	L	L	1.75	4	M	H	4.25	2	M	L	1.75	5	L	H	4.50	1	L	L	1.50	1	M	L	1.25				
	Storage Impacts		Challenges associated with pre-installation storage (e.g. humidity, cleanliness)	0.090	0.0067	0.1054	2.39%	1	H		1.00	1	H		1.00	4	L	L	3.25	3	L	L	2.50	1	L	L	1.50	5	M	L	4.50	2	L	L	1.75	2	M	L	1.75	2	M	L	1.75				
	Installation Complexity		Effort involved in product installation (duration, process chain length, technology)	0.223	0.0166	0.1133	2.57%	2	M	H	2.25	2	M	L	1.75	1	M	L	1.25	3	M	L	2.75	3	M	H	3.25	5	M	L	4.50	4	M	H	4.25	2	M	L	1.75	2	M	H	2.25				
	Installation Needs		Environmental impact of indirect product installation inputs (e.g. test equipment)	0.163	0.0121	0.1097	2.49%	2	M	H	2.25	1	M	L	1.25	1	L	H	2.00	2	L	L	1.75	2	M	L	1.75	3	L	H	3.50	3	M	L	2.75	1	M	H	1.50	2	M	L	1.75				
4. Product Operation	Installation Efficiency	31.8%	The extent of waste (material & energy) resulting from the installation process	0.183	0.0137	0.1109	2.52%	1	H		1.00	1	H		1.00	1	L	M	1.50	2	L	L	1.75	2	L	H	2.75	4	L	H	4.25	3	L	H	3.50	4	L	L	3.25	1	M	H	1.50				
	Installation Quality		The extent of certification & usability tests failed requiring rework	0.163	0.0121	0.1097	2.49%	1	H		1.00	1	H		1.00	4	L	L	3.25	4	L	L	3.25	3	L	H	3.50	2	L	H	2.75	4	L	H	4.25	3	L	L	2.50	1	M	L	1.25				
	Corporate Ethics		Non-technical aspects affecting product installation (e.g. working conditions)	0.087	0.0065	0.1052	2.39%	3	M	M	3.00	3	M	M	3.00	2	M	M	2.00	3	M	M	3.00	2	M	M	2.00	3	M	M	3.00	3	M	M	3.00	2	M	M	2.00	3	M	M	3.00				
	Operational Needs		The environmental impact of supplies for product operation (e.g. consumables)	0.290	0.0920	0.1736	3.95%	1	H		1.00	1	H		1.00	5	H		5.00	2	L	H	2.75	3	M	H	3.25	1	M	L	1.25	3	M	H	3.25	4	M	L	3.75	1	H		1.00				
	Maintenance Complexity		Maintenance/servicing effort (duration, process chain length, technology)	0.196	0.0623	0.1499	3.41%	2	M	H	2.25	4	L	H	4.25	3	L	L	2.50	5	M	H	4.75	2	M	L	1.75	3	M	H	3.25	2	M	L	1.75	2	L	L	1.75	4	L	L	3.25				
	Maintenance Needs		Environmental impact of indirect product maintenance inputs (e.g. equipment)	0.196	0.0623	0.1499	3.41%	5	M	L	4.50	5	M	H	4.75	3	L	H	3.50	2	M	H	2.25	3	M	H	3.25	2	M	L	1.75	3	M	H	3.25	3	M	L	2.75	4	M	H	4.25				
5. Product Dismantling	Maintenance Efficiency	5.6%	The extent of waste (material & energy) resulting from the servicing process	0.196	0.0623	0.1499	3.41%	3	L	L	2.50	4	L	H	4.25	4	L	L	3.25	2	L	H	2.75	3	L	H	3.50	5	L	L	4.00	3	L	H	3.50	2	L	H	2.75	3	L	H	3.50				
	Corporate Ethics		Non-technical aspects affecting product servicing and maintenance	0.122	0.0387	0.1310	2.98%	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00				
	Removal Complexity		Effort involved in product removal (duration, process chain length, technology)	0.260	0.0145	0.1116	2.54%	1	H		1.00	4	M	L	3.75	2	M	H	2.25	3	L	H	3.50	2	M	L	1.75	2	M	L	1.75	2	M	L	1.75	1	M	H	1.50	1	H		1.00				
	Removal Needs		Environmental impact of indirect product removal inputs (e.g. tooling)	0.209	0.0117	0.1094	2.49%	1	H		1.00	2	M	H	2.25	2	M	H	2.25	3	L	H	3.50	2	M	L	1.75	2	L	H	2.75	2	M	L	1.75	1	M	H	1.50	1	H		1.00				
	Storage Impacts		Challenges associated with storage of the dismantled product (e.g. humidity)	0.070	0.0039	0.1031	2.34%	1	H		1.00	2	L	H	2.75	4	L	H	4.25	2	L	L	1.75	1	M	H	1.50	5	L	L	4.00	1	M	H	1.50	3	L	L	2.50	1	L	H	2.00				
	Post-Removal Impacts		Cabin servicing needs due to product removal consequences (e.g. damage)	0.329	0.0184	0.1147	2.61%	1	M	H	1.50	1	H		1.00	1	H		1.00	1	M	L	1.25	4	M	L	3.75	5	M	L	4.50	4	M	L	3.75	5	L	L	4.00	4	L	L	3.25				
6. Product End-of-Life	Corporate Ethics	11.7%	Non-technical aspects affectingn product dismantling (e.g. safety)	0.133	0.0074	0.1059	2.41%	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00				
	Phasing-Out Transport		Delivery of the dismantled product to waste, recycling, or refreshing facilities	0.155	0.0181	0.1145	2.60%	2	M	L	1.75	1	H		1.00	3	L	L	2.50	2	L	L	1.75	4	L	L	3.25	1	H		1.00	3	L	L	2.50	1	H		1.00	2	L	L	1.75				
	End-of-Life Complexity		Effort involved in waste treatment (duration, process chain length, technology)	0.236	0.0276	0.1221	2.78%	5	L	L	4.00	1	H		1.00	2	L	H	2.75	3	L	L	2.50	1	M	H	1.50	1	H		1.00	1	M	H	1.50	1	H		1.00	5	H		5.00				
	End-of-Life Needs		Environmental impact of indirect waste treatment inputs (e.g. consumables)	0.191	0.0224	0.1179	2.68%	5	M	H	4.75	1	H		1.00	4	L	H	4.25	3	L	H	3.50	2	L	L	1.75	1	H		1.00	2	L	L	1.75	1	H		1.00	4	L	L	3.25				
	End-of-Life Impacts		Environmental impact of End-of-Life treatment processes and remaining landfill	0.295	0.0345	0.1276	2.90%	3	L	H	3.50	5	H		5.00	3	L	H	3.50	2	L	L	1.75	1	L	H	2.00	5	H		5.00	1	L	H	2.00	5	H		5.00	3	L	H	3.50				
	Corporate Ethics		Non-technical aspects affecting waste treatment (e.g. local community impact)	0.124	0.0145	0.1116	2.54%	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	3	M	M	3.00	2	M	M	2.00	3	M	M	3.00	3	M	M	3.00
								Total i:		1706.3		Total ii:		1002.8		Total iii:		2898.6		Total iv:		670.8		Total v:		861.8		Total vi:		1184.1		Total vii:		1903.0		Total viii:		301.1		Total ix:		518.4					
								Total i (%):		15.4%		Total ii (%):		9.1%		Total iii (%):		26.2%		Total iv (%):		7.8%		Total v (%):		6.1%		Total vi (%):		10.7%		Total vii (%):		17.2%		Total viii (%):		2.7%									

Table C.1-5: SSAPTI Core Sheet 5 – Strategic Assessment

Qualitative Assessment on Strategic Criteria					Seats																Cabin Linings								Bins				Cabin Floor							
Criteria Categories	Criteria ID	Strategic Criteria	Criteria Definition: "What level of < ... > is exhibited by the assessed component?"	Criteria Importance (amend as required)	i. Metallic Structure				ii. Composite Structure				iii. Comfort Interfaces				iv. Miscellaneous Components				v. Sidewall Panel				vi. Insulation Blankets				vii. Overhead bins				viii. Carpet				ix. Floor Panel			
	#		Column Designations: S = Importance Score C = Competence	B = Bias	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R	S	C	B	R				
A. Revenue Potential	1	Brand Image	impact on the operator's brand image	0.023	1	H		1.00	4	L	H	4.25	5	H		5.00	3	L	L	2.50	5	M	L	4.50	1	H		1.00	4	L	H	4.25	3	L	H	3.50	1	H		1.00
	2	Promotion Channels	operator's promotion channel facilitation	0.023	1	H		1.00	5	M	L	4.50	3	M	H	3.25	1	M	H	1.50	4	L	L	3.25	1	H		1.00	2	L	H	2.75	2	L	L	1.75	1	H		1.00
	3	Upfront Pricing	ticket pricing effect / adjustment leverage	0.023	1	H		1.00	4	L	L	3.25	5	M	H	4.75	2	M	L	1.75	3	M	H	3.25	1	H		1.00	4	M	H	4.25	2	L	L	1.75	1	H		1.00
	4	Access Pricing	ancillary pricing adjustment / expansion leverage	0.022	1	H		1.00	2	M	L	1.75	5	M	H	4.75	3	M	L	2.75	2	M	L	1.75	1	H		1.00	3	M	L	2.75	1	L	L	1.50	1	H		1.00
	5	Growth Potential	stable/growing (but not declining) demand for baseline design/version	0.018	4	M	L	3.75	5	H		5.00	4	M	H	4.25	2	M	L	1.75	2	M	H	2.25	1	H		1.00	4	M	L	3.75	3	M	H	3.25	3	M	L	2.75
	6	Innovation Capacity	viable potential for future design/version evolution	0.013	4	L	H	4.25	5	H		5.00	4	L	H	4.25	3	M	L	2.75	3	M	H	3.25	2	L	H	2.75	3	L	H	3.50	3	M	H	3.25	3	L	H	3.50
B. Collaborative Potential	7	Distribution Channels	capability/effectiveness for the operator's product/service distribution	0.014	1	H		1.00	5	L	L	4.00	2	M	H	2.25	3	L	M	3.00	3	M	H	3.25	1	H		1.00	4	M	H	4.25	1	M	H	1.50	1	H		1.00
	8	Advertising Channels	facilitation for partnering stakeholder product/service promotion	0.018	1	H		1.00	5	M	H	4.75	3	M	H	3.25	2	L	L	1.75	5	L	H	4.50	1	H		1.00	5	L	H	4.50	2	M	L	1.75	1	H		1.00
	9	Co-Branding Potential	viable collaboration potential (e.g. co-design or joint service delivery)	0.011	1	H		1.00	4	M	H	4.25	5	H		5.00	2	L	L	1.75	4	M	H	4.25	1	H		1.00	4	M	L	3.75	2	L	H	2.75	1	H		1.00
	10	Retail Channels	facilitation for partnering stakeholder product/service distribution	0.023	1	H		1.00	5	H		5.00	2	L	H	2.75	4	L	L	3.25	2	L	H	2.75	1	H		1.00	4	M	L	3.75	2	L	L	1.75	1	H		1.00
C. Passenger Perception	11	Physical Comfort	contribution to user's mechanical bodily comfort	0.025	4	M	L	3.75	5	H		5.00	5	H		5.00	4	M	H	4.25	4	M	H	4.25	1	H		1.00	4	M	L	3.75	3	M	L	2.75	3	M	H	3.25
	12	Cabin Purity	contribution to cabin cleanliness or the user's perception of it	0.023	2	H		2.00	5	H		5.00	5	H		5.00	3	M	H	3.25	4	M	H	4.25	3	M	L	2.75	4	M	L	3.75	5	H		5.00	2	M	L	1.75
	13	Aesthetics	impact on the user's subjective perception of a visually appealing cabin	0.019	3	H		3.00	5	H		5.00	5	H		5.00	2	M	L	1.75	5	M	H	4.75	2	M	H	2.25	5	L	H	4.50	5	H		5.00	2	M	H	2.25
	14	Autonomy	contribution to the user's privacy and operational independence	0.019	2	H		2.00	5	H		5.00	3	M	H	3.25	4	M	H	4.25	3	M	H	3.25	1	H		1.00	5	M	H	4.75	2	M	H	2.25	1	H		1.00
	15	Ambience	contribution to the user's mental and emotional state	0.015	1	H		1.00	5	M	L	4.50	5	H		5.00	2	M	L	1.75	5	H		5.00	4	M	L	3.75	5	H		5.00	5	M	L	4.50	2	M	H	2.25
	16	Trendiness	impact to the user's perception of cabin alignment with popular trends	0.013	2	M	H	2.25	5	M	H	4.75	5	H		5.00	2	M	L	1.75	4	M	H	4.25	1	H		1.00	5	H		5.00	4	M	L	3.75	1	H		1.00
D. Passenger Experience	17	Ergonomics	contribution to the user's operational convenience	0.027	2	L	H	2.75	5	H		5.00	4	M	H	4.25	4	M	M	4.00	4	M	H	4.25	1	H		1.00	5	H		5.00	2	L	H	2.75	1	M	L	1.25
	18	Cabin Environment	impact on the quality / properties of cabin air	0.028	1	H		1.00	3	M	H	3.25	5	M	L	4.50	2	M	L	1.75	2	L	L	1.75	5	H		5.00	2	M	M	2.00	5	H		5.00	1	H		1.00
	19	Experiences	impact on the content, quality, availability of the user's on-board experiences	0.016	1	H		1.00	4	M	H	4.25	3	M	L	2.75	5	M	H	4.75	2	M	H	2.25	1	L	H	2.00	4	M	H	4.25	3	M	L	2.75	1	H		1.00
	20	Useability	impact on the user's ability to operate cabin equipment independently	0.011	1	H		1.00	4	M	H	4.25	5	H		5.00	4	M	L	3.75	2	M	L	1.75	1	H		1.00	4	H		4.00	2	L	L	1.75	1	H		1.00
	21	Interfaces	contribution to the availability / operation of the user's system interfaces	0.013	3	M	L	2.75	4	M	H	4.25	5	H		5.00	5	H		5.00	3	M	H	3.25	1	H		1.00	4	M	H	4.25	3	M	H	3.25	2	L	L	1.75
E. Outside Interfaces	22	Outside View	impact on the user's experiences involving cabin outside views	0.009	1	H		1.00	4	M	L	3.75	2	M	L	1.75	1	M	H	1.50	5	H		5.00	4	M	H	4.25	1	M	L	1.25	1	H		1.00	1	H		1.00
	23	In-Flight Information	impact on the availability, quality, and content of inward information flow	0.020	1	H		1.00	4	M	L	3.75	1	H		1.00	5	H		5.00	1	H		1.00	1	H		1.00	3	H		3.00	1	H		1.00	1	H		1.00
	24	In-Flight Communication	impact on the availability / quality of internal & external cabin communication	0.018	1	H		1.00	3	M	H	3.25	1	H		1.00	5	H		5.00	1	H		1.00	1	H		1.00	3	H		3.00	1	H		1.00	1	H		1.00
	25	Journey Continuity	contribution to the user's preceding/subsequent journey continuity	0.019	1	H		1.00	2	L	H	2.75	2	M	H	2.25	3	M	H	3.25	1	L	L	1.50	1	H		1.00	5	H		5.00	2	M	H	2.25	1	H		1.00
F. Operational Cabin Qualities	26	Passenger Capacity	impact on passenger capacity within a given cabin	0.030	4	M	H	4.25	4	M	H	4.25	3	M	H	3.25	1	M	H	1.50	3	M	L	2.75	3	M	H	3.25	5	H		5.00	2	M	H	2.25	2	M	H	2.25
	27	Configuration	attainable freedom for cabin layout configurations	0.012	5	M	H	4.75	5	H		5.00	2	M	L	1.75	4	M	L	3.75	5	H		5.00	2	M	L	1.75	5	H		5.00	4	M	L	3.75	2	M	H	2.25
	28	Luggage Storage	attainable freedom for storage layout within given cabin	0.015	4	M	H	4.25	4	M	L	3.75	3	M	L	2.75	3	L	H	3.50	2	M	L	1.75	2	M	L	1.75	5	H		5.00	3	M	H	3.25	2	M	L	1.75
	29	Turnaround Efficiency	impact on passenger ingress/egress and cabin turnaround processes	0.015	4	M	L	3.75	3	M	H	3.25	2	M	H	2.25	2	M	L	1.75	2	M	L	1.75	1	M	H	1.50	5	H		5.00	4	M	H	4.25	1	M	L	1.25
	30	Service Capabilities	impact on the available cabin service delivery capabilities and quality	0.016	1	H		1.00	4	M	H	4.25	3	M	H	3.25	4	M	H	4.25	2	L	L	1.75	1	H		1.00	3	L	L	2.50	3	L	L	2.50	1	H		1.00
	31	Crew Information	impact on cabin service information content and availability	0.011	1	H		1.00	2	M	H	2.25	1	H		1.00	4	M	H	4.25	1	H		1.00	1	H		1.00	3	M	L	2.75	1	H		1.00	1	H		1.00
	32	Crew Operations	impact on quality (effectiveness & efficiency) of cabin service delivery	0.015	2	M	L	1.75	2	M	H	2.25	2	M	H	2.25	3	L	H	3.50	2	M	L	1.75	1	H		1.00	3	M	L	2.75	4	M	H	4.25	3	M	H	3.25
G. Integrated Cabin Quality	33	Adaptability	effort/complexity involved in adapting/adjusting to various needs/purposes	0.015	5	H		5.00	5	H		5.00	4	M	H	4.25	4	M	L	3.75	2	L	H	2.75	2	M	L	1.75	3	L	H	3.50	3	M	H	3.25	1	L	L	1.50
	34	Applicability	standardisation attainable across the different cabin versions/fleet models	0.015	5	H		5.00	5	H		5.00	3	M	H	3.25	4	M	H	4.25	4	M	H	4.25	4	H		4.00	4	M	H	4.25	3	M	L	2.75	5	H		5.00
	35	Safety	prevention, aversion, or mitigation of the possible risks/hazards	0.043	5	H		5.00	5	H		5.00	5	H		5.00	4	L	L	3.25	3	M	H	3.25	4	H		4.00	4	M	H	4.25	3	M	H	3.25	5	H		5.00
H. Implementation NRC	36	Availability	technology readiness/market maturity	0.012	1	H		1.00	5	M	L	4.50	3	M	H	3.25	2	M	H	2.25	2	L	L	1.75	2	L	H	2.75	2	L	L	1.75	2	L	H	2.75	3	M	L	2.75

Table C.1-6: SSAPTI Core Sheet 6 – Results Aggregation

Aggregated Assessment Results			Seats				Cabin Linings		Bins	Cabin Floor	
LCIA Method selected:	Combined Scores		i. Metallic Structure	ii. Composite Structure	iii. Comfort Interfaces	iv. Miscellaneous Components	v. Sidewall Panel	vi. Insulation Blankets	vii. Overhead bins	viii. Carpet	ix. Floor Panel
1. Quantitative Assessment	Contribution weight A:	60%	9%	25%	30%	4%	2%	13%	11%	4%	2%
3. Qualitative LCA	Contribution weight C:	10%	15%	9%	26%	6%	8%	11%	17%	3%	5%
2. Strategic Assessment	Contribution weight B:	30%	9%	16%	14%	11%	11%	7%	14%	11%	7%
RESULTS	Aggregated Performance		9.9%	20.4%	24.6%	6.6%	5.2%	10.9%	12.5%	5.8%	4.2%
	Component-Level Priorities		5	2	1	6	8	4	3	7	9
	Distance Between Priorities		1.0%	4.2%	N/A	3.3%	0.6%	1.6%	7.9%	0.7%	1.0%
	Product-Level Performance		61.4%				16.1%		12.5%	10.0%	



C.2 SSAPTI Framework Screenshots – Supporting Blocks

This Appendix contains the screenshots for 8 supporting blocks used in SSAPTI. Each screenshot depicts a dedicated MS Excel sheet of the original SSAPTI file uploaded in CORD (see Ref. [1] in [Section 5](#)).

Table C.2-1: SSAPTI Supporting Sheet 1 – LCIA Method Selection:

SSAPTI supporting sheet 1/8: presents the key features of various LCIA methods considered for potential SSAPTI implementation. Indicates the decision to select or reject each method. This sheet is used to justify LCIA method selection or rejection based on relevance to the task pursued when developing SSAPTI.

Table C.2-2: SSAPTI Supporting Sheet 2 – IC Generalisation:

SSAPTI supporting sheet 2/8: shows the aggregation of IC (Impact Categories) used with each LCIA method into generalised categories. It is used to derive a common set SSAPTI-specific IC used for quantitative assessment of cabin items. Helps to resolve the issue of dissimilar IC definition used with each LCIA method.

Table C.2-3: SSAPTI Supporting Sheet 3 – IC Importance Weighting:

SSAPTI supporting sheet 3/8: presents the implementation of DIVAPIME MCDA method to derive relative importance weights for the IC defined in Table C.2-2.

Table C.2-4: SSAPTI Supporting Sheet 4 – ReCiPe Material Impacts:

SSAPTI supporting sheet 4/8: presents the format and sequence for pulling the relative material impacts from the ReCiPe method using SimaPro software. This sheet constitutes an example of normalised outputs from one LCIA method. All nine output sheets are uploaded into CORD, one sheet for each method.

Table C.2-5: SSAPTI Supporting Sheet 5 – LCIA Outputs Comparison:

SSAPTI supporting sheet 5/8: compares the unweighted scores from all 9 LCIA methods used in SSAPTI for the 9 products assessed in the case study presented in Section 5.2. Numerical format is preferred to allow granular representation of product impacts for the user’s benefit when comparing the exact LCIA variations.

Table C.2-6: SSAPTI Supporting Sheet 6 – Qualitative LCA Weighting:

SSAPTI supporting sheet 6/8: presents the pairwise comparison of product life cycle steps to derive relative criticality for qualitative life cycle impact assessment.

Table C.2-7: SSAPTI Supporting Sheet 8 – References Used in SSAPTI:

SSAPTI supporting sheet 8/8: lists relevant sources used in the different blocks across SSAPTI. For example, external sources are used to define the exact size of the A320 floor to derive material content per cabin using single floor panel data.

Table C.2-1: SSAPTI Supporting Sheet 1 – LCIA Method Selection

LCIA Method	General Information	Key features	Normalisation included	Selection Decision	Ref.
BEES (Building for Environmental and Economic Sustainability)	A tool implementing the method. Measures the environmental performance in the building industry in line with ISO 14040 series.	Includes the consideration of costs (Economic assessment), focuses on the construction industry	Not reviewed	REJECT: construction is relevant for airports, but not transport cabins	[10]
WAVE (Water Accounting and Vulnerability Evaluation), 2014	Focuses on analysing freshwater vulnerability due to consumption by the product supply chain.	The first method to account for atmospheric evaporation of the water.	Not reviewed	REJECT: focused on Water scarcity; use broader methods that include water	[11]
Boulay et al., 2011	Focuses on analysing freshwater scarcity on human health and the approaches to mitigate it using financial resources.	Not reviewed	Not reviewed	REJECT: focused on Water Scarcity and Human Health; use broader methods	[12]
CML, 2001	Implemented in CMLCA software.	BL = most common IC, non-BL = deeper assessment. Contains all characterisation factors mentioned in the Handbook on LCA. Non-baseline version is extended with additional factors pulled from other recognised methods, such as Eco-Indicator 99 or EPS.	Excludes weighting; includes normalization for EU, NL, West Europe, World at various temporal levels.	ACCEPT: a detailed method for Europe region	[13], [14]
Crustal Scarcity Indicator, 2020	Midpoint mineral resource impact assessment method based on long-term global elemental scarcity proxies: reserves, reserve base, reserves + cumulative production, ore deposits.	Uses kg silicon equivalents per kg of subject element.	Not reviewed	REJECT: focused on mineral resources that are not prevalent in cabins (except AI)	[15]
Cumulative Energy Demand, 1997	A method for determining and comparing the energy intensity of processes by calculating the total primary energy input into product creation.	Used for product environmental performance screening based on quantifying its use of primary energy; does not address phasing out.	None	REJECT: focused on non-renewable energy sources; omits waste - a key cabin EOL impact	[16], [17]
Eco-indicator, 1999	A method for calculating the bespoke "eco-indicator" values of materials and processes used across the product life cycle.	Performs relative comparison to produce a single-score result. Covers production, transportation, operations, and disposal.	EUR; 0.1 for Etox cat.; 1.0 for HH & Res.	REJECT: succeeded by the ReCiPe method	[18]
Ecological Scarcity / Eco-Points, 2013	A method for assessing the relative environmental impact of pollutant emissions & resource consumption against benchmark.	Aggregates the different impacts into a single "eco-point" unit derived from the legal & policy targets defined for a specific region.	Not reviewed	REJECT: focused on Switzerland, impact calculation for other regions is challenging.	[19], [20]
Ecosystem Damage Potential	Focuses on land transformation & occupation	Not reviewed	Not reviewed	REJECT: low relevance to transport cabins (production facilities only); use broader methods instead	[21], [22]
EDIP (Environmental Design of Industrial Products), 1997	Focuses on the Danish industry	Not reviewed	Not reviewed	REJECT: narrow focus on the Danish industry, irrelevant for cabins	[23]
EF Method, 2011	A method to measure the environmental impact of goods, services and organisations from across the supply chain (extraction of raw materials, production, use, final waste management).	Includes Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF), produces a single score.	None	ACCEPT: popular, continuously developed method for Europe region	[24], [25], [26]
EN15804 Method	Provides the rules for construction products, services, and processes regardless of technical and functional performance.	Not reviewed	Not reviewed	REJECT: construction is relevant for airports, but not transport cabins	[27]
Environmental Prices, 2017	A midpoint method for calculating the monetary costs due to pollution	Produces a single-score indicator (EUR/kg)	Normalisation per region	ACCEPT: provides a monetary point of view	[28], [29], [30]
EPD (Environmental Product Declarations), 2018	Provides a transparent and objective quantitative basis for the comparison of products and services	The output is provided by the OEM and must be verified by an independent expert to be valid for 5 years.	None	REJECT: used for declaration reports in line with Product Category Rule, not relevant for cabin assessment task	[31]
EPS (Environmental Priority Strategies), 2015	Measures the criticality of environmental impact in monetary terms based on the willingness to pay for the restoration of changes.	Produces a single-score ELU (Environmental Load Unit) output	ELU includes characterization, normalization, weighting	ACCEPT: provides a monetary point of view; use the "2015d" version for full inclusion	[32]
Water Scarcity Indicator (Hoekstra), 2012	Calculates the fraction between the water consumed and available.	Includes runoff water	Includes regional factors as weighted averages	REJECT: focused on Water scarcity; use broader methods that include water	[33]
ILCD (International Reference Life Cycle Data System), 2011	A consensus from analysing several Midpoint & Endpoint methods by the European Commission.	Optimises impact characterisation by using the best sources for each IC; recommended for application in the European context	Regional, Global	ACCEPT: a popular, continuously developed method for Europe region	[34]
IMPACT (IMPact Assessment of Chemical Toxics), 2002+	Focuses on human, aquatic, and terrestrial ecotoxicity; combines bespoke factors with other impacts from existing methods.	Divides the impact / unit emission by total impact of substances in categories where characterization factors are available, per person per year; 4 damage categories	None	ACCEPT: a popular, continuously developed method for Europe region	[35]
IPCC GWP, 2013/2021	Focuses on Climate Change impacts through direct global warming potential of air emissions	Produces a single-score result in kg CO2 equivalent/kg	None	ACCEPT: provides Global Warming point of view: narrow, but important	[36]
LIME (Life-cycle Impact assessment Method based on Endpoint modelling), 2003	Not reviewed	Not reviewed	Not reviewed	REJECT: focus constrained to Japan only	[37]
LUCAS (LCIA method Used for a Canadian-Specific context), 2006	Not reviewed	Not reviewed	Not reviewed	REJECT: focus constrained to Canada only	[38]
MEEuP (Methodology study for Ecodesign of Energy-using Products), 2005	Focused on energy-using products	Not reviewed	Not reviewed	REJECT: does not apply to all cabin products	[39]
Motoshita et al 2010	An endpoint indicator addressing human health-related categories	Not reviewed	Not reviewed	REJECT: focuses on Human Health; use broader methods that include HH	[40]
ReCiPe, 2016	Combines Eco-Indicator 99 + CML factors at Midpoint, Endpoint, Intermediate levels.	Includes individualist (I), hierarchist (H), and egalitarian perspectives; 3 damage categories	Representative at the global scale	ACCEPT: supersedes Eco-Indicator method, globally used	[41]
Selected LCI Results	Assesses the impact of emissions from life cycle processes	Not reviewed		REJECT: covers the processes only - only useful where the core methods do not reflect process emissions	[21], [22]
TRACI (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) 2.1, 2008	A midpoint method for calculating the monetary costs due to pollution	Covers the North-American region	US only, and US + Canada combined	ACCEPT: focuses on US and Canada region, offers a comparison baseline for Europe	[42]
USEtox (UNEP-SETAC Ecotoxicity), 2010	Calculates environmental impact to identify and obtain human- & eco-toxicological impacts of chemicals	based on scientific consensus	Not reviewed	REJECT: uses interim characterisation factors, therefore high uncertainty	[43]

Table C.2-2: SSAPTI Supporting Sheet 2 – IC Generalisation

Generalised Impact Categories	CML(nb)	EF 3	EP 2015	ILCD 2011	IMP 2002+	ReCiPe 2016	TRACI 2	EPS 2015d
Global Warming / Climate Change	Global warming	Climate Change	Climate change	Climate change	Global warming	Global warming, Human health Global warming, Terrestrial ecosystems Global warming, Freshwater ecosystems	Global warming	Species extinction YOLL Malnutrition Fish&meat production capacity Drinking water Irrigation water Diarrhea Gravation of angina pectoris Working capacity Asthma cases COPD severe Cancer Skin cancer Low vision Poisoning Intellectual disability: mild Osteoporosis Renal dysfunction Housing availability Separations Depletion of abiotic resources Crop growth capacity Production capacity for fruit&vegetables Wood growth capacity
Ozone Depletion	Ozone layer depletion	Ozone depletion	Ozone depletion	Ozone depletion	Ozone layer depletion	Stratospheric ozone depletion	Ozone depletion	
Photochemical oxidant/ozone formation	Photochemical oxidation	Photochemical ozone formation	Photochemical oxidant formation	Photochemical ozone formation	N/A	Ozone formation, Human health Ozone formation, Terrestrial ecosystems	N/A	
Human Health (combined)	Malodorous air Human Toxicity	Particulate matter Human toxicity, non-cancer Human toxicity, cancer	Particulate matter formation Human toxicity	Particulate matter Human toxicity, non-cancer effects Human toxicity, cancer effects	Respiratory inorganics Respiratory organics Non-carcinogens Carcinogens	Fine particulate matter formation Human non-carcinogenic toxicity Human carcinogenic toxicity	Smog Respiratory effects Non carcinogenics Carcinogenics	
Ionizing radiation	Ionising radiation	Ionising radiation	Ionising radiation	Ionizing radiation HH Ionizing radiation E (interim)	Ionizing radiation	Ionizing radiation	N/A	
Acidification (combined)	Acidification (fate not incl.)	Acidification	Terrestrial acidification	Acidification	Terrestrial acid/nutri Aquatic acidification	Terrestrial acidification	Acidification	
Eutrophication (combined)	Eutrophication (incl. fate)	Eutrophication, freshwater Eutrophication, marine Eutrophication, terrestrial	Freshwater eutrophication Marine eutrophication	Terrestrial eutrophication Freshwater eutrophication Marine eutrophication	Aquatic eutrophication	Freshwater eutrophication Marine eutrophication	Eutrophication	
Ecotoxicity (combined)	Freshwater Ecotoxicity Marine Ecotoxicity Terrestrial Toxicity	Ecotoxicity, freshwater	Terrestrial ecotoxicity Freshwater ecotoxicity Marine ecotoxicity	Freshwater ecotoxicity	Aquatic ecotoxicity Terrestrial ecotoxicity	Terrestrial ecotoxicity Freshwater ecotoxicity Marine ecotoxicity	Ecotoxicity	
Depletion of Energy & Fuels	N/A	Resource use, fossils	Fossil depletion	Mineral, fossil & ren resource depletion	Non-renewable energy	Fossil resource scarcity	Fossil fuel depletion	
Depletion of Minerals & Metals	Abiotic depletion - elements	Resource use, minerals and metals	Metal depletion	N/A	Mineral extraction	Mineral resource scarcity	N/A	
Land Use (combined)	Land competition	Land use	Agricultural land occupation Urban land occupation Natural land transformation	Land use	Land occupation	Land use	N/A	
Water Scarcity	N/A	Water use	Water depletion	Water resource depletion	N/A	Water consumption, Human health Water consumption, Terrestrial ecosystem Water consumption, Aquatic ecosystems	N/A	

Special Case

Table C.2-3: SSAPTI Supporting Sheet 3 – IC Importance Weighting

LCIA Impact Categories (Generalised)	Generalised LCIA IC for Cabins	% "Required"	% "Nice to Know"	% "Low Priority" + "No Opinion"	Resulting Weight	Climate Change	Acidification & nutri.	Ozone layer depletion	Human toxicity	Ecotoxicity	Photochemical oxidation	Depletion of Minerals	Depletion of Fossil Fuels	Land use	Ionizing Radiation	Food supplies impact	Salination	Soil depletion	Water depletion	Erosion	Working conditions	Noise	Land transformation	Safety
Climate Change	Global Warming / Climate Change	94.0%	4.5%	1.5%	14.634	0.00	0.00	0.00	0.44	0.48	0.71	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Acidification & nutrification	Acidification (combined)	86.5%	12.0%	1.5%	12.734	0.00	0.00	0.00	0.00	0.00	0.02	0.71	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Ozone layer depletion	Ozone Depletion	84.5%	12.5%	3.0%	12.529	0.00	0.00	0.00	0.00	0.00	0.00	0.53	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Human toxicity	Human Health (combined)	77.0%	16.0%	7.0%	11.680	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Ecotoxicity	Ecotoxicity (combined)	76.5%	18.0%	5.5%	11.522	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Photochemical oxidant formation	Photochemical oxidant formation	74.0%	20.5%	5.5%	10.866	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.71	0.81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Depletion of Minerals	Depletion of Minerals & Metals	66.5%	25.5%	8.0%	9.078	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.11	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Depletion of Fossil Fuels	Depletion of Energy & Fuels	58.0%	25.0%	17.0%	7.302	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.53	0.76	0.85	1.00	1.00	1.00	1.00	
Land use	Land Use (combined)	54.0%	27.0%	19.0%	5.785	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.39	0.48	0.76	0.99	1.00	1.00	
Ionizing Radiation	Ionizing radiation	53.0%	32.0%	15.0%	5.322	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.30	0.39	0.67	0.90	1.00	1.00	
Food supplies impact		44.0%	33.0%	23.0%	3.066	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	1.00	1.00	
Salination	Eutrophication (combined)	40.0%	43.5%	16.5%	2.422	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.76	
Soil depletion	Water Scarcity	37.5%	45.0%	17.5%	6.856	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.53	0.67	
Depletion of Biotic Resources		36.5%	30.5%	33.0%	1.449	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.44	0.58	
Erosion		33.5%	42.0%	24.5%	0.615	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.16	0.30	
Working conditions		31.0%	51.0%	18.0%	0.066	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	
Noise		19.5%	51.0%	29.5%	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Landscape		19.5%	36.0%	44.5%	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Safety		18.0%	40.0%	42.0%	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
IC frequency data from [8]	Average:	52.8%	29.7%	17.4%	16.6%																			
MCDA method [9]	Deltas (q, p values):		23.1%	12.3%																				

Inventory-Based Adjustment	Marine eutrophication										Terrestrial ecotoxicity										Freshwater ecotoxicity										Marine ecotoxicity										Human Health: Carcinogenic									
	Seats					Linings		Bins		Floor		Seats					Linings		Bins		Floor		Seats					Linings		Bins		Floor		Seats					Linings		Bins		Floor							
	II. Composite Structure					III. Comfort Interfaces		IV. Miscellaneous Components		V. Sidewall Panel		VI. Insulation Blankets		VII. Overhead bins		II. Composite Structure					III. Comfort Interfaces		IV. Miscellaneous Components		V. Sidewall Panel		VI. Insulation Blankets		VII. Overhead bins		II. Composite Structure					III. Comfort Interfaces		IV. Miscellaneous Components		V. Sidewall Panel		VI. Insulation Blankets		VII. Overhead bins						
	I. Metallic Structure															I. Metallic Structure																	I. Metallic Structure																	
Aluminium	1.95					0.79	0.11			1.79		0.53	2.09	0.84	0.11		1.92				0.57	6.57	2.65	0.36		6.01	1.78	6.52	2.63	0.35		5.97	1.77	229.13	92.54	12.45		209.83	62.11											
Brass	0.12						0.37						3.69		11.22							3.65		11.07					3.66		11.10			4.18		12.68														
Cu wiring							0.02								0.60									0.60						0.60					0.60															
Stainless Steel						0.30	0.40							0.63	0.84								0.87	1.17						0.88	1.19					54.76	73.70				0.44									
Cotton										28.00								0.11									0.23							0.15																
Synth. Leather						83.57								0.85									1.06		0.00	0.00					0.83		0.00	0.00			14.67		0.02	0.02										
Silicone Rubber							0.00	0.00							0.00	0.00								0.00	0.00						0.00	0.00																		
CFRP	7.11												4.43										7.60						7.71							118.17		3.03	50.10	7.29										
GFRP							2.26	37.42	5.44															0.05	0.89	0.13						0.06	0.95	0.14								0.02								
Epoxy Adhesive										0.06		0.01						0.00										0.00							0.00															
Latex																																																		
NOMEX HC																																																		
PA	0.20	3.27	1.21							7.96													0.00	0.01	0.00					0.00	0.01	0.00			0.03		0.13	2.01	0.74		4.88									
PC														0.33	0.00								0.11	0.00						0.13	0.00					21.54	0.05													
PEI																								0.01								0.01					1.20													
PET Film						0.06	0.06		0.03		0.10			0.14	0.14		0.08	0.22				0.09	0.09		0.05		0.14		0.09	0.09		0.05		0.15			0.60	0.58	0.32		0.94									
PMMA									0.29							0.01								0.01								0.01					1.04													
PU Flexible Foam						12.56								0.56								0.80								0.83						22.66														
PU Rigid Foam						6.47	0.25							1.10	0.04							1.06	0.04							1.07	0.04				23.60	0.90														
PVC Film							0.01	0.00	0.04	0.08				0.01	0.01	0.06							0.01	0.01	0.04			0.11			0.01	0.01	0.05		0.11			0.06	0.03	0.25		0.60								
Total Score	2.1	7.3	107.0	2.4	3.1	37.5	8.6	36.1	0.5	5.8	4.4	4.5	13.0	0.2	1.0	2.2	0.3	0.6	10.2	7.6	6.7	13.3	0.1	0.9	6.3	0.4	1.8	10.2	7.7	6.5	13.4	0.2	1.0	6.3	0.3	1.8	233.3	118.3	232.4	101.7	6.1	50.4	219.1	6.7	62.1					
% Score	1.0%	3.6%	52.3%	1.2%	1.5%	18.3%	4.2%	17.7%	0.3%	18.1%	13.9%	14.0%	40.5%	0.5%	3.2%	7.0%	1.1%	1.8%	21.5%	16.0%	14.1%	28.1%	0.3%	2.0%	13.3%	0.8%	3.8%	21.5%	16.3%	13.7%	28.3%	0.3%	2.1%	13.3%	0.7%	3.7%	22.6%	11.5%	22.6%	9.9%	0.6%	4.9%	21.3%	0.6%	6.0%					
Rank	8	5	1	7	6	2	4	3	9	2	4	3	1	9	6	5	8	7	2	3	4	1	9	7	3	5	8	6	2	3	4	1	9	7	5	8	6	1	4	2	5	9	7	3	8	6				

Inventory-Based Adjustment	Human Health: Non-carcinogenic										Land use										Depletion of Minerals & Metals										Depletion of Energy & Fuels										Water Scarcity																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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	II. Composite Structure					III. Comfort Interfaces					IV. Miscellaneous Components					V. Sidewall Panel					VI. Insulation Blankets					VII. Overhead bins					VIII. Carpet					IX. Floor Panel					II. Composite Structure					III. Comfort Interfaces					IV. Miscellaneous Components					V. Sidewall Panel					VI. Insulation Blankets					VII. Overhead bins					VIII. Carpet					IX. Floor Panel					II. Composite Structure					III. Comfort Interfaces					IV. Miscellaneous Components					V. Sidewall Panel					VI. Insulation Blankets					VII. Overhead bins					VIII. Carpet					IX. Floor Panel																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel	I. Metallic Structure	II. Composite Structure	III. Comfort Interfaces	IV. Miscellaneous Components	V. Sidewall Panel	VI. Insulation Blankets	VII. Overhead bins	VIII. Carpet	IX. Floor Panel	X. Floor Panel																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
Aluminium	5.82		2.35	0.32			5.33		1.58	6.75		2.73	0.37			6.18		1.83		18.27		7.38	0.99				16.73		4.95	24.28		9.81	1.32			22.24		6.58		11.69		4.72	0.63			10.70		3.17																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
Brass	3.83			11.63						0.32		0.97								5.04			15.30							0.16			0.49			0.57				1.74																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										</

Inventory-Based Adjustment	Terrestrial Ecosystems: Water Scarcity						Aquatic Ecosystems: Water Scarcity						Product-Level Aggregated Impacts									
	Seats		Linings		Bins		Seats		Linings		Bins		Seats		Linings		Bins		Floor			
	ix. Floor Panel	xiii. Carpet	ix. Floor Panel	xiii. Carpet	xv. Overhead bins	xviii. Overhead bins	ix. Floor Panel	xiii. Carpet	ix. Floor Panel	xiii. Carpet	xv. Overhead bins	xviii. Overhead bins	ix. Floor Panel	xiii. Carpet	ix. Floor Panel	xiii. Carpet	xv. Overhead bins	xviii. Overhead bins	ix. Floor Panel	xiii. Carpet		
	i. Metallic Structure	ii. Composite Structure	iv. Miscellaneous Components	v. Sewall Panel	vi. Insulation Blankets	vii. Overhead bins	i. Metallic Structure	ii. Composite Structure	iv. Miscellaneous Components	v. Sewall Panel	vi. Insulation Blankets	vii. Overhead bins	i. Metallic Structure	ii. Composite Structure	iv. Miscellaneous Components	v. Sewall Panel	vi. Insulation Blankets	vii. Overhead bins	i. Metallic Structure	ii. Composite Structure		
Aluminium	2.77	1.12	0.15		2.53		0.75	2.65	1.07	0.14			0.72	2907.34	1174.17	157.94		2662.39	788.08	7689.9	349.5	
Brass	0.17		0.50					0.04		0.11				182.17		553.03				735.2	33.4	
Cu wiring			0.02							0.00						26.37				26.4	1.2	
Stainless Steel						28.00			0.09	0.11					328.74	442.45				711.2	35.1	
Cotton												28.00								838.8	38.1	
Synth. Leather		90.90							81.40							3595.78				3595.8	163.4	
Silicone Rubber			0.05	0.06					0.01	0.01						2.80	3.06			5.9	0.3	
CFRP	15.59							10.61							7109.14					7109.1	323.1	
GRP				4.46	73.69	10.72				0.78	12.84	1.87					328.40	5427.53	789.46	6545.4	297.5	
Epoxy Adhesive							0.01						0.00									
Latex						1.29												98.48		1.56	0.1	
NOMEX HC				0.96						0.15		0.37					69.82	167.84			88.5	
PA	0.35	5.55	2.05			13.49		0.06	0.93	0.34			2.26		21.43	342.92	126.81		833.43	1324.6	60.2	
PC		9.79	0.02		2.31			0.86	0.00							1798.83	4.07			1802.9	81.9	
PEI				0.54						0.05							99.94			99.9	4.5	
PET Film		0.34	0.32		0.18	0.52		0.03	0.03		0.02	0.05				54.74	52.46	29.28	85.15	221.6	10.1	
PMMA				0.23						0.00								93.65		93.6	4.3	
PU Flexible Foam	28.98							4.35								1934.59				1934.6	87.5	
PU Rigid Foam		2.75	0.29					1.32	0.05			0.07				1346.21	11.06			1397.3	63.5	
PVC Film		0.05	0.02	0.20		0.48			0.01	0.00	0.03					5.17	2.59	22.60	54.32			
Total Score	2.9	15.9	144.5	3.4	6.5	73.9	16.0	43.3	0.8	2.7	10.7	90.1	0.8	1.0	12.9	4.7	30.5	0.7	3089.5	7130.6	10581.2	1419.6
% Score	1.0%	5.2%	47.0%	1.1%	2.1%	24.0%	5.2%	14.1%	0.2%	1.7%	6.9%	58.5%	0.5%	0.7%	8.3%	3.1%	19.8%	0.5%	140.4	324.1	481.0	64.5
Rank	8	5	1	7	6	2	4	3	9	6	4	1	8	7	3	5	2	9	3	4	6	

Table C.2-5: SSAPTI Supporting Sheet 5 – LCIA Outputs Comparison

Global Warming / Climate Change	Seats				Cabin Linings	Bins	Cabin Floor		
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Full Sidewall Panel	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %									
DB: EI / M: CML(nb)	7.9%	28.8%	28.1%	1.2%	2.2%	16.3%	10.1%	3.1%	2.1%
DB: EI / M: EF 3	8.1%	30.1%	26.5%	1.1%	2.2%	16.4%	10.3%	3.0%	2.2%
DB: EI / M: EP 2015	8.1%	30.4%	26.1%	1.1%	2.2%	16.5%	10.3%	3.0%	2.2%
DB: EI / M: ILCD 2011	8.1%	29.8%	26.3%	1.4%	2.2%	16.7%	10.4%	2.9%	2.2%
DB: EI / M: IMP 2002+	8.6%	31.7%	24.1%	1.1%	2.1%	16.6%	10.8%	2.8%	2.3%
DB: EI / M: IPCC 21 100	8.7%	30.4%	25.0%	2.3%	2.0%	15.5%	10.7%	3.0%	2.3%
DB: EI / M: ReCiPe 2016	8.1%	30.1%	26.6%	1.1%	2.2%	16.5%	10.3%	3.0%	2.2%
DB: EI / M: TRACI 2	8.2%	30.6%	25.7%	1.1%	2.2%	16.6%	10.4%	2.9%	2.2%
Total Variability Range	9%	9%	16%	88%	13%	7%	6%	12%	9%
LCIA Method Comparison by IC: Ranks									
DB: EI / M: CML(nb)	5	1	2	9	7	3	4	6	8
DB: EI / M: EF 3	5	1	2	9	8	3	4	6	7
DB: EI / M: EP 2015	5	1	2	9	8	3	4	6	7
DB: EI / M: ILCD 2011	5	1	2	9	7	3	4	6	8
DB: EI / M: IMP 2002+	5	1	2	9	8	3	4	6	7
DB: EI / M: IPCC 21 100	5	1	2	8	9	3	4	6	7
DB: EI / M: ReCiPe 2016	5	1	2	9	7	3	4	6	8
DB: EI / M: TRACI 2	5	1	2	9	8	3	4	6	7
Total Variability Range	0	0	0	1	2	0	0	0	1

Human Health (Combined)	Seats				Cabin Linings	Bins	Cabin Floor		
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Full Sidewall Panel	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %									
DB: EI / M: CML(nb)	13.1%	21.9%	19.9%	16.0%	1.9%	8.9%	13.5%	2.0%	2.8%
DB: EI / M: EF 3	12.3%	15.7%	41.9%	8.9%	1.0%	4.6%	11.3%	1.4%	3.0%
DB: EI / M: EP 2015	13.5%	30.7%	21.2%	11.2%	1.0%	6.8%	11.3%	1.3%	3.0%
DB: EI / M: ILCD 2011	16.2%	21.8%	24.9%	11.4%	0.9%	5.7%	14.0%	1.2%	3.8%
DB: EI / M: IMP 2002+	11.9%	27.1%	28.6%	5.5%	1.8%	8.0%	11.8%	2.4%	3.0%
DB: EI / M: ReCiPe 2016	17.5%	23.5%	19.2%	13.3%	0.8%	6.0%	14.6%	1.1%	4.0%
DB: EI / M: TRACI 2	15.4%	25.3%	22.6%	9.6%	1.0%	7.0%	13.8%	1.6%	3.7%
Total Variability Range	39%	64%	89%	96%	97%	64%	26%	82%	36%
LCIA Method Comparison by IC: Ranks									
DB: EI / M: CML(nb)	4.0	2.5	2.0	3.5	8.0	5.0	4.0	8.0	8.0
DB: EI / M: EF 3	3.0	3.7	1.0	5.0	9.0	5.7	4.0	7.7	6.0
DB: EI / M: EP 2015	4.0	1.0	2.5	4.0	9.0	5.5	4.0	8.0	7.0
DB: EI / M: ILCD 2011	3.3	2.0	2.0	4.7	8.7	6.3	3.7	8.3	6.0
DB: EI / M: IMP 2002+	4.3	2.0	2.0	6.3	8.0	5.0	3.0	7.0	7.5
DB: EI / M: ReCiPe 2016	2.7	2.3	2.7	4.0	9.0	6.0	3.7	8.0	6.7
DB: EI / M: TRACI 2	3.5	1.8	2.0	5.3	9.0	5.5	4.0	7.5	6.5
Total Variability Range	1.6	2.7	1.7	2.8	1.0	1.3	1.0	1.3	2.0

Depletion of Energy & Fuels	Seats				Cabin Linings	Bins	Cabin Floor		
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Full Sidewall Panel	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %									
DB: EI / M: EF 3	5.7%	26.8%	29.6%	1.4%	2.6%	19.2%	8.9%	4.2%	1.5%
DB: EI / M: EP 2015	6.2%	26.7%	29.3%	1.4%	2.6%	18.6%	9.3%	4.3%	1.7%
DB: EI / M: ILCD 2011	18.8%	7.1%	12.7%	50.0%	0.6%	4.5%	4.2%	1.2%	0.9%
DB: EI / M: IMP 2002+	5.7%	26.6%	29.8%	1.4%	2.6%	19.3%	8.9%	4.3%	1.5%
DB: EI / M: ReCiPe 2016	3.4%	18.6%	36.5%	1.5%	3.2%	22.4%	7.6%	5.8%	0.9%
DB: EI / M: TRACI 2	2.9%	17.2%	37.9%	1.5%	3.4%	23.1%	7.3%	6.0%	0.8%
Total Variability Range	224%	97%	86%	511%	111%	104%	66%	112%	72%
LCIA Method Comparison by IC: Ranks									
DB: EI / M: EF 3	5	2	1	9	7	3	4	6	8
DB: EI / M: EP 2015	5	2	1	9	7	3	4	6	8
DB: EI / M: ILCD 2011	2	4	3	1	9	5	6	7	8
DB: EI / M: IMP 2002+	5	2	1	9	7	3	4	6	8
DB: EI / M: ReCiPe 2016	6	3	1	8	7	2	4	5	9
DB: EI / M: TRACI 2	7	3	1	8	6	2	4	5	9
Total Variability Range	5	2	2	8	3	3	2	2	1

Photochemical Oxidant/Ozone Formation	Seats				Cabin Linings	Bins	Cabin Floor		
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Full Sidewall Panel	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %									
DB: EI / M: CML(nb)	5.1%	20.3%	42.7%	4.8%	2.5%	13.1%	7.9%	2.2%	1.3%
DB: EI / M: EF 3	10.0%	28.9%	26.4%	2.7%	2.0%	13.3%	11.3%	2.9%	2.6%
DB: EI / M: EP 2015	9.9%	28.9%	26.4%	2.7%	2.0%	13.4%	11.3%	2.9%	2.6%
DB: EI / M: ILCD 2011	9.5%	29.6%	26.4%	2.5%	2.1%	13.5%	10.9%	3.0%	2.5%
DB: EI / M: ReCiPe 2016	10.4%	29.7%	25.1%	2.3%	1.8%	13.2%	11.7%	3.1%	2.8%
Total Variability Range	59%	34%	60%	85%	33%	3%	36%	29%	63%
LCIA Method Comparison by IC: Ranks									
DB: EI / M: CML(nb)	5	2	1	6	7	3	4	8	9
DB: EI / M: EF 3	5	1	2	7	9	3	4	6	8
DB: EI / M: EP 2015	5	1	2	7	9	3	4	6	8
DB: EI / M: ILCD 2011	5	1	2	7	9	3	4	6	8
DB: EI / M: ReCiPe 2016	5	1	2	8	9	3	4	6	7
Total Variability Range	0	1	1	2	2	0	0	2	2

Acidification (Combined)	Seats				Cabin Linings	Bins	Cabin Floor		
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Full Sidewall Panel	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %									
DB: EI / M: CML(nb)	11.4%	31.6%	22.5%	4.1%	1.6%	11.6%	11.6%	2.9%	2.8%
DB: EI / M: EF 3	11.0%	30.8%	23.5%	4.0%	1.6%	11.8%	11.3%	3.2%	2.7%
DB: EI / M: EP 2015	11.0%	30.8%	23.7%	4.0%	1.6%	11.8%	11.3%	3.2%	2.7%
DB: EI / M: ILCD 2011	11.0%	30.8%	23.5%	4.0%	1.6%	11.8%	11.3%	3.2%	2.7%
DB: EI / M: IMP 2002+	10.9%	30.6%	24.4%	3.4%	1.5%	11.4%	11.3%	3.6%	2.8%
DB: EI / M: ReCiPe 2016	11.1%	30.9%	23.3%	4.2%	1.6%	11.8%	11.3%	3.0%	2.7%
DB: EI / M: TRACI 2	11.3%	31.5%	22.8%	3.8%	1.6%	11.7%	11.6%	2.9%	2.8%
Total Variability Range	4%	3%	8%	20%	7%	3%	3%	24%	3%
LCIA Method Comparison by IC: Ranks									
DB: EI / M: CML(nb)	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
DB: EI / M: EF 3	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
DB: EI / M: EP 2015	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
DB: EI / M: ILCD 2011	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
DB: EI / M: IMP 2002+	5.0	1.0	2.0	6.5	9.0	3.0	4.0	6.5	8.0
DB: EI / M: ReCiPe 2016	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
DB: EI / M: TRACI 2	5.0	1.0	2.0	6.0	9.0	3.0	4.0	7.0	8.0
Total Variability Range	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.5	0.0

Ecotoxicity (Combined)	Seats				Cabin Linings	Bins	Cabin Floor			
	Armrests	Seat Structure	Comfort Interfaces	Misc.	Panel	Full Sidewall	Insulation Blankets	Overhead bin assembly	Carpet	Floor Panel
LCIA Method Comparison by IC: %										
DB: EI / M: CML(nb)	14.7%	14.7%	34.5%	11.8%	0.3%	1.6%	11.2%	8.1%	3.2%	
DB: EI / M: EF 3	10.5%	23.9%	43.2%	7.8%	0.8%	1.8%	8.5%	1.1%	2.4%	
DB: EI / M: EP 2015	14.9%	11.6%	33.0%	18.5%	0.2%	1.3%	9.5%	8.5%	2.7%	
DB: EI / M: ILCD 2011	22.0%	14.9%	15.2%	25.8%	0.3%	2.2%	14.4%	1.1%	4.1%	
DB: EI / M: IMP 2002+	15.6%	36.2%	13.8%	8.2%	0.8%	6.2%	14.0%	1.5%	3.8%	
DB: EI / M: ReCiPe 2016	19.0%	24.3%	9.4%	19.9%	2.6%	1.7%	9.5%	7.7%	7.8%	
DB: EI / M: TRACI 2	22.0%	14.9%	15.2%	25.8%	0.3%	2.2%	14.4%	1.1%	4.1%	
Total Variability Range	68%	123%	144%	107%	312%	205%	51%	179%	137%	
LCIA Method Comparison by IC: Ranks										
DB: EI / M: CML(nb)	2.7	2.3	2.7	3.7	9.0	7.0	5.0	6.0	6.7	
DB: EI / M: EF 3	3.0	2.0	1.0	5.0	9.0	7.0	4.0	8.0	6.0	
DB: EI / M: EP 2015	3.0	3.0	3.7	2.0	9.0	7.0	4.7	6.0	6.7	
DB: EI / M: ILCD 2011	2.0	4.0	3.0	1.0	9.0	7.0	5.0	8.0	6.0	
DB: EI / M: IMP 2002+	2.5	1.0	3.0	5.5	9.0	5.5	3.5	8.0	7.0	
DB: EI / M: ReCiPe 2016	2.3	2.3	5.7	2.7	7.7	7.3	5.7	6.0	5.0	
DB: EI / M: TRACI 2	2.0	4.0	3.0	1.0	9.0	7.0	5.0	8.0	6.0	
Total Variability Range	1.0	3.0	4.7	4.5	1.3	1.8	2.2	2.0	2.0	

Land Use	Seats				Cabin Linings	Bins	Cabin Floor
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Table C.2-6: SSAPTI Supporting Sheet 6 – Qualitative LCA Weighting

Top-level LCA Phases (Assume linear EOL)		i						Summed Weights	Importance Weights
		1. Component Supply	2. Product Integration	3. Product Installation	4. Product Operation	5. Product Dismantling	6. Product End-of-Life		
i	1. Component Supply	0.50	0.50	1.00	0.25	1.00	0.75	1.360	22.7%
	2. Product Integration	0.50	0.50	0.75	0.25	0.75	0.75	1.249	20.8%
	3. Product Installation	0.00	0.25	0.50	0.00	0.75	0.25	0.447	7.4%
	4. Product Operation	0.75	0.75	1.00	0.50	1.00	1.00	1.907	31.8%
	5. Product Dismantling	0.00	0.25	0.25	0.00	0.50	0.25	0.336	5.6%
	6. Product End-of-Life	0.25	0.25	0.75	0.00	0.75	0.50	0.702	11.7%

Score	Definition for Top-Level LCA Phases
0.00	i requires trivial resource comparing to j
0.25	i is less resource-demanding than j
0.50	i and j require similar resource
0.75	i needs more resource than j
1.00	i resource requirement outshadows j

Score	Definition for individual LCA steps
0.00	j is primary and is not affected by i
0.25	j is primary but may be affected by i
0.50	i and j are equivalent and mutual/independent
0.75	i is primary but may be affected by j
1.00	i is primary and not affected by j

1. Component Supply		i						Summed Weights	Importance Weights	
		Material Transport	Storage Impacts	Production Complexity	Production Needs	Production Efficiency	Component Quality			Corporate Ethics
i	Material Transport	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.630	9.0%
	Storage Impacts	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.630	9.0%
	Production Complexity	1.00	1.00	0.50	0.75	0.50	0.75	0.75	1.562	22.3%
	Production Needs	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.141	16.3%
	Production Efficiency	0.75	0.75	0.50	0.50	0.50	0.50	0.75	1.284	18.3%
	Component Quality	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.141	16.3%
	Corporate Ethics	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.612	8.7%

4. Product Operation		i						Summed Weights	Importance Weights
		Operational Needs	Maintenance Complexity	Maintenance Efficiency	Maintenance Needs	Corporate Ethics			
i	Operational Needs	0.50	0.75	0.75	0.75	0.75	1.448	29.0%	
	Maintenance Complexity	0.25	0.50	0.50	0.50	0.75	0.981	19.6%	
	Maintenance Needs	0.25	0.50	0.50	0.50	0.75	0.981	19.6%	
	Maintenance Efficiency	0.25	0.50	0.50	0.50	0.75	0.981	19.6%	
	Corporate Ethics	0.25	0.25	0.25	0.25	0.50	0.610	12.2%	

2. Product Integration		i						Summed Weights	Importance Weights	
		Component Transport	Storage Impacts	Integration Complexity	Integration Needs	Integration Efficiency	Product Quality			Corporate Ethics
i	Component Transport	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.632	9.0%
	Storage Impacts	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.632	9.0%
	Integration Complexity	1.00	1.00	0.50	0.75	0.50	0.75	0.75	1.544	22.1%
	Integration Needs	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.130	16.1%
	Integration Efficiency	0.75	0.75	0.50	0.50	0.50	0.50	0.75	1.217	17.4%
	Product Quality	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.074	15.3%
	Corporate Ethics	0.25	0.25	0.25	0.25	0.50	0.50	0.50	0.769	11.0%

5. Product Dismantling		i						Summed Weights	Importance Weights
		Removal Complexity	Removal Needs	Storage Impacts	Post-Removal Impacts	Corporate Ethics			
i	Removal Complexity	0.50	0.75	1.00	0.25	0.75	1.300	26.0%	
	Removal Needs	0.25	0.50	1.00	0.25	0.75	1.046	20.9%	
	Storage Impacts	0.00	0.00	0.50	0.00	0.75	0.348	7.0%	
	Post-Removal Impacts	0.75	0.75	1.00	0.50	0.75	1.643	32.9%	
	Corporate Ethics	0.25	0.25	0.25	0.25	0.50	0.663	13.3%	

3. Product Installation		i						Summed Weights	Importance Weights	
		Product Transport	Storage Impacts	Installation Complexity	Installation Needs	Installation Efficiency	Installation Quality			Corporate Ethics
i	Product Transport	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.630	9.0%
	Storage Impacts	0.50	0.50	0.00	0.25	0.25	0.25	0.75	0.630	9.0%
	Installation Complexity	1.00	1.00	0.50	0.75	0.50	0.75	0.75	1.562	22.3%
	Installation Needs	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.141	16.3%
	Installation Efficiency	0.75	0.75	0.50	0.50	0.50	0.50	0.75	1.284	18.3%
	Installation Quality	0.75	0.75	0.25	0.50	0.50	0.50	0.75	1.141	16.3%
	Corporate Ethics	0.25	0.25	0.25	0.25	0.25	0.25	0.50	0.612	8.7%

6. Product End-of-Life		i						Summed Weights	Importance Weights
		Phasing-Out Transport	End-of-Life Complexity	End-of-Life Needs	End-of-Life Impacts	Corporate Ethics			
i	Phasing-Out Transport	0.50	0.25	0.25	0.25	0.75	0.773	15.5%	
	End-of-Life Complexity	0.75	0.50	0.75	0.25	0.75	1.181	23.6%	
	End-of-Life Needs	0.75	0.25	0.50	0.25	0.75	0.956	19.1%	
	End-of-Life Impacts	0.75	0.75	0.75	0.50	0.75	1.473	29.5%	
	Corporate Ethics	0.25	0.25	0.25	0.25	0.50	0.618	12.4%	

Table C.2-7: SSAPTI Supporting Sheet 7 – References Used in SSAPTI

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C.3 MCDA-LCA Integration

Table C.3-1: Complimentary MCDA-LCA characteristics and capabilities

Quality	MCDA	LCA
Assessment basis	Evaluates relative impacts based on a mixture on objective & subjective inputs	Evaluates absolute impacts based on objective and empirical inventory
Input Sources	Fully relies on external inputs: material impacts from LCA databases, subjective evaluations from the user's organisation	Only needs material / process inventory (type, weight, distance, volume, etc.); impact information accessed within itself
Iterations	Allows low-effort iterations to test for different model settings e.g., different IC weights or material content	Each iteration is modelled in high detail and requires a separate recalculation for any change (e.g. product mass) inserted
Applicability of results	Allows informing top-level priorities that include concerns beyond sustainability, but cannot reflect on absolute impacts	Produces precise, science-based impact figures indicating the exact environmental effects, but no reflection on how to use it
Skillset Required	The level of required skillset may vary depending on MCDA methods applied and refinement required, offering simple and accessible implementation means	Requires a well-developed skillset to pick the right LCA database & method settings, build a representative up/down-stream supply chain processes, and more.
Tools required	Mostly performed using widespread calculation tools with minimum access or skills for LCA tools required	Fully enabled by dedicated LCA tools for all parts of the assessment process
Key Purposes	Acts as the analytical framework & guide	Acts as data retrieval & processing tool

Table C.3-2: MCDA-LCA integration points in SSAPTI

LCA Step	MCDA Opportunity	SSAPTI decision
Goal Definition	Prioritise among the user's many potential objectives e.g., different departments	Not used for the current study, relevant goals are presented in <u>Section 4.3.1.1</u>
	Select product scope by narrowing from a large variety of content available	Not used for the current study due to limited data available (4 products only), although can be useful on a real project to down-select among cabin products
	Define study boundaries – geographies, LCA stages, types of impacts considered	Not used for the current study due to limited focus on materiality; could be used to aid the definition of a full LCA
Product System Inventory	Handle uncertainties associated with real product/process information e.g., multiple sources offering different values or gaps	Used as the basis for qualitative blocks (LCA and strategic); not used to process product weights for quantitative block
	Convert absolute LCA impacts into relative scale to allow direct comparison between dissimilar measurement units or impacts	Used to normalise the material impacts obtained from LCA databases
Assess Product System Impacts	Implement differential importance weights of sustainability impact categories	Used to derive the importance weights for each IC in the quantitative block
	Implement circular economy effects for different possible circular scenarios	Used to aggregate the multiple effects involved in circularity considerations
Results Interpretation	Aggregate the many assessment outputs, which may be assessed on different scales, into a single impact score	Used to aggregate the different results, normalise to enable direct comparison, and rank to inform product priorities

C.4 Stakeholder Perspectives on SSAPTI Application

Table C.4: Key Cabin Design Stakeholders Perspectives on SSAPTI Uses

Stakeholder	Commitments	Constraints	SSAPTI Use Case
Passengers (<i>economy, business</i>)	Keen to make sustainable product choices and contribute to the global effort, which includes choosing a greener airline service	Cost-conscious attitude results in low price tolerance when sustainable travel or products incur premium fees	No direct use of SSAPTI by PAX, but may help the value chain to better inform them about sustainability
Operators	Sustainable cabins are desired as the way to improve both operational expenditure (via fuel economy) and travel demand	Limited profitability shifts the cost burden elsewhere in the value chain, primarily on passengers and investors	Define KPI for product RFP; pre-LCA scoping studies across the whole cabin; efficient identification of the sustainable improvement priorities
CEM, DA, Airframer, Tx suppliers	Careful pursuit of sustainable cabins is driven by airline demand and international regulations, but hindered by entry costs	Significant pricing control enabled by technology ownership and negotiation powers shared across the supply chain	Prioritise configurations, materials for new product designs; assess sustainability hotspots in BOM
Lessors	Primarily concerned with shareholder returns delivered within the regulatory envelope that increasingly accounts for sustainability and will continue to do so	Hold the major decision power and funds to support or hinder cabin design solutions based on their effects on profitability & legality of operations	Compare the various investment opportunities both across products (i.e., different equipment types) and at product level (i.e., different versions of the same product type) to compare the relative sustainable qualities offered by the alternatives

C.5 MCDA Method Selection Parameters

Table C.5-1: Parameters to select an MCDA method for IC weighting

ProBCA Settings	Task	Justification
1.1: Task	Criteria	The task is to weigh Impact Categories acting as criteria
1.2: Output format	Point Values	Need to retrieve precise values for IC weights
1.3: Ambiguity	N/A	No ambiguity is considered, precise data available from [70]
1.4: Relative Thresholds	No selection	Left open to offer a wider selection of methods to consider
1.5: Resource Needed	Light, Reasonable	“Heavy” methods are omitted to enable a simplified and user-friendly LCA tool
2.1: Criteria Count	< 25	No LCIA methods use more than 23 IC among selected
2.2: Criteria Importance	Weighted	The task is concerned with assigning IC weights
2.3: Weights Basis	No selection	Left open to offer a wider selection of methods to consider
2.4: Weights Format	Order, Ratio	[70] offers precise IC order with specific values for each
2.5: Definition Procedure	Comparison	IC weights are derived by comparing their popularity among each other
2.6: Criteria Dependence	Independent	IC do not impact each other's importance weighting
2.7: Criteria Hierarchy	Flat only	A flat set of IC is considered
3.1: Options Count	N/A	Options not involved – counting options is inapplicable
3.2: Attribute Nature	No selection	Options not involved – attribute selection is inapplicable
3.3: Rating Format	N/A	Options not involved – no ratings to consider
3.4: Rating Procedure	N/A	Options not involved – no ratings to consider
3.5: Aggregation:	No selection	Left open to return more options

Table C.5-2: Parameters to select MCDA method for qualitative treatment

ProBCA Settings	Task	Justification
1.1: Task	Ranking	The task is to rank products against a set of criteria
1.2: Output format	Point Values	Rank order is insufficient, preference intensities are needed
1.3: Ambiguity	Option Ratings, Both	All methods addressing option rating uncertainties are relevant
1.4: Relative Thresholds	N/A	No thresholds considered since criteria weights are already derived and balanced by dedicated thresholds
1.5: Resource Needed	Light, Reasonable	“Heavy” methods are omitted to enable a simplified and user-friendly LCA tool
2.1: Criteria Count	Unlimited	Over 25 criteria are used in both qualitative blocks
2.2: Criteria Importance	Weighted	Weighted criteria are used in both qualitative assessment blocks
2.3: Weights Basis	Pre-determined	Criteria are determined separately for both qualitative assessment blocks
2.4: Weights Format	No selection	Left open to offer a wider selection of methods to consider since the task focuses on option rating and is not affected by the procedure used for criteria weighting in the method
2.5: Definition Procedure	Assignment	Default option with “Pre-Determined” weights option
2.6: Criteria Dependence	Independent	The scoring of each product is independent among criteria
2.7: Criteria Hierarchy	Flat only	A flat data structure is used within each qualitative block
3.1: Options Count	No selection	Left open to offer a wider selection of methods to consider
3.2: Attribute Nature	Measurable, Nominal	The scores are numeric; Measurable is included to offer a wider selection of methods to consider
3.3: Rating Format	Distribution	Used to represent triangular fuzzy scores as per [7]
3.4: Rating Procedure	Direct Rating	Reflects the process used to fill qualitative scores
3.5: Aggregation:	No selection	Left open to offer a wider selection of methods to consider

Table C.5-3: Parameters to select an MCDA method for qualitative totals

ProBCA Settings	Task	Justification
1.1: Task	Ranking	The qualitative assessment needs to produce the outputs suitable for product ranking
1.2: Output format	Point Values	The final scores need to be presented as precise values to be used in total aggregation
1.3: Ambiguity	N/A	Rating ambiguity is treated in the previous step and aggregated using functional block
1.4: Relative Thresholds	N/A	No thresholds are used to process the simple qualitative ratings in SSAPTI
1.5: Resource Needed	Light	The nature of qualitative ratings in SSAPTI does not warrant the use of complex methods
2.1: Criteria Count	Unlimited	SSAPTI uses a total of 50 strategic criteria, rendering the methods suitable for assessing 25 criteria or less impractical
2.2: Criteria Importance	Weighted	The individual LCA steps or strategic criteria are assigned different importance weights
2.3: Weights Basis	Pre-Determined	Criteria weights are calculated in the previous steps or in HCCA using pairwise comparisons
2.4: Weights Format	Point Value	Criteria importance weights are provided as precise values
2.5: Definition Procedure	Assignment	Criteria weights are calculated in the previous steps or in HCCA using pairwise comparisons so treated as direct input into the aggregation
2.6: Criteria Dependence	Independent	The strategic criteria and LCA steps are assessed as independent dimensions
2.7: Criteria Hierarchy	Flat only	Qualitative assessment is represented by a flat, single-level matrix in SSAPTI
3.1: Options Count	Unlimited	SSAPTI may assess more than 25 products
3.2: Attribute Nature	Measurable	The final scores need to be measurable to feed the total product rating aggregation
3.3: Rating Format	Point value	The final scores need to be presented as precise values to be used in total aggregation
3.4: Rating Procedure	Direct rating	Scoring values are calculated in the previous step so no other rating procedure is required
3.5: Aggregation	Functional	The easiest, most straight-forward option to ensure clarity

Table C.5-4: Parameters to select an MCDA method for score aggregation

ProBCA Settings	Task	Justification
1.1: Task	Ranking	The task is to rank products based on aggregated scores
1.2: Output format	Point Values	Rank order is insufficient, preference intensities are needed
1.3: Ambiguity	N/A	No ambiguity is considered at the final aggregation stage
1.4: Relative Thresholds	N/A	No thresholds are used at the final aggregation stage since the weights of 3 blocks can be controlled by the user
1.5: Resource Needed	Light, Reasonable	“Heavy” methods are omitted to enable a simplified and user-friendly LCA tool
2.1: Criteria Count	No selection	Left open to offer a wider selection of methods to consider
2.2: Criteria Importance	Weighted	Block contributions are weighted on <i>Sheet 6</i> in SSAPTI
2.3: Weights Basis	Pre-Determined	No weighting procedure is offered for block contributions, the user is expected to use own pre-defined preference
2.4: Weights Format	Point Values	Block contribution weights are provided as precise percent figures
2.5: Definition Procedure	Assignment	Block contributions are directly assigned by entering the respective values in the cells within SSAPTI results table
2.6: Criteria Dependence	Independent	The three blocks are considered independent due to the different perspectives covered
2.7: Criteria Hierarchy	Flat only	While SSAPTI structure is hierarchical, the final aggregation takes a flat form; constituent scoring is derived separately
3.1: Options Count	No selection	Left open to offer a wider selection of methods to consider
3.2: Attribute Nature	Measurable	The scores are not nominal at this stage so a generic option for numeric inputs is used
3.3: Rating Format	Point value	The final scores are fed as precise values
3.4: Rating Procedure	Direct rating	No rating procedure is offered for block contributions, the scores are determined in previous steps and feed directly
3.5: Aggregation:	Functional	The easiest, most straight-forward option to ensure clarity

C.6 Qualitative Scoring Representation

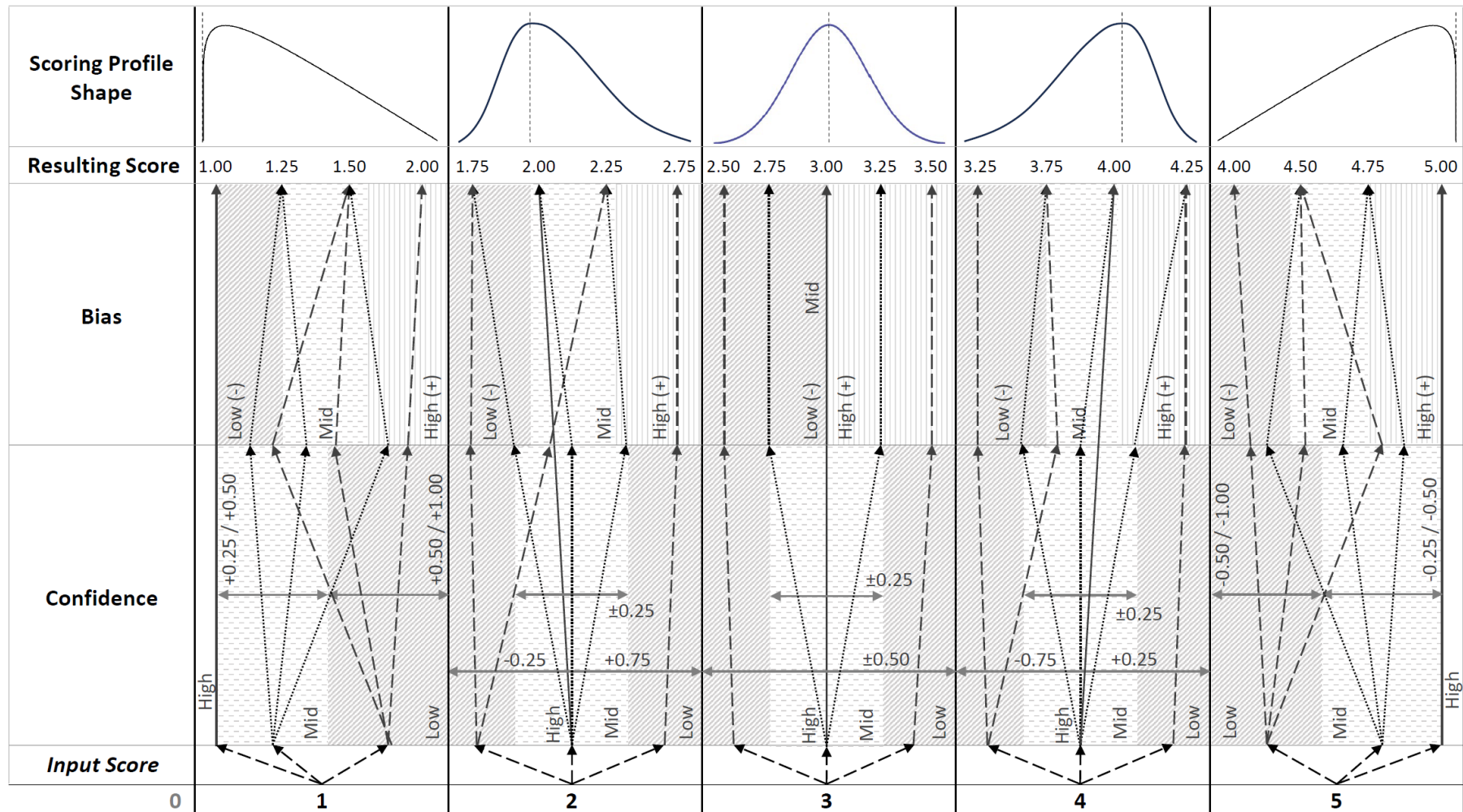


Figure C.6: Graphical Representation of the Qualitative Scoring System used in SSAPT1

C.7 Integration of Circular Economy Principles Into SSAPTI

Table C.7-1: Definition of R types and R values for SSAPTI CE tool

R type	Meaning <i>(The best available option)</i>	Sustainability Effect (a)	Justification	Strategic Benefit (b)	Justification
R1: Refuse	Reject the need	5.00	<i>Reduced impact with respect to baseline</i>	2.5	<i>Cost cutting vs. revenue opportunity loss</i>
R2: Rethink	Revise the application	4.85	<i>Several impacts reduced into one</i>	5.0	<i>Retain revenue sources at reduced cost</i>
R3: Reuse	Return directly into primary use	4.65	<i>Original impact unchanged</i>	4.5	<i>Retain revenue sources at small added cost</i>
R4: Repair	Update and return into primary use	4.30	<i>Minor impact due to maintenance</i>	3.0	<i>Large cost recovery vs. large repair cost</i>
R5: Remanufacture	Retrieve components for reproduction	3.50	<i>Shortened resupply chain impact</i>	3.5	<i>Medium cost recovery vs. small disassembly cost</i>
R6: Recycle	Secondary use of purified raw materials	1.50	<i>Extended resupply chain impact</i>	2.5	<i>Small cost recovery from recyclers and/or users</i>
R7: Recover	Recover material energy content	0.50	<i>Minimum impact recovery</i>	1.5	<i>No cost recovery from incinerators</i>
R8: Reject	Dispose without circular action (current baseline)	0.00	<i>No impact recovery</i>	1.0	<i>Cost impact due to waste management fees</i>

Table C.7-2: Calculation Route for CE Impact on Effective Product Life

R type	Circularity Impact Formula
R1: Refuse R2: Rethink	$I_i = (m_{\%} \cdot l_i) \cdot (w_a R_{ia} + w_b R_{ib})$
R3: Reuse	$I_i = (m_{\%} \cdot l_i) \cdot ([w_a \cdot R_{ia}] + [D_i \cdot w_b \cdot R_{ib}])$
R4: Repair R5: Remanufacture R6: Recycle	$I_i = (m_{\%} \cdot l_i \cdot \eta_i) \cdot (w_a R_{ia} + [D_i \cdot w_b \cdot R_{ib}])$
R7: Recover R8: Reject	$I_i = m_{\%} \cdot (w_a R_{ia} + w_b R_{ib})$
Combined Impact	$I_{product} = \sum_{i=1}^8 I_i$

Where:

- I = added product life impact due to circular opportunities
- $m_{\%}$ = material mass as proportion of the whole product mass
- l_i = the number of re-life loops achievable through route R_i
- w_x = contribution weight of a particular perspective
- a = environmental perspective
- b = strategic perspective
- R_i = R-value for given material fate/circularity route
- D_i = D-factor of the given circularity output
- η_i = recycling efficiency (as recycled material content in final product) for given route

C.8 SSAPTI Application Process Flow

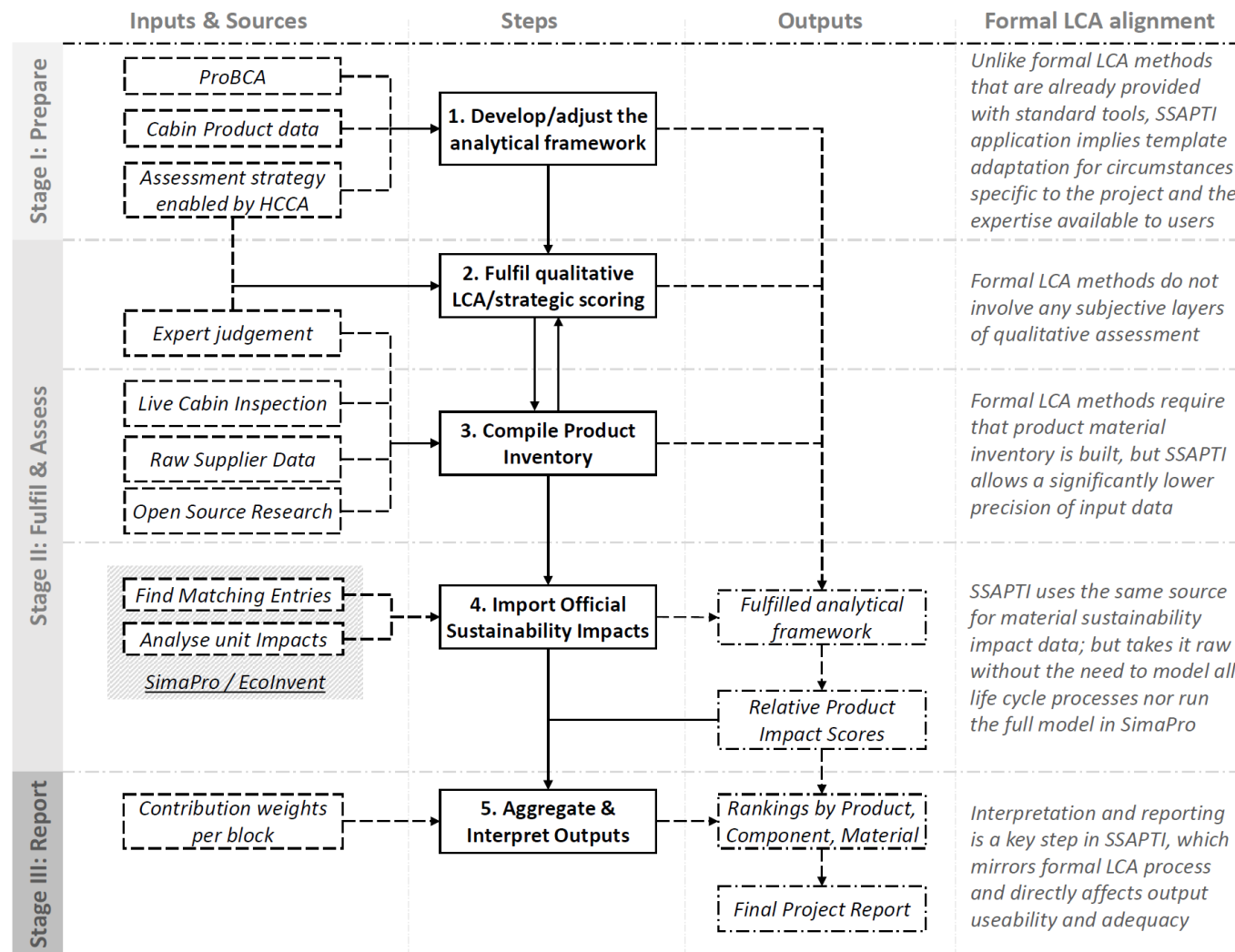


Figure C.8: Overall SSAPTI Application Process Flow and Comparison with Formal LCA Process

C.9 Product Material Inventory

Table C.9-1: Product inventory identified from FlyZero project outputs

Top-Level Product	Sub-Assembly	Inclusion Comments
Economy Seats	i. Metallic Structure	seat frame and mounting interfaces
	ii. Composite Structure	the core of the seat back and pan
	iii. Comfort Interfaces	a stack of softer materials mounted onto the structure
	iv. Miscellaneous Components	various enablers for interfaces, kinematics, operation, etc.
Cabin Linings	v. Sidewall Panels	includes ceiling panels of similar composition
	vi. Insulation Blankets	a soft layer between the sidewall panels and outer fuselage shell
Overhead Bins	vii. Overhead Bins	listed as separate product due to its different architecture and function
Floors	viii. Carpets	comfort and safety interface between the cabin occupiers and the hard floor basis
	ix. Floor Panels	structural basis carrying the weight of passengers and most cabin equipment

Table C.9-2: EcolInvent entries used for aircraft cabin assessment

Cabin Material	EcolInvent Entry Selected
Aluminium	Aluminium, wrought alloy {GLO} market for Cut-off, U
Brass	Brass {CH} market for brass Cut-off, U
Copper	Copper {GLO} market for Cut-off, U
Steel	Steel, low-alloyed, hot rolled {GLO} market for Cut-off, U
Cotton	Fibre, cotton {GLO} market for fibre, cotton Cut-off, U
Silicon	Silicone product {RER} market for silicone product Cut-off, U
CFRP (Carbon Fibre Reinforced Polymer)	Carbon fibre reinforced plastic, injection moulded {GLO} market for carbon fibre reinforced plastic, injection moulded Cut-off, U
Epoxy	Epoxy resin, liquid {RER} market for epoxy resin, liquid Cut-off, U
GFRP (Glass Fibre Reinforced Polymer)	Glass fibre reinforced plastic, polyamide, injection moulded {GLO} market for Cut-off, U
Latex	Latex {RER} market for latex Cut-off, U
DMA (Dimethylamine)	Dimethylamine {RER} market for dimethylamine Cut-off, U
PA (Polyamide)	Nylon 6-6 {RER} market for nylon 6-6 Cut-off, U
PBDE (Polybrominated Diphenyl Ether)	Decabromodiphenyl ether {GLO} market for decabromodiphenyl ether Cut-off, U
PC (Polycarbonate)	Polycarbonate {GLO} market for Cut-off, U
PET (Polyethylene Terephthalate)	Polyethylene terephthalate, granulate, amorphous {GLO} market for Cut-off, U
PF (Phenol Formaldehyde) Resins	Phenolic resin {RER} market for phenolic resin Cut-off, U (49.4% in Nomex HC)
PMMA (Polymethyl Methacrylate)	Methyl acrylate {GLO} market for Cut-off, U
PU (Polyurethane) Flexible Foam	Polyurethane, flexible foam {RER} market for polyurethane, flexible foam Cut-off, U
PU (Polyurethane) Rigid Foam	Polyurethane, rigid foam {RER} market for polyurethane, rigid foam Cut-off, U
PVC (Polyvinyl Chloride)	Polyvinylchloride, bulk polymerised {GLO} market for Cut-off, U

C.10 SSAPTI Sensitivity Study Samples

The screenshots collected in this Appendix present the output table versions produced by the different settings applied to the various SSAPTI parameters. They serve to demonstrate how each of the settings affects SSAPTI final outputs.

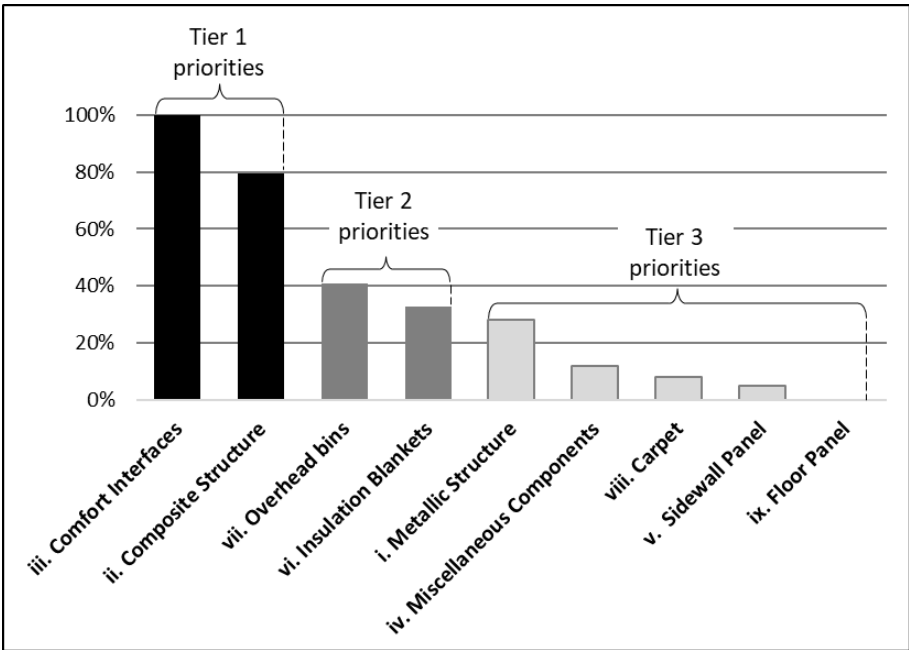


Figure C.10-1a: Sensitivity Assessment – Baseline Ranking

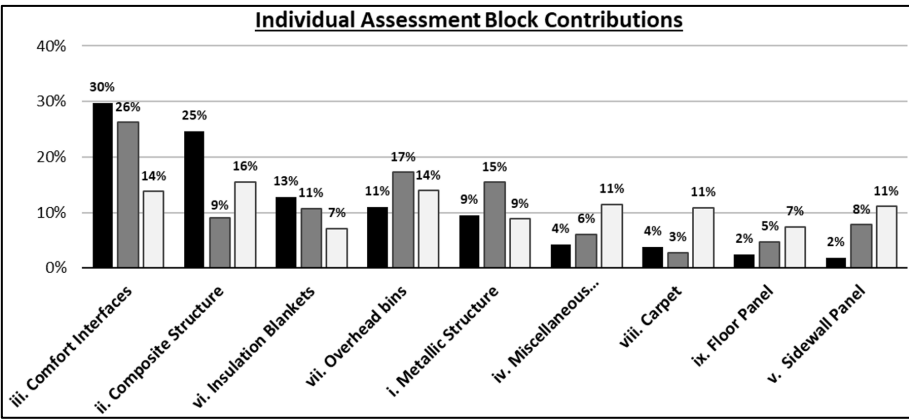


Figure C.10-1b: Sensitivity Assessment – Baseline Scoring

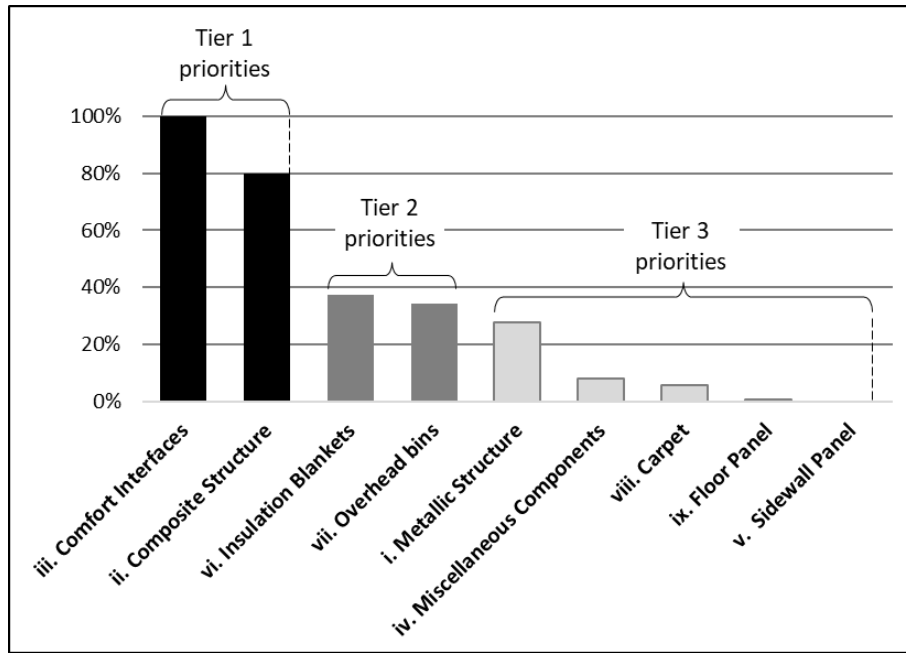


Figure C.10-2a: Sensitivity Block Contributions – Quantitative focus

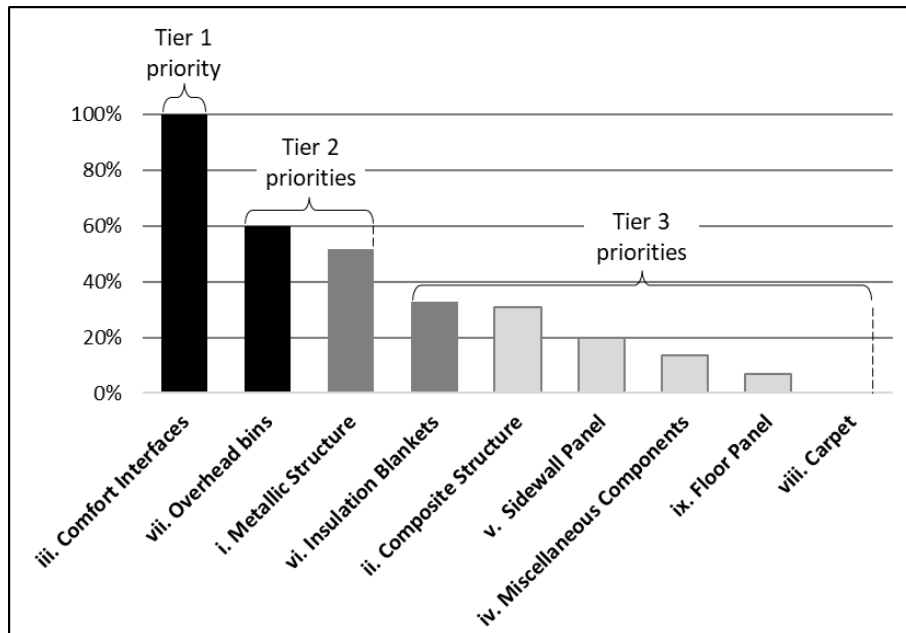


Figure C.10-2b: Block Contributions – Qualitative LCA focus

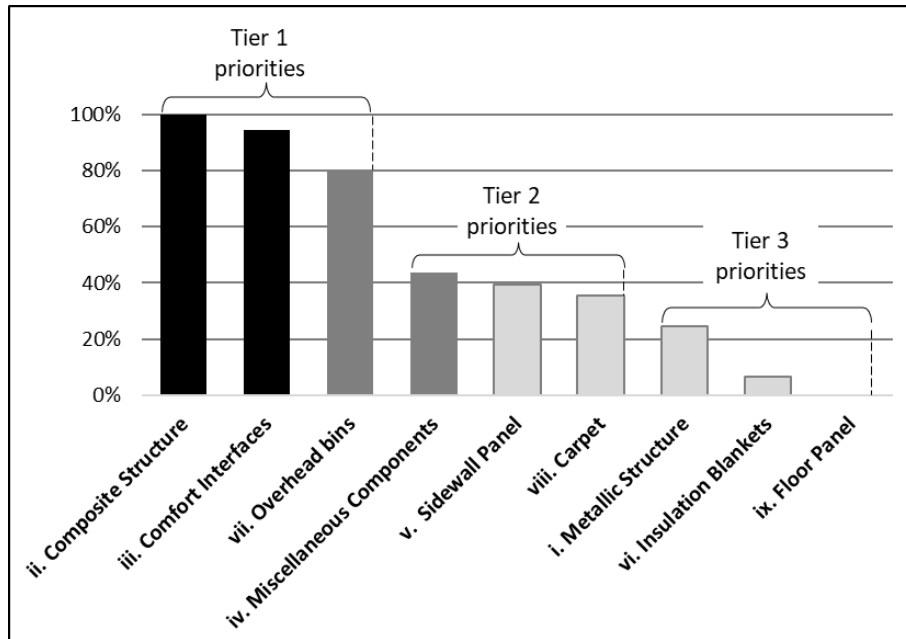


Figure C.10-2c: Block Contributions – Strategic focus

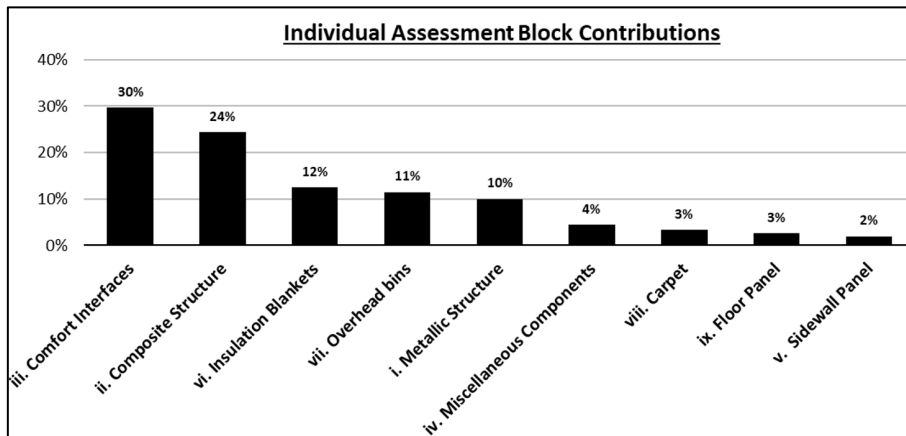


Figure C.10-3a: Quantitative Settings – IC Importance Weights

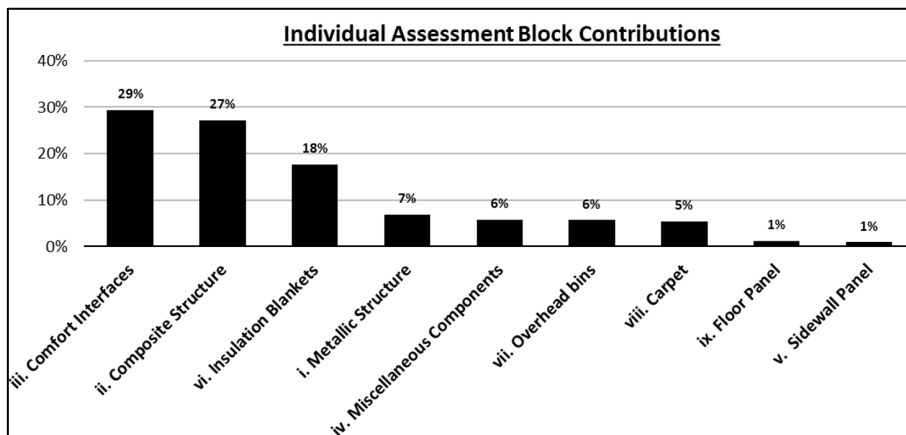


Figure C.10-3b: Quantitative Settings – Circular Life Cycle

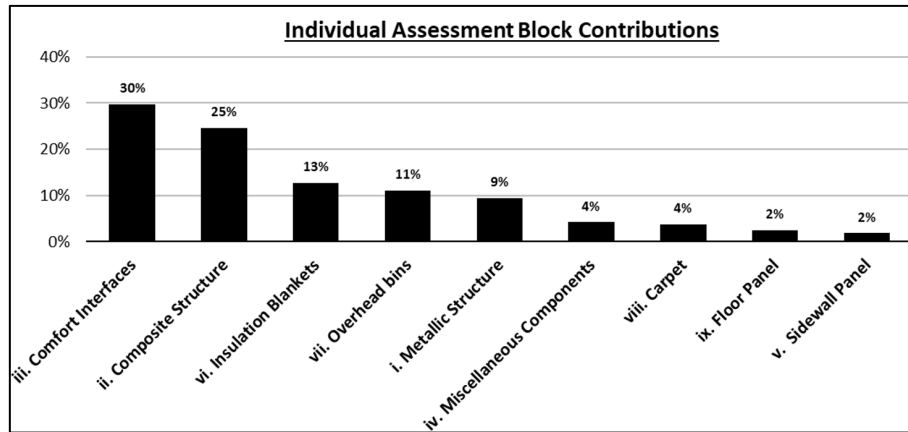


Figure C.10-3c: Quantitative Settings – Assessment Horizon

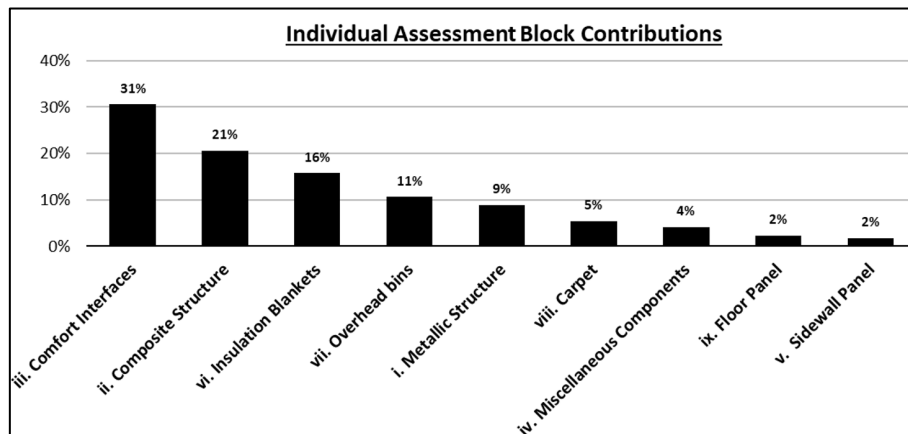


Figure C.10-4a: LCIA Preference – ReCiPe method

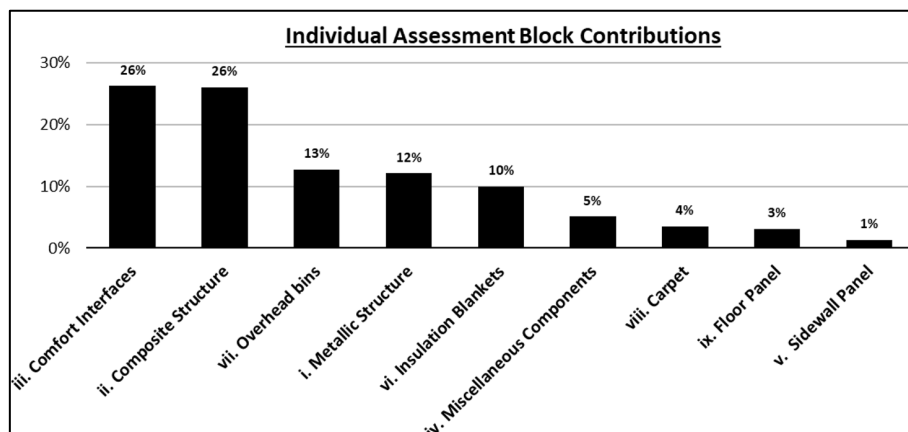


Figure C.10-4b: LCIA Preference – ILCD method

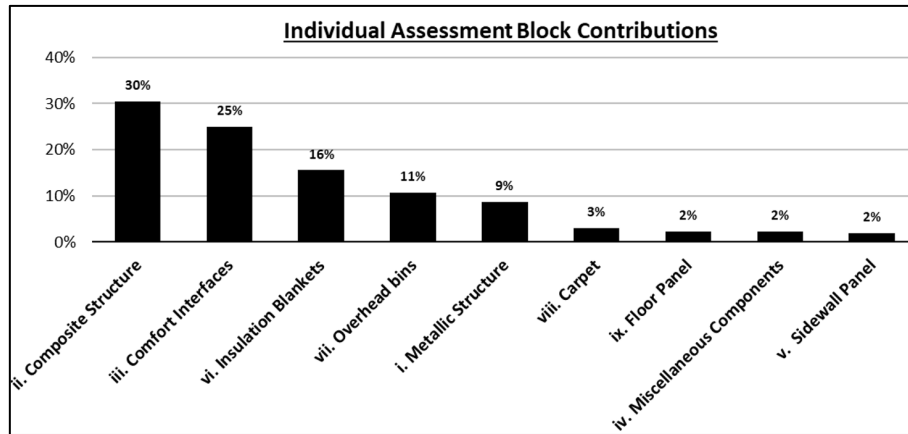


Figure C.10-4c: LCIA Preference – IPCC method

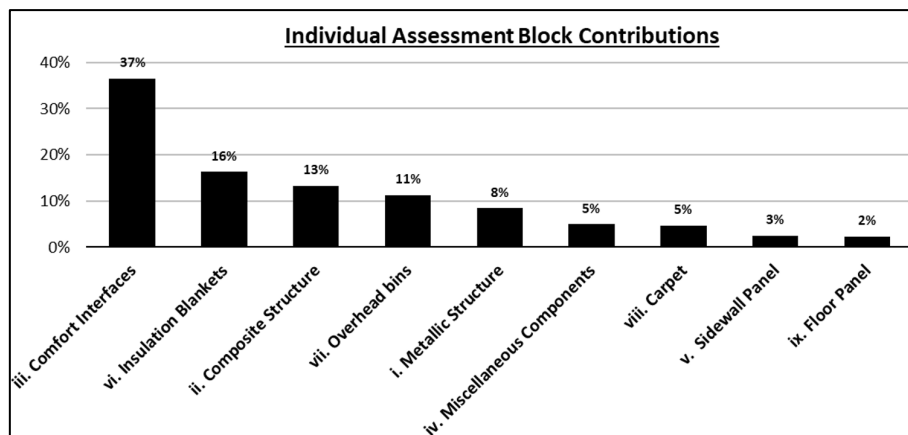


Figure C.10-4d: LCIA Preference – EPS method

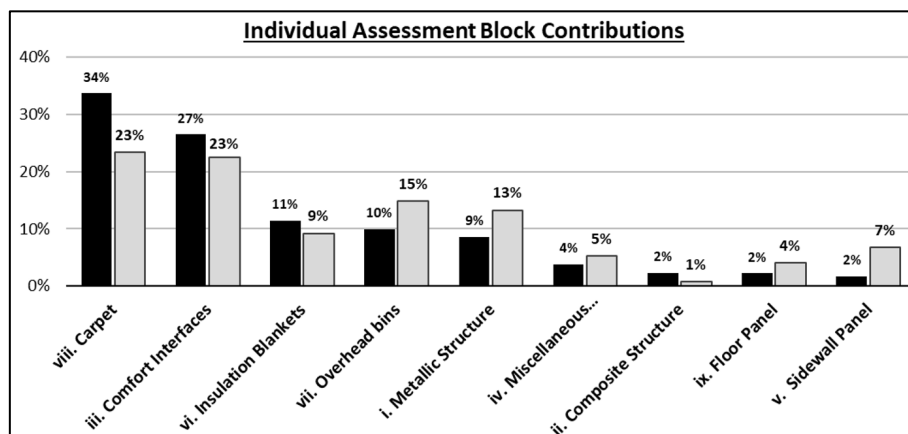


Figure C.10-5: Changing Material Quantities