

CRANFIELD UNIVERSITY

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DEVELOPING ENGINEERING SYSTEMS WITH STAKEHOLDER
ENGAGEMENT

SCHOOL OF WATER, ENERGY AND THE ENVIRONMENT

PhD in Water
Academic Year: 2019 - 2022

Supervisor: Dr Heather Smith
Associate Supervisor: Prof Leon Williams
May 2022

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ABSTRACT

The activities of the early stages of new product development (NPD) projects have a significant impact on its results. This is evident by the failures of outputs to meet expected levels of adoption being traced back to inadequate elicitation of requirements and validation of the need for the output itself. To address this, the development of consumer goods, software and large-scale construction projects have been shown to benefit from the early involvement of stakeholders in these outputs. However, few studies focus on how this early involvement of stakeholders might advance the development of engineering systems. Although studied in the context of complex products and systems (CoPS), which includes large-scale constructions, engineering systems differ significantly to these and other NPD project outputs. This is due to the absence of end-users, or the general public, being involved as such systems are often automated and hidden within other systems or infrastructure. Adhering to development frameworks prioritising technical maturation furthers this difference, although, like consumer products, a market needs to be addressed. To explore this phenomenon, a single case study of the beginning of a wastewater system NPD project is conducted and supported by studies that identify, engage and evaluate the extent stakeholders can affect its activities. The results support the need for a dedicated early stage for stakeholder engagement. This will help address the implications of findings evidencing problems engineering systems need to address so to achieve expected levels of adoption. Successfully incorporating this new stage whilst prototyping the engineering system itself requires further research. The contributions of this thesis challenge prioritising technical interests during early stages of development, demonstrate the extensive value of analysing qualitative data and support iterative and collaborative NPD approaches. Incorporating these findings will contribute to ensuring highly innovative engineering systems effectively address the needs of their salient stakeholders.

Keywords:

Complex Product or System (CoPS), New Product Development (NPD), Radical Innovation, Problem Framing, Requirement Elicitation, Prototyping Strategy, Boundary Object, Stakeholder Identification, Document Analysis, Semi-Structured Interviewing, Single Case Study

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LIST OF ABBREVIATIONS

ACSI	Alaska Cruise Ship Initiative
CAD	Computer-Aided Design
CET	Controlled Emission Toilet
CoPS	Complex Product or System
DfT	Department for Transport
EU	European Union
HELCOM	Baltic Marine Environment Protection Commission (Helsinki Commission)
IMO	International Maritime Organisation
IT	Information Technology
NASA	National Aeronautics and Space Administration
NPD	New Product Development
OEM	Original Equipment Manufacturer
PRM	Persons with Reduced Mobility
ROSCO	Rolling Stock Leasing Company
TOC	Train Operating Company
TRL	Technology Readiness Level
US EPA	United States Environmental Protection Agency
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

The rate products fail at launch has been estimated to be as high as 40% (Cooper, 2019). This could mean that the product has failed to meet the expectations of the firm in addressing a market opportunity leading to its termination (Castellion and Markham, 2013). The causes of this failure are often studied in the context of its new product development (NPD) process. How the NPD process can fail to deliver a product that meets expected levels of adoption is often inferred by comparisons with NPD processes that deliver successful outcomes (Panizzon, Vidor and Camargo, 2022). A significant factor in these cases is the involvement of customers and the responsiveness of the project to the demands of the target market (Cooper, 2019). This responsiveness has extended to considering supplier involvement (Marzi et al., 2021) and further downstream interests involved in more complicated procurement (Martín, Reinhardt and Gurtner, 2021) leading to the emergence of the practice of understanding and responding to external demands, which can be referred to as stakeholder engagement. This practice could then contribute to the integration of findings into determining the products' capabilities (Driessen and Hillebrand, 2013; Rodriguez-Calero et al., 2020).

The practice of stakeholder engagement has been explored extensively within the context of mass-manufactured goods that are consumer orientated, such as medical devices (Deiningner et al., 2019) and electronics (Lauff, Kotys-Schwartz and Rentschler, 2018). Similar studies have focused on the methods for engaging end-users in software development (Burnay et al., 2020). Studies show where engagement is best suited within the NPD process to prevent impacting project performance, such as the time and costs taken to complete them (Martín, Reinhardt and Gurtner, 2021), how it can support a company's ability to explore a range of concepts (Dorst and Cross, 2001), the effectiveness of prototyping methods to communicate and test different solutions (Camburn et al., 2017) and requirements elicitation techniques in being able to provide specific responses (Pacheco, Garcia and Reyes, 2018). Whilst most of these studies either focus on customers or end-users as the focal stakeholder, the stakeholder term could also

apply to a broader array of interests, as theoretically defined by Freeman as “any group or individual who can affect or is affected by the achievement of the organisation’s objectives” (1984, p.46). However, in the context of NPD studies this comprehensive approach to who constitutes a stakeholder, beyond customers, suppliers and end-users, has seldom been applied to this extent.

Complex product or systems (CoPS) share similar challenges in being a successful NPD outcome compared to mass-manufactured goods, such as addressing a significant opportunity for a new product, but have significant differences that can affect how this could be achieved. This is evident in how CoPS are defined as “...high cost, engineering-intensive products, systems, networks and constructs ... the term ‘complex’ is used to reflect the number of customised components, the breadth of knowledge and skills required and the degree of new knowledge involved in production, as well as other critical product dimensions.” (Hobday, 1998, p.690). For the purpose of this thesis the term CoPS will be divided into two groups.

One group concerns large-scale megaprojects involving the development of complex infrastructure, such as dams, nuclear power plants and telecommunication systems (Hobday and Davies, 2008). Studies of these projects have shown the importance of stakeholder engagement in being an activity that encompasses a much wider range of interests to serve different purposes throughout design and construction (Lehtinen, Aaltonen and Rajala, 2019). This engagement can affect where and how the project will be built (Newcombe, 2003) through to ensuring these interests do not feel motivated to disrupt the project as a result of a lack of clarity as to its aims and environmental and societal impact (Olander and Landin, 2005). Ultimately, the study of stakeholder engagement in these contexts reflect the multi-organisational dimension of CoPS that concerns providing the necessary expertise required to deliver them and the interests that will be affected in doing so. Whilst failure to meet levels of adoption would manifest differently in large scale CoPS development contexts, due to the project output not leading to repeatable market transactions that can be measured through adoption quantities, the lack of use of

infrastructure once built could provide a similar indicator of potential failure. However, failure within infrastructure project literature is often measured in cost overruns and delays rather than a lack of adoption and as such the aims of stakeholder engagement are driven by the former (Olander and Landin, 2008).

The second group of CoPS that this thesis will focus on will be referred to as engineering systems. These are small-scale sub-systems of larger platforms, market-orientated in their development and produced in small volumes but reflect the organisational and technical complexity of the larger forms of CoPS. Examples of the type of CoPS focused on for this thesis are aircraft engines, robotic equipment and particle accelerators (Hobday and Davies, 2008). This type of CoPS is one of the least studied, also referred to as machinery and equipment, with attention paid more often to complex constructions, telecommunication systems and other large digital systems (Ranjbar, Park and Kiamehr, 2018). However, threats to the successful completion of engineering systems are similar to those faced by other CoPS owing to the need to coordinate a breadth of expertise across multiple organisations (Dedehayir, Nokelainen and Mäkinen, 2014). Moreover, engineering systems share a similarity with consumer goods in that they need to be able respond to market demand and consider the extent of adoption as a key measure of their success. As a result of these characteristics, stakeholder engagement for engineering systems could be more expansive so to include commercial and regulatory interests as well as operational and technical interests. Furthermore, the engagement methods applied could affect prototyping and requirement elicitation activities so to ensure demands that are market-driven are identified, a dimension that could be largely be absent from larger-scale CoPS projects.

This introduces an area of research that has received little attention as to how stakeholder engagement can support the NPD process in leading to a successfully adopted engineering system. One key difference that appears to be overlooked in extant literature is that, compared to consumer and digital goods, engineering systems are unlikely to involve a single individual who is both the customer and the end-user. As such identifying the needs for the system will need

to address may require a comprehensive analysis of who can affect the procurement process and the system's operation including who could be affected by system once in use. In addition, such research may also need to include interests that would not directly benefit from its adoption and operation, such as those responsible for maintaining it and ensuring regulatory compliance. This reflects a significant gap in knowledge as to how to identify these stakeholders, how their needs can be elicited and how the technical development methods applied during an engineering system NPD can integrate the insights gained through this engagement.

Further evidence of the challenge faced by engineering system development can be seen in the failure rates of capital goods. This category includes all forms of CoPS and their less technically innovative equivalents, and is estimated to be at 35%, compared to 45% for consumer goods (Castellion and Markham, 2013). These failure rates suggest engineering systems could be the form of CoPS that could benefit the most from identifying how stakeholder engagement practice during their NPD process can positively impact the extent of adoption, considering the presence of characteristics they share with consumer goods. By doing so, the findings from this thesis could contribute to ensuring such products are both highly technically advanced and reflect a deep understanding of the needs of the stakeholders in their eventual operating environments which in turn could ensure they meet expected levels of adoption.

1.1 Research Context

This thesis contains research produced in connection with the new product development project concerning a wastewater processing system that was to be installed onboard passenger trains in the UK. This project was funded by GBR-Rail (formerly trading as Garrandale), a private company. GBR-Rail designs and manufactures passenger wastewater retention tanks, referred to as controlled emission toilets (CET) tanks, and other components for the rail sector. Due to the access the author had to this initiative it was selected as a case study to represent an atypical case of engineering system development owing to the extent of expertise present in both the academic institution involved and this company. The

author was involved as a participant-observer throughout the first 3 years of the project contributing the findings from the proceeding studies.

At the time this research was conducted, train operating companies (TOCs) would either collect wastewater from onboard toilet facilities or discharge it directly onto the railway tracks. Collection was made using CET tanks for emptying at a rail depot into a municipal sewer network. In order for the toilet systems to work, a freshwater tank is required to supply water to the handbasin tap and to flush the toilet. If this tank becomes empty or the CET tank becomes full then the toilet is automatically locked out of use. GBR-Rail conceived the idea of offering a solution that would treat this wastewater onboard so that the train would not need their wastewater tanks servicing as often at the depots. The idea also included recycling greywater from the handbasin, which would be used for toilet flushing, so to have a similar impact on servicing frequency. The emergence of changes in government policy that would prevent TOCs from operating rolling stock, the industry term for trains, that discharged directly onto the tracks was also a reason to assume market interest in this system.

Cranfield University was approached by GBR-Rail to help engineer and test the system's liquid and solid processing units and the composition of the various liquids, solids and vapours to ensure they were safe and compliant. This project was referred to as Project Safe Waste and was initiated with Cranfield University's involvement whereby shortly afterwards research for this thesis began. At this time the concept for the system had been agreed upon by the project's principal investigator and the sponsoring firm's managing director, as described above. A TOC was introduced to the project by GBR-Rail enabling visits to their depot and later for wastewater sample collection to take place. Project Safe Waste was comprised of three researchers; the author of this thesis, and two others that developed the solid and liquid sides of the system respectively. The team was based at the same location prior to the onset of the SARS-CoV-2 pandemic and was supported by their respective supervisors, the principal investigator, a project manager, a system integrator and a control system developer all based at Cranfield University's main campus. GBR-Rail's

involvement included regular input by the managing director, a senior manager for R&D marketing, who was this author's main point of contact as regards GBR-Rail, and a specialist contractor who consulted on the design and manufacturability of the system.

1.2 Research Aim and Objectives

Using the project described in the prior section as a case study of engineering system development, the focus of this thesis is to examine the operational, commercial and regulatory demands that will be expected of a solution that can address wastewater and freshwater challenges faced by the rail sector, specifically in relation to toilet systems. Through this focus, broader contributions will be made that can help shape the development of engineering systems in general that incorporate a high degree of technical innovation. Therefore, this thesis aims to:

Understand whether, and how, engaging stakeholders during the development of an engineering system might better align its technical capabilities with the needs and constraints of its industrial operation.

The following research questions will be answered by meeting each of their objectives, the results of which are presented in individual chapters:

RQ 1. Who are the stakeholders involved in the adoption of the engineering system in this research context and how do they relate its development?

- 1.a. Identify and compare the roles and responsibilities of stakeholders in the development and operation of similar technology in industries related to the case study's engineering system.
- 1.b. Analyse the stakeholder landscape of the case study's engineering system to determine how the problems it addresses could affect them.

RQ 2. How can stakeholder input influence engineering system development, and how is the value of that input understood and captured through the engagement methods applied?

- 2. Evaluate the extent stakeholder needs are being addressed by the direction of the system's development.

RQ 3. What are the challenges and opportunities for advancing stakeholder engagement during engineering system development?

- 3.a. Evaluate the ability for a prototyping strategy applied during the development of an engineering system to incorporate stakeholder input.
- 3.b. Synthesise findings from the case study to provide theoretical and practical implications for prototyping highly innovative engineering systems with stakeholder engagement.

1.3 Structure of the Thesis

The thesis is comprised of 9 chapters structured in the conventional thesis-by-chapter format. This introduction chapter has presented the justifications for studying the development of engineering systems through the lens of stakeholder theory and the extent existing technical development methods address identifying and incorporating the needs of salient interests. To provide context to these studies, a literature review is presented in the following chapter that explores multiple related domains followed by a chapter that explains the methodological approach. This concerns the use of qualitative data, a specific reasoning logic and the chosen methods that will be applied to address each research question and objective, the results of which then follow in the proceeding chapters. These methods have been adapted in various ways to meet the specific research context and to address a lack of approaches towards collecting and analysing stakeholder data in engineering systems-related fields. The discussion and conclusion are then presented in individual chapters. Figure 1-1 illustrates how the chapters call on specific bodies of literature, relate to the single case study

and meet specific objectives in addressing the aim of the thesis. An overview of the contents of each chapter is as follows:

Chapter 2 reviews the literature that relates to the overlap between studies of complex products and systems, stakeholder theory, new product development processes and practitioner methods used to engage stakeholders and to develop new products. As the topic of developing engineering systems with stakeholder engagement is a nascent field, a narrative approach was chosen due to the lack of studies that could form a cohesive corpus for systematic review. As a result, the extent to which these separate bodies of literature address how stakeholder theory and the practice of engagement can explain, and be used to contribute to, successful engineering system outcomes reveals the gaps in knowledge that the thesis will then address by answering the research questions previously introduced.

Chapter 3 details the reasoning for how a single case study research design can contribute to meeting the aim and objectives of this thesis and how, and why, abductive reasoning will be used during the analysis for some of the later results chapters. The chapter explains why the chosen methods for the supporting studies are suitable for the stakeholder identification analysis, for the analysis of their needs and for identifying the factors that could have influenced whether and how their needs were addressed during the engineering system development project.

Chapter 4 presents a review of stakeholders, derived from literature from a range of sources, in the development and operation of passenger wastewater treatment systems so to provide context to the case study's project's focus on the UK rail industry. Articles from both academic and non-academic sources are systematically reviewed to reveal the types of interests stakeholders may have in the development of such systems, inferred by the topics of the publications reviewed. The findings then compare across all forms of transport the stakeholders' levels of interest, inferred by the volume of publications, in relation to the nature of their interests, revealing which stakeholders could be the most

influential in affecting the development of this type of engineering system and for what purpose.

Chapter 5 presents results from a document analysis of the UK rail and water sector that contributes several findings. The first is the identification and analysis of stakeholders to form an interview sample for later engagement in the proceeding study. The main contribution, however, is how the documents also reveal the extent of the problem of passenger wastewater operations and supports an estimation of the level of interest and influence these stakeholders could have in the case study's project. Through the application of a problem framing model, the documents are then used to synthesise alternative approaches to addressing the challenges that surfaced in relation to their wastewater and freshwater priorities.

Chapter 6 presents the results from an interview study of the stakeholders deemed to be most interested and influential in the operating environment, ranging from both public and private organisations, using a semi-structured interview method. Insights were elicited that related directly to the needs of the researchers involved in the engineering system development project in the form of requirements that were in scope and could potentially be addressed. However, needs that reflected the external stakeholders own concerns which could be considered future design considerations, without significant change to the project, or out-of-scope also emerged. These insights provide evidence as to the extent the project would need to further align to stakeholder needs. How and why the system developed once these findings were shared would be captured in the following results chapter.

Chapter 7 presents results from the case study of the team that developed the system during its first stage of prototyping. Interviews, observations and diagrams were collected that follow the progress of the system and the extent the design changed in response to the findings of the prior study. As an indication of this study's use of abductive reasoning, the concept of boundary objects was introduced into the analysis, shifting from the initial focus on stakeholder theory, to guide an evaluation of the conditions that affected the team's ability to

incorporate stakeholder insights. Through focusing on the prototypes and related artifacts, how future development could further incorporate these insights supports advancing the processes and techniques used to create them.

Chapter 8 provides a discussion as to how the findings can address how the development of engineering systems, that have an unknown commercial and regulatory dimension to their operations and are highly innovative, can align to stakeholder needs through engagement. How the findings of these studies can be generalised and transferred is then discussed in relation to several theoretical contributions that are made to inform future studies. These include proposals for adapted methods and terminology that can support expanding the field of engineering system development study by addressing the unique challenges this type of product faces in ensuring their stakeholders are identified and effectively engaged. Specific implications for practice concerning passenger wastewater system development are detailed with recommendations for how these contributions to knowledge could also be applied in practice.

Chapter 9 concludes this thesis by answering each research question in relation to both the specific findings for future passenger wastewater system development and what could be applied more generally to other types of engineering systems. Factors that could inform multiple-case study sampling are listed that could influence the extent stakeholders can be incorporated, including how this requires further development of prototyping techniques. This conclusion identifies where some of the most valuable areas of future study could be for engineering system development and details the practical and theoretical achievements made by this thesis in applying qualitative research methods to inform the development of such a system.

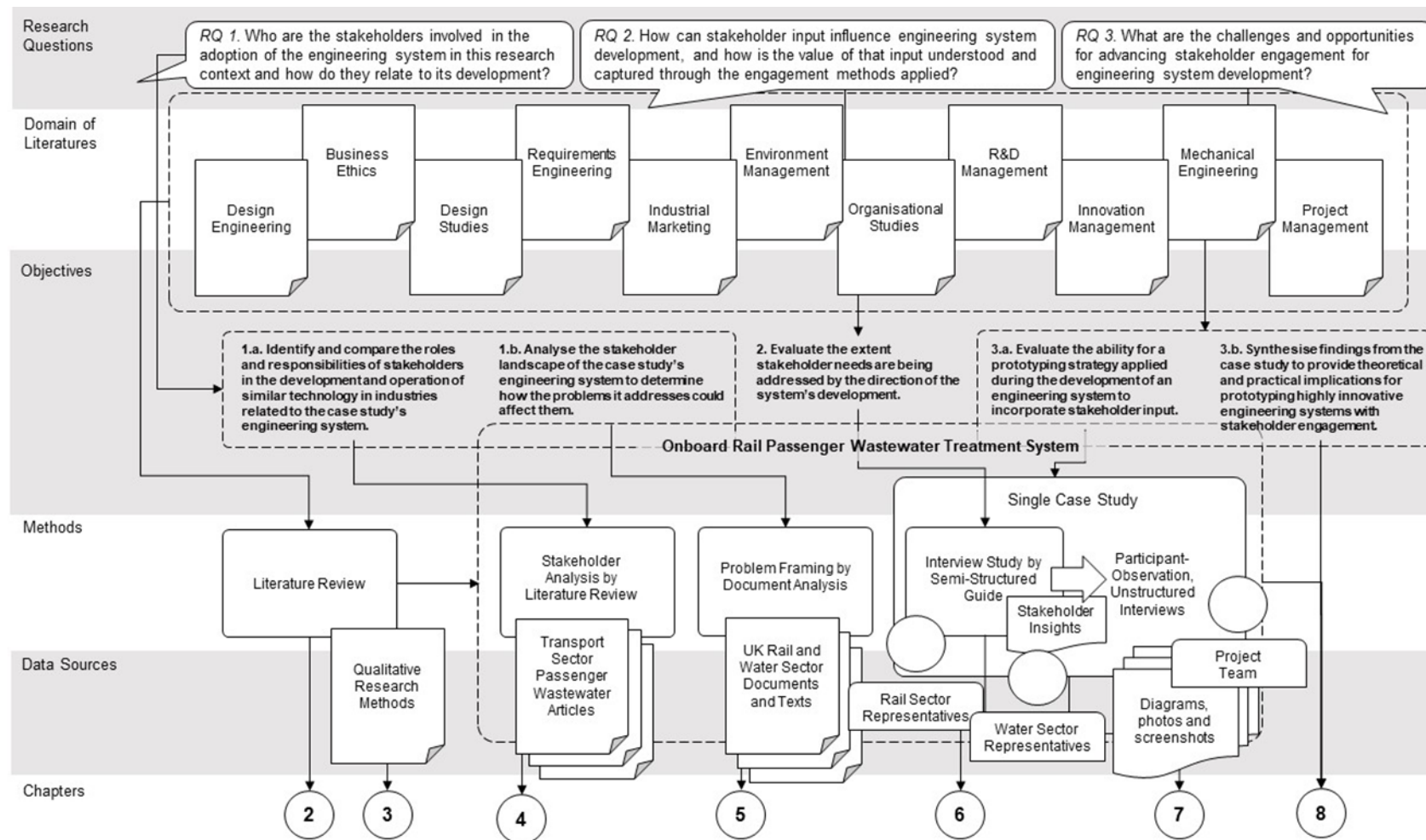


Figure 1-1 Diagram showing the structure of the thesis and how the results chapters relate to the passenger wastewater system case.

2 LITERATURE REVIEW

2.1 Introduction

Through reviewing literature of product development project practices in relation to stakeholder theory, the extent advances have been made in the integration and resulting impact of salient interests on project outputs can be revealed. With this aim, this chapter will contribute to our understanding of whether and how the processes and methods applied balance the interests of those developing the technical capabilities of a new engineering system with those who will be responsible for adopting or enabling its adoption. As this review concerns this form of product and stakeholders that are yet to be extensively studied, this chapter begins with contextualising stakeholder definitions and theory in new product development (NPD) and engineering systems-related literature to identify how this term, its theoretical model and these contexts relate.

The review then explores the implications of technological and organisational aspects of engineering system development that could differentiate it from that of consumer goods and software, the dominant foci of product development studies. This is evident by journals and conferences from this domain either implying this focus or explicitly referring to these types of product. These differing aspects concern the use of development frameworks and management processes during their initial stages of defining the purpose of a new product. In addition, these aspects could also concern, how, during the initial stages of defining a new product, the extent of innovation can also differentiate types of products and the demands this has on the development process. This is relevant to this review due to the extent that engineering systems can utilise advanced emerging technology in contrast to the more often studied consumer-orientated product types. The extent these differences are known and could affect the application of stakeholder theory during engagement practices will form the focus of this review.

With an appreciation of the extent engineering system NPD and stakeholder theory manifests in development processes, this review then considers the extent

literature reflects these findings when considering the efficacy of specific methods for requirement elicitation and executing prototyping strategies to deliver outcomes that contribute to meeting expected levels of adoption. Given that software and consumer goods are dominant product types in the literature, this review explores the potential limitations of established practice in being able to incorporate stakeholder interests in an engineering system development context. Recent advances in approaches to NPD and development frameworks are then reviewed to understand how the challenges and opportunities of stakeholder engagement and integration are transforming its purpose in practice and through scholarly contributions to theory development.

This review provides the basis for the following chapter to explain the methods that will be used to contribute to filling gaps in academic attention and help scholars and practitioners alike understand the role stakeholder theory plays in the development of complex engineering systems. These findings will be revisited in the discussion chapter to explore the extent the learnings from the case study in Chapter 7 provide empirical evidence of whether and how engineering system development can face unique NPD challenges, of which have been seldom researched. This will also contribute to understanding the extent stakeholder theory can explain the limitations and successfulness of processes and methods for developing such products in meeting the needs of those responsible for ensuring its uptake.

2.1.1 Stakeholder theory and new product development

The influence a consumer has on the development of the products they will use or benefit from demonstrates how activities of an organisation responsible for producing them can be affected by an external interest. This model is an example of applied stakeholder theory, whereby both the consumer and the producer have stakes in the success of the outcome. The term “stakeholder” can be used in a variety of contexts with different motivations for study (Miles, 2017), owing in part the broad theoretical definition given by Freeman (1984) and subsequent expansion of the field. The resulting adoption of the theory can be found in contexts as diverse as environmental governance (Reed, 2008) to the

development of medical products (Martín, Reinhardt and Gurtner, 2016) inspiring wide scholarly application beyond its original strategic management field. For the purpose of this review, this model will be used to guide the selection of literature that concerns studies that identify and analyse organisations. This could be either public, private or groups of individuals with a common stake, such as a functional department or a specific occupation, who could affect or be affected by an engineering system development project. This reflects the dichotomic approach to stakeholder modelling involving internally and externally positioned interests (Miles, 2017) and as such will enable a comparison between that of the often studied consumer-orientated goods and engineering systems.

Through viewing the process and frameworks of developing engineering systems through the lens of stakeholder theory, this review will consider the extent they succeed in integrating the interests of those affected by this type of output. This will include the external commercial, regulatory and operational environment it resides within. Studies that adopt a stakeholder theory perspective in considering these interests can explain why a product succeeds or fails to meet adoption targets regardless of whether technical goals of the project have been met (Cooper and Kleinschmidt, 1993). Moreover, these studies can explain how similar projects compare in terms of avoiding delays and cost increases when different approaches to managing external stakeholder relationships have been used (Olander and Landin, 2005).

Studies that have demonstrated successful engagement have provided insights into other factors beyond the processual stages and technical development methods that can contribute to a project incorporating the needs of a wider array of stakeholders (Brown and Katz, 2009; Markham et al., 2010; Reid and de Brentani, 2012). For example, the role of culture in creating an environment that can encourage this transformation, and how this effects internal and external communication norms, project assessment criteria and procedures, have featured significantly in studies that seek to identify contributory factors of failed new product development (Kahn et al., 2012). However, by examining the practitioners' technical development methods this review will attempt to ascertain

the extent these approaches could limit such cultures in being able to take hold. This could concern the extent theory can be applied to explain the extent such techniques are able to create positive relationships internally and outwardly with salient stakeholders in the engineering system's intended operating environment.

2.2 Applying stakeholder theory to engineering systems

Donaldson and Preston's (1995) justifications for applying stakeholder theory can provide a framework for why, and how, an organisation could pursue gaining an understanding of the interests that they may affect or be affected by. More recent developments of the theory have incorporated the emergence of collaborative stakeholder landscapes that consist of a shared goal as a catalysing factor rather than the activities of a focal firm (Savage et al., 2010). For the purpose of this review, however, we will consider the application of theory from a single organisation's perspective and how they may need to partner with other interests to realise their goal in developing an engineering system, reflect the research context of this thesis.

The theoretical framework applied in these studies comprises three distinct justifications to guide data collection and analysis; descriptive, instrumental and normative. As the study of engineering systems relate to larger-scale technical infrastructure projects, as both are forms of complex products or systems (CoPS) (Hobday, 1998), including studies of the latter in this review could contribute to understanding the former to an extent in terms of how stakeholder theory can be applied.

A descriptive approach identifies stakeholders and their relationships to the organisation through categorising particular characteristics of their interests, such as the amount of power, legitimacy and urgency they have (Mitchell, Agle and Wood, 1997). An example CoPS study concerns analysing the individual internal interests involving a rail signalling system to reveal who should be closely monitored as a result of their high levels of influence within the project (Aragónés-Beltrán, García-Melón and Montesinos-Valera, 2017). The implications of the finding suggest ways of reducing delays by prioritising and addressing concerns presented by these specific stakeholders. Such studies can, by themselves,

provide sufficient implications for practice. For example, the purpose of the study could be to identify how stable a stakeholder landscape is based on the level of complexity, dynamism and uncertainty in how and why they affect an organisational activity (Aaltonen and Kujala, 2016). Alternatively, this justification could be used to identify potential risks and threats to an organisation's objectives, reflecting an established motivation for conducting stakeholder analyses (Mendelow, 1981).

Conducting a stakeholder analysis for a particular purpose to inform an activity reflects an instrumental justification. Such a study could contribute recommendations as to how a firm can manage stakeholder relationships to achieve a desired outcome or operating environment, such as one that is appropriately compliant as a result of successfully incorporating health and safety concerns, for example. In the context of engineering system development this could also concern undertaking activities or acquiring capabilities that can, for example, enable the project to adapt to changes in demands originating from these stakeholders (Watson et al., 2018). As such, an instrumental approach would aim to identify ways to increase support for a firm's activities and to reduce negative impacts, such as delays and cost increases, stemming from remedial actions as a result of poorly engaged yet influential stakeholders, for example (Lehtinen, Aaltonen and Rajala, 2019; Martín, Reinhardt and Gurtner, 2021).

The commonality of these approaches is that their studies aim to prioritise the interests of the organisation undertaking an activity. From a descriptive angle, this could help communicate the lack of risk or uncertainty surrounding the support for an engineering system NPD project or, driven by an instrumental aim, to inform strategy to increase support and reduce potential threats to a project's completion. In cases whereby the interest of the organisation is to be influenced, or even defined, by the stakeholders themselves this justification can be described as normative. Schaltegger, Hörisch and Freeman (2019) argue that organisations ought to identify and incorporate stakeholder's actual interests, rather than only those that are considered to be instrumental to a project. A NASA case study of autonomous flight systems reflects this approach to an extent as

the agency had originally intended to develop an entirely new aircraft to meet an assumed need from the research community (McGowan, Bakula and Castner, 2017). The project was driven by the normative basis of empathising with potential users and beneficiaries derived from methodologies used by product and service design practitioners (Brown and Katz, 2009) which resulted in a significant change in direction to the potential outcome of the project.

However, few studies have demonstrated normative approaches being applied to engineering in practice, instead, the focus has been on academic-led experiments or efforts to improve education, for example, whereby students learn to prototype for perceived desirability rather than just technical feasibility (Menold et al., 2016). In the cases that have been normatively inspired, an instrumental justification has delimited the potential for stakeholders to significantly determine the purpose of a project. This is owed to the strategic primacy of an organisation remaining within their capabilities and expertise, reflecting a tension between resource-based and stakeholder-led theories of how an organisation succeeds (Donaldson and Preston, 1995). Considering that the desired solution of the NASA study previously mentioned did not involve the development of an aircraft, but instead software and service provision, the project could be considered to be unlikely to progress. As such, the failure to align with the capabilities and interests of the focal organisation could explain why the project would be terminated, or receive fewer resources, despite achieving supportive external stakeholder involvement, thereby illustrating a practical limitation to normative justifications.

This dilemma reflects how an organisation may be less inclined to pursue collaboration with stakeholders on normative grounds. However, ensuring there is a capability to respond and incorporate findings from descriptive and instrumental approaches reflect how this can be addressed to an extent. As a result, dilemmas may not always exist, for example, in cases that are able to integrate stakeholder engagement outcomes that lead to a solution that is both within the expertise of the organisation, or prompt the search for suitable partners, and the needs of those that are able to support its adoption (Deininger et al., 2019). A recent study concerning the medical device industry revealed that "... a

broad involvement of all the stakeholders that directly influence whether products reach the market and are adopted is key to successful innovation” (Martín, Reinhardt and Gurtner, 2021, p.147). Such an approach combines a normative appreciation of the breadth of interests to involve, including within an organisation, and an instrumental driver to ensure the resulting output meets expected levels of adoption. The extent to which this approach was adopted due to the product being a medical device could be explained by its specific stakeholders, development methods and industry norms. As such, these elements, when involved in the development of engineering systems, could determine the extent stakeholder theory can be applied in a similar manner.

2.3 Stakeholders in the development of engineering systems

The state of stakeholder involvement within NPD project practice specifically concerning an engineering system can be inferred by the implications of the widely adopted Technology Readiness Levels (TRL) framework. This framework was created by NASA to ensure manufactured components for spacecraft development programmes had reached the same level of technical maturity before being integrated into an assembly (Mankins, 1995; Sadin, Povinelli and Rosen, 1989). More recently, the framework has been used to set developmental targets for EU-funded technology intensive academic research projects (Héder, 2017). Table 2-1 shows the first three TRLs that help explain the practical aims of developing engineering systems and the foci of the initial activities. As a result the TRL framework provides an insight into how advanced engineering is pursued and can help reveal the extent it reflects specific justifications of how stakeholder theory is applied in practice.

Level	Criteria for achieving TRL maturity
TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept

Table 2-1 Showing the first three TRL definitions that describe the early stages of engineering system development activities (European Commission, 2014).

The technical nature of these levels demonstrates the significant influence of internal stakeholders have on the capabilities of the technology itself. In order for an engineering system project to achieve reaching each level, the stakeholders involved in determining whether and how this can be achieved would most likely be the most influential in determining the direction of the project. However, transitioning between TRLs can create a potential for differences to form in these interests as Olechowski et al. explain “different stakeholders may hold conflicting perspectives when it comes to how mature the technology is, and to what degree it has been demonstrated” (2020, p.403). The TRL framework does, however, indicate that a project can progress without significant external engagement beyond technical interests. This could be seen to be reducing the necessity for stakeholder analysis and integration to be conducted more comprehensively within an intended operational environment. This approach stems from its original purpose as a tool to be used specially for space programmes (Héder, 2017).

Whilst progressing through the initial readiness levels prioritises interests that can directly affect technical decisions, the final aim is to reach an operational stage of maturity, as shown in Table 2-2. This introduces the question as to whether the TRL framework’s focus supports establishing relationships between internal, and predominately technical, and external stakeholders with operational, commercial or regulatory interests.

Level	Criteria for achieving TRL maturity
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment (competitive

	manufacturing in the case of key enabling technologies; or in space)
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Table 2-2 Showing the final three TRL definitions that describes how engineering system development incorporates its operational environment (European Commission, 2014).

In considering the wider context of CoPS, the extent to which external stakeholder landscapes influence technical development could vary depending on its type, i.e. whether a large-scale megaproject or smaller-scale industrial machinery (Hobday and Davies, 2008). However, empirical descriptive analysis have predominantly concerned dichotomies of specific stakeholders, rather than any implications of a specific type. For example, the study of CoPS have concerned the roles and responsibilities of either suppliers (Crespin-Mazet, Romestant and Salle, 2019), regulators (Dedehayir, Nokelainen and Mäkinen, 2014) or consultants (Roehrich et al., 2019) in relation to that of the focal organisation. As a result the diversity of interests and their specific roles in supporting, or obstructing, the completion of advanced engineering projects, could suggest that each CoPS project could have a unique stakeholder landscape and thereby unique sources of external influence on its technical capabilities.

Whilst all construction-related CoPS may have similar stakeholders, such as local residents, the extent generalisability can be applied at a sectoral level for smaller-scale CoPS, i.e. across medical device, aircraft and consumer products industries (Martín, Reinhardt and Gurtner, 2016), is yet to be supported by empirical evidence. As such, applying a stakeholder landscape from a technologically different industry could underestimate the potential for unique roles and responsibilities found within its development, adoption and operation. As a result, for a given project, who these external stakeholders could be represents an area for further study.

Furthermore, in considering studies that have concerned the market orientation aspect of products, the potential plurality of engineering system stakeholders contrasts the study of mass-manufactured products and the dominant role of a specific stakeholder who is both customer and end-user. This is evident by how

the Voice-of-the-Customer (VoC) method for eliciting requirements features prominently in such studies (Cooper and Dreher, 2010; Melander, 2020). However, this implies that voices of stakeholders that collectively form these customer and user roles could also have significant impact on determining the technical nature of a new product and how a project would be executed, reflecting the conditions of a multi-organisational engineering system project (Hobday, 2000). Whilst studies have attempted to transition to encompassing wider stakeholder needs beyond those of customers, they are yet to demonstrate methodological or developmental implications of doing so with empirical evidence (Thompson, 2013). As a result, the identification of stakeholders in engineering system development projects beyond advancing TRL maturity could contribute to understanding how such products are intended to be operated, and the requirements for the underlying technology. Moreover, influence could also originate from those that are not involved in daily operations, such as regulators. However, whilst related studies indicate a potentially complex stakeholder environment for engineering systems, how descriptive analyses can be applied to reveal this extent are yet to be demonstrated.

2.3.1 Engagement during the development of engineering systems

The TRL framework represents significant technical milestones for stakeholders in an organisation developing an engineering system to achieve. To address challenges in achieving this goal, approaches have emerged that support the argument that a lack of stakeholder diversity and inclusion can negatively impact the time and costs involved in reaching completion. As such, from an internal technical perspective other readiness levels have been proposed that address the lack of inclusivity of stakeholders across different functions of an organisation of the original scale. For example, involving those responsible for component integration and operability so that this could contribute to increasing accuracy of project scheduling and monitoring (Magnaye et al., 2014). However, these refinements do not directly address the phenomenon whereby projects that reach the middle levels, as shown in Table 2-3, can either be terminated or receive

fewer resources, referred to as crossing the “valley of death” (Frank et al., 1996; Kobos et al., 2018).

Level	Criteria for achieving TRL maturity
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)

Table 2-3 Showing the middle three TRL definitions that describe the activities where engineering system development may terminate due to the “valley of death” phenomenon (European Commission, 2014).

Whilst studies have indicated that limiting the amount of engagement early in a project can positively impact the cost and time required to reach technical readiness of routine development (Martín, Reinhardt and Gurtner, 2021), scholars have identified that in general organisations have more successful project completions if this is encouraged. Adopting an approach that incorporates wider external interests (Ellwood, Williams and Egan, 2022) as well as internal interests responsible for later stage resource allocation, whilst the project instigator significantly reduces their influence over the project as it progresses (Markham, 2002), supports crossing these middle TRLs. As a result, development activities are encouraged to become more outwardly orientated towards the influence of stakeholders within the intended operating environment whilst involving those in latter stages of technological maturity.

However, the early involvement of external interests can have significant positive impact on a project’s performance, as evident in studies concerning larger-scale CoPS. Studies by Olander and Landin (2008) have shown how communication between construction project instigators and external stakeholders can be a reliable means of avoiding potential delays caused by the need for substantial

explanation to reduce the perception of overlooked alternatives for site locations, for example. In a study by Roehrich et al. (2019) the close working relationship between engineering consultants and a water utilities company was considered to be instrumental in meeting increased customer satisfaction metrics whilst avoiding the tension that could have arisen between internal sources of similar expertise. However, the extent to which these outside interests also influenced the purpose of the project, the exploitation, for example, of early stage fundamental science research, is yet to be explored in-depth by such studies.

As such, the aim of the engagement of external interests prior to a project having significant resources allocated to it could be inferred as a means to support improved project performance (Markham, 2002), which, in the context of this review, could mean reducing potential sources of disruption to the progression of the TRLs. Whilst engagement that leads to the purpose of the project itself being influenced has been evidenced, for example by previously mentioned NASA case study (McGowan, Bakula and Castner, 2017), the lack of studies suggest this is a potential outcome that current approaches seldom aim for. Therefore, studies of NPD processes and development methods that concern the engagement of interests appear to be applying stakeholder theory by prioritising instrumental approaches to addressing performance-related concerns.

2.3.1.1 Implications of the stage of development

In order to understand the priorities during the development of engineering systems we can consider how organisations have adopted a formalised approach to managing NPD through the use of the Stage-Gate process popularised by Cooper (1990, 2019). This initially encouraged the incorporation of market-orientated interests during the first stage, as due to the use of defined stages of product development activity, the criteria for passing “gates” stipulated that research into the needs of customers had to be satisfied. This generalised development process is also evident in how product design processes are described (Ulrich and Eppinger, 2016) and as such could be applied to the development of engineering systems.

However, these early activity stages and gate reviews also included focusing on the technical and financial aspects of a new product reducing the emphasis on this market element. This has resulted in organisations prioritising activities that focused on delivering technically feasible and cost-effective solutions, rather than those primarily informed by market conditions (Cooper, 1975, 2019). To address this concern, an aspect of the Stage-Gate process that has received significant attention concerns the structure of the first stage, described as the “idea” stage. As the initial description of the process inferred it could be conducted and reviewed in a similar manner as each later stage, this could lead to an underestimation as to how ideation might differ to, for example, producing, and reviewing, a physical prototype that demonstrates TRL 3. This has become apparent during studies that revealed how organisations that produced successful products managed this ideation stage differently in terms of the aims of engagement and the influence of findings during the gate’s review (Carbone and Tippett, 2014).

To address the lack attention given to the early stages, a management model referred to as the “fuzzy front-end”, in reference to the lack of initial clarity as to what the project needs to eventually deliver, can be applied. The model involves delineating the “idea” stage into multiple separate phases of which are shown from the model by Khurana and Rosenthal (1998) in Table 2-4. The final phase excludes the specification and design activities of the first stage of the NPD, which would proceed if the focal organisation considered there to be sufficient stakeholder support (Gassmann and Schweitzer, 2014). By completing each “pre-stage 1” phase, developers can avoid selecting ideas solely on the merits of internally derived interests, such as demonstrating technical feasibility and cost effectiveness that align with the organisation’s capabilities and budgets (Eling and Herstatt, 2017).

Phase	Activity outputs
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Pre-Phase Zero	Preliminary opportunity identification, idea generation and market and technology analysis
Phase Zero	Product concept
Phase One	Feasibility and project planning

Table 2-4 Front-end phases to be completed prior to the development of detailed designs (Khurana and Rosenthal, 1998).

However, whether an engineering system requires an extensive fuzzy front-end is itself a challenging decision to make. Organisations would need to have an awareness of the extent of the uncertainty and the equivocality surrounding the external interest for a new offering. This may only become apparent during the latter stages of development (Zhang, Cao and Doll, 2019). Furthermore, the risk of these unknowns being underestimated could be due to the need to reduce the time and cost implications of this more resource intensive start to a project, although, literature suggests greater emphasis is being placed on exploratory front end phases (Park, Han and Childs, 2021).

However, in comparison to the definitive, albeit potentially challenging to determine TRL maturity stages (Olechowski et al., 2020), the outputs of these front end phases could be difficult to assess as being successful. The lack of certainty in the context of rigid criteria set during gate reviews could therefore lead to projects being prematurely terminated (Peña Häufler et al., 2021; Sethi and Iqbal, 2008). To overcome this eventuality, larger organisations are able to cater for this due to the resources and capabilities to adopt more extensive research and collaborative practices (Dorst and Cross, 2001; Lifshitz-assaf, 2018; Power, 2014). This remains a challenge for smaller firms, however, who may prioritise developing products that originate from established stakeholder landscapes, such as their existing suppliers and customers, as a result of the constraints on their resources (Marzi et al., 2021) which could limit applying fuzzy front-ends to their projects.

As the involvement of external stakeholders is seen as a means to complete these pre-stages, literature has identified several factors that could limit this approach. These concern protecting intellectual property (Ellwood, Williams and Egan, 2022) and managing internal influence over how a development effort is perceived when represented by its prototypes (Schrage, 1996). Furthermore, the activities of the pre-stages need to counter perceived negatives of increasing an internal team's exposure to the "turbulence" of external demands such as slowing a project's progress (Safayeni et al., 2008). Despite these difficulties for practitioners implementing a fuzzy front-end to their NPD projects, scholars argue that these costs and challenges could be far less significant than the rework incurred later in a project as a result of these activities not being undertaken (Agouridas et al., 2006; Wynn and Clarkson, 2018).

To reduce the potential for a fuzzy front-end to impact a project's performance, stakeholder involvement and integration has been studied as an "intensity" that can be managed to correspond to the level of uncertainty in technology and market demands (Lehtinen, Aaltonen and Rajala, 2019; Martín, Reinhardt and Gurtner, 2021). Frequency of specific interaction can inform engagement sampling so that those representing greater uncertainty, such as the state of competing technologies, could be higher than the interests representing regulatory positions or market conditions, if they are more stable, and help provide more evidence-based project review criteria (Sethi and Iqbal, 2008).

Whilst there are rationales for such engagement in academia, from a practitioner's perspective, a project needs to have the resources to execute them. Organisations that were shown to be successful in integrating external interests had specific capabilities that enabled them to manage potentially differing views that contribute to the acquisition of new knowledge and framings (Watson et al., 2018). This implies that if an organisation's capabilities to integrate external stakeholder interests are under resourced, the NPD process could commence without significant influence from the stakeholders who will be responsible for its eventual adoption. As a result a project could risk being unable to incorporate these interests at a later stage without incurring significant costs and delays

should the product concept itself negatively affects these interests, or fails to engender sufficient commercial, regulatory or operational support.

Owing to fuzzy front-end literature relating closely to new product development studies, the implied mass-manufactured nature of the solutions suggests that engineering systems could present an extreme case for when technology-intensive projects could benefit from such an approach. This is due to the use of the TRL framework supporting engagement occurring at the end of a project, noted by scholars researching fuzzy front-end conditions as appearing “back to front” (Eling and Herstatt, 2017). This is due to how the framework stipulates technology is expected to be able to operate in its intended environment and be suitable for “commercialization” as inferred during the final TRLs, detailed in Table 2-2.

The implications of this practice result in pursuing a scientific discovery through basic research and then attempt to find an application for it thereby calling for this external engagement. For example, a case involving the application of photosynthesis as a source of electricity demonstrated how product designers, acting as the external input, developed potential solutions with the initial researchers to utilise this functionality (Moultrie, 2015). This study helped evidence the conflicts and tensions that can occur within a cross-functional team. In terms of the approach towards external engagement, as argued by Dorst and Cross (2001) and Héder (2017), whereby starting with the desired outcome defined by the intended beneficiaries so that the resulting technology could be more aligned with their needs, was not a focus. Owing to the limited scope of this study, whether the solution would address the needs of those who would benefit from it required further research. As a result, this case was unable to validate whether this method of energy generation could be of benefit to those that required greater access to electricity.

The adoption of the pre-phase zero “opportunity identification” activity with these stakeholders could have potentially contributed to achieving this goal. However, this case inferred that owing to internal struggles for influence over a project’s direction the potential for greater external engagement could further exacerbate

this tension, reflecting findings this could be perceived as “turbulence” (Safayeni et al., 2008). This suggests adopting fuzzy front-end approaches could require more than just additional engagement activities of external stakeholders if the findings are to have significant influence on a project’s direction and be seen as a positive impact. However, how organisations transition to adopting fuzzy front-end stages and overcome these challenges has seldom been studied.

2.3.1.2 Implications of the extent of innovation

Relevant to both the study of CoPS and the fuzzy front-end of NPD projects is the understanding of how the process of developing an engineering system can be viewed in terms of innovation. This helps to delineate the technological capability from the value the outcome will have once in operation. As explained by Garcia and Calantone “a discovery that goes no further than the laboratory remains an invention. A discovery that moves from the lab into production, and adds economic value to the firm (even if only cost savings) would be considered an innovation.” (2002, p.112). When considered a process, rather than a physical object or construction, innovation concerns managing the “discontinuity” the outcome will produce in its application (Veryzer, 1998). For example, how the engineering system will require a different operational procedure, regulatory framework or commercial benefit to be adopted could indicate the extent of discontinuity with prior conventions. Through considering the extent the solution will either be deemed entirely novel or significantly impact an existing system (Kovacs et al., 2019), practitioners could factor this into their approaches towards the analysis of affected stakeholders and how to prioritise engagement with those that could be instrumental in enabling this discontinuity.

In instances whereby the development is routine, the resulting engineering system could be described as an “incremental” innovation (Pisano, 2015; Satell, 2017) whereby an organisation could be less likely to require intensive engagement owing to the needs and the interests of affected stakeholders being already established and met with gradual improvements (Martín, Reinhardt and Gurtner, 2021). Therefore, an engineering system incorporating new internal

processes (Henderson and Clark, 1990), performance-improving material or a manufacturing method (Satell, 2017) would not be innovatively incremental.

How an innovation's discontinuities relate to existing solutions would determine whether those with a stake in them would support its adoption. For example, a "disruptive innovation" that introduces a lower quality and lower priced solution to a market that was underserved could present a challenge for regulators to embrace if the safety or reliability of the engineering system was in question. In such cases, "lower quality" refers to a technology at its initial stages of maturity, with subsequent iterations transitioning the innovation to an incremental development and thereby improves its technical capabilities leading to a higher quality product (Pacheco and Garcia, 2012).

Owing to the need to comply with industry standards, such disruptive innovation could be less likely to succeed in an industrial context, compared to a consumer context, as evident in a case involving novel cost-effective and environmentally-friendlier machinery for copper production that used a completely novel method (Dedehayir, Nokelainen and Mäkinen, 2014). This CoPS study demonstrated that due to the inability for copper to be produced and sold at a quality that was below regulations the company could only launch the machinery after it had significantly improved. Furthermore, research into the effects of price in such contexts have demonstrated that this can also fail to translate into interest due to the costly operational and compliance transformations required as a result of incorporating this more economical initial expenditure (Cooper and Kleinschmidt, 1993). Therefore, despite the cost benefit, only once the technology was proven to meet and exceed current production capacities and qualities the machinery developed in the copper manufacturing case study garnered required support. This was the result of the establishment of stakeholder relationships within the wider industry and regulatory authorities demonstrating an equitable common interest due to the sustainability improvements of the operations, reflecting how stakeholders can be driven by shared goals (Savage et al., 2010).

The copper manufacturing machinery case further demonstrates how engineering systems can differ to mass-manufactured goods when viewed from

an innovation perspective. For example, the case of digital consumer cameras being able to eventually disrupt higher quality film cameras after, rather than prior to, launch was a result of the lower quality image production not being constrained by industry standards that could have required otherwise. As a result, the product could meet consumer demand for images that did not need to be high quality whilst providing the benefits of the novel digital format (Christensen, 1997).

When innovation disrupts established technology norms and their markets, this will be due to either an existing product being introduced to a new market or the organisation developing it is new to the technology involved, but a market already exists, albeit underserved. When there is novelty on all fronts, this presents a significantly higher level of innovation. The term “radical innovation” can be applied for engineering systems that involve such novelty. In such cases, they will be developed with significant uncertainty as to whether both internal and external stakeholder interests will support the project given that there is little prior evidence due to the factors that contribute to its novelty (Garcia and Calantone, 2002).

Whilst having a level of continuity can help identify existing stakeholder positions, such as in incremental or disruptive cases, organisations could be motivated to be the first to provide a solution for a problem that has yet to be addressed in any form. As a result, the output will lack a pre-existing market or regulatory context resulting in the innovation being categorised as radical. By doing so, however, the organisation will be challenged as to how to identify, analyse and engage stakeholders they may be affected or be affected by an as yet to be known technical capability. Approaches used for incremental innovation, that support existing stakeholder demands, for example, may fail to cater for this. As explained by Peña Häufler et al. an organisation that fulfils demand for established products “...tends to rely more on well-known routines and technologies ... and thereby struggle to realize innovation and renewal”, suggesting that committing to existing demand is a reflection of “...risk-averse sectors like utilities ... including firms in the electricity, water, sewage service, and natural gas business” (2021, p.463).

Organisations that develop complex engineering systems could, therefore, gain the most from adopting a proactive approach to managing the implications of the extent of innovation being pursued in order to reduce the risk that a radical innovation would negatively impact or fail to incorporate otherwise supportive interests.

The challenges in developing highly innovative engineering systems could reflect the innovation demands for CoPS more broadly. Whereas the introduction of novel consumer products can pursue ever increasing quality through newer versions, the expectation that CoPS are already of a high capability when adopted means the focus of continued development concerns the ongoing servicing and upgrading of these innovations whilst in operation (Hobday, Rush and Tidd, 2000). These scholars refer to this phenomena as “collapsing” the innovation and diffusion aspects of introducing a new CoPS as the stakeholders involved in its operating context are partly responsible for developing the output’s capabilities. This type of innovation could be referred to as “breakthrough” if the problems being solved, although difficult to do so, are well defined as a result of this close working relationship with intended operators, however, the technology involved would be a considerable advancement (Satell, 2017). As such the stakeholders in a CoPS play a critical role during its development due to their expertise. This explains the multi-organisational aspect of CoPS development (Hobday and Davies, 2008) the achievement of which would be one of the initial challenges facing engineering system development.

Thus, market-orientated small-volume engineering systems that embody radical innovation in how they address a problem and in their technical processes could be presented with unique challenges in reaching expected levels of adoption. Owing to the lack of studies of engineering systems, how organisations identify who their industrial partners could be and how the technology could co-evolve with their input represents an opportunity to further understand how radical innovation affects such developments. This research would need to involve how to navigate the commercial sensitivities of potentially competing operators, differing regional regulatory environments and operational norms that may be

discontinued as a result of the implementation of this system, all aspects that also differentiate engineering systems from other types of CoPS and mass-manufactured consumer products.

2.4 Engagement activities during engineering system development

Literature that contributes to the development of techniques and their approaches for the creation of physical engineering systems can reveal the extent the uncertainty and equivocality of stakeholder needs are being responded to. Specifically, this literature concerns how requirements are elicited and prototypes produced in the context of integrating insights derived from stakeholder engagement. We can also consider the extent studies concern specific levels of innovation and the implications of the physical and industrial, rather than digital or consumer, nature of engineering systems and how they may inform these methods. Through reviewing how engineering systems are developed in practice, we will also be able to explore the extent theoretical approaches are being incorporated and how stakeholder engagement is addressing these concerns.

2.4.1 Requirement elicitation techniques

The practice of eliciting requirements concerns ensuring statements describing what a solution needs to do are of a suitable quality. This can be measured in a number of ways. For example, ensuring requirements are traceable to specific needs as well to specific capabilities (Bruehl et al., 2021; Würfel, Lutz and Diehl, 2016), are divided between those that concern the operational environment and those that concern the intrinsic ability for the solution to function regardless of the conditions (Agouridas et al., 2007), and that all stakeholders are identified, in order to support achieving requirement completeness (Khan et al., 2022). These methods emphasise how this practice adopts a descriptive and instrumental approach towards stakeholder analysis and engagement so to, for example, ensure a solution could be used on the basis of operable functionality (Sharp, Finkelstein and Galal, 2008). Studies, however, are yet to demonstrate a normative justification for looking beyond where technical requirements are commonly found. This reflects the dominant focus of this literature on software

development (Dick, Hull and Jackson, 2017; Nuseibeh and Easterbrook, 2000) and the established stakeholder landscapes that surround it, primarily in the form of end-users, in contrast to the potential uncertainties surrounding who requires what and why for a successful engineering system.

The widely adopted method of using structured interviews, with questions for requirements determined by the organisation pursuing the development as to what the solution will need answers for, could explain how there is little analysis of approaches to sampling or alternative interviewing methods. This is evident in the reviews of techniques that imply the use of positivist approaches to knowledge being separate to the social environments in which it resides (Hinds, 2008; Pacheco, Garcia and Reyes, 2018). This approach could be sustained due to the pursuit of routine innovation producing incremental improvements on how software functions; both who should be interviewed and what should be asked are therefore well established. As a result the role innovation plays in requirement engineering literature is yet to be considered at great depth neither the implications of the phenomena whereby questions cannot be predetermined due to a lack of knowledge of the challenges and technical needs faced.

The challenges that are studied concern the connection between projects that fail to deliver and the requirements elicited for it. Here scholars have identified potential factors that relate to how stakeholders are sampled and qualified. Pacheco and Garcia (2012) recommends assigning roles to individuals to recognise them as stakeholders based on how suitable they are to provide quality requirements through the use of personality tests, for example. Earlier studies, however, have argued against this practice of seeing requirements as a positivist construct that could justify the exclusion of responses, and stakeholders themselves. This is owing to the discrepancy in attempting to avoid the subjectivity of their value claims as to what constitutes a “quality requirement” but not by those eliciting the requirements (Hinds, 2008). Given the software context of requirement engineering literature, the emphasis placed on improving project outcomes by increasing the accuracy of requirement statements could explain why the type of product and its need does not feature prominently. Rather the

assumed certainty that stakeholders will need software overlooks the implications of fuzzy front-end project stages in identifying what a physical product could be expected to do and the requirements for its technology.

Furthermore, the practical constraints of developing physical engineering system solutions, the extent of unknowns, especially in the context of advancing fundamental science, could suggest the demands placed on eliciting requirements for digital and incrementally improved solutions could overlook this added complexity. Few studies have empirically explored the transferability of methods to other forms of product, although this has been implied through the use of more general terminology to propose stakeholder identification methods (Alexander and Robertson, 2004). This concern has been exemplified by Agouridas et al. (2006) in studies involving electromechanical engineering whereby the goals of stakeholders in providing requirements need to be more deliberately defined and any solution needs alignment demonstrated given the breadth of possibilities, and limitations, that such a form of engineering could be capable of achieving. This contrasts with the presence of an overarching established goal in software development projects which is reflected in formalized software specification and design requirement language that focus on the capabilities of processing digital information.

A position that remains consistent across software and non-software studies is that changes in, or additions to, requirements near the end of a project continue to prevail and are far more costly to implement than at earlier stages (Agouridas et al., 2006; Carr, 2000; Cooper, 2019) and that poor requirements, i.e. incomplete, inaccurate etc., are a significant factor contributing to a project's technical faults (Bijan et al., 2013). Therefore, eliciting quality requirements in non-software engineering contexts, whilst ensuring the type of product, and related engineering, is the most suitable form of solution, could represent a significant achievement that is yet to be thoroughly researched as to how to ensure. This success, or failure, in eliciting requirements will be embedded throughout a NPD project through the production of diagrams, physical

prototypes and illustrative depictions, thereby highlighting the significant implications of this practice and its methods.

2.4.2 Prototyping strategies

Producing physical artifacts during the development of a physical product can serve a wide range of purposes and involve multiple techniques (Ulrich and Eppinger, 2016). In contrast to requirement elicitation often being described as a singular data collection activity occurring at the start of a project, prototyping continues throughout the duration of a project and can form part of the requirement elicitation process itself (Rueda, Panach and Distant, 2020). Adopting a strategy that justifies applying particular methods reflects how an organisation responds to the level of technical uncertainty surrounding a product's development (Park, Han and Childs, 2021). This uncertainty is considered from the perspective of the engineers and experts involved, whilst equivocality is suggested through internal tensions and differing views between marketing, leadership and development teams on these artifacts being extensions of their respective professions and priorities (Schrage, 1996). However, much of these studies involve mass-manufactured consumer goods whereby the extent of stakeholder involvement focuses on the role of an end-user or customer. Owing to the inclusion of these internal interests in this literature, the relevance to the development of engineering systems could be apparent and support understanding the extent the method pursued by internal interests respond to and incorporate external influence.

Reviews of prototyping literature and studies proposing methods have focused on inductive problem identification and deductive solution refinement of a mechanical, structural or electrical concern (Camburn et al., 2017; Christie et al., 2012; Coutts, Wodehouse and Robertson, 2019) reflecting relevance to the development of engineering systems. With this emphasis on internal and technical interests, studies that explore approaches to prototyping involving outside actors, and how they contribute to this process, seldom consider cases that do not involve consumers, i.e. stakeholders with neither interest in purchasing nor direct use. In typical cases, consumer involvement is justified due

to the products needing to be interacted with and as such ergonomic, aesthetic, intuitiveness and the safety of use factors are the driving motivations behind a particular prototyping strategy (Boer, Donovan and Buur, 2013; Bogers and Horst, 2014; Rodriguez-Calero et al., 2020). Here, the term prototyping strategy is defined as “the set of decisions that dictate what actions will be taken to accomplish the development of the prototype(s)” (Christie et al., 2012, p.2). Whether and how the aims of these internal technical development activities incorporate these external stakeholders could, therefore, form part of this strategy.

Literature emphasises that much could be learnt from the inclusion of potential customers of mass-manufactured and digital products during a prototyping research activity beyond testing physical factors (Deiningner et al., 2019; Melander, 2020). If the aim is to refine a proposed concept, the insights gained can contribute to the exploration of variations through to more fundamental changes in the purpose of the product itself. Depending on how the prototypes and demonstrative material are created, the latter can be intentionally pursued, reflecting how an organisation could approach an innovation they deem to be significantly non-incremental. This is a common practice within the field of design which utilises ethnographic research emphasising the importance of exploring a problem prior to solving it through empathising with the needs of the customers and end-users (Brown and Katz, 2009).

The development of the “provotype”, to provoke discussion as to whether established needs are still valid (Boer, Donovan and Buur, 2013; Mogensen, 1992), reflects one of the few exploratory approaches towards prototyping for engineering purposes in which the artifact explicitly questions the problem to be addressed with those who could benefit from a new product. This exploratory potential for this method contrasts the approaches taken in requirement elicitation, whereby the use of such artifacts during the early stages of a project could unintentionally restrict responses that could support alternative needs and understandings of the problem, especially if they are delivered in a manner that makes them appear more functionally capable than they actually are (Hansen

and Özkil, 2020; Schrage, 1996). As such, the introduction of prototypes into the requirement elicitation process would need to be supported by an understanding of their changeable nature if not reflected by the production of multiple competing solutions.

However, in cases involving significant innovation, a lack of knowledge of the technology and its application, in contrast to prototyping incremental improvements, could impact the ability for external interests to effectively assess the veracity of such concepts. Whilst not within the context of engineering system development specifically, studies have addressed how shared uncertainties can motivate collaborative stakeholder relationship building through “co-creation” of a project’s purpose with suppliers (Christensen, Munksgaard and Bang, 2017) and customers (Roberts and Darler, 2017) reflecting a normative “democratisation” of the process (BenMahmoud-Jouini and Midler, 2020; von Hippel, 1976; Lüthje and Herstatt, 2004; Moultrie, 2015). The NASA autonomous flight system study demonstrated how this approach could impact the methods involved whereby the structure of interviewing and the fidelity of prototypes was greatly reduced. This enabled for greater accuracy as to the needs of the system’s stakeholders owing to the opportunity for them to determine the course of development rather than the researchers (McGowan, Bakula and Castner, 2017). This approach could also positively impact the overall performance of a NPD project by reducing the costs and time involved in the production of prototypes, whilst potentially avoiding misdirected requirement elicitation that could result costly in rework. Whether and how such an approach can be sustained throughout a project would require further research as the longitudinal aspects of such an approach are yet to be extensively studied.

However, there are several constraints to engaging stakeholders more comprehensively and frequently when prototyping is viewed as a commercial profit-motivated, rather than academic or community-led, endeavour. From a practitioner’s perspective within a for-profit firm, the costs and time required to conduct any form of prototyping could be seen as quantities to reduce in order to improve short-term project performance (Tiong et al., 2019). As such a resource-

constrained organisation may only focus on the interaction required by regulators, such as for the testing of medical device safety (Deininger et al., 2019; Martín, Reinhardt and Gurtner, 2021).

Moreover, the link between greater engagement and the increase in adoption of a new solution being seen in the context of it being taught to future engineers (Menold, Simpson and Jablokow, 2019), rather than through cases concerning industry, suggests a lack of established practice on the part of the industry. This could form a potential contributing factor to the limited adoption of prototyping strategies that concern wider stakeholder involvement and integration (Daly et al., 2012; Studer et al., 2016). Furthermore, this suggests a gap in the knowledge as to how to pursue a prototyping strategy that navigates the internal demands for it to progress technical capabilities cost-effectively and external demands for the prototypes to be a reflection of their interests. The lack of studies of practice could suggest that theoretical approaches towards prototyping may be overlooking limiting factors to achieving these ends.

2.5 Advances in engineering system development and approaches towards stakeholder engagement

Proactively analysing, engaging and integrating stakeholders from within and beyond an organisation requires specific project capabilities of which are a relatively recent development in management practice. The gap between academic contributions and practitioner adoption can be seen with the first edition of the Project Management Body of Knowledge (PMBOK) to incorporate Freeman's stakeholder theory, first published in 1984, being the 5th edition published in 2013 with a dedicated chapter. This chapter recommends methods drawn from literature as to how to conduct a stakeholder analysis, such as using Eden and Ackermann's (1998) power versus interest grid, and the production of issue logs and change request documentation resulting from engagement (PMI, 2013). This recency of adoption is further evident in Pedrini and Ferri's (2019) descriptive analysis of stakeholder management literature which revealed a gradual increase in studies starting from 2007. However, few demonstrated the incorporation of insights derived from stakeholder interaction, suggesting that this

is still an emerging practice yet to fully establish itself as an influential capability within wider project management priorities. Furthermore, given the generalised nature of management literature, whether and how this capability incorporates the technical complexity of an advanced engineering development project is seldom addressed directly.

Through reviewing recent advancements in established development frameworks and processes we can, however, see an indication that there is an emerging trend to transform how products are created through greater involvement of their stakeholders. This is so to increase the likelihood of improved project performance and for outputs to meet expected levels of adoption. These evolutions concern existing frameworks, processes and the technical development and managerial capabilities to implement them. However, whilst much remains generalised in terms of the specific types of products being developed and within the theoretical realm of academic managerial implications, the following sections will help provide an understanding of the extent engineering system practitioners are contributing to or could benefit from these advancements.

2.5.1 Expanding the scope for readiness level frameworks

Since the TRL framework became an established means to measure the maturity of technology during development, its focus on the technical capability of a single function, and thereby the interests of those involved in this pursuit, has prompted its adaption to other contexts and interests. As reviewed earlier, examples of variations of the original readiness level framework are the integration readiness level, that measures the compatibility of technologies during development, and the system readiness level, that concerns the collective maturity of integrated technologies (Sauser, Ramirez-marquez and Tan, 2008). These developments reflect wider internal stakeholder influence on an organisation's ability to assess the maturity of a technology, i.e. those responsible for managing compatibility in addition to those responsible for individual functionality, ensuring their voice is incorporated into such an assessment. From an external perspective, commercial interests can be assessed through the demand readiness level (Paun, 2011) or

the market readiness level (Dent, 2011). However, these frameworks are yet to be widely studied being applied in practice, although they have been proposed in relation to how TRLs are followed.

The incorporation of the TRL framework into government-funded programmes has encouraged scholars to propose variations that concern the social aspect of a developing technology; measuring how ready a project is to engage external stakeholders and create impact (Delioglanis, 2018) and the extent a project is preparing society to increase its readiness to adapt to a new technology (Innovation Fund Denmark, 2018). These latter variations were developed as a means to address the concern that publicly-funded research was progressing at a faster pace than the ability to disseminate findings, however, such variations of the TRL framework are yet to also be demonstrated in practice in being able to address this concern.

Whilst the majority are yet to be demonstrated empirically as contributing to a project's success, these readiness level frameworks could be a step towards addressing the overreliance most appear to have on technical maturity. Scholars have argued that this could limit a project's capacity to consider the implications of failing to advance the maturity of social acceptance, regulatory compliance and commercial interest, for example (Bruno et al., 2020; Kobos et al., 2018). However, as these cannot be quantified and definitively measured in the same manner that a physical prototype can be demonstrated to function, evidencing that a societal readiness level has been met, for example, could prove difficult to achieve. This could be due to the potentially changing dynamics of stakeholder landscapes (Aaltonen and Kujala, 2016) and the qualitative and subjective nature of such assessments.

2.5.2 Evolution of processes for developing new products

In considering the implications of the overall management of the development process, the established NPD approach can be seen to produce successful outcomes for incremental innovations. Such projects pursue success criteria such as meeting time, cost and quality expectations, reflecting the original purpose of the Stage-Gate project process structure (Cooper, 1990). As a result,

the NPD process would be suited for gradual improvements of an existing product focusing development activities on exploiting an organisation's existing capabilities through optimization emphasising monitoring and control. The original Stage-Gate NPD process becomes a means to continually optimise on project performance and product functionality with each new generation.

However, since the implementation of formalised approaches to product development, the implications of the extent of innovation being pursued on the development processes have attracted scholarly attention. This has concerned how their linearity and sequential nature could limit the ability for an organisation to adopt an exploratory, rather than exploitative, approach more suited to greater extents of innovation. As radical innovation requires significantly more iteration than routine development, an organisation needs to both understand what is required externally and to ensure a project remains responsive to these findings (Garcia and Calantone, 2002). To address this need, the adoption of advances in software-orientated processes, specifically Agile management, has provided a reference for how manufacturing-orientated Stage-Gate NPD projects can balance incorporating new knowledge whilst providing control for, and maintaining influence of, internal interests (Cooper and Sommer, 2018).

Agile NPD reduces extensive up-front planning in favour of developmental decisions resulting from the use of multiple cycles that aim to produce demonstrative instantiations of a product (de Borba, Trabasso and Pessôa, 2019). Using these outputs, both external and internal feedback is elicited to inform the direction of continued maturity of the technology. The benefits of such an approach reduces the risk of a project producing an outcome that is significantly out of alignment with stakeholder interests, as evident in successful consumer and digital product development (Cooper and Sommer, 2016). As a result, the outcomes of these intermediate activities are given greater influence than the initial predictions as to what would be required to develop a solution. This contrasts with the conventional approach towards the decomposition of a proposed solution into constituent development projects which are then

recombined and tested once each individual functionality is matured (Turner, 2007).

Should demands change, as is the likelihood in turbulent and ambiguous industrial contexts of radical innovation, projects that adopt an Agile approach are in a more responsive position to reduce the risk of being unable to, firstly, recognise these changes and, secondly, reduce the cost and time required to respond to them. Whereas projects that focus on the development of individual parts of a larger whole would need to continually address how these changes, firstly, affect the intended output and then the prototyping activities themselves.

Other variations of the NPD process focus on specific aspects of how greater stakeholder engagement can manifest in individual management activities of those leading a project such as continuously questioning and validating the concept behind a product, as proposed by the Dynamic Product Development process (Ottosson, 2004). The specific integration of suppliers and the need to ensure internal communication and responsiveness exploit findings from this relationship is proposed by the Collaborative Product Development process (Luo, Mallick and Schroeder, 2010). In comparison to these variations, Agile NPD illustrates how iterative approaches to progressing development could affect each stage, from design through to production. If applied in practice, these NPD processes could represent comprehensive implications for highly innovative engineering systems projects leading them to increasing the frequency and responsiveness of the interactions with those who can affect and are affected by the project's outcome.

2.5.2.1 Emerging sources of stakeholder influence

Whilst some NPD processes have evolved to respond to greater uncertainty surrounding the technology and market potential, others have focused more specifically on how to engage specific interests. Collectively referred to as Integrated Product Development (IPD) processes, different functions of an organisation can be managed in such a way so to reduce project duration whilst improving internal communication. This approach can support activities occurring in parallel rather than sequentially, referred specifically as Concurrent

Engineering (CE) (Hassannezhad and John Clarkson, 2017). When concurrency is pursued with other functions, another IPD process, Design for “X” (DfX), refers to the activity of designing for the interests of specific later stages, so that products can be more easily engineered, manufactured and assembled (Kuo, Huang and Zhang, 2001). Cases involving external interests concern organisations that fulfil these roles, for example, if capabilities are outsourced. The nature of such an external relationship is explained by Roehrich et al. in the context of a water utilities company and an engineering consultancy, “...partnering organizations in CoPS need to build trust over an extended period of time [and are] required to share knowledge, communicate frequently, and interact informally when solving problems and responding rapidly to unanticipated events.” (2019, p.91). This encapsulates the growing interest in improving collaborative practice in order to ensure product development processes utilise expertise from those who can affect this activity so to avoid impacting how well a project performs (Savage et al., 2010).

However, as evident in a review of IPD-related literature, studies that explore cases that involve external interests that would be affected by the product once in operation, beyond those who are customers are lacking (Hassannezhad and John Clarkson, 2017). The academic-led Prototype for “X” (PfX) variation of the DfX targeted development method (Menold, Jablokow and Simpson, 2017) attempts to address this lack of influence. Whilst the proposed process aims to support the education of future engineers in considering demands originating from those responsible for adopting, and enabling the adoption of, a solution, it is yet to be extensively applied in practice and to be shown to build upon existing NPD advances.

Other developments that have focused on external engagement concern the initial ideation stage of a project process. Organisations that look to increase the amount of involvement in their development projects can adopt an “open innovation” approach (Chesbrough, 2010). This approach’s aim prioritises increasing the quantity of inflows of knowledge supporting the organisation being “closer to their markets and lead users and to access the best talents worldwide”

(Chesbrough, 2010, p.219). As a result NPD processes that adopt open innovation practices ought to ensure the increase in resources required to manage such openness corresponds with the extensiveness of the knowledge to be acquired. This indicates that this approach could be best suited to the initial stages of opportunity identification rather than the exploitation of a detailed design specification (Marzi et al., 2021). Moreover, having a clearly defined problem derived from an existing product that requires solving could ensure responses are able to be integrated into NPD activities. As such this implies open innovation could be more suited to incremental improvements rather than the exploration of radical innovation (Florén and Frishammar, 2012). However, the emphasis on attracting interest could also appear to underemphasise an organisation's actual stakeholder landscape so to identify which interests are the most salient to be engaged with. As a result successful open innovation could be more suited to an organisation having an established understanding of their stakeholders and can manage a project that takes advantage of the potential to be more open to their involvement.

2.5.2.2 Advances in requirement elicitation and prototyping methods

Whilst advances in product development processes could prove applicable to engineering systems and the adoption of frameworks that measure beyond technical maturity, the implications of these changes could have significant impact on the development techniques themselves. This concerns both how requirements are surfaced and the purpose of the prototyping strategy. As inferred by the differing approaches to a product's functional decomposition; rather than developing individual parts and then combining them, Agile NPD aims to deliver a complete series of functional outputs with increasing fidelity (Cooper and Sommer, 2016). Through each instantiation a project is able to continuously test and align how the product's concept reflects the needs of those responsible for adopting it. In software and consumer product contexts this results in prototypes that mature from low-fidelity demonstrators through to increasingly refined production-ready examples (Opiyo, 2016).

However, within engineering system contexts, studies are yet to capture how the concept of an engineering system, and how it integrates into a mobile platform or industrial plant or infrastructure, can be conceived with low-fidelity capabilities and gradually matured through iterative cycles. This can explain how the ease at which software can be developed to provide basic functionality has resulted in internal software development capabilities within manufacturing organisations adopting this approach more readily in comparison to other organisational functions (Cooper and Sommer, 2018). Furthermore, the low costs involved in creating consumer product prototypes that can generate significant insights reflect another benefit to Agile processes that could be more achievable by projects that involve consumer-orientated concerns such as perception and comfort, for example, aspects that could be less relevant to an engineering system.

However, as a result of Agile management processes demonstrating its effectiveness to both improve project performance and alignment with stakeholder needs, attempts by manufacturing functions within an organisation to adopt the approach have introduced new forms of prototyping. Cooper and Sommer (2016) outline several cases involving the adoption of Agile development processes leading to outputs, referred to a “protocepts”, resembling reports, rather than physical artifacts, that describe a solution in ever increasing detail used to embody and further elicit requirements. Whilst this approach can contribute to a cost-effective means of validating the concept of a new product, aspects of a concept’s manifestation could be more suited to this approach than others. Identifying these will determine what needs to be validated through a physical artifact in order to support the technical development interests of the organisation, however, this requires further research to identify (Coutts, Wodehouse and Robertson, 2019). This research will aid understanding how established and more recent advances in prototyping and requirement elicitation methods balance the interests of both internal and external interests. Moreover, whether and how these methods overcome the challenges of expanding the TRL focus and the Stage-Gate linearity could address the practicality concerns of Agile and iterative approaches.

2.6 Conclusion

This review has brought together a range of literatures that provide the basis for understanding the extent stakeholder theory is reflected in the processes and methods involved in developing small-scale sub-system forms of CoPS. A concern that has been seldom addressed within the context of stakeholder studies nor as the focus of NPD, prototyping and requirement literature. Despite these latter literatures' attention towards mass-manufactured consumer goods and software, the implications of how stakeholder theory is evident in these methods supports considering how these approaches can be applied to the analysis and engagement of stakeholders in engineering systems. Adopting a similar manner to that of customers and end-users could enable a wider scope for the contexts in which engagement has been studied and to understand the effects on the development of the engineering system itself.

However, as evident by the aim of the TRL framework and the advances in development processes being yet to establish in practice, engineering system NPD projects may yet to succeed in adopting a more comprehensive analysis of their stakeholder landscape. As a result, this could limit how such projects are able to respond to external needs that could influence the technical direction taken in addition to positively impacting its performance. This could then reduce the likeness of success in reaching expected levels of adoption once the engineering system is introduced into its target markets. This supports the first research question of this thesis: *Who are the stakeholders involved in the adoption of the engineering system in this research context and how do they relate to its development?* Contributing to demonstrating how this question can be answered, and answering it for the purpose of participating in the case study of this thesis, will be valuable for both practitioners in developing engineering systems and scholars to further expand the field of stakeholder identification and analysis and theoretical approaches towards technical development methods and project processes.

Identifying the extent stakeholder theory is evident in the approaches towards developing engineering systems could contribute to understanding what

theoretical justifications are used and the level of interaction intensity and influence the practice of stakeholder engagement may have. Within the fields that relate to engineering systems this has been shown to be seldom studied, instead the cases have primarily concerned descriptive and instrumental approaches that support improving the performance of a project to deliver a new system, such as reducing the potential for delays, cost overruns and termination. This is evident in the use of linear development processes and the importance placed on meeting success criteria at each stage; identifying internal interests and how they can affect this performance. This approach was also evident in requirement and prototyping literature; the need to gather specific information to inform technical decisions determined who would be involved with an emphasis placed on data collection techniques that could provide accurate and complete responses. As such, this thesis will seek to explore how a project can achieve a greater level of exposure to stakeholder needs and how this could contribute to understanding the extent an engineering system development project can incorporate them by asking the second research question: *How can stakeholder input influence engineering system development, and how is the value of that input understood and captured through the engagement methods applied?*

By broadening the scope of product types in this review to include cases involving consumer goods and software, as evident in the NPD, prototyping and requirement literatures, we saw greater potential for external engagement to influence the concept of a new solution itself in order to ensure the needs of those responsible for adopting it are met to the greatest extent. However, given the lack of relative complexity involved in adopting these solutions, a descriptive justification as to who these interests are, namely customers and end-users, remains unchallenged. In considering an engineering system context, this approach lends itself to a normatively-inspired justification owing to the potential for these interests to be a greater number and to be granted greater opportunity to exercise their influence on products that will affect them, reflecting democratic norms and societal values. Through considering who else may be affected and be able cause an affect, a more detailed landscape of stakeholders, beyond the specific pathways for technology adoption, could be created.

However, prototyping strategies that have proven successful in consumer goods contexts may fail to be transferable due to the specific types of engineering involved and the asymmetry of understanding of the technology itself between internal and external interests. Furthermore, the extent of innovation involved in an engineering system NPD project could also have an impact on the intensity and purpose of wider external stakeholder engagement. A radical discontinuity of extant operational, regulatory or procurement procedures could conflict with the organisational capabilities that are more suited for incremental improvements that build upon existing stakeholder relationships and needs. As few studies have explored prototyping in these contexts, empirical research is required that can identify factors that could limit or enable current approaches in meeting the interests of both internal and external actors. This could help contribute to the wider application of advances in development processes that involve significant levels of innovation and support organisations in adapting their capabilities for engaging and integrating stakeholders. Through uncovering these factors and exploring the practical implications of the contributions from the prior research questions, the final research question: *What are the challenges and opportunities for advancing stakeholder engagement during engineering system development?* will be addressed.

The proceeding chapters will address these knowledge gaps to further our understanding as to how stakeholder theory can be used to justify the approaches taken to develop engineering systems, specifically ones that are faced with significant operational, commercial and regulatory uncertainties. The extent the nature of physical engineering practices result in unmet developmental demands, so to support aligning technical capabilities with the needs of those who will benefit from their operation, represents a significant area of research that has received little attention. This review will be revisited in the discussion chapter to explore the extent these gaps in literature have been addressed with the proceeding studies. Moreover, the discussion will explore whether and how the methods and theories themselves are applicable in their current forms or could be developed by, or emerge from, the study of small-scale engineering sub-system CoPS.

3 METHODOLOGICAL APPROACH

3.1 Introduction

The methodology of this thesis centres around the exploration of a single case to address research questions that relate to the fields of stakeholder theory, new product development (NPD) and engineering systems when studied as a complex products or system (CoPS). The case is explored from a variety of dimensions to identify stakeholders, understand their needs and the extent they are met during the development of the system itself. This chapter begins with an introduction to the rationale for using qualitative data and a single case study research design and how this will contribute to addressing this field of stakeholder engagement and engineering system development. The logic of abductive reasoning is then introduced to explain how this differs to deductive and inductive approaches to analysis and how it will direct the studies within this thesis. The implications of using this type of data and reasoning on theoretical development are then introduced. The sections following these introductions explain the chosen methods for each chapter and how they address each objective of the thesis. The final section then introduces expected limitations of the studies and how quality assurance of the data collection and analysis will be pursued.

3.1.1 Using qualitative data and analyses

Qualitative studies involving the development of engineering systems are yet to be conducted at a significant intensity (Szajnfarder and Gralla, 2017). The differences in research methods and the application of findings in comparison to dominant quantitative approaches could explain potential inhibitors for scholars of the natural and physical sciences in adopting this form of research (Daly, McGowan and Papalambros, 2013). From a social scientist's perspective, the exemplary studies in qualitative research reference resources (Flick, 2018; Yin, 2018) suggest that the level of qualitative scholarly interest in this phenomena reflects a lack of severity of the social issues concerned. However, the rationale to pursue this approach can be found tangentially through the studies of

organisations developing engineering systems (Carlile, 2002; Henderson, 1991) and the perception and impact of existing systems (Marincioni and Appiotti, 2009), all of which could provide insightful practical implications for, but are not embedded in, the actual development of an engineering system.

Through embracing qualitative enquiry, engineering system development practitioners could be presented with the opportunity to proactively address socially important issues through understanding the implications of their activities. For example, through complying with regulations aimed at improving social and environmental standards, integrating into existing operations, being commercially competitive or reflecting government policies. These could potentially increase the wider societal benefit, albeit indirectly, of the engineering system, reflecting the breadth of knowledge that can be gained. For example, such motivations can be found in the development of consumer and medical products with direct impact on people's lives (Bogers and Horst, 2014; Deininger et al., 2019). This thesis argues that successful engineering system development could incorporate similar methods for similar ends.

The extent existing practice can forge a link between technical capabilities and these contextual social concerns requires further qualitative study. Currently, scholarly attention has been given to managerial concerns, such as how the purpose of activities during the initial development phase of manufactured goods relate to later stages (Cooper, 2019) and the organisational behaviour that contributes to successful development maturation throughout their projects (Reid and de Brentani, 2012). Due to the differences that distinguish engineering systems from mass-manufactured goods (Hobday, 1998), the extent these studies provide applicable insights into how this type of technology can successfully develop with the use of qualitative research reflects the gap in knowledge this thesis aims to address. Owing to the lack of an end-user and the complex nature of developing advanced technical processes that involve the physical and natural sciences, these factors require exploration as to their effects on the development activities undertaken. Whilst the behaviours of development teams and the capabilities of engineering systems may lack immediate

importance to the social sciences, the potential implications of understanding how hidden technology can incorporate qualitative research could help them to address the significant societal and environmental impact challenges of tomorrow.

The methodology of this thesis is structured around a single case that enables broad contextual and targeted processual analysis to be conducted. As the research progresses, the focus of the methods shift from evaluating the extent the case reflects comparable stakeholder landscapes to evaluating and synthesising findings specifically from how an engineering system NPD project. The focus then concerns how such a project affects and is affected by external interests and balances them with internally-derived priorities. This exploratory nature of this methodology is driven to uncover how a developmental process in engineering practice takes place, how this practice relates to its wider context of similar technology development and to provide empirical support for further qualitative or quantitative study.

Whilst the subject is seldom the focus of similar methods used in the literature, there are two aspects of this methodology that are particularly absent. These are the use of a single case study rather than multiple case study research design and an approach to analytical reasoning described as abductive, that is neither deductive nor inductive, both of which will be explained in the following sections as to their suitability for these studies.

3.1.1.1 Single case study research design

Case study research reveals how and why a particular phenomenon occurs. Using this method enables for a rich description of the events and their causes drawing on multiple sources of data (Yin, 2018). This depth is required due to the issue that is to be studied being intrinsic to both place, time and the people involved thereby supporting longitudinal observation, if the phenomenon is not a singular event, and surveying or interviewing of those affected. This thesis applies the case study research method to the initial stage of an engineering system development project to understand how and why its technical capabilities can be affected by the relationship between stakeholders directly involved in the

development and those in the intended operating environment. The dearth of studies focusing on how stakeholders interact during the development of engineering systems would make selecting multiple cases for this study challenging. Being aware of the conditions that would determine the nature of these relationships would be required for the formulation of hypotheses and to determine variables to compare between cases to create an informed sample. Therefore, this lack of empirical evidence to support experimental designs with multiple cases suggests a single case study could contribute to providing these grounds for future studies. However, a single case can contribute transferable findings determined by the readers themselves (Daly, McGowan and Papalambros, 2013) and to offer a possible explanation for a specific phenomenon.

Understanding how a single case relates to the issue that is being studied can also justify the decision to pursue an individual case should multiple cases be accessible. Flyvbjerg (2006) outlines several strategies that can be used to determine what could be learnt by how the conditions of a case compares to similar phenomena. If a case represents an extreme or atypical occurrence, which relates specifically to the issue that is being studied, then cases that are more common could be explained on basis as to whether that extreme element was instrumental, or not, in affecting an outcome. A case that contains a critical dimension reflects a similar strategy; if the case concerns an element that is expected to be shared across all other cases and if it proves valid, or not, in affecting an outcome then all other cases would be expected to behave in a similar way.

A paradigmatic case would reflect an exemplar description of a phenomenon that would be seen as a reference point or standard for how such an occurrence can contribute to furthering research in a particular domain, for example, as in the case of the NASA study demonstrating how the concept for a technical solution can significantly change as result of the engagement of a wide variety of stakeholders (McGowan, Bakula and Castner, 2017). Whilst an intention can be made to select a particular case, both the findings and the analysis can determine

this fact, as explained by Flyvbjerg, “the interpretation of such a case can provide a unique wealth of information because one obtains various perspectives and conclusions on the case according to whether it is viewed and interpreted as one or another type of case” (2006, p.233).

The single case explored in this thesis could be considered atypical owing to the extent of innovation and the level of capabilities at the disposal of the project team, therefore, if these factors are evidenced to affect whether and how external stakeholders can positively influence the direction of the engineering system’s technical capabilities, cases that involve incremental innovation or have less expertise could be less likely to succeed in establishing relationships to the same extent. However, an intentional selection could prove challenging due to the lack of knowledge of the factors that could contribute to such an exemplar or atypical engineering system case. Whilst multiple case study designs could experience changes to how a researcher interprets a case during analysis, the extent would be limited to the relevance of the initial grounds for comparison.

A single case could, therefore, demonstrate greater scope to apply a particular approach to reasoning that is neither inductive or deductive. As will be explained in the following section, abductive reasoning can enable a wider range of interpretation to be derived from the findings themselves and as such determine what would make this case valuable as a single study (Dubois and Gadde, 2002).

3.1.1.2 Applying abductive reasoning

Whilst deductive reasoning seeks to test theories to demonstrate whether and how a outcome can be arrived at, inductive to offer new theories for those that already exist, abductive reasoning is the analytical process of deriving a possible explanation through expanding existing theories (Kennedy and Thornberg, 2018). This involves identifying a desired outcome and then working backwards to formulate an understanding of how certain factors could contribute to it occurring if a particular hypothesis, grounded in a known theory, proved applicable (Peirce, 1935). The implications of this approach on both the motivations for conducting research and the way the research is analysed explain how academic contributions can respond to phenomena without the use of inductive or deductive

methods. In these approaches a clearly defined focus is the subject of either an experiment or a test, the former driven by a desired result, the latter an understanding of how a specific factor produced such a result. To ensure such research is focusing on a significant concern, prior knowledge is required to justify why a particular outcome needs an explanation or why a particular test needs to be conducted. The use of abductive reasoning within research can therefore form the basis for initial exploration that can contribute to determining an area of focus (Kennedy and Thornberg, 2018).

Depending on the research design, case studies can be driven exclusively by abductive reasoning if they are exploratory in nature rather than used as a means to compare variables, the latter reflecting an inductive approach. Through abductive reasoning, a case is constructed as a result of a researcher considering a phenomena to be “surprising” owing to it being difficult to deduce through a combination of known factors (Nubiola, 2005). The novelty of the case study explored in this thesis is caused by the engineering system being the first-of-a-kind developed by a project team consisting of academic and industry interests and how they respond to stakeholders in the intended industrial application. Depending on how this unfolds will impact the possible theories that can be used to explain how particular practices contributed to this outcome.

The role the author played as a participant-observer, particularly through disseminating interview findings, acted as a starting point for this analysis with a theoretical lens derived from stakeholder theory (Freeman, 1984). However, if other practices, captured within the case, and theories from literature can offer an alternative interpretation as to the reasons for the resulting extent of stakeholder engagement, abductive reasoning would justify the logic for re-examining the case as a result of these findings. This analytical process extends to the readers themselves who can apply the same theories to their own contexts. This explains another difference between this form of reasoning and others as the findings are intended to be transferable rather than generalisable owing to the particular phenomena that remains intrinsic to these contributions (Flyvbjerg, 2006; Piekkari and Welch, 2018; Verleye, 2019) limiting how applicable they can

be to unrelated cases. A comparison of the approaches to reasoning, including deduction, is shown in Figure 3-1.

- a. WHAT + HOW = ???
- b. WHAT + ??? = RESULT
- c. ??? + ??? = OUTCOME

Figure 3-1 How the analytical logic differs between deductive (a.), inductive (b.) and abductive (c.) whereby the question marks indicate what is unknown at the start of a study. Adapted from Dorst (2015).

Whilst the analysis of the case at the centre of this thesis will demonstrate abductive reasoning applied to understand a social phenomenon, the use of this approach to direct future outcomes reflects how it can be applied to develop the engineering system itself (March, 1976). In support of understanding the industry's stakeholders, the studies in the fifth and sixth chapters apply this reasoning during the analysis of the findings that evaluate the proposed outcome of the engineering system and in the seventh chapter to understand how and why the development process approaches stakeholder engagement.

This method of framing a problem in an operating environment, and the development process of a solution, enables multiple interpretations to be analysed. This will aid evaluating the extent those chosen to analyse the case study and the engineering system within it concern the most significant aspects of the challenges faced (Dorst, 2015; Schön, 1984). In these studies, abductive reasoning is used as a means of synthesis as well as analysis, reflecting the iterative processes commonly found in design-led research (Brown and Katz, 2009). This describes encountering a problem and aiming to understand how different framings could lead to different types of solutions, the opportunity to apply different theories and expand upon them, and thereby move, or iterate, between the two. However, a decision would need to be made as to the goal of the outcome, such as who will benefit and why, concerning both the engineering system's technical capabilities and the development processes used to create it, which would be defined in terms of subjective values, such as normative

approaches towards social inclusion, for example, a key distinction to the definitive nature of results-driven study (Dorst, 2011).

3.1.2 Theoretical development

Single case studies enable the expansion of existing theory either by demonstrating that they can explain a particular phenomenon, through the iterative evaluation of competing theories, or suggest new theories need to be generated. This then can support inductive enquires that seek to compare possible contributing factors across multiple cases and for deductive studies to then test their validity empirically. As a result, the significance of a single case study to contribute to a field of research is to determine the foundations for these subsequent studies should the field be emergent with few extant cases. However, scholars argue that cases should avoid incorporating theory prior to data collection and analysis and adapt theoretical directions during the study, enabling theoretical analysis to emerge. Referred to as grounded theory (Strauss and Corbin, 1994), this approach attempts to assure the quality of the research by countering potential biases in theory development as a result of the collection and analysis occurring through a predetermined theoretical lens (Piekkari and Welch, 2018). By doing so, subsequent study could produce a potentially more novel theoretical contribution through their respective methods.

In the case of this thesis, however, prior theory has been considered to an extent, that concerning stakeholder theory, along with models from innovation and organisational theory, to suggest how a particular outcome that involves radical innovation could be explained (Garcia and Calantone, 2002). For example, how interacting with external interests is a positive factor in navigating the “fuzzy front-end” by reducing uncertainties and equivocalness (Reid and de Brentani, 2012). The purpose of including this theory in the eventual discussion of the findings of this thesis is that existing studies are yet to concern the actual development of engineering systems (Eling and Herstatt, 2017; Markham, 2002). As such this thesis will provide an understanding as to whether and how the nature of the product is addressed by existing stakeholder theory, other theories or requires new theories to explain its effect on stakeholder relationships.

Whilst an exploratory approach will be given to the overall theory applied to the analysis, the data collection itself will be informed by an instrumental and normatively-inspired justification for applying stakeholder theory (Donaldson and Preston, 1995). Owing to the aim of these studies at one level being to support the development of an engineering system, the instrumental approach will ensure the data supports this effort, and in aid of understanding how external and internal stakeholders interact, a normative approach explains the wide scope of the sampling and the chosen methods. This is so that those most affected by the development of the system and its operation can be included in decisions that could affect their interests, reflecting a normative value. Therefore, reflecting how stakeholder theory could explain why those with a stake in an organisation's objectives could affect it (Freeman, 1984), a combination of instrumental and normative justifications will ensure its comprehensive application during sampling.

A constructivist perspective of how knowledge can be generated and acquired will also be evident in the approach towards this data collection, enabling participants to provide insights that reflect their understanding of the problem and their priorities. This will help ensure subsequent theory development is based on empirical evidence that addresses the potential limitations of more positivist views of knowledge. In such cases the implications of who is providing data and why this could affect its content could be overlooked (Hinds, 2008; Piekkari and Welch, 2018). As such should the success of the project appear to be in question despite this being achieved, and that positive, supportive relationships are formed, stakeholder theory may not offer the most adequate explanation, without further development, in this context. If stakeholder relationships are shown not be the main factor in aligning technical capabilities with the needs of those in the engineering system's commercial, operational and regulatory environment other theories that relate to these other causes could prove more effective in providing a possible explanation.

3.2 Chosen Methods

The single case of a small-scale engineering system forms the basis of each of the four studies of this thesis. Choosing to centre the case across multiple studies reflects the participation element of this research; the findings from the first three studies were contributed to the development of the engineering system featured in this case study. Given this opportunity to engage internal and external stakeholders was situated within the initial stages of a NPD project, there was a significant level of uncertainty as to how the development team could learn from the project's stakeholder context and the approaches they would use in responding to the findings. Moreover, who the specific individuals responsible for enabling its adoption might be was uncertain, thereby justifying the need for this breadth and depth of study.

Furthermore, as discussed in the prior literature review of engineering system development and related studies, the significant gaps in scholarly attention also supports the need for such a case to be studied to this extent focusing on the activities undertaken to design and develop the engineering system. The final study in Chapter 7 aims to contribute more directly to this gap by analysing the extent findings from the prior three studies were incorporated into the technical development methods and outcomes. However, each study in itself demonstrates methods that could be applied to collect and analyse data to help reduce the extent of the unknown nature of stakeholder interest and influence when developing any CoPS involving radical innovation. The following sections explain how and why the chosen methods are applied and contribute to meeting each objective of this thesis as illustrated in Table 3-1.

Objectives	1.a. Identify and compare the roles and responsibilities of stakeholders in the development and operation of similar technology in industries related to the case study's engineering system				
	1.b. Analyse the stakeholder landscape of the case study's engineering system to determine how the problems it addresses could affect them				
	2. Evaluate the extent stakeholder needs are being addressed by the direction of the system's development				
	3.a. Evaluate the ability for a prototyping strategy applied during the development of an engineering system to incorporate stakeholder input				
	3.b. Synthesise findings from the case study to provide theoretical and practical implications for prototyping highly innovative engineering systems with stakeholder engagement				
Methods	1.a.	1.b.	2.	3.a	3 b.
Data collection	Literature review	Document analysis	Semi-structured interviews	Participatory observation and unstructured interviews	Contributions to knowledge will be discussed in the context of literature and the results of addressing each objective. Practical implications will then be presented derived from these contributions.
Data analysis	Descriptive and thematic, derived from article topics	Thematic, derived from evidence supporting "problem frames"	Thematic, derived from needs, design considerations and technical requirements	Thematic, derived from approaches towards developing the system	
Abductive Reasoning	Not applicable	Combined with inductive	Primary approach to reasoning		
Relationship to the case	Contextual	Contextual and retrospective	Embedded	Longitudinal	
Data sources	Journal articles, papers and trade publications	Trade and public sector publications	Public and private sector system stakeholders	System development team	
Chapters	4	5	6	7	8
Results			Discussion		

Table 3-1 A summary of the methods that will be applied to address each objective.

Each study incorporates thematic analysis techniques drawing on abductive reasoning where appropriate as the primary approach towards analysing trade publications and empirical evidence collected through interviews and case observation, as shown in meeting objectives from 1.b to 3.a. Deductive and inductive approaches towards conducting descriptive and speculative analyses of stakeholder identities and their relationships is undertaken using evidence from scholarly as well as industry sources in order to meet Objective 1.a and contribute to Objective 1.b. These approaches were chosen based on the epistemological aims of each phase of the study; from identifying what is already known, such as who is responsible for specifying wastewater systems for passenger trains, through to understanding what needs to be known in order to support the engineering system achieving expected levels of eventual adoption.

In addition to applying the following methods to data collection and analysis, stakeholder identities, as they emerged from the various publications and interviews, were collected and analysed. This process involved starting with an onion diagram that adapted the model proposed by Alexander and Robertson

(2004) to act as means to organise stakeholders based on their potential proximity to the engineering system. To aid the sampling collection for the interviews a power-interest grid (Eden and Ackermann, 1998; PMI, 2013) was chosen to prioritise which organisations to approach. A stakeholder map of the most salient was created using the methods from Bryson (2004) as a speculative exercise to consider a future state when the system has been adopted. Results of this research can be found in Appendix A-Appendix C appendices. Figure 3-4 shows how stakeholder identities were moved across each stage of the stakeholder analysis. The first and second methods were conducted using sticky notes on laminated canvases positioned in the team office to disseminate results and aid transparency of findings as part of the authors role as a participant-observer.

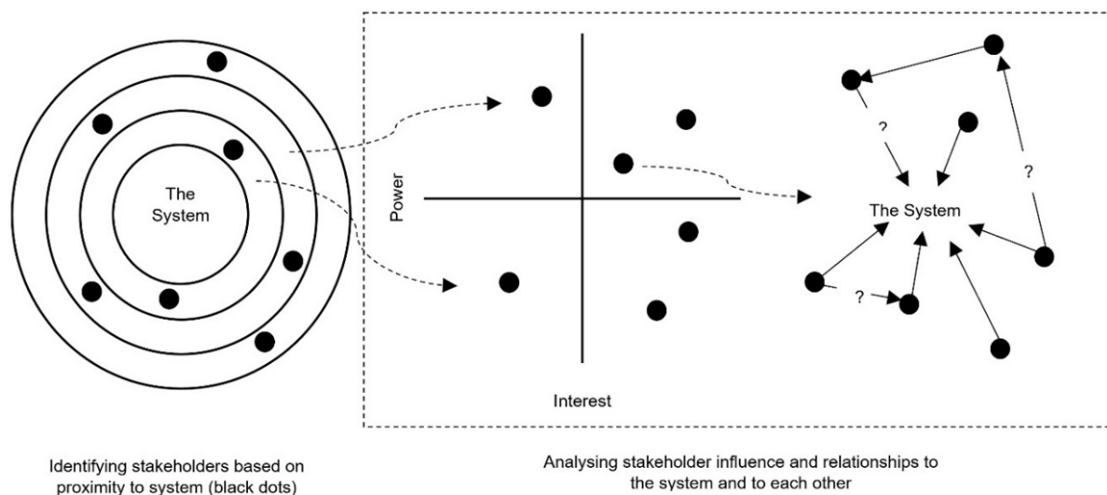


Figure 3-2 An overview as to how stakeholder identities in the case study's engineering system development project were collected and analysed. Drawn by author.

3.2.1 Stakeholder analysis by literature review

Chapter 4 presents the results of the first objective of this thesis which was to *identify and compare the roles and responsibilities of stakeholders in the development and operation of similar technology in industries related to the case study's engineering system*. This was met by conducting a literature review to identify these stakeholders as present in the articles' affiliations, acknowledgements and text bodies. How their interests and influence can be inferred was derived from their roles and responsibilities in relation to the topic of the articles.

This method is an adaption of other data collection and analysis methods due to stakeholder identification being an activity that has received little attention in receiving a formalised method to apply (Pacheco and Garcia, 2012). Whilst the term has frequently been used, the exact nature of the activity and its implications vary. For example, stakeholder identification can be the result of an analysis that aims to identify stakeholders that could have certain characteristics, such as power or legitimacy, and as such the term is used in relation to data analysis rather than data collection (Mitchell, Agle and Wood, 1997). This reflects bodies of literature that have established stakeholder identities, such as within land conservation and sustainability, that could affect, for example, families and households and local traditional authorities (Borrini-Feyerabend and Brown, 1997). As such using a predefined role-based classification can direct efforts to identify who these stakeholders actually are for further research, the aim of which would be to collect data and then analyse their relationships to a specific issue or to each other (Bryson, 2004). Given that passenger wastewater operations is a highly specialist and emerging area, there are yet to be studies that determine which roles apply. Moreover, in addition to the challenge in identifying individuals and organisations, potential roles and responsibilities of stakeholders offered by literature (Alexander, 2003; Martín, Reinhardt and Gurtner, 2016) are yet to be derived from empirical evidence.

Studies that do involve novel technology may be able to inherent stakeholder roles and their identities, such as a product's users, from conventional consumer

goods contexts and imply that there are no other salient stakeholders that may need to be identified (Bogers and Horst, 2014). However, given the potential diversity of stakeholders in engineering systems, related studies may share little in common, and as such this could translate to the affected stakeholders' specific commercial, operational or regulatory roles and responsibilities. To address this lack of method, this study adapts elements from systematic literature review methodology to provide a comprehensive and updatable means to collecting stakeholder identities in the field of any significantly innovative technology that does not yet have a known stakeholder landscape.

Whilst developers could assume identities based on prior knowledge of related cases, this approach could introduce biases towards identifying stakeholders who may only relate to the immediate operation of the technology and may only be supportive risking overlooking significantly important stakeholders that are not directly related to the development process. As such a systematic approach to stakeholder identification can draw on the strengths a systematic literature review applies to producing a corpus that is comprehensive and unbiased towards a particular research aim (Denyer and Tranfield, 2009).

However, there are a number of ways in which the adapted method in this study differs. This is due to the focus being on stakeholder identities rather than primarily on the intellectual contributions of the articles. This is evident in the lack of a specific question to guide this review, rather, the search is driven by exploring the adoption of a technical capability, derived from the engineering system. As a result, findings will avoid being limited to a specific area of knowledge with stakeholders identified being restricted to that field. Furthermore, the review could reveal the extent a certain application's stakeholders, for example within the rail sector as reflecting the case study, compares and contrasts to stakeholders in related applications. Furthermore, by including this wider scope for a technology's application the review could also address the potential for the novelty of a specific application to result in few studies.

To formulate the focus of this review, and to ensure that the applications are comparable, a common technical purpose is defined, derived from the

engineering system developed in the case study, which ensures that the identified stakeholders' relationship to the system can be compared based on how it concerns that purpose, as shown in Table 3-2. As a result, systems that do not share that purpose, commonalities and constraints would be excluded from the corpus as they could potentially introduce stakeholders that have little in common with other contexts. As the case study concerns a passenger wastewater system, its influent was chosen to form this focus due to it being the primary source of novelty.

Case study's engineering system's input:	Wastewater from train passengers
Contextual constraints:	<ul style="list-style-type: none"> • System is built to operate on a mobile platform • System primarily processes greywater and blackwater collected from toilets and sinks
Contextual commonality:	Passengers
Related system applications:	<ul style="list-style-type: none"> • Cruise ships and ferries • Passenger aircraft • Coaches • Passenger spacecraft
Common purpose:	To collect and treat wastewater from passengers

Table 3-2 The elements that are used to construct a cohesive corpus derived from the system developed in the case study.

3.2.1.1 Data collection

The corpus was compiled using a systematic review using the aforementioned approach encompassing articles from both peer-reviewed and non-peer-reviewed sources in order to ensure emerging developments in technology and practices are captured (Adams, Smart and Huff, 2017). The articles concern both the technical capabilities of the system and its operational, commercial and regulatory implications. The keyword search strings are shown in Table 3-3. As

the term *passenger wastewater* is not an established term used in wastewater literature, a variety of related terms were used. The terms used for the article topics were chosen to represent the types of interest stakeholders could have in the system. Wastewater types and article topics that may be exclusive to a particular transport mode were excluded so to ensure articles could be compared and potentially share stakeholders with similar roles and responsibilities, hence the focus on wastewater sourced from passenger activities including both black and greywater. Due to the variety of wastewaters and the tangential modes, i.e. military and cargo-related, present in preliminary search results, the exclusion criteria required refinement, hence the terms “navy”, “de-icing” and “accident” were added, to ensure articles that related to specific modes or did not reflect planned commercial passenger operations could be filtered out. EBSCO and Web of Science databases were chosen due to the former having access to trade articles and both having access to quality journal and conference publications. The combined search returned 809 articles.

Once duplicates and false positives, that referred to either different types of wastewater or transport modes in different contexts, were removed, 135 articles were retained as they met the inclusion criteria described in Table 3-4. An additional 3 were found through snowballing as their titles and abstracts contained either operating context terminology or names related to specific events or regions that were not present in any of the search strings.

Aspect of Article	Search String
Wastewater Type	(wastewater OR blackwater OR greywater OR “passenger wastewater” OR “faecal contaminated wastewater” OR sewage)
Topic	(characterisation OR treatment OR processing OR discharge OR recycl* OR pollution OR regulat* OR govern* OR policy OR operati*)

Operating Context	(aviation OR airport OR aircraft OR airplane OR aeroplane OR "marine travel" OR ship OR cruise OR seaport OR "cruise terminal" OR rail* OR "train travel" OR "rolling stock" OR "rail depot" OR coach OR spacecraft OR "space flight" OR "space travel" OR "space tourism")
Excluded Terms	NOT (nav* OR "air force" OR military OR de-ic* OR deic* OR outfall* OR spill* OR wash* OR accident*)

Table 3-3 Search strings were linked with the Boolean operator (AND) so that articles had to have at least one of each aspect of study in their titles and/or abstracts.

Criterion	Inclusion	Exclusion
Article Type	Journal articles, conference proceedings papers and trade publication articles (including public sector publications)	
Language	English	Written in a language other than English
Relevance	Publication concerns blackwater sourced from passengers	<ul style="list-style-type: none"> • Publication concerns blackwater from other sources (i.e. military personnel, accidental spillages, residential or agricultural) • Publication does not explicitly state the type and/or source of wastewater studied or referred to • Prioritises terms from exclusion search string

Table 3-4 Inclusion and exclusion criteria.

3.2.1.2 Data analysis

The 135 articles were added to an Excel spreadsheet and were labelled based on descriptive criteria (date of publication, transport mode, stakeholders, topic, region and article type). The topic themes and stakeholder group identities emerged from the articles' affiliations, acknowledgments and from within the text itself, primarily in the form of organisations. The quantity of articles per transport mode varied widely and there was significant variety in both the quantities of references and identities of the stakeholders. However, it was possible to form stakeholder groups and topic themes that consisted of contributions from across the majority of types of publications and transport modes, owing to comparable roles and aims in affecting the development and operation of passenger wastewater treatment systems.

Adopting analytical approaches applied in systematic reviews, whereby each article can be considered a case (Watson et al., 2018) enables the articles to be analysed as an organisational objective to pursue a passenger wastewater-related concern, such as the production of research findings or reporting on industry or regulatory activities, being produced by or in reference to a range of stakeholders. Adopting Freeman's model of a stakeholder as any individual or organisation that is affected by or can affect another organisation's objectives (1984), stakeholders' interest and influence within the case was then analysed both interpretively and through aggregation, albeit using an inductive approach (Tranfield, Denyer and Smart, 2003) given the subjective nature of influence. Interests of these stakeholders were inferred by the topic themes that were compiled using articles that referred to them and the extent of influence was determined by quantifying their number of references; the larger the number of references the potential for them to be more influential.

The nature of this influence, whether it was positive, negative or neutral in relation to the development and operation of the systems was interpreted using the evidence of their role and responsibilities that was reflected in both their identities and interests, i.e. article topics. This final stage of analysis was applied to the stakeholders that were found to be the most widely referenced in their groups so

to provide a detailed overview of who could be the most influential. This would reveal where their interests might lie in terms of the transport modes and the nature of the activities in affecting the development and operation of these systems. Presenting stakeholder identities in this manner could support the creation of purposive sampling for further research into providing empirical evidence of this affect and to offer explanations as to the reasons for the extent of interest and influence. Furthermore, these findings indicate the transport modes and stakeholder groups that feature significantly less than others, reflecting a knowledge gap that could be addressed so to evidence whether this demonstrates either a lack of interest in or influence over this type of wastewater processing system. The findings presented in Chapter 4 contribute to both addressing the lack of systematic methods in conducting stakeholder identification and provide a comprehensive resource for future studies of passenger wastewater systems.

3.2.2 Problem framing by document analysis

Chapter 5 presents the results of the second objective of this thesis which was to *analyse the stakeholder landscape of the case study's engineering system to determine how the problems it addresses could affect them*. A document analysis of industry reports, press and government texts from the case study's target region, the UK, was conducted to identify the current discourse on passenger wastewater operations in the rail and water sectors. With these findings the extent the system could address their needs was evaluated and alternative problem framing was explored.

The document analysis method was chosen due to the need to understand whether and how the issue of rail passenger wastewater operations is perceived by stakeholders directly responsible for adopting new technology as a priority and how this compares to other stakeholder contexts that are affected by these operations. Furthering the need for stakeholder identification methods (Pacheco, Garcia and Reyes, 2018), examining a specific region for a technology application presents additional difficulties in understanding who the salient interests are. As such, this method has been adapted to be used also as an exploratory tool to

uncover these identities through their own publications. As studies of these stakeholders, specifically in the region of the UK, are absent from academic literature, as discovered in the findings of the prior study, publications that are written for and by those concerned can offer an insight into this novel field of enquiry (Adams, Smart and Huff, 2017). Furthermore, by analysing how the issue is discussed in relation to the aims of the organisations responsible will provide further insight into possible explanations for how positions evolve and differ (Rapley, 2018).

Using the problem framing from the project brief from the research context of this thesis as the primary point-of-view, through analysing documents from across the sectors and audiences, this study will aim to “trace the ‘birth’ and development of specific discourses and so offer alternative readings of the problem alongside alternative solutions.” (Rapley, 2018, p.132). Through explaining how stakeholders’ published views may differ, what their priorities may be and what could motivate them to adopt, or support, the proposed solution, an evaluation can be made of the potential of the central case study’s engineering system to succeed once launched. This will also provide a basis to determine if consideration of alternative approaches is required. Through the use of documents and texts, these insights could be acquired without the need for directly engaging with these stakeholders and as such represent an unobtrusive means of understanding the how and the why of rail passenger wastewater operation challenges that have been documented and published (Yin, 2018).

3.2.2.1 Data collection

To ensure stakeholder voices are not excluded from the analysed documents and texts, a range of sources were chosen so to cover both public and private sector contexts. The Google search engine was the primary means of identifying websites that contained this data after which searches were made within these websites and hyperlinks were followed to further explore related material. Where possible, if articles referred to other sources these were also reviewed directly on the websites that published them to view quotes in their entirety and to further

expand the number of sources, and stakeholders identified, that could contribute to this analysis. The types of documents are listed in Table 3-5.

Document Type	Description
Government policy papers	Detail the government's position on rail passenger wastewater operations and their approach to both investing in and regulating the rail and water sectors
Sector strategy plans	Produced by the commercial players in the rail and water sectors communicate their priorities and progress in advancing their operations
Trade and public media articles	Report on events associated with rail passenger wastewater operations and evidences the roles the general public, trade unions, private companies and public sector organisations have in this issue
Legislation and guidance documents	Detail how rail passenger wastewater is subjected to legislative constraints and explain how rail service operators can comply with them

Table 3-5 Documents and texts collected from government, industry and public media sources.

Where possible multiple reports of the same concern were reviewed to ensure conclusions drawn from their content would not be biased towards the political or commercial interests pursued by these publications (Rapley, 2018). Furthermore, by including a wide range of sources from both public and private sectors the overarching aims of these organisations can be made apparent through how they influence the way the issue of rail passenger wastewater operations is approached and considered. This is a particular concern owing to the objective

of this study to examine how all stakeholders regardless of their immediate power within the rail and water sectors are affected by the problems the wastewater system seeks to address.

3.2.2.2 Data analysis

The documents and texts will be analysed and synthesised using Dorst's (2015) frame creation model, detailed in Appendix Appendix D, as a structure to present the collected data and to then explore how the framing of the case study's engineering system compares to the framings that emerge from these publications. This model will contribute to evidencing the potential differences between the "presented problem" described by the project brief of the engineering case study and the "discovered problems" that emerge from this analysis (Getzels, 1979). These findings support the study's objective in constructing a localised stakeholder landscape and gaining an understanding of the problems the system will need to address as evidenced by their reported interests and how they are affected.

Owing to the novelty of this system, the potential for the problem being difficult to solve could be high, as inferred by the lack of already existing solutions indicated by the findings of the prior study. This difficulty could be the result of challenges in appreciating the implications of a solution's inherent framing, reflecting an inability to succeed with an "obvious solution" that fails to address a paradox within the problem context (Studer et al., 2017). For example, a technical solution continues to be applied without addressing this difficulty *because* of the interests of various stakeholders that support it and who may not be significantly affected by it. For the current solution to solve the intended problem, and the problem it would cause by doing so, would be paradoxical. However, this is due to the nature of the solution that manifests a particular view of the problem that fails to incorporate the needs of other stakeholders.

Through exploring the documents and texts of these stakeholders, themes will be inductively coded so to identify how they perceive the problems associated with

passenger wastewater operations and whether there are opportunities they seek that could be shared with other stakeholders. These themes then support the shifting of perspectives as a core synthesising step in problem framing through the phrasing developed by Dorst being “*if the problem situation is approached as if it is ..., then ...*” (2015, p.78) indicating a solution space could exist that comprises multiple means to address a problem based on how, and for whom, it is formulated, or “framed” (Schön, 1984). Through applying this synthesis to the findings of this document analysis this study will be able to then consider how these new frames compare to the framing of the “presented problem” and the implications on the stakeholders involved that would be expected to support it.

Synthesising these frames will contribute to the latter part of this second objective, concerning how the problems the system will address affect the stakeholders in the operation of passenger wastewater systems. To achieve this an iterative co-evolutionary approach (Maher and Tang, 2003) to problem exploration will be used that will result in frequent revisits to the document analysis findings to identify stakeholder needs and assess whether alternative frames could address them. By revisiting, and potentially expanding through additional searches, the documents and texts collected, the interpretation of the problem will be able to benefit from new knowledge that may significantly impact the formulation of future frames and the nature of the resulting desirable outcomes.

An example of this abductive synthesis is shown through how a discovered problem can evolve from a presented problem, in Figure 3-3, using a 5 Whys analysis (Murray et al., 2019; Public Affairs Division, 2003) to demonstrate the limitations of an initial framing and how this technique could otherwise fail to address a wider concern without this type of reasoning. In this case the number of bins had to be increased but were limited by the amount space required for passengers, i.e. the paradox, drawn from a case study by Dorst and Cross (2001) in which this impasse was resolved by engaging stakeholders in the cleaning processes. It became evident the amount of rubbish could be significantly reduced if newspapers were made available onboard the train, which was a large

portion of the collected waste. Without this awareness the solutions would be restricted to ever more inventive ways of reducing the size of bins and the cleaners would be looking for faster ways of emptying them.

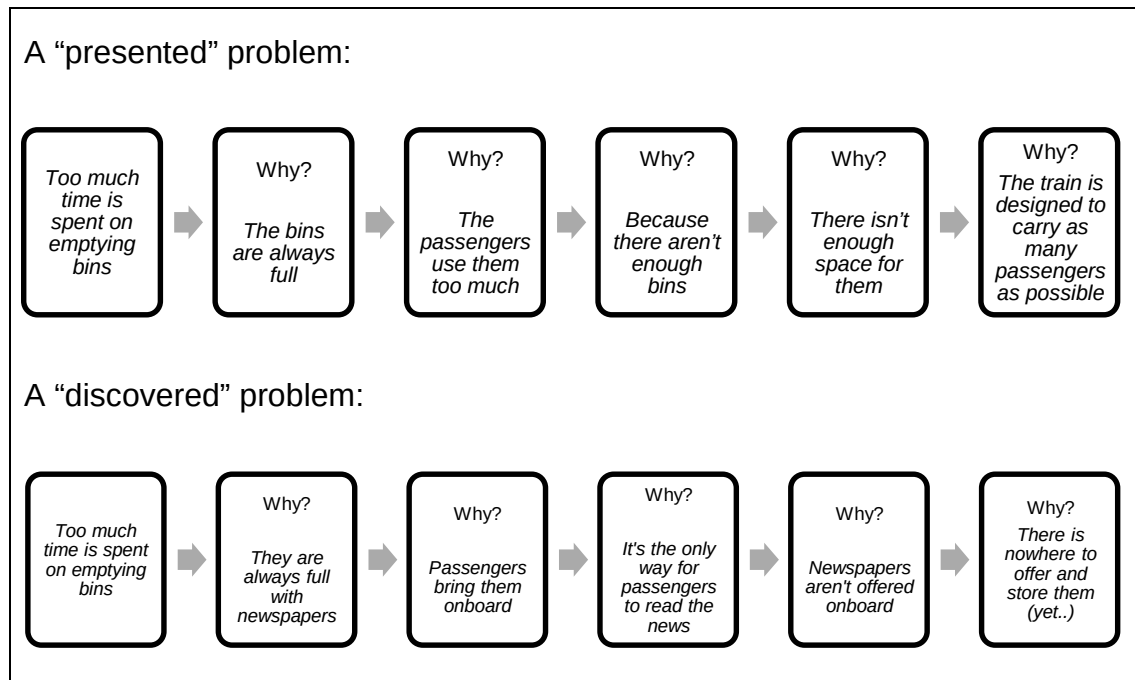


Figure 3-3 A demonstrative 5 Whys analysis of the train passenger waste collection case study (Dorst and Cross, 2001) reflecting the limitations of not having additional information (top) that would lead to a new problem frame (bottom). Drawn by author.

Through applying abductive reasoning, the study will then construct desirable outcomes through these alternative framings to support the creation of possible solutions that, if realised, could overcome these paradoxes. Delimiting a solution space could be a pragmatic approach given that practitioners may be unable to ensure every stakeholder can be identified and thoroughly analysed and that not every potential solution can be produced by the organisations involved. For the purpose of this study, however, these pragmatic constraints will be relaxed to demonstrate the extent a document analysis can be used for the purposes of generating problem frames to be fully explored. These results will aid questioning whether accepting these constraints is actually within the long-term interests of organisations that may be unable to overcome the limitations of their existing

framings. Alternatively, this finding could reveal whether the transformation and integration of the proposed solution could prove a realistic undertaking using an organisation's current capabilities and expertise in a way that had not been considered before, demonstrating a known benefit of problem exploration (Murray et al., 2019).

3.2.3 Requirement elicitation by semi-structured interview

Chapter 6 presents results in pursuing the third objective of this thesis which was to *evaluate the extent stakeholder needs are being addressed by the direction of the system's development* whereby semi-structured interviews were conducted for requirement elicitation. This method was chosen so that questions could focus on problem exploration (Studer et al., 2018) whilst remaining within the context of a proposed solution. Adapted from medical and design fields (Deininger et al., 2019; Kallio et al., 2016), this method has received little attention within requirement engineering literature owing to the current scholarly emphasis being on how to elicit requirements that can effectively lead to precise specifications (Rueda, Panach and Distant, 2020) rather than to explore the problem space. However, improving requirements has inspired researchers to consider the statements that participants offer during an elicitation activity as a means to achieve this, with ideal properties concerning a high degree of creativity, objectivity, exhaustivity, i.e. how complete they are and ready to be phrased as requirements, steadiness, i.e. how unlikely they are to change over time and orderability, to aid prioritisation (Burnay et al., 2020).

However, missing from these properties is an indication as to whether and how the statements evidence support for the proposed system or support framing the problem differently to incorporate these interests behind these statements (Dorst, 2015). This could be explained given the nature of studies conducted in requirement engineering literature whereby the solution can be fictive and as such the involved subjects may or may not see the problem or the solution as a priority in their own settings. One such example is the development of fictional web platform whereby participants were expected to respond as if they were

interested in its purpose (Rueda, Panach and Distant, 2020). However, as outputs from requirement engineering practice and design-led interviewing practice can be complimentary, scholars have recommended integrating them to provide human-centred perspectives to detailed specifications. Whilst the implications on how this would affect the methods are yet to be explored, the use of semi-structured interviews could contribute to this goal (Hehn et al., 2020). To address this gap in research, this study expands how requirement elicitation practice considers quality so to include the extent stakeholder statements reflect their most significant needs.

To achieve this, through the use of the semi-structured approach, the interview method will balance collecting requirements for the system whilst evidencing the extent the system is validated through enabling participants to discuss their needs within the broader industrial context of the case study; namely passenger toilet facilities and related wastewater, rail sector wastewater in general and freshwater consumption relating to both the system and the sector, including the water sectors' perspective. These topics would emerge if the participant chose to discuss them as an indication of where they see the greatest challenges and opportunities, reflecting grounded theory approaches (Kroeger, Davidson and Cook, 2014). If they centred on the proposed system then this could indicate its salience is validated; however, to ensure this topic was not overlooked structured follow-up questions that specifically relate to the proposed system will be asked if necessary (Coulin and Zowghi, 2005). Furthermore, enabling interviewees to direct the interview towards their own interests could help increase the quality of the data by reducing the risk of bias towards the interviewer's position, especially considering this author's role as a participant in the case study's engineering system development project. Requirements elicited that are not directly relevant to the current direction of the system, however, could prove useful for future developments as alternative or additional design considerations.

3.2.3.1 Data collection

To identify participants for the study, purposive sampling was used that applied the findings of the power versus interest stakeholder analysis grid (Eden and

Ackermann, 1998) that positioned organisations from the document analysis of the prior chapter into four quadrants, detailed in Appendix Appendix B. Organisations that were placed in and near the top right were selected to be contacted as they were evidenced to potentially have the greatest interest and influence in supporting or adopting the system. Representatives who held senior decision-making roles were contacted via introductions made by the organisations leading the case study project (the academic institution and the sponsoring firm), through the author's networking at industry trade shows and by contacting the organisations directly via phone and email.

30 potential interviewees were identified with 15 agreeing to take part in the study, described in Table 3-6. The remaining 15, summarised in Figure 3-4, did not participate due to a variety of reasons ranging from not responding to participation requests to the topic being considered too commercially sensitive either by themselves or the sponsoring firm that had initiated the case study's project, further details are given in Appendix Appendix H. The large number of train operators in this portion of participants that were not involved reflects how in the UK there are significantly more of these companies, due to the government's approach towards privatisation, than other organisations with influential roles involved in the rail and water sectors. The sample succeeded in representing every major industry and government interest. Fortunately, the train operators that agreed to take part represented both ends of the service spectrum, those being long-distance and commuter routes, which was the rationale for seeking greater participation from this stakeholder group.

Participant (P)	Role and Organisation	Sector
101	Rolling Stock Policy Manager, Passenger Services (UK Government)	Rail
102	Environment and Business Senior Advisor (UK Government)	Water

103	Rail Safety Standards Advisor (Non-Profit)	Rail
201	System Integration Engineer, CET Tanks (Train OEM)	Rail
202	System Development Engineer (Train OEM)	Rail
301	Procurement Manager (ROSCO)	Rail
401	Engineering Assurance & Development Director, Regional and Commuter Services (TOC)	Rail
402	System Development Engineer, Long-Distance, Regional and Commuter Services (TOC)	Rail
501	Project Manager, Water Reuse (Water Wholesaler)	Water
502	Technical Lead, Treatment and Abstraction (Water Wholesaler)	Water
601	Managing Director (Water Retailer)	Water
701	Managing Director (Wastewater Filter OEM)	Water
702	Project Manager (Train Equipment Distributor)	Rail
801	Environment Manager, Train Depots (Train OEM)	Rail
901	Fleet and Engineering Director, Railway Maintenance (UK Government)	Rail

Table 3-6 Interview study participant details.

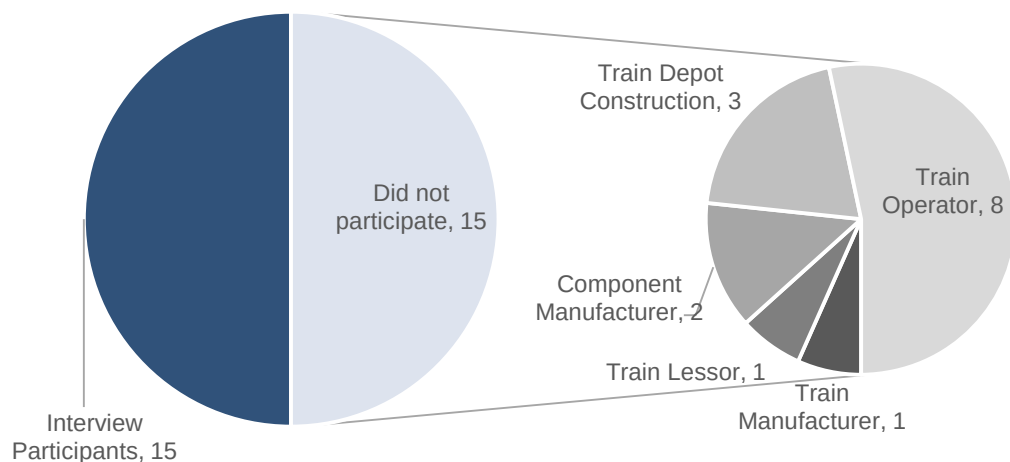


Figure 3-4 Details of participants who were unable to be involved.

The semi-structured approach to the interview meant that the list of questions would be formulated as a guide focusing on themes rather than specific points to address (Robson and McCartan, 2011), shown in Appendix Appendix E. Therefore, the questions would be, through adopting the method as described by Kallio et al., “participant-orientated and not leading, ... clearly worded, ... single faceted and open-ended” (2016, p.2960). Derived from the proposed benefits of the case study engineering system and the framing of the operational impacts of passenger wastewater, the questions that would be derived from these interview themes aimed to ensure the system would be thoroughly examined without leading the interviewee into offering positive or supportive responses. This was reflected in the follow-up questions and the manner in which the guide was worded to focus on the specific professional backgrounds and industry constraints relevant to them. The follow-up questions were generated during the interview using the active listening technique (Brownell, 2017) that ensured the questions would closely follow the preceding responses by examining the topics raised through clarification and confirmation. This approach to the interview would aim to address the challenges structured formats may have in being responsive to new knowledge that could emerge, a likelihood given the uncertainty and novelty surrounding the engineering system’s problem space justifying this need to adopt an exploratory approach for requirement elicitation (Coulin and Zowghi, 2005).

Prior to the interviews commencing, participants were required to complete a consent form, shown in Appendix Appendix F, which described the aims of the project to develop the passenger wastewater system, the roles of the organisations involved and how their data would be used including the option for their names and details to be anonymised. This study was conducted in accordance with an ethics protocol, as shown in Appendix G. The interviews were recorded and their durations ranged from 23 to 76 minutes. The duration was determined by the level of interest and knowledge possessed by the participants. The recordings were then transcribed for later coding using NVivo 12 Plus with notes taken during the interviews as a means of formulating follow-up questions.

3.2.3.2 Data analysis

The transcripts were initially coded deductively identifying statements that would lead to requirements that were within scope and supported planned capabilities, a design consideration, i.e. for future development, or out-of-scope. Table 3-7 shows the list of statements extracted from the case study project brief that was used to determine these assessments. This analysis was completed with the support of the supervisors involved in the project to ensure a correct understanding of the technical implications of the statements. Given that whilst some were clearly out-of-scope, the extent to which a requirement was within scope or a future development goal required domain knowledge of related aspects of the system in order to understand whether they could be achievable within the duration and budget of the project. These findings were presented to the project team as a series of presentations and an Excel spreadsheet, shown in Appendix K, as part of the author's role as a participant-observer to then evaluate, as part of the proceeding chapter's case study, the engineering system's development processes and methods' capabilities in responding to this, and potentially further, stakeholder engagement.

Statements that infer the nature of the problem
<ul style="list-style-type: none">• Reduce disruptions to the railways caused by servicing water and CET* tanks.• Reduce operating costs - no specialised servicing equipment or operatives required.• Improve sustainability - no sewage or wastewater treatment infrastructure required.
Statements that outline the functionality of the desired solution
<ul style="list-style-type: none">• Handle liquids present in rolling stock** toilets/washrooms such as urination, hand washing.• Purify liquids for reuse or safe discharge into the rail track environment.

- Render solid waste inert (e.g. faeces and toilet paper) safe for discharge into existing depot infrastructure systems.
- Designed to be integrated into existing rolling stock structures on a “plug & play” basis.
- System data logging to ensure safety and enable maintenance on a “predict & prevent” basis.
- Interface with existing rolling stock toilet/washroom systems & power supplies.

*CET refers to Controlled Emission Toilets, the name given to passenger wastewater retention systems fitted to the underside of trains

**Rolling stock is a rail industry term for all types of rail vehicles, including, in this case, the carriages used for passengers.

Table 3-7 Problem and solution statements extracted from the case study’s project brief.

The analysis then continued to consider how these statements could contribute to problem exploration and the extent there was significant support for the existing framing and the framings synthesised in the prior study. The statements coded as *design considerations* and *out-of-scope* were also included in further analysis as to formulate them as requirements that contextualised the stakeholders’ roles in their settings, motivations and desired outcomes adapting the “when <situation>, I want (to) <motivation>, so that (I can) <expected outcome>” (Lucassen et al., 2018, p.228) phrasing drawn from software development. In order to fit engineering system contexts this has been rephrased as *when <situation>, the system (should be able to) <functionality>, so that (the system or platform) <expected outcome>*. This method enables this study’s objective to produce stakeholder engagement outcomes that demonstrate, if pursued, how semi-structured interviewing can lead to requirements for solutions that are

evidenced as aligning with stakeholder needs and as such will demonstrate whether this additional dimension could be used measure a requirement's quality.

3.2.4 Case study of the early stages of an engineering system development project

Chapter 7 presents the findings of a case study so to meet the fourth objective of this thesis which was to *evaluate the ability for a prototyping strategy applied during the development of an engineering system to incorporate stakeholder input* by using an extreme case within a development setting that is both highly resourced and involves the pursuit of a high degree of innovation. This case can provide transferable learnings (Daly, McGowan and Papalambros, 2013) derived from the extent the capabilities of the organisations involved and the novelty of the technology being pursued could affect the integration of stakeholder contributions. As these factors are yet to be evidenced as variables that could be experimented with, the suitability of a single case study research design can be justified in the pursuit of identifying what these could be (Flyvbjerg, 2006; Szajnfarber and Gralla, 2017). Focusing on these aspects during the data collection stage will ensure the case findings could be potentially transferable within this context. However, if it becomes apparent that other factors were of greater salience the case could evolve to reflect this through both the direction of data collection and analysis (Dubois and Gadde, 2002). This flexibility will be applied in how the objective is addressed; by the case exploring various ways in which the prototyping strategy responds to stakeholder input, how that input is formed and who those stakeholders are in relation to the system.

The case concerned a longitudinal study of the initial stages of a small-scale engineering system designed to process rail passenger wastewater as an integrated part of the train, the details of the project are described in the research context of Chapter 1. The system was developed in parallel to the studies conducted in this thesis enabling the author to both research and contribute to the project. As evident in these prior studies, the author's role was contributory and supportive and so would unlikely be seen as an intrusion or disruptive to the

activities of the project team whilst engaging as a participant-observer for the purpose of conducting this case study (Jorgensen, 1989).

3.2.4.1 Data collection

To aid the triangulating findings, the case study comprises a range of data types including interviews, observations, photographs and diagrams (Yin, 2018). The interviews were conducted with the complete team comprising of 4 individuals including the project sponsor. All the interview sessions were conducted via the Teams web conferencing platform with the exception of the final interview with the liquid sub-system researcher. The majority of the interviews were conducted whilst examining technical drawings, presentations and photographs of their respective sub-systems at their current stage of development over the course of 3 years. Researchers were asked to present their progress and to explain the reasons for the development decisions which occurred throughout the duration of the project involving 5 sessions. Whilst the developers were aware of the author's work in eliciting stakeholder insights, the interviews were not conducted with questions relating specifically to this dataset, rather, questions revolved around the presented work and the discussion was largely directed by the participants themselves. This would enable the identification of stakeholder input from other sources and for the dataset to only be mentioned should it be relevant to a development decision.

However, this approach to the stakeholder insight dataset differed during the 2 collaborative workshops that were organised by the supervisors and attended by the team whereby the author would advocate the interests of the external stakeholders when invited to contribute. Table 3-8 lists the participants and their roles in relation to the project including when the interview sessions and the workshops took place. The absence of the system assembly and integration developer towards the end of the case study and the involvement of the project sponsor was not an intentional choice made for this research but the result of a management decision made by the project sponsor. As the researchers had significant control over the direction of their research, the supervisors themselves were only involved during the workshops.

Participant(s) Session	Solid Processing Sub-System Researcher (P1)	Liquid Processing Sub- System Researcher (P2)	System Assembly and Integration Developer (P3)	Project Sponsor (P4)	Researcher Supervisors and Project Manager (P5, 6, 7)
9 month review progress	•	•	•		
2 nd year review progress	•	•	•		
Solid conveyance workshop	•	•	•		•
Liquid separation workshop	•	•	•		•
End of 2 nd year progress	•	•			
Final year review progress	•	•		•	
End of final year progress	•	•			

Table 3-8 Case study data collection participants and periods.

In addition to these interview sessions and workshop transcripts several other data types were collected. Photography was taken at the laboratories where the system was being developed and the train depot where passenger wastewater would be collected. Observations were made during visits to 2 industry trade shows where the project was being promoted by the sponsor and promotional material was witnessed. Diagrams of the system were collected from the project team's shared folder or sent directly to the author's email account. Collecting this data would contribute to capturing how the system appeared during the early-stages of the development phase to add further detail to the descriptions made by the interviewees and workshop participants. Furthermore, depending on the context in which the passenger wastewater system appeared, i.e. as component test rigs in the laboratories or artist impressions, inferences could be made as to

how this effected the system's ability to incorporate responses from stakeholders. However, opportunities to collect these types of data were severely restricted as a result of the SARS-CoV-2 pandemic which cancelled trade shows and prompted laboratories and facilities to close or operate with reduced access. As a result, this data could only be collected during the end of the first year and the first few months of the second and towards the final year, although developmental progress was limited resulting in little change in the material that had already been collected.

3.2.4.2 Data analysis

The analysis of this study was initially focused on considering how stakeholder theory (Freeman, 1984) could explain how and why the interests influenced the direction of the prototyping strategy's activities. However, it became clear the artifacts produced within the strategy contained an intrinsic quality that could determine the extent stakeholder input would be integrated regardless of the influence and interest of the stakeholders themselves. This theoretical evolution reflects the central contribution a single case study design can make whereby abductive reasoning is used select and deselect existing theories in a process to find a theory that can be expanded to encompass a new context, that being the phenomenon at the centre of the case study (Dubois and Gadde, 2002).

How the prototyping strategy would be analysed to identify the extent it could respond to input from stakeholders in the engineering system development and its intended operating environment would now draw on the boundary object concept (Star, 1989). This concept concerns how an object can be studied to contain different meanings depending on the context of the person addressing and interacting with it. This experience could indicate a "partial jurisdiction over the resources represented by that object, and mismatches caused by the overlap become problems for negotiation" (Star and Griesemer, 1989, p.412). This presents a theory that boundary objects need to embody "interpretive flexibility" (Star, 2010) so that problematic encounters can be mitigated and the object succeeds in having different meanings to different people whilst remaining a recognizable entity. In engineering cases, this concept has been applied to reveal

how technical drawings can lose their effectiveness as boundary objects when presented via CAD, restricting the ability for spontaneous interaction through annotating with pencil whilst preserving the control of those who create the CAD files (Henderson, 1991). Other studies have shown the mismatch between the maturity of the drawing and the progress made with the design frustrating the decision-making process whilst preserving power dynamics within review meetings (Carlile, 2002). In considering the range of purposes the artifacts created during the case study possessed to aid prototyping, adopting the boundary object concept will help guide the evaluation as to whether and how they succeed in meeting the needs of those who interact with them.

However, a limitation has been argued as to the extent the boundary object concept can be applied to prototypes to justify this flexibility. When the needs are significantly different a single prototype could struggle to embody all these demands (Rhinow, Köppen and Meinel, 2012). For example, a prototype may be produced in a way that does not make it self-explanatory, as a conventional boundary object it would be considered to fail in meeting the needs of those ill-informed of its purpose. Attempting to ensure every prototype and related artifact is developed a priori to be a successful boundary object would be challenging due to their interpretation being constructed at the point of interaction (Klerkx et al., 2012). As such the analysis will apply this concept with an initial focus on the purpose for which they were created. With this basis considered, the role of prototypes to be artifacts in flux that manifest a particular instantiation of a solution as it matures (Ewenstein and Whyte, 2009) will be explored to identify how new developments are realised, how their origins can determine the extent the prototype responds to stakeholder input and why prototyping methods and techniques are applied if success in achieving this proves challenging.

3.2.5 Synthesis of thesis findings

Chapter 8 will fulfil the final objective of this thesis which is to *synthesise findings from the case study to provide theoretical and practical implications for prototyping engineering systems involving radical innovation with stakeholder engagement*. This will encompass the findings from the prior studies that were

contributed to the project as the focus of the case study. The outputs of this synthesis will help contribute to understanding specifically the opportunities and challenges present in the study's focus on passenger wastewater through to the wider context of engineering system development and how the methods adapted could be applied to aid practitioners and scholars alike. The contributions to knowledge will highlight how stakeholder theory and other theoretical findings that surfaced during analysis can be studied with a specific focus derived from the unique characteristics of an engineering system and the conditions in which they develop. Furthermore, the contributions will be discussed as to how framing engineering system problems can demonstrate the theoretical and practical value of applying abductive reasoning and the significant potential for qualitative research to impact how engineering is studied and practiced.

3.3 Limitations and other methodological approaches

The limitations in applying these methods concern the nature of the interviewee and case samples and the amount of relevant literature. Both are affected by the novelty of the focus of the research context and as such whether they will be able to provide sufficient data to analyse could pose a risk to opting for a qualitative-led enquiry that is driven by specific purposive sampling. Reducing the extent the studies focus on being relevant to the case study could reduce this risk, and using quantitative, survey-based research that could draw on much larger sample sizes could help avoid the potential that the few individuals that form the single sources of knowledge specific to the case study are unavailable. As a result, the proceeding studies may be limited in the directions they can explore at such granularity and as a result could be influenced by more pragmatic decisions rather than academic. However, due to the exploratory nature of the research questions, the need to direct the research towards a specific hypothesis was not an objective and as such the flexibility in being able to develop, direct and expand both the corpus and interviewee samples based on the findings that began to emerge would justify this approach (Piekkari and Welch, 2018).

An alternative approach could have been to use multiple small sample sizes through the use a multiple case study design. However, as multiple engineering

system development projects occurring at the same stage of development would be an unlikely occurrence, this approach would furthermore call for an experimental design to rationalise what the variables were that determined which cases to sample. As the nature of this research seeks to identify what those variables could be, focusing on internal validity has been the priority (Szajnfarder and Gralla, 2017). For example, the factors that affect the ability for prototyping engineering system to respond to stakeholder inputs. A multiple-case case study would be suitable if there was an established body of knowledge that could be drawn upon. However, as shown in the literature review, the development of engineering systems has few studies that relate specifically to the integration of stakeholders nor how the practice of prototyping can affect this aim thereby such an approach could lack justification as to the decisions taken to form this sample.

3.3.1 Quality assurance and approach towards generalisability

Whilst small sample sizes could be biased towards the opinions and experiences of those participating, the intention of the studies in this thesis to research salient stakeholders and niche applications of technology justify this approach. This is an unavoidable reality of the industry's structure whereby individuals hold significant influence and domain expertise. This same limitation could be evident in the grey literature that will be reviewed, however, during the analyses the interests and influences of these stakeholders will remain within the context of their roles so that potential biases in their actions can form part of the understanding of how a particular technology develops.

As the aim of this research is to identify possible causes for how engineering system development could maintain or lose alignment with the needs of those responsible for adopting and supporting its introduction, the findings will also be limited in generalisability due to the focus being on identifying these factors first rather than being able to experiment and test with known factors. This will contribute to predominately transferable, rather than generalisable, findings that could either be used to further the study of the engineering system at the centre of the case study or be applied to other engineering contexts as a means to justify

different single-case case studies or multiple-case case study research designs (Daly, McGowan and Papalambros, 2013).

To ensure trustworthiness in the analysis, where possible, triangulation of data collected was made, both by the inclusion of multiple articles of the same concern and different forms of data, as evident in the case study findings of Chapter 7, involving photography, transcript quotes and diagrams (Yin, 2018). With this variety and extent of data, how analyses were made will appear more evident as they will be supported by this range of data. To address potential bias in the interview study analysis, codes of the stakeholder interviews were constructed with the support of the supervisors of the project, including those involved in technical development of the sub-systems who each had different research priorities to that of the author. Transparency of the analysis was aimed for through sharing these findings with the team to identify any potential errors in the author's understanding of the technical implications of the needs of the stakeholders, reflecting ideal case study practice (Reynolds et al., 2011). External reviewing of the codes by researchers not involved in the industry or technology could have helped further reduce this bias. However, the confidentiality of the project, as a result of its commercial nature, meant that the findings produced throughout the duration of the research were given restricted access and could only be shared within the teams involved. As such this aspect of the research context could pose a limitation as to the extent empirical studies offer results that are not influenced by the aim of the project to produce an engineering system to process passenger wastewater.

4 RESULTS: STAKEHOLDER ANALYSIS OF AN ENGINEERING SYSTEM BY LITERATURE REVIEW

4.1 Introduction

This chapter presents the findings of a review of literatures and trade articles that address the challenges in developing and operating an engineering system, specifically a passenger wastewater treatment system. This review identifies several aspects of the stakeholders involved in such systems. These include the extent the specific application of an engineering system, in this case each type of transport mode, relates to the level of stakeholder interest and what the drivers are of this interest. Furthermore the review uncovers how the identities and responsibilities of these stakeholders differ depending on the application itself and the geographical region the activity surrounding the engineering system occurs within.

The chapter begins with a descriptive analysis of the corpus identifying the extent the transport modes are represented. This will contribute to the overall finding as to whether and how the specific industrial constraints of each mode affect the level of interest in such systems. How this interest is represented across a variety of publication types will then be quantified to identify the extent interest in this type of technology resides across established and emerging academic contexts, as represented by journals and conference proceedings, and practitioner contexts as represented by trade publications. The years of publication are then presented to identify overall trends and whether there are any commonalities between the modes and the potential reasons for the quantities of publications produced each year. The chapter then proceeds to present findings as to the drivers of this attention through a thematic analysis of the topics of the articles. This introduces a more granular understanding of the stakeholders as to their roles and responsibilities in progressing the development of this technology. The chapter then presents the most influential stakeholder groupings in the context of their interests, transport modes and their regions in which their articles concern,

where applicable, to add further appreciation of whether and how the interests and influences of similar stakeholders can differ depending on the transport mode or region the stakeholder may specifically concern.

4.2 Descriptive analysis

Developers of a new engineering system that relate to passenger activities could find that the chosen transport mode has significant impact on both the amount of scholarly and industrial attention given. This was the case with the development of wastewater systems as shown in Figure 4-1. Sea travel, encompassing cruise liners, ferries and river boats, represented a substantial majority at 73%, with road travel, i.e. via coach, represented the least at 1%. Rail and space contexts were also in the single digit percentages at 3% and 4% respectively. The publications focused exclusively on a specific transport mode with the exception of 2 articles that concerned transportation via coach which was combined with studies of passenger aircraft wastewater systems (Atilano-Camino et al., 2020; Moreno-Andrade et al., 2014) and 1 article that concerned SARS-CoV-2 being discovered in wastewater collected from both cruise liners and passenger aircraft (Ahmed et al., 2021). The second largest share of the corpus, air travel at 20%, suggests that, despite a mode being a popular form of transport that would include passenger toilet facilities, the differing commercial, operational and regulatory constraints and opportunities could affect the extent of interest in systems that process passenger wastewater.

Given the large difference between the most and least shares of publications per mode the accuracy of further analysis of the latter would be limited due to these small numbers. However, in an attempt to mitigate against this issue, and in order to ensure findings are not constrained to a specific type of publication, a range of academic and non-academic articles have been included, however, specific inferences will be limited as to how the transport modes compare.

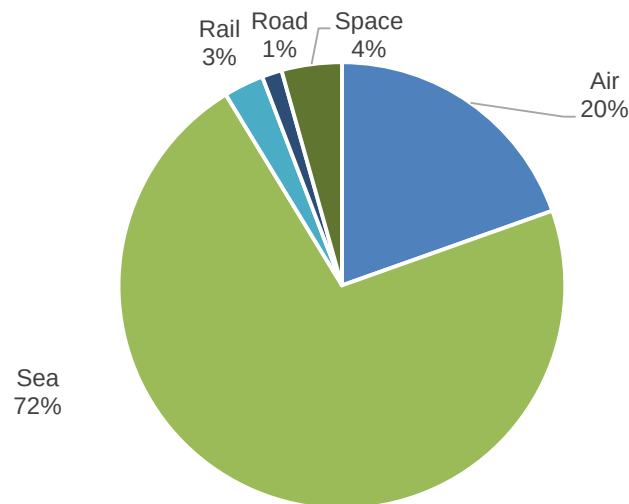


Figure 4-1 Percentages of articles per transport mode.

As shown in Table 4-1, journal articles comprise the largest majority at 70 titles with contributions relating to all modes. Trade articles represent the least at 32 and lack contributions that concern passenger wastewater topics from rail, road and space tourism. Conference papers, the total being similar to the trade corpus at 36 articles, lack contributions from coach travel, however, contribute the most to rail with 3 articles in comparison to the single journal article. As sea travel is the mode most published, further analysis of the content of these articles could help reveal the extent article types influence whether and how specific stakeholders are represented. Owing to the few studies that concern the remaining modes, these findings could contribute to forming a speculative understanding of how similar stakeholders could affect, and be affected by, other modes, in relation to general passenger wastewater concerns. However, given the lack of publications, this absence could be interpreted as a lack of interest, awareness or severity of these concerns and that other forms of wastewater, or other types of engineering systems, could be given a higher priority.

Transport Mode	Journal Articles	Conference Papers	Trade Articles	Total articles per mode
Sea	45	27	27	99
Air	19	3	5	27
Space	3	3	0	6
Rail	1	3	0	4
Road	2	0	0	2
Total articles per article type	70	36	32	138*

Table 4-1 Quantity of articles per transport mode and article type. *Total is 135 if excluding 3 article counts that concerned 2 transport modes, 2 by air and road and 1 by air and sea respectively.

Through examining the publication dates we can identify trends and commonalities between the modes of transportation. This distribution is varied but with a positive upward trend as shown in Figure 4-2. Beginning with air travel as the first mode to be studied through a consideration of the operational impacts of passenger wastewater systems. This produced a speculative proposal for an engineering system that would recycle wastewater onboard to reduce the amount of water required for flushing (Sekoulov, Figueroa and Oles, 1991) reflecting interest from operators of the mode in weight reduction to improve flight performance. The first significant peak occurred in the early 2000s and came as a result of the growth in sea travel publications prompted by pollution events within the Alaskan coastal region leading to research being commissioned to support the development, and assess the effectiveness, of discharge regulation. The early 2010s saw a return to an increase in attention but with a greater variety of modes and motivations. The strengthening regulatory landscape sustained interest within ocean and river passenger transport, with the wastewater limits set by the International Maritime Organisation (IMO) often cited when additional

amendments come into effect. The interest in sustainability, specifically reducing freshwater consumption through wastewater recycling, and assessing health hazards and environmental impact across all modes became an established rationale for conducting research and proposing solutions throughout the late 2010s. A combination of these factors and the opportunities to study the effects of the pandemic caused by the SARS-CoV-2 virus contributed to producing the publication peak in 2019 and the similar level the following year, however, there was no common majority as to the publication rationale. The sudden decline in publications could have potentially been a result of this global health event impacting the ability for this research to be sustained as shown by the resulting level in 2022 not seen since 2008. The following thematic analysis explores the areas of interest shown in these publications in detail so to gain a deeper understanding of why they were published.

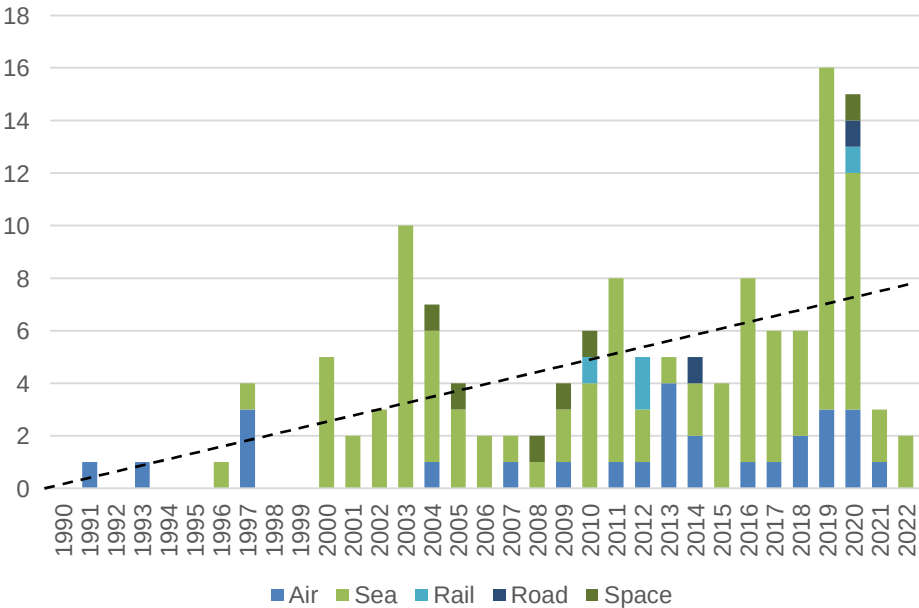


Figure 4-2 Number of passenger wastewater-related articles per transport mode per year.

4.3 Thematic analysis

To gain an understanding of the stakes in passenger wastewater system development, the corpus was analysed to identify common themes that described the purposes of each article. Five themes were identified that demonstrated how stakeholders seek to influence the development of such systems by identifying implications for practitioners, and stakeholders affected by, or who can affect, the practice of engineering system development, and future research areas. These five themes were *management practice development*, *operational impact on the environment*, *regulatory impact on operations*, *wastewater composition characterisation* and *wastewater treatment development*.

As shown in Figure 4-3 each of these themes were present in the journal article collection, whereas *regulatory impact on operations* and *wastewater composition characterisation* were absent from the conference proceedings and trade articles respectively. The portions also vary across publication types, with both commonalities and differences, for example, *wastewater treatment development* was the largest in both journal and conference publications with *management practice development* and *operational impact on the environment* sharing similar volumes. The most significant difference was the amount of attention paid to *regulatory impact on operations* forming the majority of trade articles at 55% whereas the same theme comprised only 5% of journal articles and was absent from conference proceedings. These differences could be explained by publishers catering for specific interests, for example, understandably, the wastewater themes reflect concerns that apply to scholars of the natural sciences, whereas the operational and regulatory themes affect both academic and non-academic concerns. The latter theme having relevance to the general public affected by detrimental wastewater-related activities who could potentially form the readership of such publications. The following sections explore these themes in the context of each transport mode, the extent to which they are present is illustrated in Figure 4-4.

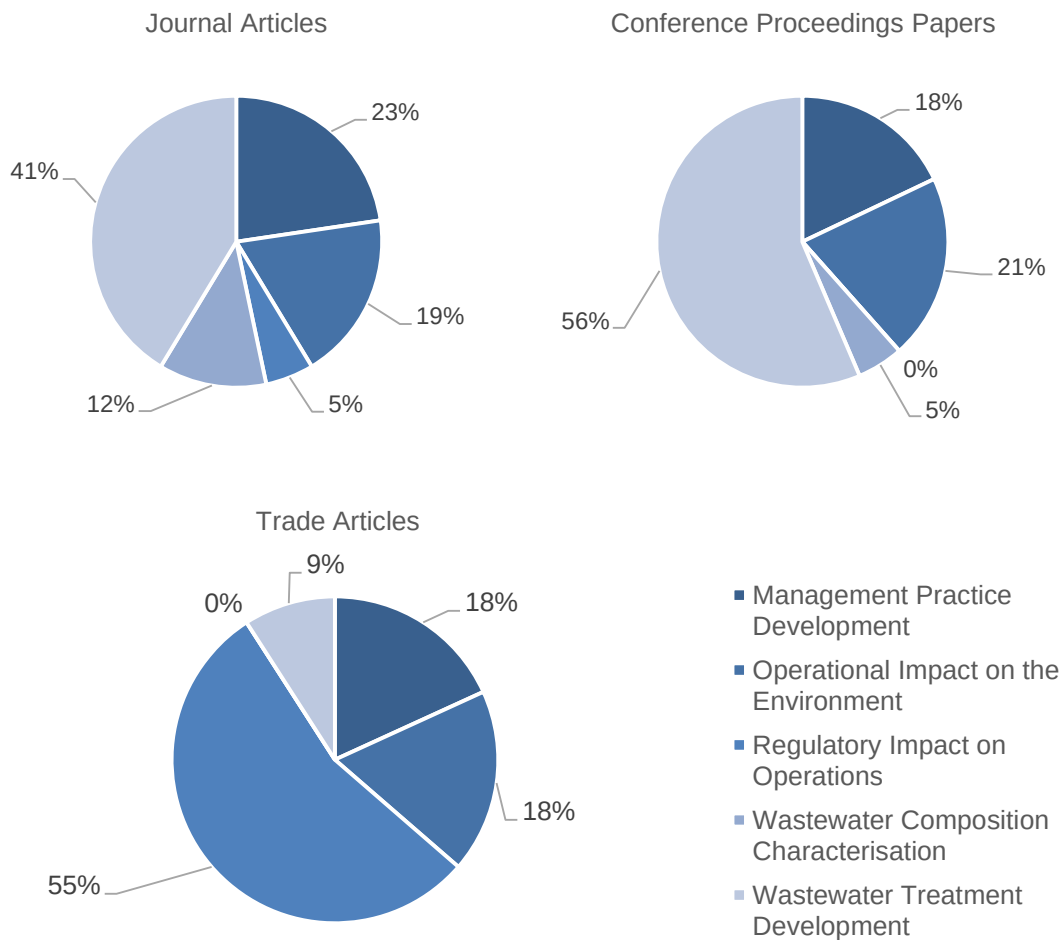


Figure 4-3 Proportion of article topic themes per article type.

4.3.1 Management practice development

The management of passenger wastewater systems presents the role of technology as a means to improve an organisation's sustainability performance and responsibility towards the environment. In addition this theme concerned articles demonstrating how efficient and optimized their processes were. This latter objective was evident in the studies that examined existing systems' technical capabilities and the operator's procedures so to identify, for example, how effective their treatment was at meeting a particular effluent standard (Ma et al., 2012; Yao, He and Chen, 2019) which was explored in both rail and air travel contexts. Practitioner challenges such as understanding the implications of new

regulations (Wilewska-Bien and Anderberg, 2018) and how consistent their wastewater treatment policies are across a group of operators (Wang, Li and Xiao, 2019) are examples of other related areas of focus that concerned existing wastewater systems and management practices within the larger sea travel portion of the corpus.

Articles that demonstrated the extent these systems could contribute to an organisation's positive environmental impact concerned both addressing how they could be used to reduce freshwater consumption and discharging pollution. Relevant to both objectives were studies that aimed to support practitioner decision-making in selecting a suitable wastewater system (Çiçek, 2019; Reshnyak et al., 2018) and, in the case of space travel, how they would need to be further developed to address greater demand on wastewater collection capacity (Ribeiro et al., 2013). Trade articles highlighted successful implementations demonstrating that such systems can also support how an organisation is perceived by the public as being environmentally-friendly (Carinci, 2009). The driving motivation behind these articles was to capture progress made in sustainability management, especially evident in the operation of airports (Carvalho et al., 2013).

When covering the issue of pollution reduction, a topic found exclusively within the cruise ship and ferry context, articles concerned the management of monitoring activities rather than the systems themselves. Whilst discharging untreated wastewater into the environment could be addressed by the installation of treatment systems, cases were made for how this practice may still need to be enforced. For example, this was evident in research that proposed the use of satellite observation of vessels in real-time, and to support modelling, to identify current, and forecast potential, areas of pollution (Fan et al., 2019; Liu and Chu, 2020; Vicente-Cera et al., 2020). The incorporation of the practical constraints of operating conditions and established management practices were another approach (Jiao and Liu, 2018; Xin and Gao, 2019; Yang, Shao and Zhu, 2015), which could support policies to provide effective control measures thereby restricting discharge to particular areas and ensuring operators are aware of

these regions (American Laundry News, 2006). This reflects specifically the difficulties in preventing operators of ocean-going vessels from discharging all forms of wastewater, rather than collecting for treatment at seaports or onboard, due to the remoteness of this activity which is a concern evident in both academic and trade publications (Xin and Gao, 2019). These factors support the study into methods of either incorporating or encouraging the transformation of current management practices which could lead to greater adoption of passenger wastewater treatment systems.

4.3.2 Operational impact on the environment

The extent wastewater, of which passenger sources are present, contributes to environmental damage has been extensively studied and reported within ocean and river contexts. Sediment and water samples have been characterised to identify a range of contaminants that provide evidence of the presence of untreated passenger wastewater (Basak et al., 2010; McGee and Loehr, 2003; Wang, Lu and Zhang, 2016). This has been explored in the context of measuring the impact on marine life and the dependent coastal communities (Mearns et al., 2003; Parks et al., 2019), methods to detect this form of pollution (Zeng et al., 2014) and how this impact can be modelled and predicted based on vessel location and activity (Tina, Vice and Nikola, 2019). The newsworthy nature of this operational impact can be seen by environmental campaign groups' efforts to raise awareness, and propose the installation of treatment systems, along with government co-ordination as seen by the Alaska Cruise Ship Initiative (ASCI). This particular case brought together participants from local Tribes to industry representatives and federal agencies which contributed to this theme featuring in trade publications as well as academic studies involving the same events (Johnson, 2003; Morehouse and Koch, 2003).

However, the severity of the environmental impact of passenger wastewater discharge in ocean settings has been questioned when the implications of the vessel itself are factored into the analyses. Dilution caused by the wake and the turbulence caused by the propellers reduce the intensity of the contaminants thereby creating an indirect treatment process reducing the hazards posed to the

environment (Keinen et al., 2003; Loehr et al., 2003). This has contributed to understanding how the physical dimensions of the vessel can in itself support the treatment of wastewater thereby enabling the assessment as to the extent discharge will be diluted during the design stage of the ship (Şahin and Vardar, 2020). Whilst this finding has been the result of academic interest, scholars have noted that it has had little impact on how the issue is perceived by regulators (Loehr et al., 2006). Due to the practice of discharging whilst stationary in ecologically sensitive areas, the risk that this treatment technique cannot be relied upon has resulted in caution being noted as to being a feasible approach to reducing environmental impact, and could potentially explain the failure to reduce public concern (McGee and Loehr, 2003). However, in the context of ocean and river pollution from land-based sources, operators and scholars have also observed that the attention paid to vessels could be overlooking more significant causes of environmental pollution given their greater volumes of wastewater discharge (Wang, Lu and Zhang, 2016).

In considering passenger aircraft and the airports that serve them, whilst this mode has received less attention, focus has been placed on a different aspect to environmental impact. This concerns how these operations can contribute to exacerbating water stress, which depletes natural freshwater sources, as a result of airports being within the same regions as densely populated, high water consumption urban areas. How this relates to the issue of wastewater treatment can be explained through the practice of recycling wastewater to a suitable water quality in order to reduce reliance on freshwater (Leung et al., 2012). The unique operational demands for water at airports, such as landscaping, cleaning and cooling, enable non-potable standards to be acceptable (Ribeiro et al., 2013). Studies into the metrics used to measure the effectiveness of this activity, such as the “L/passenger” index to measure water consumption efficiency across airports (Carvalho et al., 2013), how the operations of specific airports are currently achieving this objective (Baxter, Srisaeng and Wild, 2018, 2019) and proposals for new wastewater systems (Leung et al., 2012) reflect academic efforts to understand how this mode’s operational impact on the environment can be reduced through valorising wastewater from passengers and other sources.

4.3.3 Regulatory impact on operations

The majority (55%) of trade articles focused on revealing how industry regulations have become increasingly more constraining for operators in the cruise sector when managing wastewater. These reports have primarily focused on the case of the Alaskan state government's efforts to regulate this practice and how the legislative mechanisms of this region have sought to replicate their successes as seen in coverage of the passage of bills and acts in California and the wider US (Geiselman, 2004a; Tobin, 2002; Travel Agent, 2008). These articles provide multiple viewpoints from government officials (Geiselman, 2004b), cruise ship operators (Renstrom, 2005) and campaign group representatives (O'Rourke, 2004) that provide insights into the aftermath of the recommendations from academic studies into operational impacts. Whilst there were reports of operators installing systems and adjusting their discharge operations, the overall attitude is one of overcoming disruption rather than an opportunity to embed sustainable practices. Reports of heavy fines reflect the negative sentiments between operators and regulators (Management of Environmental Quality, 2006). This is further supported in the one academic study that explored the views of recreational boat users in Australia and their resistance to ending the practice of untreated discharge (Grant-Smith and Mayes, 2017). In this case reasons mirrored that of larger operators; the perceived lack of environmental damage, the costs and inconvenience incurred due to installing treatment or collection systems and the need to then empty these tanks at facilities onshore or at permitted distances from the coast.

However, this issue appears to be considerably less contentious in the context of the regulations applied to operators in the Baltic Sea. Studies explain that due to the established regional co-operation of the neighbouring countries, the alignment with the directives and conventions of European and global public bodies, operators through their respective governments played a more proactive role in preparing themselves for the tightening of discharge constraints (Backer, 2018; Grant-Smith and Mayes, 2017; Szumilas et al., 2000). Furthermore, how this change in industry norms was shared by both vessels and seaports reflects an understanding of the operational constraints by the organisations responsible

for regulating them. The latter was expected to install port reception facilities to collect wastewater if it was not processed onboard to a suitable standard prior to discharge. Absent from these developments are the political motivations that compelled the Alaskan government to be seen to combat cruise operators that were depicted as being irresponsible (Del Rosso, 2000). Articles that report on the operational impracticalities of these measures due to deadlines for installing systems and the defensive tone further emphasise the different regulatory impacts experienced across these regions (Travel Agent, 2008; Waste News, 2005). Interestingly, whether the introduction by the International Maritime Organisation (IMO) of a global regulatory framework for controlling discharge limits at sea was a contentious issue, or how a consensus was arrived at, does not feature in this theme due to the absence of articles. However, as will be evident in the *wastewater treatment development* theme later reviewed, this regulation proved instrumental in guiding the development of such systems.

In contrast to this mode, the lack of regulatory intervention in the operations of airports reflects how the air travel mode instead adopts industry-led constraints for the purposes of improving sustainability (Carvalho et al., 2013; Krop et al., 2016) potentially explaining the absence of articles related directly to this activity within this theme, as shown in Figure 4-4. The only article that concerned this mode reported on potential regulations to restrict the construction of treatment plants near airports due to the attraction of birds which risk colliding with aircraft (ENR: Engineering News-Record, 1993). However, whilst untreated discharge could occur from airport facilities, the discharge of passenger wastewater from aircraft during flight is not a technically feasible proposition and as such the modes are not directly comparable on the grounds of regulating similar operations.

4.3.4 Wastewater composition characterisation

Studies that focused on characterising the chemical and biological composition of passenger wastewater were conducted for two main purposes. Firstly, to assess the treatment efficiency of the engineering system (Liu et al., 2007; Morehouse, 2003; Passos, von Sperling and Ribeiro, 2014) and, secondly, to

determine the extent passenger wastewater can contribute to the dissemination of pathogens and pose a risk to human health and, in the context of cruise ships, marine life (Ahmed et al., 2021; Shieh, Baric and Sobsey, 1997). Whilst similar in nature to the studies following the environmental impact theme, these findings focused on samples collected from within aircraft and vessel wastewater tanks or airport wastewater treatment plants rather than from ocean waters and rivers. This could explain the greater presence of air travel in this theme as a result of the comparatively easier access to these samples, as shown in Figure 4-4, given that cruise ship or ferry wastewater would need to be collected at sea before it is treated or discharged. This is evident by the single study in the context of the Alaskan initiatives to assess the quality of treated effluent (Morehouse, 2003) and the collection of samples only made possible when a vessel had to undergo repairs (Vicente-Cera et al., 2019).

However, these sample collection challenges were overcome so to research the potential hazards caused by passenger wastewater containing contaminants of concern. These have been found to be the SARS-CoV-2 virus (Ahmed et al., 2021; Albastaki et al., 2021) antibiotic-resistant bacteria (Heß et al., 2019) and other pathogens found in blackwater, such as *E. coli* (Vicente-Cera et al., 2019) and in greater quantities when compared to municipal influent (Albastaki et al., 2021; Zhang et al., 2020b) due to the lack of dilution from other wastewater sources. These discoveries have resulted in implications that can inform future engineering system development so to provide more effective treatment (Westhof, Köster and Reich, 2016) and aid public health management practices that could apply these analysis methods to detect outbreaks (Albastaki et al., 2021).

4.3.5 Wastewater treatment development

The development of the engineering systems themselves that treat passenger wastewater is the aim of the largest portion of the corpus with 49 articles from all modes, as depicted in Figure 4-4, and from all publication types, as depicted earlier in Figure 4-3. This theme specifically concerns researching and demonstrating the physical, chemical and biological processes that can produce

effluent that meets regulated standards. Whilst these articles relate to the previously described themes, through their use to justify the proceeding research, the contributions to knowledge are primarily driven by the creation of a new or improved treatment method. This topic theme is driven by both internal and external concerns; with developers looking to improve existing systems, others responding to the introduction of stricter regulation or to realise the potential in improving the overall performance of the platform or infrastructure the wastewater system is integrated into.

Improving treatment processes was guided primarily by increasing the effluent quality by addressing known limiting factors. These concerned the presence of microorganisms with antibiotic resistance, in the context of rail travel (Wei et al., 2020), the use of blue sanitization chemicals used in passenger aircraft and coach toilets (Moreno-Andrade et al., 2014) and the salinity of passenger wastewater in cruise ships due to the use of seawater for flushing (Cai et al., 2019c). Other improvements focused on aligning the wastewater volume capacity with expected demand, for example as a result of the anticipated arrival of passengers for the World Cup and Olympic Games (Da Paixão Filho et al., 2017) and reducing the cost of operating systems from a biodegradation perspective to improve their commercial viability (Atilano-Camino et al., 2020; Peters, Günther and Vossenkaul, 2000). Other areas of improvement concerned exploring an “eco-friendly” approach through the reduction of chemical usage (Korkmaz et al., 2017) and aiming to improve the reliability of these systems (Thomas and Muirhead, 2009; Thomas, Weislogel and Klaus, 2010) and significantly improve energy efficiency (Zhou, Dai and Lei, 2005). These latter areas were both a key concern for spacecraft applications due to the extreme operating conditions impacting the ease of repair and available power sources.

Contributing to the improvement of the operations of the vehicles, vessels and plants that contained the passenger wastewater treatment systems received similar levels of attention, with contributions from all modes of transport. Although these could also lead to a treatment efficiency improvement, the motivation for developing these systems were explained in terms of achieving success in their

specific operational constraints. For example, reducing the size of the systems to meet the volumetric constraints onboard vessels could be made possible by creating a system that process all forms of wastewater onboard (Sun et al., 2010b) or through miniaturization (Cai et al., 2019b, 2020; Zhang and Xu, 2011). In aviation, the first study into passenger wastewater systems considered the need to reduce the weight of aircraft to improve flight performance. This supported recycling passenger wastewater to reduce the amount, and thereby weight, of freshwater required to be stored (Sekoulov, Figueroa and Oles, 1991) which was also a concern in spacecraft contexts, although measured in an overall operating cost that could be reduced (Xia et al., 2008). Other external factors concerned integrating existing energy sources, such as solar heat owing to its abundance in a specific geographical rail context (Lu and Wang, 2010), and the heat from a cruise ship's engines to treat passenger wastewater (Hawley, Barton and Reader, 1996). A similar motivation concerning energy was the production of biogas from this wastewater to meet a ship's energy demands, albeit a small percentage (Schumüller, Weichgrebe and Köster, 2022). Building on the research within the environmental impact theme, systems were also developed to reduce freshwater consumption, such as the use of wastewater to produce non-potable water for airport irrigation systems (do Couto et al., 2013) and recycling systems that aimed to maximise the amount of reclaimed water from all forms of wastewater onboard vessels (Sun et al., 2010a).

An often mentioned external factor supporting the development wastewater treatment processes concerned responding to changes in the regulatory environment, as seen by the cruise ship and ferry travel mode. The International Maritime Organisation (IMO), a UN agency, produces conventions that operators of countries that are signatories need abide to. One such convention is MARPOL 73/78 of which Annex IV details discharge limits. This regulatory aspect to this theme has received significant attention with systems being developed specifically to demonstrate their effluent is within the biological and chemical limits set by this standard. One particular form of treatment technology, the membrane bioreactor, has received particular attention in this regard through various implementations (Cai et al., 2019a; Klie and Daly, 2002; Shi et al., 2012;

Zhang et al., 2020a; Zhu, He and Wang, 2016). Although there has been significant other regulatory development stemming from concerns over the water qualities of the Alaskan coast and the Baltic Sea, the development of systems, with few exceptions, have not cited these as rationales for pursuing compliant systems, instead focusing on the IMO's contribution. The exceptions include one study that assessed the technology that had been installed or modified as part of the Alaskan government's initiatives (Eley and Morehouse, 2003) and a speculative study considered future restrictions in European waters based on the regulatory trends at the time and proposed a potential solution that could meet these constraints (Reader, Barton and Hawley, 1997).

There were several articles that did not explicitly state any factors that prompted the development of their systems, however, based on how they described success, a general interest in demonstrating an effluent quality was evident (Chen et al., 2009, 2011; Zhu, He and Wang, 2015). This reflects the range of integration the development of these systems had with their operational environments. At one end were studies that were acutely aware of the unique demands and opportunities for systems that exploited their transport mode using wastewater that was generated in these contexts (Hawley, Barton and Reader, 1996; Lu and Wang, 2010) through to studies that used simulant feedstock or municipal wastewater in laboratory settings to develop a treatment process (Sun et al., 2010b; Zhang et al., 2020b). The only modal connection of the latter being the relationship the proposed systems share with those currently in use or the addition of contaminants known to be present in wastewater from these sources. Whilst the aims of the research could explain why the collection of samples of actual wastewater was chosen, the decisions to use simulant wastewater lacked explanation, although a potential factor could be to avoid the challenges of collecting samples that are difficult to access. However, this suggests that studies of the former could potentially offer more accurate results as to the treatment efficiency of their systems.

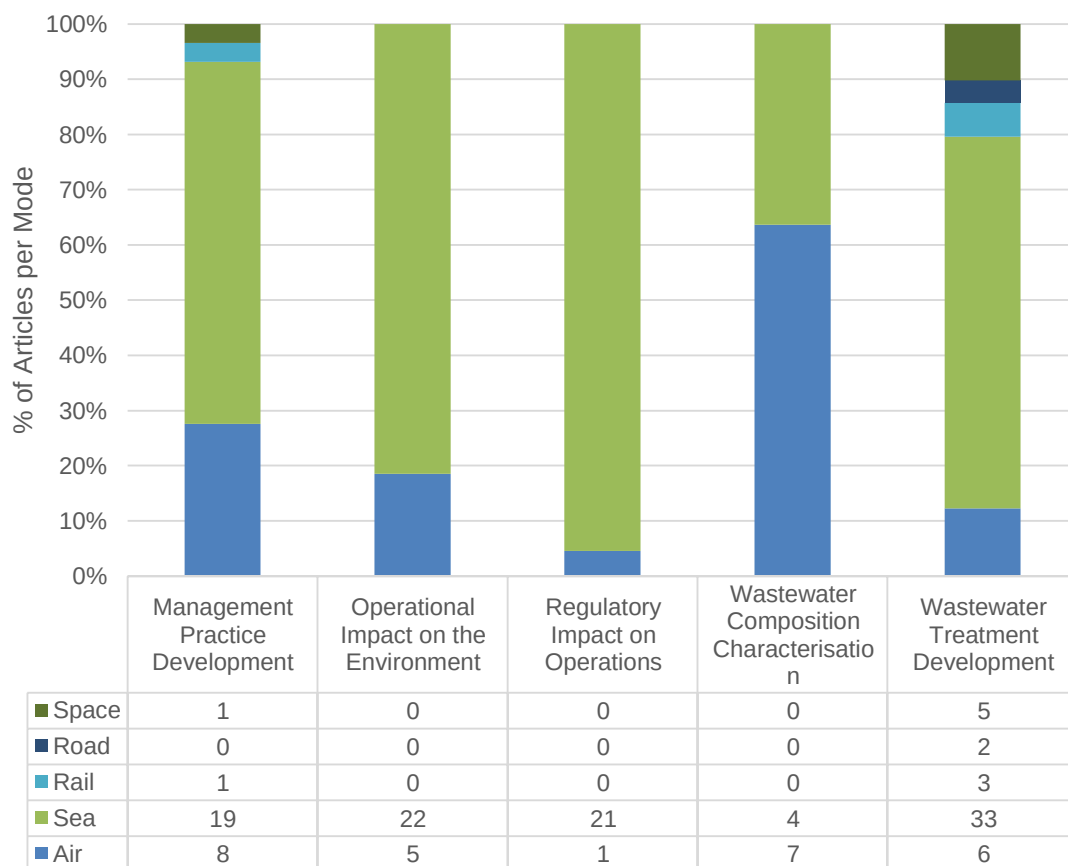


Figure 4-4 Comparison of the percentage of articles per mode per article topic theme.

4.4 Stakeholders in passenger wastewater system development and operations

Having developed a comprehensive understanding of the interests evident in passenger wastewater publications through an analysis of topic themes across each transport mode, identifying the sources of influence in establishing these themes could contribute to understanding why particular activity may be localised in certain modes and whether this indicates a supportive environment for pursuing this type of engineering system development. Deriving the extent of influence through the quantity of references made in the body of the texts, through affiliations and acknowledgements we can identify who those salient stakeholders are in relation to these interests and how they relate to each other

and each transport mode. Five stakeholder groups have been identified, shown in Table 4-2.

Public organisations are the stakeholders with the largest presence in this corpus, with academic institutions and the general public, in this case specifically passengers and local communities, following with significantly fewer references. Owing to public organisations encompassing a large variety of interests, from funding through to enforcement, this finding suggests that the interest in this issue is wide ranging and not specific to one particular type of public sector body. As for academic institutions and the general public these numbers could be explained by a scholarly work only having one type of organisation associated with this group, i.e. the institution conducting the research, and there potentially only being one passenger or community region to refer to. However, in comparison to the presence of public organisations, which might have provided funding, regulations to cite and access to state-owned facilities, these articles would contribute to demonstrating their higher level of influence in supporting such studies through multiple organisations. This supports the analysis that the more organisations from a particular stakeholder group are referred to in an article the greater the influence that organisation may have in that particular area of interest and transport mode. The low number of references to organisations that are non-governmental, non-profit and for-profit could indicate that whilst these organisations are instrumental in supporting these systems once operational, their potential lack of perceived relevance to the development processes results in their organisations having less influence.

Stakeholder Group	Description	Number of References
Public Organisations	National and international government bodies with responsibilities ranging from funding research and setting regulations to monitoring and enforcement, includes state-owned organisations such as infrastructure operators	237

Academic Institutions	Grouped by the institutions' geographical locations and responsible for conducting research	102
Passengers and Local Communities	Signifies whether an article concerned a specific group of people related to the transport mode	75
Non-Governmental and Non-Profit Organisations	National and international organisations responsible for setting and certifying industry standards and advocating for improving and enforcing them, includes trade associations and publicly-funded independent laboratories	58
For-Profit Organisations	Operators of infrastructure and transport mode services, manufacturers of engineering system and companies responsible for engineering and construction of facilities	27

Table 4-2 Stakeholder groups and the number of references made to them in passenger wastewater publications.

To understand whether certain transport modes receive equal or greater attention from each stakeholder group, the references are illustrated in the chart in Figure 4-5 in relation to the mode of their article. Public organisations appear to support the development and operation of wastewater treatment systems in ocean and river transport contexts the most at 180 references with 65 for the second most referenced, that being academic institutions. This mode appears to be the most popular across all other groups with the exception of for-profit organisations that have been referenced in a slightly larger number in aviation contexts at 14, which is 2 articles more, and is the second most popular mode amongst all other stakeholder groups.

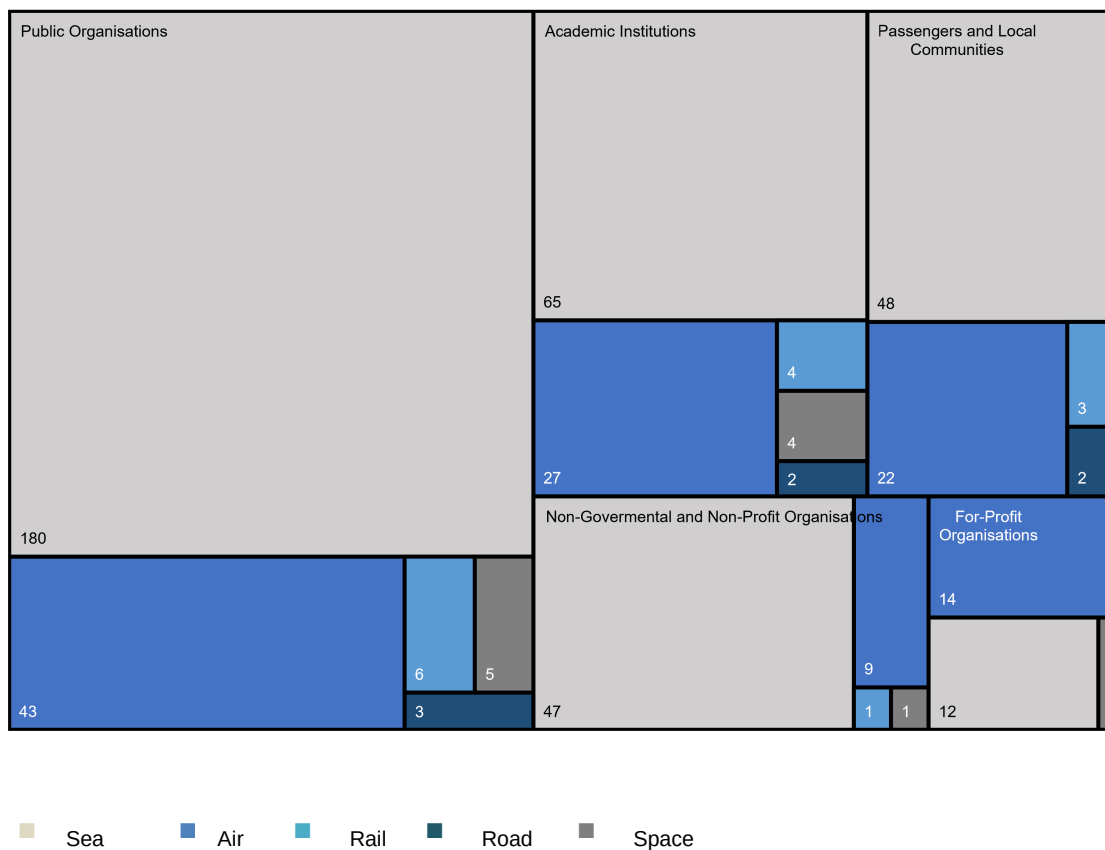


Figure 4-5 Number of stakeholder group references per transport mode.

To help form an understanding as to whether and how these stakeholder groups share similar interests, as inferred by the topic themes of the articles that reference them, Figure 4-6 contextualises these groups in these themes illustrating the range of quantities of references from most widely referenced stakeholders and their interests to the least referenced. The topic theme that features as the largest portion of the corpus for both the top 2 most widely referenced, public organisations and academic institutions, and the least, for-profit organisations is *wastewater treatment development*. The next most widely studied or reported on is *operational impact on the environment* which is the theme featured in the largest portion of articles shared by both passengers and local communities and non-governmental and non-profit organisations.

Other commonalities concern for-profit organisations and academic institutions both sharing a second most popular theme being *management practice*

development whereas for public organisations their second most popular theme is the first for the general public and non-governmental and non-profit stakeholders that being *operational impact on the environment*. This latter group represents the greatest difference in inferred interests as the quantity of articles for *wastewater treatment development* is placed third whilst this theme is either first or second for all other stakeholders. However, given that there is a relatively even portioning of topic themes within these groups, with the exception of the academic stakeholders, identifying areas of interest across groups that could be a potential priority appears to be inconclusive owing to there being a lack of significantly large portions of single themes per stakeholder group.

Through considering how the main themes within each group relate, we can, however, infer that academic, commercial and operational stakeholders have greater interest and potential influence in developing systems that address immediate concerns such as how these systems function and how they should be managed. This contrasts the interests shown by articles that concern the general public and non-commercial entities, whereby how these systems impact the environment is a greater concern. As the largest portion of stakeholder references concern public organisations, the development of these systems could be further inferred to be a reflection of how funding and policy from public sources is more aligned with their capabilities than that from commercial contexts.

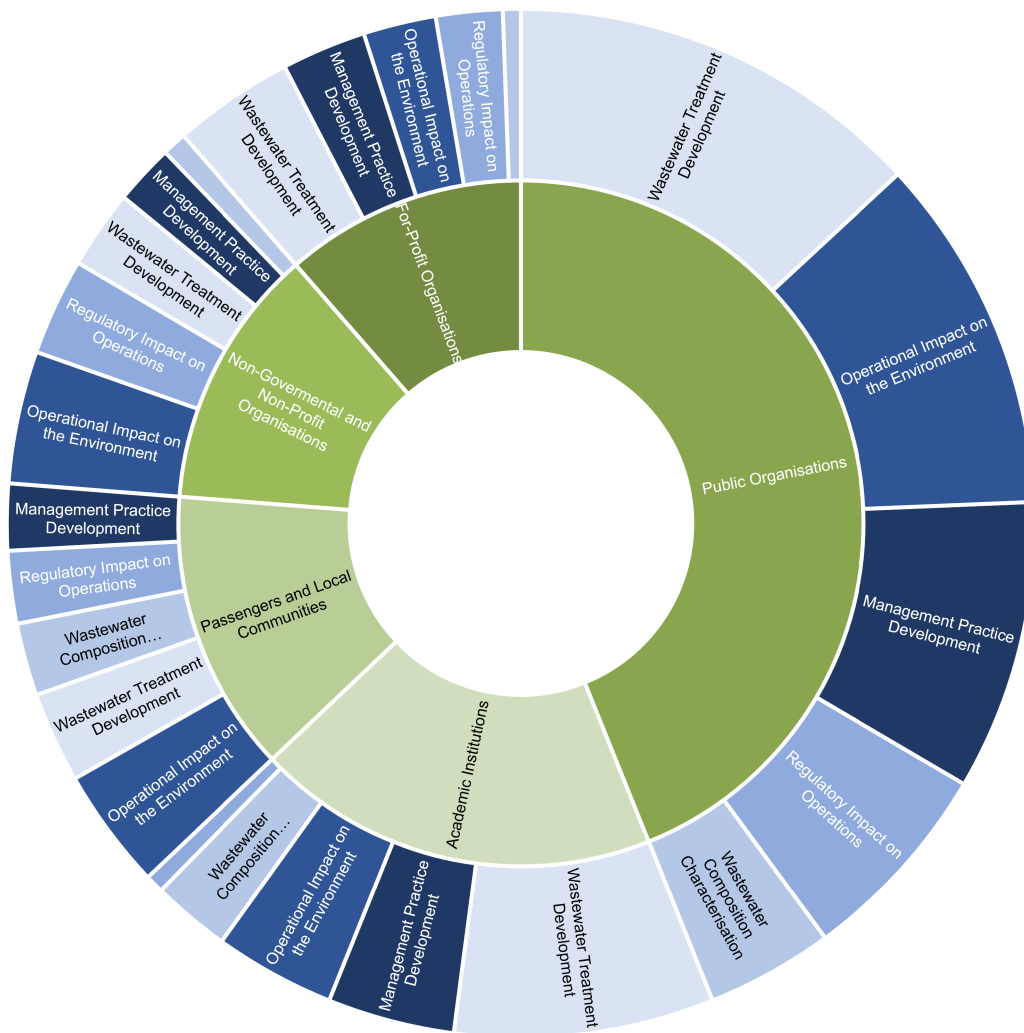


Figure 4-6 Stakeholder group portions and the portions of article topics that referred to them (topic portions without labels are the same topic as the portions with the same colour).

Through examining how the number of articles differ depending on the stakeholder group and their topics we can appreciate how these publications can demonstrate the varied nature of the interests that explain the development and operation of passenger wastewater systems. However, at this level of abstraction we are unable to discern whether these interests are supportive, inhibitive or neutral. Furthermore additional analysis is required to uncover whether stakeholders are affecting the organisations involved in the research of these systems, such as through proactive and supportive engagement, or whether the

interest forms as a result of being affected by these organisation's activities, which may be attempt to slow the development and adoption of such systems. Whilst we have inferred that the number of articles correlates to the level of influence, further analysis is required to ascertain the nature of that influence in relation to the interests and their stakeholders. Whether supportive, inhibitive or neutral, the quantities of references could help us understand the extent they would affect the development or operation of this specific engineering system.

To gain this understanding we will examine the stakeholder identities at a closer level at which they are referred to in the articles described in Table 4-3, and listed per article in Appendix Appendix I, whereby organisations that concern multiple governments or are referred to from multiple geographic regions of study are named directly. By doing so we will be able to understand the nature of the influence as evidenced by the context in which they were referenced. By examining stakeholder interests using the identities they are referred to in the specific articles will enable a comparison of the modes as well as the stakeholders that share common interests; whether the stakeholder or the mode could determine whether an interest, as inferred by the topic themes, has a positive or negative affect, if any, on the development and operation of an engineering system. The chart in Appendix Appendix J illustrates all the constituent stakeholder organisations that make up these 5 groups and the portions of articles that reference them in the context of each topic theme. Figure 4-7 illustrates the transport modes and the interests of the stakeholders of each group that are referred to the most. The following section compares and contrasts these stakeholders as to how their interests and influences differ in relation to the transport modes.

Stakeholder Group	Stakeholder Identities
Public Organisations*	International Maritime Organisation (IMO), Government Departments, Funding Agencies, Enforcement Agencies, United States Environmental

	Protection Agency (US EPA), Other Government Agencies, European Union (EU), Baltic Marine Environment Protection Commission (HELCOM), Government-Owned Corporations, World Health Organisation (WHO), United Nations (UN), Organisation for Economic Co-operation and Development (OECD), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organisation (UNESCO), World Tourism Organisation (UNWTO)
Academic Institutions	Referred to by their geographical region (Asia, Africa, Europe, North America, South America, Oceania)
Passenger and Local Communities	Referred to by their geographical region (Asia, Africa, Europe, North America, South America, Oceania)
Non-Governmental and Non-Profit Organisations	Non-Profit Organisations, Private Research Organisations, National Standards Organisations, International Non-Governmental Organisations (NGO), International Standards Organisation (ISO), Accredited Registrar and Classification Society (DNV)
For-Profit Organisations	Transport Service Provider, Engineering System Manufacturer, Infrastructure Operator, Construction-Related Company

Table 4-3 Identities of constituent stakeholder organisations of the 5 groups in passenger wastewater system development and operation.



Figure 4-7 Stakeholders with the largest portions of references from each of the 5 groups, shown in full in Appendix J, in the context of their transport modes (topics of the portions without labels are the same as the portions with the same colour).

4.4.1 Comparing and contrasting stakeholder interests and potential influence within transport modes

Through exploring how passenger wastewater is managed, regulated and studied the review found that specific applications of an engineering system can receive greater research and development attention than others. This can be due to a specific stakeholder that catalyses this research, in the case of passenger wastewater system development, the international maritime organisation (IMO).

This influence could be inferred by how the most involved region of academic institutions, that being Asia, explores a specific aspect of the issue, namely wastewater treatment development, which is the main area of interest for studies that refer to this international public body. Furthermore, this prompts research into meeting national standards as is evident by the topics concerning regulatory impact on operations which was one of the most popular across all other major stakeholder groups. However, whilst influential, the extent the IMO demonstrated engagement with other stakeholders was limited. Their publication, specifically Annex IV of MARPOL Convention 73/78, was widely referenced, but the creation of it nor the efforts to encourage governments to endorse it did not feature.

In contrast, other regulatory regimes were more widely evidenced as demonstrating how engagement can facilitate the realisation of new legislation, such as the ACSI and the Baltic Sea Marine Environment Protection (Helsinki) Commission (HELCOM), whereby local communities and vessel operators, and in the case of the Baltic Sea, national governments, were involved in their creation (e.g. Backer, 2018; Morehouse and Koch, 2003). In the case of the Alaskan coast this explains why the largest group of passengers and local communities referred to were located in North America. In support of this engagement, non-profit organisations played an important role in representing the interests of the environment and industry with both campaign groups and trade associations featuring prominently. Due to the inclusion of grey literature in this analysis it was possible to understand how types of organisations, specifically cruise ship operators, had opposing views on regulating passenger wastewater operations (Badin, 2015) despite earlier efforts that appeared supportive (Del Rosso, 2000). The high quality of wastewater that can be discharged and the distances from the shore required by these regulations appeared to have been considered excessive when viewed from the context of land-based ocean polluters such as tourist resorts, reflecting how less than supportive relationships can form between stakeholders.

Through reviewing articles concerning the engineering system across different applications, stakeholders that were found to have similar roles could have

different motivations and approaches for supporting the development of the technology. In aviation settings the interest from operators has been derived from meeting sustainability goals through a reduction in freshwater usage by recycling this wastewater rather than the existence of regulations, contrasting the key motivating factor in the cruise ship and ferry contexts (e.g. Baxter, Srisaeng and Wild, 2018). This supported greater engagement between institutions and the airport operators for the purposes of characterising their wastewater composition so to understand how efficient their treatment processes were and the extent the water quality could be reused for non-potable purposes.

Moreover, by reviewing the range of applications for this type of engineering system it became evident that whether the system was installed onboard or onsite, the extent of engagement between the various stakeholders could be impacted. Whilst wastewater treatment development was pursued by academic institutions it did not result in significant collaboration with cruise ship and vessel operators. This could be explained by the operational realities hindering sampling collection but also the lack of cases whereby both the infrastructure operators and the funding agencies are the responsibilities of public organisations, such as shown by the involvement of the state in the operation of airports in Brazil, for example (e.g. Da Paixão Filho et al., 2017). If organisations are driven by similar public interests, the potential for greater collaboration could be evident. However, with the establishment of port reception facilities in European Union (EU) member state seaports this could present an avenue for further engagement between stakeholders in sea travel contexts, albeit driven by compliance (e.g. Wilewska-Bien and Anderberg, 2018).

In comparison to air travel contexts, whereby the passenger wastewater collected and processed reflected a more supportive and proactive environment for the development of this type of engineering system, a lack of similar interest could be considered to exist in cruise ship and ferry operations. If it were not for the regulatory constraints, the pressure from non-profits and local communities these findings suggest that, due to the lack of interest originating from, this transport

mode operators could still be continuing to discharge untreated wastewater close to the shores and in ecologically sensitive areas.

By encompassing all forms of travel in this review, it has become evident that some forms of travel, whilst common, represent a lack of stakeholder interest and subsequent engagement, especially as regards coach and rail travel. In the context of rail travel, passenger wastewater operations appear not to warrant significant interest from regulatory or industrial concerns. The few studies that do exist for this travel mode, however, demonstrate a nascent field of scholarly research for engineering systems that process passenger wastewater. The approach could be showing similarities to air travel owing to the role train depots play, like airports, in collecting, and potentially processing, wastewater. However, as there are so few articles it is difficult to state whether these areas of interest are indicative of the stakeholders in the transport mode. Similarly, the presence of studies relating to applications in space travel operations could explain how the pursuit of engineering system development can be sustained by the interests of academic and public organisations without the need for support from commercial stakeholders or the influence of regulators. The significant amount of knowledge that can be generated by researching extreme operating conditions could be a potential reason for the lack of interest in more terrestrial forms of transport.

4.5 Summary of key findings

Below is a list of key findings, that are then expanded upon, from a review of passenger wastewater literatures from across all transport modes which was undertaken to identify, analyse and compare stakeholders:

- The most commonly researched and reported transport mode was sea travel, representing a significantly larger portion of articles compared to all other modes at 72%, suggesting stakeholders in this mode have the greatest interest.
- Operational and regulatory concerns feature most prominently in sea travel contexts with the development of treatment techniques and systems

present in articles across all modes, inferring the main topics of stakeholder interest.

- The most commonly mentioned stakeholder, whether in article affiliations, within the body of the texts or through acknowledgements, were public organisations, the least being for-profit organisations.
- The development of wastewater systems were the main interest of both public and for-profit organisations, the latter reflecting academic institutions' interests concerning both technology and management development.
- Whilst contributing the most to the corpus, articles concerning sea travel did not reflect a consistently supportive environment for such systems, in contrast to aviation contexts.
- Rail travel was one of the least studied and reported on transport modes in relation to this type of system.

A review of literature, from both academic and trade sources, focused on the development and operation of passenger wastewater systems, has revealed a significant difference in the amount of attention paid to each mode of transport, as inferred by the volume of publications. The most commonly researched and reported mode comprises of cruise and ferry travel, representing 72% of the corpus. Passenger aircraft travel comprised less than a third of this amount. Train, coach and speculated space tourism all formed significantly less than either mode. Within the period reviewed, 2019 was shown to have the highest number of publications comprising primarily of sea travel contexts. This reflects an upward trend in interest in this field of technology. A sudden decrease after 2020 could have been caused by the impact of SARS-CoV-2 pandemic.

Depending on the type of publication, the nature of this attention reveals different areas of interest. Whilst journal and conference publications share similarities in this regard, the topics of trade articles demonstrate how the priorities of the industry may differ. When viewed from the perspective of the transport modes, the portion of articles concerning each mode reveals that the operational and

regulatory concerns feature most prominently in sea travel contexts. In general, sea travel features significantly across all topics, reflecting their large presence in the corpus, with one exception concerning air travel being more often the context for articles involving characterising wastewater. Only the development of treatment techniques and systems was revealed to be studied and reported on in relation to all modes.

As the analysis so far had only revealed what transport applications of a specific type of engineering system were most common, and the reasons for researching and developing them, in order for a clear picture of their stakeholders to be revealed, an understanding of the identities of the organisations behind these interests was required. These were found referenced in the publication's affiliations, texts and acknowledgements and comprised 5 distinct groups. These were, starting with the largest number of references, public organisations, academic institutions, passengers and local communities, non-governmental and non-profit organisations and, the least referenced, for-profit organisations. This could be an indication of how the development of this type of engineering system is led primarily by public funding and policy support. The application with the most interest from all stakeholders was within sea travel contexts with the exception of air travel, which was slightly more referenced in relation to for-profit organisations.

In order to understand how the stakeholder groups compared in terms of their interests, the number of references in relation to their identities and article topics was used to reveal both similarities and differences. In comparing the most and least referenced, both public and for-profit organisations supported the development of wastewater treatment the most. The second most widely referenced stakeholder group, academic intuitions, reflected similar interests to for-profit organisations, mirroring their top 3 interests, that being *wastewater treatment development*, *management practice development* and *operational impact on the environment*. This could demonstrate the research potential for both the technology and the responsible management of the engineering systems that could apply it.

Through reviewing the publications which referenced the most prominent stakeholders from each of the 5 groups, the nature of their influence was then inferred, such as whether it was proactive and supportive or potentially inhibitory. For example, the revealed that passenger wastewater treatment development for sea travel applications is more commonly studied by academic intuitions in Asia and that this effort was rationalised by the IMO's regulations. However, despite being widely referenced in academic contexts, regulatory impact on operations was not their principle focus of study. Evidence of unsupportive or unengaged stakeholders was also reflected in how for-profit organisations were affected by regulations in the Alaskan region. However, other sea travel contexts, and the aviation context in general, reflected a more encouraging and collaborative environment.

While there was a significant number of publications in relation to cruise ship or ferry transportation, which enabled inferences about stakeholder interests and relationships to be made, comparing these findings with other modes of transportation proved difficult in achieving the same level of analysis, although differences could be seen with air travel. This was due to the limited number of articles and the resulting limited evidence base to aid comparison. The lack of studies concerning rail transport could be considered surprising due to it being a popular form of travel and one which provides toilet facilities for passengers. However, this finding in itself supports the need for further research, using different methods, to gain an understanding of the stakeholder landscape of this transport mode and how they relate to this type of engineering system.

5 RESULTS: PROBLEM FRAMING AN ENGINEERING SYSTEM BY DOCUMENT ANALYSIS

5.1 Introduction

This chapter presents the results of applying the frame creation model (Dorst, 2015), outlined in Appendix Appendix D, to a document analysis of rail and water sector publications. These concern passenger wastewater operations that relate to a proposed engineering system, described in the research context section of Chapter 1. The following sections detail the results using the model's process to firstly explore the initial framing of the problem the system would be engineered to address and then synthesise a description of an alternative solution. This would be derived from how the problems could be framed through how they were evidenced to exist by these documents.

5.2 Applying the frame creation model

The model consists of 9 stages that transition from analysis of current evidence of the problem to synthesis of potential solutions and then to analysis of how it could be implemented. The results of this study are ordered into sections that are titled with the names of each stage from this model. The first stage of the process model starts with a structured data collection that requires an exploration of the “archaeology” of the problem, which in the case of this study concerns discharge of untreated rail passenger wastewater and the failure to adopt retention tanks, by examining who is responsible and why. This then contributes to the second stage which involves analysing this evidence to construct the “core paradox” statements which offer an explanation as to what prevents this issue from being easily resolved. Stakeholders' roles and responsibilities are then analysed in two proximities to this concern; the “context”, stakeholders who have the power to affect the issue, and the “field”, stakeholders who are primarily reacting to the problem occurring. Themes are then inductively collected derived from commonalities in terms of shared needs and motivations of these stakeholders. These themes are then synthesised to form the basis of alternative framings,

which are different ways of looking at the same problem but presenting significantly different approaches to solving it. The final stages synthesise these findings further to create a potential future in which a solution is proposed using these frames through abductive reasoning whereby the desired outcome and the how of the frame, i.e. how a problem would be addressed, is interpreted to create a possible what being the proposed solution form.

5.2.1 Archaeology of the problem situation

To understand who is responsible for addressing the problem, a review of the structure of the industry could indicate if this can be identified. The problem “owner” of ensuring the rail sector manages its passenger wastewater operations responsibly in the UK could be the Department for Transport (DfT) (Williams Rail Review, 2019). Through the DfT’s governance of the rail sector, how trains are equipped with the means to prevent discharging untreated wastewater onto the tracks is specified through the process in which they award private companies, the lessors and operators of the trains, the right to operate passenger services. However, it could be argued that these companies themselves are responsible, as the lessors, referred to as rolling stock leasing companies (ROSCOs) can make modifications to their trains throughout the period in which the train operating companies (TOCs) have access to a route, such periods can last over a decade and as such the need to upgrade the trains could concern passenger wastewater systems (Butcher, 2017). Moreover, an argument can also be made that the responsibility lies with other government agencies, such as the Environment Agency who is responsible for preventing pollution, which could concern passenger wastewater, or Network Rail, the agency responsible for the maintenance of the railways and granting access to TOCs. This creates a complicated picture for understanding why problems associated with managing passenger wastewater occur, why efforts have failed to address them and who is ultimately responsible for doing so.

The problem that this study frames concerns the operation of controlled emission toilet (CET) systems. This problem had been presented by a company that manufactures these systems and has proposed an alternative which will process

the wastewater within the tank itself and produce inert solids and non-potable water. The rationale for this functionality, according to the company, was that CET tank servicing operations require trains to be taken out of service and as a result impact train availabilities for passenger services. Moreover, the task of emptying these tanks requires the trains to be moved around depots so that they can be next to suitable equipment to empty them.

To validate these claims and to assess the extent this solution could meet the challenges faced by the rail industry an understanding of why the practice of track discharge has continued and whether the financial and operational cost of CET systems are responsible is required. This entailed analysing news coverage, industry reports and government and legislative publications that pertain to the rail and water industries as to how the management of rail passenger wastewater is and should be conducted in the UK, the target market chosen by the sponsoring firm.

News coverage of the issue provides an insight into its persistence. Since passenger rail services were privatised in the UK in 1995, trains that were in operation at the time and have continued to be in service today may continue to discharge untreated wastewater as they would not have been built with CET tanks. As a result, government policy has been to specify new trains with CET tanks, through the process in which train leasing companies procure the specified trains for train operators to then operate, and encourage existing fleets to have them retro-fitted. This approach, whilst ensuring newly manufactured trains would not contribute to the problem, has not succeeded in fully addressing the issue caused by the trains that were in service in 1995 that have not been completely upgraded. The rationale to only focus on new trains was that there was an assumption that older trains without CET tanks would be retired and as such the prevailing narrative in responses from government and industry was that this was a problem that would eventually solve itself. However, one estimate of the year given by the sector in which the last trains without CET tanks would be in operation was 2023 (Love, 2020).

Through further exploring the problem we can see that the original understanding overlooked some of the conditions that determine whether the practice of track discharge continues. Given that it could most likely be a question of when, rather than if, all trains have CET tanks installed, the problems that CET tanks cause, or fail to address, should be the focus that could determine the nature of the solution. As there were no reported claims that servicing these tanks were impacting passenger service availability nor creating operational headaches for depot managers, looking more broadly at the related issues of freshwater and wastewater challenges could provide a basis for an alternative direction or additional functionality to consider.

5.2.2 Establishing the core paradox

To help guide the formulation of different ways of looking at the problem, analysing the way the problem is defined will contribute to identifying the central issues that prevent it from being easily solved. In the case of the engineering system of the case this study supports, three statements emerge that together form the paradox; with each positive step a negative result occurs which cannot be overcome without eliminating the previous productive action:

Because passengers are able to have access to a toilet during their train journeys, operators have to manage wastewater that is generated

Because train operators are expected to manage wastewater responsibly, they need to install collection tanks and take the trains out of service to empty them at depots

Because train operators take the trains out of service to empty the tanks at the depots this leads to a reduction of service availability for passengers and an increase in operational complexity

These paradoxes should explain why the problem cannot be easily solved, however, there is evidence of the first paradox being resolved and rendering the rest irrelevant. A TOC decided that passengers should not have access to toilets (BBC, 2010). Whilst this decision was framed by the train operators as a means to reduce overcrowding, toilets were removed to increase the number seats. By

doing so this would also eliminate any problems caused by operating CET systems. In defence of this move, the operator claimed to have increased the number toilets in their stations, however, this could still have created additional paradoxes as passengers who are elderly, young or ill may require access to toilets whilst on the train.

The second two statements involve a specific interpretation of the problem which could constrain potential alternative framing. If operators do not take their trains out of service but instead schedule these activities within routine depot operations and if their depots are suitably equipped that they do not need additional train movements, only the first paradox would still be relevant for any future framing. Through considering a slight widening of the paradox we can consider an additional aspect that is crucial to the functioning of any toilet facilities; the consumption of freshwater. As such the paradox that this analysis will focus on will concern:

Because passengers are able to have access to a toilet during their train journeys, operators have to manage wastewater that is generated and ensure freshwater is available

5.2.3 The context

Through analysing the central stakeholders in this problem situation we can identify the priorities and approaches of those who have either been affected by the concern or are able to affect future solutions. As we have previously introduced the DfT and their approach towards only ensuring new trains are fitted with CET tanks, and that they expect existing trains to be eventually retired or retro-fitted, we will now consider the other organisations who could also be responsible for this situation; namely the government agencies and the private rail companies.

Should the gradual phasing out of trains preferred by the DfT continue to fail to end the practice of discharging passenger wastewater onto the railway tracks, the regulatory framework governing wastewater operations could be called into question. Relevant legislation is derived from EU directives that stipulated

wastewater discharge restrictions and for toilets to be fitted that are accessible for passengers with reduced mobility (Polhill, 2018). This latter aspect prompted TOCs to upgrade their trains that dated from 1995 and in the process install CET systems. As for the rules governing wastewater discharge, the UK's Environment Agency offers a specific exemption, the D2, on the grounds that a train may be "older" and as such can "deposit sanitary waste onto the track" (Environment Agency, 2019). This appears to be the mechanism that has enabled this practice to continue without any regulatory repercussions. Moreover, as the government-owned company that controls access to the railways, Network Rail, does have oversight in this area, there lacks evidence they are able to prevent operators from discharging wastewater onto their tracks despite contravening track access agreements to not cause environmental damage (Network Rail, 2017; Office of Road and Rail, 2016). As such, despite there being regulatory attention given to this issue, a combination of a mechanism that exempts compliance and ineffective enforcement results in this practice continuing.

Furthermore, a recent DfT effort to have all trains retro-fitted ended with the government granting dispensations for TOCs that were planning to retire their noncompliant trains but had keep them in service longer (Topham, 2019). This would be in line with the position of the Office of Road and Rail, the agency responsible for regulating health and safety of the rail sector, who stated "it would not be appropriate to impose a requirement to retro-fit toilet retention tanks to older stock because the costs associated would be grossly disproportionate" (Office of Road and Rail, 2016, p.3). Moreover, The Rail Safety and Standards Board (RSSB), a non-profit industry-owned research organisation, commissioned a report that recognised the risk towards trackside workers. However, the advice given, among a range of recommendations to implement, stated "a system for reporting lost working time resulting from contamination related symptoms (sickness and diarrhoea). This will help to track the status of the problem" (Rodger and Dunn, 2004, p.10) but did not recommend that CET tanks must be fitted. As such, it would appear government policy at the time would be unlikely to use regulatory means to prevent this practice and that its views were strongly aligned

with those that can be considered to be beneficial to the commercial concerns of the industry.

A reluctance for CET tanks to be installed onto trains can be further explained by the complicated engineering assessments and work involved. As the train carriages built prior to privatisation that were still in use were not designed to retain effluent, rather a pipe connected to the toilet would discharge directly to the track, installing a tank, according to a firm contracted to do so, required ensuring there was suitable strength and space on the underframe and that pipework would need to be installed as they would be unable to be fitted directly below the toilets (Love, 2020). This could explain the apparently high costs involved and the potential for trains to be taken out of service for longer durations than routine maintenance. The risk of reducing the availability for passenger services was an argument made that supported enabling TOCs to continue using these trains after the government had attempted to commit the industry to ending this practice after 2019 (Topham, 2019).

Whilst there could be complications in installing the tanks, there is little reference to challenging operational implications of using CET tanks. In a report that looked to examine causes of train delays in the UK, 23% were identified as being related to faults with the train, the largest portion of causes, and only 5% stemming from depot operations (Preston et al., 2009). Whilst the cost of CET operations has been noted as a reason to explore alternative solutions, this specific claim has not received significant corroboration from other sources describing similar operational impacts (IXC, 2016). However, the rail industry's Key Train Requirements publication that sets the standards for new trains, issued by both private and public organisations, has stated electrically-powered trains could face more exposure to this increase in servicing tasks as result of installing retention tanks compared to diesel-engine trains given that they would not require refuelling at the depots inferring that such tasks would be combined (Polhill, 2018).

In general, however, the interest the industry has towards looking for ways to improve their operations through the introduction of radically new technology

could be limited. This is due to the “risk-averse nature of the industry and the lack of incentives to introduce innovation into projects” (Rail Supply Group, 2016, p.36), as described by the trade association that represents the suppliers to the UK rail sector. A small-scale sub-system that can treat passenger wastewater within the size constraints of an existing CET tank would be considered highly innovative given that its technology is yet to be established in any other industry. This risk extends to the required expenditure, as from an operational expenditure perspective, the installation of the system would need to reduce the cost of maintaining the fleet so that ROSCOs could be motivated to install the systems.

If successful, this could result in ROSCOs being able to offer a more competitive fleet for TOCs to select during the process of being awarded contracts to operate passenger services (Steer Davis Gleave, 2015). To help encourage greater adoption of more innovative solutions, the UK government has recognised its role in addressing the “lack of innovation opportunity in contracts due to current procurement methodology [and intends to support] promoting ... contracts to increase system reliability and avoid risk averse behaviours” (HM Government, 2018, p.17) through the use of public funding to invest in rail innovation competitions targeting SMEs with early-stage technology. If these initiatives are to be successful then the rail sector could become more proactive in looking for solutions that could improve their operations, including the management of passenger wastewater. However, as the industry is yet to demonstrate progress on this front, the level of innovation within such a system could prove to be a dissuade adoption.

Looking beyond the immediate issue of operating CET tanks to how the operation of the toilet facilities themselves could be a source of problems, evidence emerged of the impacts faced by one major TOC as a result of blockages caused by passenger items being flushed down the toilet (Longhorn, 2019). This resulted in significant cost to the operator and “18,000 lost toilet hours per year”. The same article by Longhorn explained that wet wipes were the main cause of the blockages. Efforts to prevent this passenger behaviour included an onboard recorded humorous message that stated “Please don’t flush nappies, sanitary

towels, paper towels, gum, old phones, unpaid bills, junk mail, your ex's sweater, hopes, dreams or goldfish down this toilet." However, potentially due to this solution being closely aligned with the brand of the train operator, when the contract to operate the route was awarded to a different company this was discontinued (Schrader, 2021). This problem reflects a potentially more pressing concern within the context of passenger wastewater; the role foreign objects can play in impacting depot operations and increasing the costs of maintenance.

The immediate context of the problem situation has revealed the positions and approaches of the key stakeholders who are involved in determining how passenger wastewater operations affect the rail industry. It would appear that there is little regulatory or political interest in addressing this issue or, when efforts are made, the commercial structure of the industry can make these initiatives short-term and fail to address the technological core of the problem. However, if the solution can be shown to significantly reduce the cost of operations then this could be of potential interest and could result in either being specified by the DfT for new trains or retrofitted onto existing ones by the ROSCOs that own them.

5.2.4 The field

Through expanding the scope of stakeholders analysed who could be affected by or affect the problem situation and any potential solution, we will consider the relevance of the role the water sector plays in providing wastewater and freshwater services to the rail sector thereby supporting the analysis in exploring how a solution's benefits could be more widely felt. This expanded analysis will first consider the less influential but significantly interested; rail sector workers who have also been impacted by the practice of wastewater discharge and the general public.

As previously introduced, Network Rail is responsible for managing the operations of the UK railways. They have been vocally supportive of ending the practice of track discharge (Topham, 2017a) and have attempted to enable this through offering to fund the installation of CET tanks (Office of Road and Rail, 2016). However, despite TOCs refusing to clean up discharged wastewater citing historical contamination, Network Rail has been limited in actioning their criticism.

This contrasts deeply with the position taken by the union representing workers from Network Rail and other organisations that work directly on the tracks which is the RMT. Throughout the decades the industry has failed to install tanks on all their fleets, RMT has repeatedly called for action, highlighted the poor working conditions that result and demanded schedules for when this practice would end (RMT Press Office, 2017). When evidence emerged that trackside workers were still being exposed to passenger wastewater during the pandemic, a means in which the SARS-CoV-2 virus can be transmitted (Kumar et al., 2021), the union issued a statement describing the situation “Promise after promise and deadline after deadline has been missed to end this practice once and for all and this revolting saga is now a totemic symbol of the decades old failure of privatised railway. RMT demands that this practice ends now to ensure our members health and safety is put first.” (RMT Press Office, 2020). Their position aimed to remind the public and parliament of the potential for the practice to continue and the risks to human wellbeing as a result to remain.

An insight into an additional risk that can occur when CET tanks are fitted involves the tragic fatality caused by the close proximity of the tank to the electric rail used to power trains in the southern region of the UK. This led to the death of a cleaner after coming in contact with it after a fall. However, this was an isolated occurrence due to the protection boards that prevent the rail from being exposed were not in place. This resulted in a substantial fine given to the TOC and the subcontracted cleaning company. A lax approach to visual inspections, training and supervision were considered to be the cause (Topham, 2017b). This demonstrates the challenges faced by track and depot workers as a result of current industry practices and the need for solutions that are safe to maintain and guarantee an end to track discharge.

Whilst less severe, the general public plays various, yet conflicting, roles in being affected by this practice. ROSCOs failing to install CET tanks could lead to discharge affecting residential properties situated alongside railways (BBC, 2015) and accumulate at train stations where it would be clearly visible to passengers (Williams, 2017). Understandably, these accounts portrayed a negative

perception of the rail industry, however, earlier reports suggested a lack of interest from passengers in ending this practice as indicated by an absence of responses during surveying (BBC, 2013). This could be due to the design of the survey itself failing to directly address the issue, however, whether passengers would refuse to use toilets that discharged onto the tracks was an outcome that had not been reported as being plausible. Evidence to support this being unlikely was shown by news coverage during a period when these facilities were locked out of use. This was caused by a train operator's inability to service their CET tanks, including replenishing the freshwater supplies, as a result of safety measures that had to be installed at their depots (Harris, 2018). Accusations that the action discriminated against passengers with medical conditions highlighted the reality that having access to toilets should be considered essential. As such, whilst the public can be directly affected by the practice of track discharge, the need for toilets to be available suggest that they have few options but to continue using them, even if CET tanks fail to be fitted. When they are, and trackside workers benefit from less hazardous working conditions, they can be affected by depot-related interruptions to servicing them thereby illustrating a benefit of the prior approach.

A TOC being unable to empty CET tanks can be one cause for toilets being locked out of use. Another concerns the freshwater tank used to supply the toilet flush and the hand basin taps being empty (Harris, 2018). As such, the role water-related operations play in this problem situation highlights some of the reasons for why the rail sector could be interested in water recycling. The RSSB commissioned further research into the potential benefits of using wastewater recycling systems with an interest in reducing the weight of the train, freshwater expenditure and operational costs, such as those associated with train movements at depots and tank replenishment. Findings indicated that there would be little gain in weight or expenditure reduction, however, being able to reduce the need to visit depots for freshwater operations could bring cost benefits. This benefit was noted as being primarily only for electric trains due to diesel trains being required to visit depots daily for refuelling, which as previously mentioned is coupled with CET tank servicing (Watters and McDermott, 2007). A

follow up study suggested that passengers could be concerned by the quality of the water if it was used for hand washing and as such freshwater may still be required, albeit in smaller quantities (IXC, 2016). This concern is warranted by the reports of legionella contamination (RMT Press Office, 2021) and the cleanliest of toilets lowering customer satisfaction scores (TransportFocus, 2020). In addition to these systems appear not to be widely recommended, the gains the industry made in reducing freshwater consumption by switching to vacuum toilets instead of using toilets that operate with a gravity-flush appear to have been sufficient to reduce interest in water recycling. Furthermore, by doing so, such toilet flush systems can reduce the size and servicing frequency of the CET tanks themselves as a result of the reduction of water required for flushing and as such the tanks do not reach maximum capacity as often (Love, 2020).

However, by considering the wider field of stakeholders in water and sewage operations, the implications of improvements achieved by the rail sector could be more widely felt and provide additional benefits to the sector beyond immediate CET tank servicing and freshwater replenishment costs. This is due to the rail sector contributing, in part, to the over-abstraction of water bodies as a result of the dense urbanisation of the regions in which they operate, particularly the South-East of the UK (European Environment Agency, 2017a). In addition to water stress, the sector will also be affected by and potentially affect the amount of freshwater that is lost due to pipe and tank leakages and wastage through spillage. However, as the UK economic regulator for the water sector, Ofwat, primarily focuses policies by separating user into two groups, “household” and “non-household”, the extent the rail sector contributes as a non-household user is challenging to identify (Ofwat, 2015). We can infer by how the European Environment Agency groups users into agriculture, electricity, manufacturing and domestic that the rail sector could be included in domestic consumption due their depot buildings being located within residential areas. As such their consumption may contribute to the group becoming the largest by 2030 due to the decline in estimated usage by the electricity sector (European Environment Agency, 2017b).

The rail sector has stated that they will aim to reduce their water consumption and increase their use of recycled water, through following a set of Rail Sustainable Development Principles, although by how much and by when have not been stated (Rail Safety and Standards Board, 2016). A combination of industry-funded innovation led by the water sector (Ofwat, 2019) and the competition introduced by the Water Act 2014 that enables non-household companies to choose their suppliers (Ofwat, 2015) could help support the rail sector in reducing its freshwater consumption. As inferred by one of the questions posed by the UK 2050 Water Innovation Strategy that asked “How do we ensure that we are working collaboratively with the non-household market?” (UK Water Sector Alliance, 2021, p.4) suggests that there is at least appetite to address this issue from the water sector’s position. However, in terms of environmental priorities, the rail sector may consider their carbon emissions to be more pressing as this challenge in reducing them is frequently referred to in sectoral publications (Department for Transport, 2017).

As previously mentioned, the rail sector’s role in discharging untreated passenger wastewater into the environment is a concern that could eventually be eliminated. However, by considering the stakeholders in wastewater treatment plants (WWTP) and sewer networks, we can also see that as a non-household user, the rail sector could be contributing to their challenges as well. The problem of WWTPs reaching capacity results in untreated effluent being discharged into rivers and the sea (Fleming, 2021). This can be caused by the plants themselves failing to increase in size with the growing populations that use them or sudden increases in stormwater which risk overloading the networks and are therefore diverted using storm overflows (Department for Environment Food & Rural Affairs, Environment Agency and Pow, 2021). Whilst it is difficult to tell the extent the rail sector contributes to this problem, solutions that can reduce the amount of wastewater added to the network through CET tank emptying could help address this issue. However, understandably, this amount of wastewater would be significantly less than the wastewater generated through cleaning the trains and stormwater collected by the depot aprons.

Through considering the expanded field of stakeholders in a rail passenger wastewater engineering system to be launched in the UK we see a diversity of evidence supporting the need for operators to improve their wastewater operations, from the arguments made by trackside workers to the industry's own goals to be considered more sustainable. However, the commercial realities that have prevented widespread adoption of CET systems and more advanced wastewater recycling solutions continue to be evident, even from the perspective of the water sector that is looking for market competition to improve the provision of services. If the engineering system can be considered to be a means to reduce costs whilst preventing discharge to the environment, then it could potentially meet the needs of both the rail and water sector stakeholders.

5.2.5 Themes

Through considering the motivations of the stakeholders in the immediate context of the problem situation and within the expanded field we can identify the common goals that could contribute to developing themes that will inform the proceeding framing. With the solution to a lot of the challenges appearing to be the installation of CET systems, in other rail sectors in the world that are not as privatised, this could potentially have been achieved by a centralised organisation capable of co-ordinating and funding the required works. However, as the UK represents a heavily profit-driven privatised sector, this mechanism for technology adoption does not exist in significant capacity and as such solutions have to appear to offer substantial financial benefits to the owners and operators of the trains. As such the themes will be developed based on a view to increasing the profitability of the industry, however, with any initiative this could take investment and as such this larger paradox could prove to be intractable. These themes concern how the industry is perceived by passengers and how addressing the issues relating passenger wastewater operations could contribute to increasing passenger numbers.

As the effects of track discharge were not equally felt by those across the context and field, the rationales for inaction would receive few supporters outside of the immediate context. However, as an industry that is constantly in the public eye

the need to improve working conditions and the desirability of the careers could present a common goal. This issue of perception was also drawn from the need to achieve positive customer satisfaction scores and press coverage.

Another shared responsibility could be seen to be the relationship the industry has with the environment. This would reflect the interests of passengers who may opt to travel by train because of its green credentials. Current and past attitudes towards how passenger wastewater has been managed ultimately fail to align with the view that the mode is a sustainable form of travel. This could be caused by contributing to unsustainable abstraction of freshwater and discharging untreated wastewater by overloaded treatment plants and sewers. Should the sector continue to contribute to furthering environmental degradation, an opportunity to help reduce the overall impacts of their operations could be lost.

A reliable way of ensuring operations are not disrupted reflects the needs of both passengers and operators and can be seen in the issues specifically concerning freshwater. Whilst this theme reflects the environmentally-conscious theme, the commercial implications of reducing freshwater consumption align with the concerns driving the decisions of the rail sector. Furthermore, the issue draws on the need for confidence and dependability in the provision of passenger services. This could be affected by toilet facilities that are locked out of use as a result of a freshwater tanks' depletion. Such occurrences could severely reduce certain passenger's willingness to travel if not essential and risk operators being fined if toilet availability becomes enforced.

5.2.6 Frames

The following frames interpret the themes as alternative problem definitions for the engineering system to address. The framing will remain within the confines of a solution being a physical small-scale engineering sub-system rather than an alternative form of solution, such as software, so that it can be compared more easily with the approach taken by the organisations in the case study during the discussion in Chapter 8. The following framings will consider the original paradox by attempting to reduce the negative aspect of the need to manage the system and seek ways of this being a means to benefit the affected stakeholders. The

frames are described using speculative *if* and *then* phrasing to firstly outline a way of naming the problem before detailing an approach towards addressing it.

If the problem situation is approached as *if* it is a problem of improving working conditions, *then* the engineering system should be...

To bring about an improved working environment for all involved in operating the system so that it requires minimal intervention and ensures all outputs are collected and not discharged. This could involve automating the servicing of a CET system, for it to have sensors to detect its condition and for these actions and information to be easily accessed without needing to be within its vicinity. This will reduce the risks and hazards of being exposed to the content of the tanks and the wider dangers of the railways themselves whilst enabling the work to be completed remotely, such as from home.

If the problem situation is approached as *if* it is a problem of reducing impact on the environment, *then* the engineering system should be...

To be able to process all types of wastewater generated by TOC activities so that it no longer needs to discharge into the municipal sewers. This could potentially reduce the costs of operations as the operator would not need the services of wastewater treatment providers. In addition to this system, sources of freshwater leakages and spillages could be addressed to reduce the water footprint of the depot. Promoting the amount of water that is saved and wastewater diverted would communicate the efforts made by the sector and help counter the negative narrative created by earlier practices.

If the problem situation is approached as *if* it is a problem of increasing service reliability, *then* the engineering system should be...

To enable a TOC to have their own continuously recycled source of water and significantly reduce the reliance on needing to replenish their freshwater tanks to maintain toilet availability. The engineering system could be installed as part of the water tank onboard so that it could collect hand-basin water and recycle it for toilet flushing. Alternatively, the system could be installed at a depot for rainwater harvesting which could reduce the need for depots to be connected to the mains

thereby enabling operators to install the systems where they stable their trains. However, efforts would need to be made to ensure toilets' guaranteed availability is understood to be the benefit of using recycled water as this could help customers feel more accepting as to why they no longer used freshwater. In addition, an intervention would be needed to be made with the toilet itself to prevent blockages, enable considerably easier maintenance or further research into passenger behaviour may be required to understand their intent, if ensuring bins are available and routinely emptied does not contribute to reducing this occurrence.

5.2.7 Futures

In envisioning a solution that combines these frames the purpose of the engineering system shifts from attempting to address passenger wastewater operational concerns directly to one that enables TOCs to operate without relying on interruptible freshwater supplies, unsafe working practices and systems that fail as a result of passenger misuse or accidents. The solution could be formed of two parts; one that processes wastewater collected from CETs, using robotic de-tanking arms, and from the depot aprons, including train wash and stormwater to non-potable standard. Onboard the trains the second part of the solution is installed which is a system that continuously recycles hand-basin water; its tank is topped up using the recycled water from the depot. When either the CET tank is near full or the hand-basin and flush water tank is near empty a signal is sent to the depot operator so that when the train is cleaned, and refuelled if not electric, the tanking services can be conducted as they may not need to occur every time the train is cleaned and/or refuelled. As this system is decentralised and does not need connections to sewers or the mains, these trains can be serviced close to the stations they serve. If there is a blockage then potentially the CET tank and pipework can be designed so that they can be swapped out during the cleaning for it to be serviced without impacting the availability of the train. Much of this could be managed remotely, with the conditions of the tanks being monitored for automatic servicing.

In returning to the original problem concerning the operational impacts of CET tanks being a possible cause of the lack of adoption, the framing has been addressed by this proposed solution through automation and integration into both the depot and train carriage. The technology being situated where it is needed can address the major causes of disruption and provide significant benefits that current operations are unable to achieve such as a reliable source of water. As such the value proposition of this solution can be described in terms of meeting the needs of operators who do not have extensive depot facilities and are limited to where they can service their tanks (Watters and McDermott, 2007), in terms of employees who no longer need to be placed in hazardous environments to ensure tank servicing is conducted (Topham, 2017b) and in terms of the wider need for the rail sector to become a more innovative and sustainable industry (Rail Safety and Standards Board, 2016; Rail Supply Group, 2016). Furthermore, as the lack of adoption of existing solutions has also been shown to be due to the impacts of the activity of installing CET systems, in terms of time, cost and technical complexity, these could also be factored into the design of the solution. Making it easier to install may rely on better communication between the manufacturer and the ROSCOs which may support technical advancements in the installation mechanisms and procedures themselves.

5.2.8 Transformation

The adoption of this engineering system would face the same challenges faced by the adoption of CET systems; overcoming or mitigating the disruption caused to passenger services as they are installed. To support reducing this impact, as the system comprises of two parts, the depot located solution could be installed and begin providing benefits before the onboard system is integrated. This might begin with installation in phases across each toilet header tank, that previously would only have contained freshwater but would now contain a degree of recycled water. Lastly, the ability for the system to be automated would require electrical adjustments to be made to the trains. To reduce the amount of work that would need to be done in one project, the installation of these systems could be completed after the other systems are operating. As such, this would require

existing practices to monitoring and scheduling servicing to be used initially, i.e. through visual inspection and the use of indicator lights.

The operational and financial costs of implementing the solution, could be mitigated through the transformation, previously detailed, of how the UK government supports the adoption of innovation. However, if this does not materialise, separating the system into individual technologies that are integrated over time could help address these concerns whilst ensuring benefits are gained by each new system. A cost benefit analysis to identify how a ROSCO could manage the expenditure required to install this solution could draw on multiple factors that would support a TOC leasing such a train. These could include the costs saved by closing depots, no longer using connections to sewers, reducing the amount of freshwater procured and by reducing the number of train movements at the depot. Furthermore, in terms of benefits, the potential increase in revenue from passenger fares resulting from toilet dependant travellers switching to trains as their preferred transport mode are weights a TOC could use to balance against the expenditure required to install this solution.

5.2.9 Integration

Once this system is fully adopted, rail sector stakeholders could have a range of methods that can potentially increase both the profitability and sustainability of the industry. ROSCOs could start measuring the water efficiency of their fleets and start marketing this as a potential differentiator to other providers of trains. Moreover, the DfT could incorporate the requirement for trains to have a minimum standard of water efficiency. As for the TOCs, they could develop their brands to be more in line with eco-conscious consumers by publicising their water footprint. The water sector could establish new businesses that specialise in the advice and support required for the adoption of such systems. Furthermore, the technology that is developed to meet the compact, energy constrained environments of trains and depots could be applied to other transport modes or land-based applications that have similar constraints.

5.3 Summary of key findings

This study that has used a document analysis to explore the problem framing of an engineering system has demonstrated both theoretical and practical findings for the development of such a system. The following key findings, before being expanded upon, are divided between the two, starting with theoretical findings:

- Reviewing documents from, or related to, stakeholders provided sufficient data to propose an alternative framing of an industrial problem to be addressed by identifying a more significant paradox.
- Further stakeholder analysis identified that there was little interest in addressing the original framing of the problem which could affect the success of alternative solutions.
- Through applying a new framing, abductive reasoning has been shown to be effective in justifying a solution after desirable outcomes have been identified.

Practical findings concerning the framing of system:

- Adoption of any new wastewater system could prove challenging as influential stakeholders have demonstrated a lack of commitment to adopting existing solutions.
- The implications of related systems such as freshwater supply and piping all present significant challenges that would not be addressed by the current solution described by the project brief.
- Interest in addressing the problems caused by the rail sectors' approach towards wastewater and freshwater operations from less powerful stakeholders could justify the creation of alternative solutions.
- The proposed alternative solution concerns a system that is to be integrated into both the train and depot so to improve water supply to the toilets through recycling and provide a means to address blockages.
- The alternative framing concerns how a solution could address improving the working conditions, environmental impact and passenger services of the rail sector.

How the frame creation model can be applied, to an industrial context, to explore reframing a problem through abductive approaches to analysis, has been shown to be adaptable to challenges that are not focused on consumer-orientated needs. As such, by exploring alternative solutions and ways in which these problems could be addressed has enabled a passenger wastewater system to be evaluated as to whether it would provide the greatest benefit.

Through applying the frame creation model, several findings emerged that help provide an understanding of the difficulties in introducing a solution that addresses passenger wastewater concerns in the rail sector. As evident during the first step of this model involving the “archaeology” of the problem’s context, the involvement of several public and private organisations meant that no clear “owner” could be found. As a result, any solution would have to meet the needs of multiple interests. This analysis would form the basis for the next stage of examining the original framing of the problem which concerned reducing the impact existing systems have on the availability of train services as set out by the project brief. This finding demonstrated there was significantly more evidence to suggest that the “core paradox” concerned the overall management of toilet facilities; the disruption to train services was not widely supported by the published evidence. As such, how passengers could utilise toilet facilities without depleting onboard freshwater supplies or exceeding the capacity to collect and treat wastewater appeared to be a paradox that would be affecting the range of interests initially identified as owning the problem.

Whilst existing systems have proven to be problematic, due to the occurrence of blockages, the practice of removing toilets or delaying the installing CET tanks reduced the incentive to address these issues, another key finding that could affect interest in adopting an alternative solution. A lack of support from the most influential stakeholders from both the public and private sectors appeared to evidence this. However, by analysing the contributions made by stakeholders in the wider field, such as those that represented trackside workers and industry interests, we see a significant contrast in how the problem is perceived. As a way

to improve working conditions and meet strategic environmental goals, the adoption of systems that can reduce freshwater consumption and eliminate untreated wastewater discharge could therefore be seen as a priority and contribute to the later stages of the model involving the creation of alternative problem frames.

To counter the apparent lack of interest, a key finding was that several of the themes that emerged from the analysis appeared to support alternative framings of the problem the proposed system was seeking to address that could support greater adoption. As evidenced by the range of stakeholder interests, those that demonstrated the least interest often referred to the cost implications of retrofitting and maintenance. Whereas, those that supported them referred to the environmental and social benefits, including whether toilet facilities could be relied upon by passengers to be operable. These themes supported the creation of 3 frames that could be used to evolve the purpose of the proposed solution. These frames concerned a way to improve working conditions, reduce the impact on the environment and increase the reliability of the facilities themselves.

In considering how these frames could influence the development of the wastewater system, a solution was proposed through abductive reasoning. This proposal synthesised the findings from the document analyses to address both the onboard and depot element of the problem. The combined system would address blockages and provide a source of recycled water, which could reduce the reliance on freshwater replenishment operations. To mitigate the challenges of adopting such a system, benefits could be gained by installing the solution in a phased manner by prioritising how the system could reduce operating costs. A key finding from demonstrating how the frame creation model can be applied to an industrial context concerned how the benefit of a solution could evolve from being framed as a way to reduce negative operational impacts. Instead, a solution's problem could be framed as a way to support the employability, sustainability and dependability of the transport mode, aspects that could engender greater interest in adopting the solution.

6 RESULTS: ELICITING REQUIREMENTS WITH A SEMI-STRUCTURED INTERVIEW METHOD

6.1 Introduction

This chapter presents the results from an interview study using a semi-structured approach to requirement elicitation. The details of the participants in this study can be found in Chapter 3. The results are structured by the coding used to capture the extent they support the proposed technical capabilities of an engineering system. This includes potential design considerations that could affect either immediate or future development goals. Statements that are out of scope as a result of the needs being significantly distant from the capabilities of the proposed system and the expertise of the project team are also captured. These statements are then used to formulate requirements. The anonymised interviewee details, their quotes and codes can be found in Appendix Appendix K.

6.2 Elicited requirements

The scope of the technical development that was being undertaken by the project these findings contributed to focused on the treatment of the liquid and solid fractions of rail passenger wastewater. Responses from the interviewees that supported the need for such a system with this capability would be considered within scope. Whilst the project brief problem and solution claims, listed in Chapter 3, described further functionality, these would not be considered within the scope of this immediate development effort. Such capabilities would be considered near-term design considerations if they emerged in the interviewee responses, however. Responses that did not relate to the project brief directly were coded as being future design considerations; due to the need being beyond the capacity of the development team to address and the scope of the initial proposed system's capabilities. Responses that supported requirements that were out-of-scope consisted of concerns that did not relate to passenger

wastewater or to freshwater required for toilet operations, although they would still relate to rail sector wastewater, freshwater usage and train toilets in general.

A total of 219 statements were collected from the interview transcripts with the largest portion being considered out-of-scope and the smallest being in scope, shown in Figure 6-1. This might imply that the interviewees felt there were more pressing concerns relating to wastewater and freshwater operations in the rail sector than presented by the engineering system development project's proposed solution. As will be shown in the following sections, whilst there were statements given that supported the current development direction, the reasons for this support were put in the context of other challenges that the system was not being designed for. However, by including them in these results we can see how a semi-structured interview technique can provide significant evidence of the extent the need for the planned functionalities of a system could be validated. Furthermore, they can provide additional insight into determining future development directions to better align these functionalities with salient commercial, operational and regulatory interests.

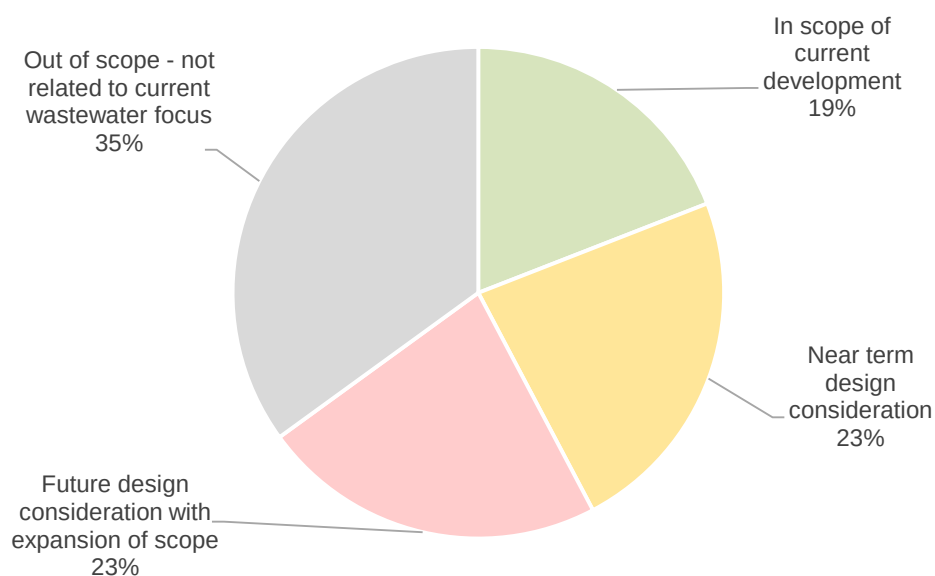


Figure 6-1 Portions of stakeholder statements that were coded based on their immediate relevance to the project's technical requirements.

6.2.1 In scope of current development

The intended purpose of the system received general comments of support due to how it would not result in the removal of toilets, continued track discharge of untreated wastewater or continued consumption rates of freshwater, all challenges that are needing to be addressed by any form of solution. This was evident in the responses provided by a range of stakeholders.

Explaining why there could be inherent benefits of a system that supports toilets being installed on trains, the system development engineer for a major European operator described situations in which toilets had been removed by other operators. This led to additional challenges both in terms of keeping the trains clean and the legal and ethical implications of the harm towards passengers that considered these facilities essential (P402). However, the interviewee added that the EU directive for passengers with reduced mobility (PRM) could be a possible barrier for train operators looking to remove toilets to aid the cost and complexities of operations, adding a regulatory incentive to any system being an available alternative to this practice.

In discussing ending track discharge, which could be achieved by solutions already available, in the form of controlled emission toilet (CET) tanks, the potential for systems that could process the wastewater onboard would help align its performance with other improvements. Due to the realities that, as other train systems become more reliable and require less frequent maintenance, CET tank servicing is becoming more isolated and as such is a candidate for its own frequency to be reduced (P402). From an environmental perspective, the ability for a system to recycle water was also supported by the environment and business senior advisor to a UK government agency who explained the growing need for more sustainable freshwater consumption and the benefits recycling could bring to areas experience significant water stress (P102).

These overall benefits of a system that can process passenger wastewater, whilst they are not unique to the specific system proposed, reflect how the project's focus could be meeting expectations that were not originally claimed in the project

brief. We could formulate several requirements that take the view of the management of the rail sector who would be represented by these strategic goals such as:

- *When the PRM regulations come into effect, I want to ensure my operations are compliant, so that I can avoid any penalties and restrictions to operating.*
- *When scheduling maintenance and servicing, I want to be able to see that all systems are gradually improving on reliability and longevity, so that I can perform fewer operations.*
- *When operations consume freshwater, I want to be able to identify demands that can use recycled water, so that we are contributing to more sustainable practices.*

The introduction of this system as initially proposed could therefore contribute to the improvement of wastewater and freshwater management as well as the operational needs expected of it. However, this would be dependent on its functionality aligning with these needs.

6.2.1.1 Existing framing of the problem

More specifically, in considering how the problem was framed in its wider industrial context in the project brief, detailed in Chapter 3, the extent to which the issues of reducing “disruptions to the railways caused by servicing water and CET tanks”, reducing “operating costs” due to “no specialised servicing equipment or operative required” and to “improve sustainability” due to “no sewerage or wastewater treatment infrastructure required” received a smaller amount of supportive statements than the proposed solution itself and how it would need to operate. However, these statements offer evidence to support the formulation of requirements that reflect a more nuanced understanding of the potential for this system to solve the problems as initially outlined in its project brief.

One supportive statement from the engineering assurance and development director of a train operating company (TOC), that provided both regional and

commuter services, of the problem's framing relates to the claim of a passenger service disruption being mitigated but describes how the operational burden of CET tank servicing would be felt more likely by electric fleet operators than diesel, as explained (P401):

"If you've got an electric train it is a very different situation [to a diesel train]... the most frequent thing you would do with it is send it for its toilets to be either both filled and emptied ... So actually a lot of the operational planning around electric vehicles can be about emptying the toilet."

This operational planning can also be further impacted by the lack of facilities to empty CET tanks, as the interviewee further explained:

"They have probably got a case [to install a competing system] because they are an electric train operator... It is much easier in sidings to put fresh water filling in for filling up the tank ... than it is to put in all the drainage for emptying them. So they have probably got a case where they are looking at building additional sidings or they have got existing sidings that don't have toilet emptying facilities, but they can fill up with water... We've certainly got sidings like that ourselves... They are fully equipped for water replenishment, they are not equipped for emptying. That is partly historic because when you dumped everything on the track all you needed in your sidings was fresh water filling points."

As such, a system that could reduce CET tank emptying and freshwater tank replenishment could be of a lesser concern for diesel operators who need to visit their depots frequently for refuelling or operators who had existing facilities where they needed them. By significantly reducing this task for electric operators, the potential improvements to operations, as a result of the flexibility gained due to no longer needing to visit depots, could enable these operators to be able to respond to disruptions caused by other factors more readily. These insights demonstrate how this framing could evolve to reflect more specific operational realities and to shift the focus to specific types of operators whom it relates to most.

Supportive statements of the second problem framing, to reduce costs associated with servicing, were given by a former depot manager (at the time of interview they were a project manager for a major train equipment distributor) who described how cost reduction was already an influencing factor. This was evidenced by experience with an alternative onboard wastewater processing system revealed to be significantly more challenging to maintain than desired, suggesting simpler to maintain solutions were preferable, and how these operational cost savings could be extended to other areas. These concerned avoiding the need to build facilities with CET equipment and the power required for trains to transport freshwater being reduced by this system leading to cost savings (P702). However, whilst the proposed system might not be as costly as the alternative processing technology, it could struggle to cost the same or less than the current CET tanks to maintain (P402, P101). As such, this could be a design consideration the project would have to consider so to support operational cost savings and how maintenance would need to be conducted to meet one of its own goals as this was not within the scope of the immediate development focus of the project.

The third problem frame, concerning the solution being seen as a means to improve sustainability, by eliminating the need for sewage or wastewater treatment infrastructure received clarification as to why this may occur. This finding expanded the benefits of the prior frame by adding further detail to the cost of connecting to sewers, as explained by the engineering and assurance development director of a train operator (P402) in the context of past operational experience:

“...we started operating trains out of Stourbridge ... We had to put in toilet emptying facilities there. It was particularly problematic because there wasn't a mains drainage connection to the site... So initially we actually had to empty the toilets into another tank that was then emptied by a tanker every day. After a few years of doing that we got fed up and actually put in a proper mains connect... It's just the cost ... You have got the cost of getting a load of pipes laid in the ground and the design and the hassle of getting all the diggers in...”

Whilst supportive, the statement does not suggest that there could be sustainability implications of avoiding this activity, rather the driver is on the immediate cost. This was a concern that was further explored from the perspective of the water sector by the environment manager for train depots operated by a global manufacturer (P801):

“... are (the water wholesalers) going to look at the big residential development next door and say actually no, the sewers ... not just ... capacity related, but there is also the flooding element as well. Are they going to be happy with us bringing additional water down into the system, how is it going to impact them... basically being implied that we are at the top capacity of what we could do if we wanted to do any more it might not get through, but so far we haven't had any pushback from them...”

This reflects another situation whereby, in order to reduce the demands on a local wastewater treatment plant, tanks had to be installed onsite so they could discharge at night when demand from residential needs were low. However, this wastewater consisted primarily of rainwater (P401) and as such was not a direct indication of the demands placed on treatment plant infrastructure by passenger wastewater. This could impact sustainability targets of the wastewater treatment plant operators who could be looking to reduce the resources consumed by their facilities to treat ever increasing volumes of wastewater. However, as explained, this does not yet appear to be a demand placed on the rail sector to help meet.

These statements, whilst supportive of the project's immediate goal to develop a system to treat passenger wastewater, suggest that how the solution would address disruption, cost effectiveness and sustainability were lacking to a degree in alignment with how these concerns were evident in practice, compared to how there were described by the project brief. Therefore, if disruption did occur as a result of depot visits, it could be less felt by electric operators as they could eliminate the need to visit depots with this technology unlike diesel operators. If operating costs were a concern, the solution could most likely cost more to maintain than existing solutions, but could cost less than alternative similar technology. In terms of sustainability, whilst the responses indicated there could

be positive implications, this benefit would most likely relate to achieving the reduction of freshwater consumption rather than the reduction of wastewater treatment.

6.2.1.2 Existing and planned capabilities of the engineering system

In considering how the solution was presented in the brief, there was considerably more supportive statements concerning how it would need to technically work in comparison to the prior statements supporting the problem itself. This suggests that there was either greater interest for or knowledge of the functionality rather than the problem in which it was being designed to address. Due to the focus of the project at the time of this study being on treatment process development, the solutions in the brief that described “plug and play”, “predict and prevent” and interfacing with existing systems and power supplies were not considered to be in scope, however, some of the ongoing development work proved relevant to the statements that were made supporting them.

The proposed capability of the engineering system to “handle liquids present in rolling stock toilets/washrooms such as urination, hand washing” was supported through the contribution of insights that described the factors that would make this solution succeed. The interviewees from TOC backgrounds (P401, P402) provided significant detail as to how the type of train service can impact the composition of the wastewater. These insights revealed long-distance operators would subject the system to greater loads than commuter services and how operational realities of both could have implications for the system. This concerned findings that current systems may not collect hand-basin water which would affect the planned recycling of it and that taps can break and continuously flow therefore significantly diluting the wastewater and increasing its volume. However, in general, the chemical composition of passenger wastewater is significantly different to domestic sources due to the higher concentrations of urine as a result of fewer additional dilutionary wastewater streams. With this information we can construct a more complete requirement now that we have a better understanding of the situations and motivations an operator may experience when expecting this functionality to process these liquids:

- *When the type of train service changes, or in the event of a change in the concentration of freshwater, the system should be able to handle different loads and compositions of wastewater, so that the type of service or amount of liquid fraction does not impact its performance.*

The proposed capability of the engineering system to “purify liquids for reuse or safe discharge into the rail track environment” was supported with advice as to the types of water qualities that should be achieved if the goal was for recycling and reuse. Drawing from analogous experience, the interviewee who was involved in a reuse project for the London Olympics (P501) recommended focusing only on toilet flushing rather than hand basin use due to the risks of ingestion. These would be caused by the difficulties of educating the public not to drink non-potable tap water. Additional advice suggested adopting US EPA regulations due to the lack of similar recycled water standards in the UK. In terms of the operational benefits of this capability, the need for a significant amount to be reused so to reduce the need for depot operations was stated as a requirement (P401) and if safe discharge were pursued, the system would require permitting from the Environment Agency (P101). However, as a means to support a sustainable approach to freshwater consumption through reduction, this was mentioned as not being a demand expected of the rail sector from their freshwater suppliers (P801). Although a lack of interest was evident, a requirement that captures the intentions for this capability as evidenced by these responses could be formulated as:

- *When water is used in the washroom, the system should be able to collect and recycle it to a regulated standard, so that the train does not require to visit the depots as often to replenish its tanks.*

The proposed capability of the engineering system to “render solid waste inert (e.g. faeces and toilet paper) safe for discharge into existing depot infrastructure systems” was supported with advice from a range of stakeholders. This included the knowledge from the chemical characterization of passenger wastewater by the operator of a major European passenger service (P402) that identified the

complex nature caused by the presence of the toilet paper. This impacted whether it could be suitable for processing by alternative systems and as such could affect the project's system's proposed treatment processes. However, the desire for the outputs to be disposed of in a certain way suggests this challenge would be expected to be overcome, as explained by the fleet and engineering director for the railway maintenance government agency (P901):

"...if there was a product that could come off that was bagged or packaged in a way that it's not going to spill, not going to go anywhere, that we can just put in the general waste then that would be so much easier for us to manage."

This benefit was further highlighted by the system integration engineer for CET tanks at a major train manufacturer (P201):

"...If a product gets developed that is proven to be environmentally friendly means that we can dispose of waste safely (on tracks) ... it's a massive benefit to maintenance costs and saving yourself a lot more money in the long run."

However, to produce a reliable and consistent output could prove challenging due to the sensitivities of the chosen thermal treatment process, which was not introduced during the interview by the author due to confidentiality constraints. The environment and business senior advisor for a government agency (P102) referred to the process by their own volition and highlighted how the contaminants in the solid fraction can vary considerably due to the composition of the inputs and the temperature in which they are processed. With this knowledge we could formulate a requirement for this functionality as:

- *When any type of solid is processed by the system, the system should be able to produce an expected quality of output, so that it is not hazardous to handle and dispose of.*

The proposed capabilities of the engineering system that involved how it would be installed, operated and maintained, whilst out-of-scope for the project's current stage of development, received a number of supportive statements. These demonstrated how the ongoing system integration aspect of the project, that was

primarily focused on building a prototype to fit onto a train, was also successfully factoring in these concerns raised by the interviewees. Understandably, existing rail standards for any engineering work done to trains was raised (P401). Also included was the need to ensure adequate ventilation and that the system could function within limited volumetric dimensions (P501) and that it should be easy to install in comparison to alternative processing systems (P702), all of which were being addressed by the project at the time of the interviews. Furthermore, due to the system operating differently to CET tanks, the challenges faced by their faulty sensor readings due to the movement of the large volume of wastewater liquid would not be a problem that would exist with this system (P201). With these insights a general performance-related requirement could be formulated as:

- *When the system encounters a fault, the system should be able to communicate its condition, so that it can be monitored and controlled in accordance with existing safety standards and operation management systems.*

The evidence supporting how the system was planned to address the ways in which the problem was being framed in comparison to the statements supporting the solution reflect a level of ambiguity. Whether these functionalities would solve these problems could be in doubt given the lack of specificity of the responses given that related to the problem frames set by the project brief. The formulated requirements demonstrate that these problems can more accurately described in relation to the functionality as discussed by the interviewees themselves. By combining their industry knowledge with the proposed capability and an outcome expected by themselves, the project could better ensure its wastewater treatment development remains aligned with their needs. The importance of ensuring the system adapts its purpose and capabilities is evident if it is to be successfully adopted. However, this only concerns the statements that were made that support the current direction being pursued. In the following sections, we will be able to see the extent other passenger wastewater challenges exist that would not be covered by the proposed capabilities. Moreover, nor would treating other types of wastewaters that are creating challenges in the industry that could

indicate a greater priority than that generated by train washrooms. However, these could form the basis for future stages of development for the system.

6.2.2 Near-term design considerations

Half the statements that could support future phases of the project based on their relevance to the direction currently being pursued could be considered near-term, such as within a few years of the initial phase of the project. As a result, they would not be evidence in themselves to validate the need to develop the passenger wastewater system in its current form. Rather, if the considerations were addressed and if there was interest in the system then these findings would help ensure its reaches it maximum levels of adoption. Several insights were gained as to how a given engineering system's benefits would need to be communicated to support adoption in addition to addressing later stage technical considerations.

These included needing to incorporate the risk-adverse nature of the rail industry by emphasising the safety of the recycled water once achieved (P103, P501). This could be achieved by exploring partnering with other technology companies with more established processing systems (P202) and ensuring support from train maintenance companies, or the divisions of manufacturers who offer this service (P401). The need to address the cost concerns could be achieved by ensuring the support from influential stakeholders, such as the procurement interests within lessors and manufacturers (P201), and emphasising the cost benefits in terms of operational rather than capital expenditure (P402). Furthermore, addressing the unique operational realities faced by types of operators and how the system could specifically address these would be necessary to communicate. This would concern how it would benefit the operations of TOCs who already have a commitment to CET tank usage, new operators who are yet to invest in CET facilities (P402) and freight and railway maintenance operators who are starting to install toilet facilities onboard their trains but are unable to make regular depot visit stops due to the nature of their work (P901).

The implications of addressing how the solution should be communicated could influence the near-term design considerations of the system. If priority was given to demonstrating addressing particular stakeholder needs, or responding to feedback from further engagement that supported specific considerations, then the technical direction of the project could change accordingly.

6.2.2.1 Complying with standards and regulations

Beyond the immediate goal of ensuring the system could produce safe water and solids, further implications on technical capabilities could be derived from how the industry itself regulates. Whilst applying US EPA and UK national water standards can guide this initial development, the risks specific to the rail context may call for additional considerations to ensure safety of passengers, for example, in the case of system faults. A range of possible considerations for the system to incorporate were described by the interviewees. This included the development of signage or ensuring there is no part of the toilet module where recycled water could come into contact with passengers, crew or cleaners (P501). This consideration reflects how train operators are expected to ensure they are meeting applicable standards, such as any Technical Specifications for Interoperability (TSI) regulations that could in future address this concern (P201). Furthermore, train operators should also be willing to conduct their own water quality tests (P801). As such, how the solution to ensure the system is compliant could be arrived at through a combination of applying regulations from other regions and identifying and responding to specific concerns that only relate to the rail context.

TOCs could potentially feel encouraged to opt for the safest solution due to the absence of any existing industry-wide policy (P101). However, past changes to regulatory positions, such as the need for trains to become PRM compliant and proposed restrictions on track discharge, were seen to have been introduced with an unrealistic timeline for compliance (P201, P401). This could suggest that to prepare for any future changes, a proactive approach to ensuring the highest standards can be achieved by the capabilities of the system, rather than the efforts of the TOCs themselves, should be aimed for.

In terms of the quality of the solids, this presents a more complicated issue to navigate due to their contents being unknown at the time of this study. Furthermore, as waste regulations are devolved in the UK to each country, policies on dealing with this output were noted to potentially differ (P101, P102), although they would stem from the EU's Waste Framework Directive. However, the UK government appeared to be cognisant of this difficulty as was evident in a response from a senior representative of the responsible agency (P102) who indicated their approach as flexible:

“...we might turn (meeting existing standards) in the future into an exception if the risks is considered to be sufficiently low. Failing that, if we can't confer to regulatory position or we are not satisfied that a regulatory position is appropriate then it would be a permitting requirement...”

This indicates that developing the solid processing capabilities of the system could be influenced by the involvement of this government agency. Whereby if the level of hazardousness of the output enables operators to apply for exemptions, or a permit if the level is too high, the processing capabilities could be tailored to ensure this is met. This approach to developing the capability of the system could be potentially onerous, as it will require understanding both the variations of the solid fractions and how their processing affects this output. The need for the liquid side of the system to incorporate industry risk-adverseness could present additional challenges as well. This is due to the lack of certainty as to how this may manifest across the numerous operators in the UK who could be responsible for their own water quality, in contrast to the fewer regulatory agencies responsible for permitting or exempting solid waste disposal. However, these insights can contribute to understanding how the system would be able to meet the aforementioned requirements for safe water and solids processing.

6.2.2.2 Incorporating demands placed on new rail technology

There were several general needs that emerged due to the system being a unit that would be installed onto a train and how it would relate to prior CET solutions. These needs concerned meeting existing expectations for servicing and be

compatible with existing practices. These included how servicing would have to fit within the same 4 hour window taken by all other tasks (P702) and that the equipment used should be developed in mobile form to aid operators without suitable depots space for them to be fixed (P301). Drawing on the experience of the CET adoption, the installation of the system should be optimized so that it can be quickly installed without having to rectify any problems, especially relating to pipework (P301). Further integration expectations concerned existing remote condition monitoring processes so to contribute to reducing an industry metric “toilet non-availability” (P401). An additional benefit could be to reduce the amount of cabling required to be installed onto the train by using Bluetooth wireless connections (P301). Finally the solution should cost the same or less than CET systems (P201). Therefore, near term design considerations could be directed towards ensuring the system will be able to meet these expectations so that later stage rework can be avoided. These insights would help the system achieve its “plug and play” capability so that there would be no difference to how the train operates.

However, requiring the system to be designed for retrofitting could be questioned as to its desirability, as explained by the procurement manager for a major train lessor, organisations referred to as rolling stock leasing companies (ROSCOs) (P301):

“... one of the issues we’re having with the older fleets is that we’re putting all this extra kit on it, they were designed to be able to take x amount of weight so we are on the extreme of some of them, mechanically and electrically as well. New systems we’re putting on we’re draining the electricity as well so it’s one thing we have to be careful of when we’re looking at new things because there’s only so much power we can generate from certain units.”

This reflected the approach taken by a train operator in how they installed CET tanks by replacing the train itself with a new train that had these installed rather than retrofitting them, although retrofitting had been done, it was only for a few cases which was rationalised by the age of the fleets (P401).

Technical complexities were also highlighted in ensuring that the system would be compatible when retrofitted. This was due to it needing to have the same weight as existing CET tanks due to the design of the trains using this to maintain balance (P201). Furthermore, trains may not have enough space between the tracks and their underside due the introduction of fleets that are PRM compliant and are lower to the ground to aid wheelchair access (P402). Therefore, this “plug and play” capability might be better referred to in the context of operations remaining the same when a new train with this system installed is introduced rather than the need to integrate “into existing rolling stock structures”. However, given that fleets in the UK are going through significant renewal, the opportunity for technology to be included in a new train may be in several decades if they are not made during this period. As such, a change in how TOCs and ROSCOs invest in their fleets may need to be encouraged to support retrofitting.

The demands placed on new technology from the train manufacturers’ perspective, that affect the design of the system, concerned their interest in reducing the weight of the carriages. As such how the system could be designed and manufactured to be lightweight could be an important early stage consideration. However, given that the magnitude of reduction that can be achieved through the structure of the train and the bogies is far greater than the CET and freshwater tanks, this was not stated as a priority focus (P202). However, whether retrofitted or installed as part of a new train design, the process could enable the system to be tailored to specific technological demands resulting in a collaborative approach, as supported by the rolling stock policy manager for the UK government (P101) who stated:

“The success for this [system] would be the train operator [in] question developing their own solutions that best suit their needs for their own stock and the passenger services they operate.”

6.2.2.3 Incorporating demands placed on new wastewater technology

In similarity to the demands made of new rail technology, there were expectations for the system to be able to continue, if not improve, upon existing operational

capabilities regarding wastewater processing. For example, the interviewee from the operator of a major European fleet stated they were able to reduce between 35%-50% of their freshwater used for their washrooms through recycling (P402). Other expectations concerned how the general public may expect the water to be completely clear (P501) which can be made possible if the correct filtering process is used (P701). In terms of servicing, an expectation that the frequency will be the same or less than other competing systems (P402) which can take 3.5 hours to clean (P702) was also stated. These insights could be used as a baseline to measure the extent the proposed system currently compares and form the basis for where to focus future development.

In contrast to the demands relating to rail technology, wastewater related statements also concerned expectations that are currently not the norm but indicate the direction that new wastewater technology could be heading towards. For example, having better insights into the consumption of freshwater use in washrooms was mentioned as a means to optimise the size of their tanks (P202) and to achieve closer alignment between consumption and supply volumes (P702). How it can be initially stored without becoming contaminated past 2 days was also mentioned (P202). Furthermore, more advanced recycling processes could target unexpected contaminants such as blood (P501). From the perspective of the solid fraction, interest in valorising this material for use in construction and agriculture suggests potential benefits for collecting the output rather than disposing it (P501, P102). However, when discussed it became apparent the volumes produced by the rail sector on each train would be considerably less than at a centralised municipal plant thereby potentially affecting its viability. How the proposed system currently addresses these areas of interest in wastewater technology could also act as a means of focusing future development.

There were also statements that referred to known unmet challenges of existing solutions, such as the odours they can emit (P301) and the restrictions placed on the reuse of solids due to the potential for microplastic contamination (P501). Furthermore, freight and railway maintenance fleet operators cannot use systems

that expect operators to return to a depot every 12 hours, due to the nature of their work (P901). These concerns could potentially already be met by the proposed engineering system and could be verified. For example, by characterizing the quality of the outputs to determine the risks they would have in being used for other purposes and a determination of the extent of malodours have been designed out of the system. The benefits of onboard processing would address the specific constraints of specialist and freighter fleets, however, this could have implications on the characteristics of the influent and as such could require the processing control to be adjusted.

6.2.3 Future design considerations with expansion of scope

There were several topics raised by the interviewees that did not fall within the immediate or potential short-term development goals of the project. They did, however, relate directly to invalidating the current problem frame as described in the project brief. Furthermore, they highlighted the importance of aspects of the solution that if addressed would either require additional team expertise or significant changes to the current research focus of the project team. Committing to these changes would require further data collection to understand the full extent this would be required. Collecting this data would have been out of the scope of this study as the primary aim was to focus on the existing proposed solution to elicit requirements whilst evaluating the extent it was supported by the most salient stakeholders. As such, the level of detail that was captured was not prompted but was offered. This indicates the genuine interest and technical expertise in the wider context of passenger wastewater operations, such as in the maintenance involved and other toilet-related operations.

The most frequently raised concern that was not being addressed by the project, nor were there future plans at the time of the interviews to do so, concerned blockages. There were 9 statements coded that related to this problem from 7 different interviewees demonstrating that it was a widely known and salient issue. These included statements expressing interest as to how the system would be able to handle foreign objects (P101) given the variety of objects that could be disposed of in this manner (P402) as a result of passengers' disregard for signage

requesting this not be done (P601). Further experience was given as to how this issue could be more of a concern on commuter trains, with items such as wet wipes and nappies mentioned resulting in the blockage remaining for a week (P201). Blockages were also noted to form at any point in the system, with particular concern regarding the pumps (P701). Moreover, due to the use of fluid-based systems, compared to incinerator or track discharge, damage to carriage interiors could occur when they overflow due to a blockage (P901). However, lessons could be learnt from passenger aircraft operators as there was an assumption that they may not experience the same challenges (P701).

This problem formed part of a larger concern that contextualised the operation of passenger wastewater processing as being a potential cause of passenger service disruption. This evidenced that the focus of the system was not the main priority in this regard, as according to one of the train operators (P401):

“...typically toilet non-availability across those nine operators is 3%. The reasons for non-availability tanking, which is either the waste tank is full or there is no fresh water, is 32% of the reasons, and 68% is for other factors such as blockage, locks, toilet door locks, toilet doors failing, tap not working, toilet not flushing... if you looked at toilets across the network that were not working on trains 1% of that would be due to CET or no fresh water...”

This research referred to in this quote was conducted by the trade association that represented all train operators in the UK. The issue concerning other reasons for toilets not being available was due to the door systems being less reliable than the toilet systems (P401, P402). This was highlighted as a concern due to the impending regulatory changes that could put pressure on operators to ensure their toilets were available in order to comply with the persons with reduced mobility (PRM) technical standards (P401). As such two requirements for a future system that focuses on toilet availability could be phrased as:

- *When foreign objects are placed in the toilet bowl, the system’s flush mechanism should be inoperable, so that the objects do not lead to blocking or damaging the system.*

- *When a passenger enters and exits the washroom, the door mechanism must have a reliability rate derived from the planned PRM implementation, so that the availability % of the washroom is compliant.*

Considering that the project only focused on the processing of the wastewater, the only requirement that could be pursued could be phrased as:

- *When foreign objects are flushed down the toilet, the system should be able to separate them from the rest of the wastewater, so that objects can only block the toilet module itself, the pipe leading to the system or be collected within the system.*

As the concept involved a unit installed on the underside of the train with no intervention made regarding the toilet washroom itself, to fulfil the “plug and play” promise, the majority of causes for the toilet non-availability would remain unaddressed.

Whilst the cost of the system could be a near-term consideration to calculate, i.e. whether the reduction in servicing costs makes the larger capital expenditure more attractive, the benefit derived from similar systems did not demonstrate significant operational savings. Furthermore, the servicing of the system would prove to be considerably more expensive should a fault occur (P402). These concerns were evidenced by a response from an expert from the water sector (P501):

“...(biggest barrier to the rail sector) is likely to be the cost, because implementing this is going to cost far more than just have a tank that you empty and ... you fill with water... Because what you are speaking about is ... if there is one toilet per carriage, and you have a 12 carriage train ... therefore [it] is [a] 12 [unit] decentralised system ... and the smaller the [unit] the higher the cost is to operate”

Whilst the system could be designed and engineered to a high standard to mitigate these maintenance risks, the operators themselves would possibly require a more complex system to ensure the water quality remains safe as a reflection of their risk adverse approach (P501). A further complication relating to

operating such a system was highlighted, demonstrating how the rail industry could learn from the challenges faced in other sectors:

“...as a water company we don’t want the responsibility of [decentralised wastewater recycling systems] because there is a maintenance cost and [residential] developers don’t want to be responsible for it because once the development is sold then they have no reason to stay in the development or to be addressed to the development. Then it would depend on the users, which are the people. The people buying the property might not want to pay for the maintenance. So, in your case I would say the rail company, or whoever is maintaining the trains, would be responsible for maintaining the system.”

As responses explained that changes in the industry are resulting in manufacturers of new trains also being the maintenance providers (P301) they could potentially acquire the capability to also maintain the system. However, TOCs, or ROSCOs, may need to contract a specialist service provider. This could form a future consideration to explore how the system could be maintained and how such a provider could be established. An additional constraint would be for the system to be repaired within 6 days to remain in accordance with industry norms (P401). Without this support the system could struggle to reduce the perceived risks in its operation.

Another related concern involved the handling of the solids. Whilst the ease of disposal was highlighted as a potential benefit (P901), the implications of this practice could result in an increase in the carbon footprint of wastewater operations. This could be caused by the increase in disposal trucks needing to visit the depots, or sidings, which could be in addition to regular collection of general waste if the solids were to be aggregated for reuse in construction or agriculture rather than sent to landfill (P502, P501, P601). As such this could result in an additional operating cost, therefore a solution would need to be devised that would explain how this could be mitigated.

Disposing the solids produced by the system would enable the solution to remain competitive with current operations as discharging wastewater into municipal sewers had not been evidenced as being a cost, or practice, that requires

reducing. However, given the practice of directing untreated wastewater into rivers during high rainfall and the interest in reducing water stress, the water sector was explained to be looking for opportunities to improve its operations (P501). Systems that can contribute to the water sector's aims could potentially galvanise support from outside the rail industry. This could inform future efforts to communicate the system's benefits in these terms and rationalise the pursuit of recycling water and decentralising wastewater processing (P701).

Returning to the initial problem frame that the system will reduce disruptions to passenger services caused by servicing CET tanks, this was evidenced as not being a significant operational reality. If tanks become full for some operators they will allow them to overflow onto the tracks and if other problems occur rendering the toilet unavailable the train will not be taken out of service specifically to fix it (P401, P301). As a result, other aspects of the system's potential capabilities would need to be focused on to demonstrate that they were meeting the needs of the industry. For example, the performance would need to be significantly beneficial that it would warrant the investment. This would require the system's processing capability to be considerably more resilient, economical and reliable than alternative systems and its maintenance service provision would need to be able to quickly resolve any problems that occur, such as blockages. As a result, despite its greater complexity and higher initial expenditure compared to CET systems, the system's technical capabilities could remain within its current scope.

6.2.4 Out-of-scope stakeholder statements

Due to the semi-structured nature of the interview, a significant amount of statements were made that did not directly relate to requirements for the system. However, this enabled the system's proposition to be thoroughly validated by contextualizing it in how the problems it would seek to solve are currently being addressed. Statements would also concern how completely different approaches to the solution could be conceptualized, how different wastewater and freshwater challenges are caused or addressed and general comments on the direction of the industry. Such statements could prove useful as they could aid a variety of

decisions made regarding the ongoing development of the system or its future alternative technical development directions.

Whilst the solution described in the project brief would look to reduce disruptions to the operations of the industry and potentially reduce freshwater usage, there could be far simpler ways of achieving this. Whilst not ideal, but a reflection of what could be possible, evidence from the responses suggests toilets are disappearing off trains but being installed in stations. This was explained as the result of certain trains having low usage of these facilities because they were now used on high frequency stopping services and that cost savings in not needing to clean the washrooms is significant motivator (P402). This solution would eliminate any disruptions caused by the toilet operations. Whilst not applicable for all services, such as long-distance routes, if more stations have toilets installed there could be a knock-on effect on the use of, or need for as many, onboard toilet facilities for other types of train services as well.

When framed as a solution to save water, and contribute to simplifying depot operations, the system's overall consumption of freshwater could be reduced by far simpler means compared to recycling. Due to the practice of refilling freshwater tanks without non-return valves and the option of only two volumes for the automated system to use, this can result in hundreds of litres being lost to the drains for each tank (P601, P801). Furthermore, the process of cleaning the freshwater tanks was noted as incredibly water intensive (P801). As such, it would appear that there is a significant amount of opportunity for the rail industry to reduce their water consumption without the need to use recycled water systems by focusing on reducing wastage and more efficient use.

As for how the system was intended to operate, a finding indicated that it would need to adapt to a significant constraint. The restrictions on operating thermal treatment systems on trains was noted as a result of the need for them to have a constant source of power when processing. This would not reflect the operational reality of trains being powered down when not in use (P901).

There were also several alternative concepts suggested for the system, such as a process whereby trains would discharge waste at centralised facilities, described as “treatment hubs around on the network”, that would then treat the wastewater for reuse or discharge to the environment (P502). This reflected another similar idea with a cost implication demonstrating a perspective from the water sector (P701):

“...(we could) focus on more centralised systems so when a train enters a station it can discharge its water to a tank and from this tank the water treatment is done, because otherwise you will have water treatment systems on every train, so more decentralised, as in general this will drive cost up if you have the larger centralised systems that make more sense if you look at cost ... if every train needs its own water treatment system ... they also need maintenance from time to time. If you look at these logistic operations it is huge, there is a lot of cost involved.”

However, the practicalities of building treatment facilities were questioned by a representative of the rail industry with experience of depot operations (801):

“...putting in treatment plants for example has been floated as an idea ... to avoid having to do it on civil works ... But the issue is, as you know, once your depot is built it is built and quite often they are kind of sandwiched into really tight spaces ... in between a commercial zone or residential area ... where do you actually put them and how easy is it then to ... make sure it is easy for them to be maintained.”

A range of other wastewater types and technological solutions were mentioned that addressed the largest consumption of water being train wash (P401) and rail wash, which was estimated to be over a million litres a year (P901). This evidences how the proposed system would not be addressing the largest demands on freshwater which could impact the level of interest it receives if marketed to emphasise this capability as a reason for adoption. Another concern that would not be addressed could be met with robotics to service tanks and clean trains (P401). This could address one of the problems mentioned regarding the need to reduce the frequency of replacing hoses used for CET and freshwater

servicing due to damage and to address the health and safety concerns of spills as a result of using them (P801).

Statements that considered changes to the rail industry drew on an analogous case from another transport mode's potential regulatory environment, specifically the shipping industry. Strict limits on discharging ballast water could force vessel operators to install adequate processing systems onboard (P701). If not incentivised by regulations, further support for the need for improved wastewater operations was found in a comment on the future of work and how it should be made more desirable in the rail sector provided by an interviewee from a regional train operator (P401):

"...we have got to be aware as an industry at both the national government level we need to take on the Unions and actually have technology available that will do that for us... people don't want to spend their lives emptying toilets. If I talked to my son and said, now then I want you to spend the next 40 years emptying train toilets, I think I know what response I will get from him. And actually I don't think that people in the future will want to do that type of work. I think we will struggle to employ people to do that type of work, particularly when you say oh yes and also I want you to do it at night in the freezing cold."

As these statements were out-of-scope of the project's immediate technical development commitments, how they could prove useful in forming requirements was limited. However, as evidence for considering alternative concepts involving different wastewaters, interventions, whether onboard or onsite, or a commitment to addressing existing problems concerning freshwater consumption, these statements could support further research into a considerable pivot away from the current project's focus or an expansion in scope for its capabilities and application.

6.3 Summary of key findings

The key findings from this study list below, before being expanded upon, both the effectiveness of a requirement elicitation method and the requirements themselves for a solution that addresses perceived problems affecting passenger

wastewater operations in the rail sector. The following lists starts with how the method was received and then what would be required of the system:

- A significant difference could be seen between the number of statements supporting the project and those that required either minor or major changes to its scope, the latter being the largest.
- Through starting with the intended solution, interviewees were able to offer expertise as to how it could prove successful, although these responses would not necessarily address the need for the solution.
- The ability for the interviews to be guided by the participants enabled the severity of the problem to be challenged with insights into alternative needs.

Key findings concerning the system:

- A system that processed passenger wastewater would not address the most prominent toilet-related challenges; that being washroom mechanical faults and blockages.
- Significant deciding factors in keeping toilets onboard trains are the cost and ease to maintain, monitor and ensure compliance, as such any system would need to prove effective in all areas.
- The system could meet the needs of operators without existing connections to water mains and sewer networks, although this does not represent a common constraint.
- Servicing the proposed system could be seen as complex in comparison to existing systems and due to the need to remove retained waste and maintain high qualities of recycled water.
- An expectation that an ideal solution would need to address other sources of wastewater and freshwater use was apparent, due to their greater volumes, however, this did not appear to be a high priority.

The use of a semi-structured interview method enabled interviewees to provide statements describing their priorities and expectations whilst being guided

towards validating or challenging the proposed benefits of a specific engineering system. The sample comprised of stakeholders in the commercial, operational and regulatory environment of the system and as such their responses would ensure the broadest range of salient demands could be identified.

With regards to the requirements for a solution, findings revealed that a significant amount of responses were not directly in support of the aims of the original project brief and as such those that were formed the minority. However, just under half related to both near term and future design considerations that would support processing passenger wastewater, the system's primary function, to a certain degree, if there was interest in such a system. Responding to findings that were out-of-scope would require significant changes to the nature of the output of the project as this would not involve processing passenger wastewater onboard the train, although, such an alternative output could still address rail wastewater and freshwater-related concerns.

The requirements that aligned with the engineering system concerned its overall objectives. These included supporting operators to enable passengers access to toilets, looking for ways to reduce maintenance and potentially identifying ways of reducing freshwater consumption. Whilst these were emphasised by those interviewed as preferable, these requirements did not relate directly to how the system would meet these objectives and as such offer little validation as to the proposed system's approach. As such, the existing framing of the problem indicated that the system may only be relevant for operators without the required facilities and access to freshwater and sewer networks, such as new, electric or remote location operators. As such, this would not meet the needs of established operators or those that use diesel trains that require frequent visits to well-equipped depots for refuelling.

Through continuing the questioning in a more structured manner, so to focus on the requirements for the system as proposed, statements offered a greater awareness of the needs for the system to prove cost-effective and technically feasible, especially in terms of what would be required to enable the safe use of recycled wastewater. These findings, however, emerged as an intentional

change in the discussion away from the high priority needs of the industry. If the system were to be developed as planned, albeit for the fewer operators that could benefit from adopting it, by incorporating them, the capabilities could be better aligned with their needs for safe and reliable operation by meeting these requirements.

As an indication of the flexibility of this requirement elicitation approach, should responses diverge from supporting the initial assumptions of need, statements could also be used to formulate requirements for alternative solutions. These statements further contextualised the proposed system revealing the extent it could create other problems. For example, finding the expertise and support required to maintain the systems and to address the knock-on effects of collecting and disposing of residual waste in a sustainable way. The responses that detailed the operation of toilet facilities themselves revealed that wastewater collection and freshwater elements of the systems were not a high concern, rather blockages and reliability of the mechanical components such as toilet doors and taps. Framing the system as a means to ensure reliable toilet availability for passengers would therefore demand that these problems were addressed.

Looking beyond an intervention that formed an onboard small-scale engineering sub-system, other types of solutions, such as being located within the depot, emerged. These could address the water sector's ability to sustainably provide the rail sector freshwater and to effectively treat its wastewater, although, despite these being larger volumes than that which would be processed by the proposed system, this was not described as a pressing priority. As these solutions would require a substantial change in the direction of the project this study supported, the questioning did not delve into eliciting requirements for such approaches. However, these responses demonstrated the capability for semi-structured interviewing to provide evidence to support such changes in a project's direction so to address any major misalignment between stakeholder needs and the technology being developed.

7 RESULTS: CASE STUDY OF THE EARLY STAGES OF AN ENGINEERING SYSTEM DEVELOPMENT PROJECT

7.1 Introduction

This chapter presents the findings from a case study conducted to understand how and why the process and methods used during the development of an engineering system could affect the extent stakeholder needs are integrated. The case concerns a project to develop a passenger wastewater treatment system to be installed on the underside of a train carriage. This was initiated by a company that specialised in manufacturing controlled emission toilet (CET) tanks, the installation of which is current industry practice for collecting such wastewater, as well as assembling depot equipment for servicing the tanks, and other metal components. The company contracted an academic institution to provide expertise on the design and engineering of the system. The academic institution managed the development of the system by determining the overall process that would be followed as well as how the components that would be developed would be tested and integrated. This involved progressing from TRL 1 to TRL 4 of the technology readiness level framework. The development would be undertaken primarily by two teams, each comprising of a researcher and supervisor, focusing on the solid fractions and liquid of the wastewater separately. A system integrator would work with both the sponsoring firm and the academic institution's project leadership to ensure the components could connect and fit in the desired assembly. The sponsoring firm's role was to manufacture the components and eventually oversee the integration of the system onto a train carriage for further development thereby progressing from TRL 5 onwards after the project of this case study was completed.

The project's initial aim was to develop a prototype that could be installed on a train within 18 months of the project starting. This timeframe was set in order to meet the dates of a major industry trade show and later a UK government funding

opportunity that required a demonstration. To meet these deadlines an approach that favoured speed was used that would seek to use off-the-shelf components. However, as the component that would process the solid fraction of the wastewater would involve the discovery and exploitation of fundamental science, this unit was made entirely by the sponsoring firm using designs produced by the relevant team. The design for the components that comprised processing the solid fraction of the wastewater were understood by the sponsoring firm as being a better alternative to other commercially available systems due to the lack of chemical or biological inputs required to treat the wastewater. The liquid processing side of the system, however, was able to adapt readily-available parts. To identify which parts would be suitable, the project used a morphological grid analysis to arrange and compare alternative ways of addressing clearly defined technical problems, such as separating wastewater solids from liquids. According to the project's principal investigator, in addition to the potentially quicker and lower cost implications of this approach to engineering, the aim was to achieve create a fully working system as a soon as possible. Once reached, the system would be optimized through the swapping out of components so to avoid the potential for the project teams to focus on improving individual stages of the system in isolation. Such an approach could reduce the likelihood that a complete system would be able to be demonstrated in the available time.

During the first year of the project, the researchers and supervisors were invited by the sponsoring firm to visit train depots to understand the state of the current technology. The author observed the process of emptying CET tanks, shown in Figure 7-1, whilst freshwater, oil and sand (to aid traction) were replenished concurrently. The depot technician would connect the various hoses to the tanks and begin the operations whilst walking down the length of the train. The freshwater operation was noted to lead to significant spillage as the tank would overflow until the hose was removed. The CET tanks, whilst there were indicators that state if they were full or half full would all be emptied as these were either not consulted or were inoperable. After the tanks and consumables were serviced the front of the train was then cleaned.

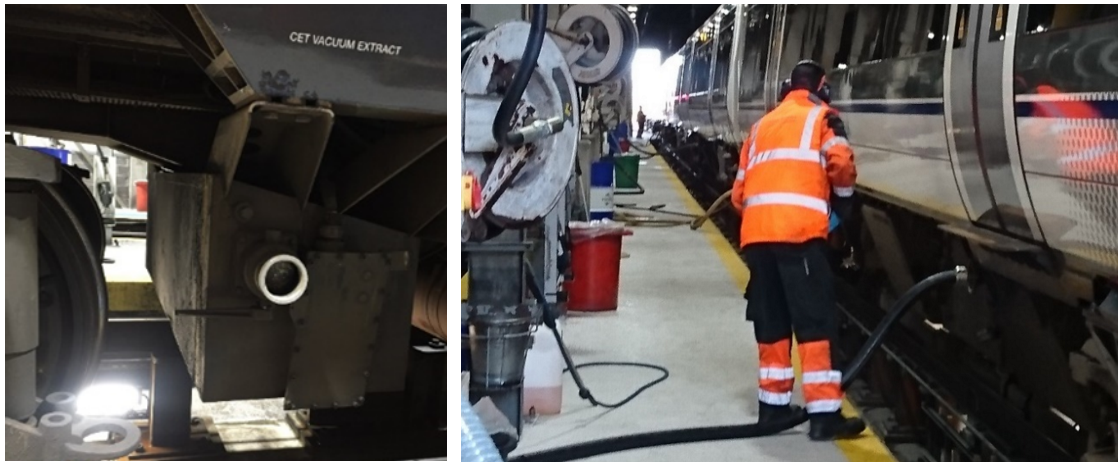


Figure 7-1 Each toilet on the train would have a CET tank (left) installed to collect passenger wastewater. The tanks would be emptied during routine servicing when the train was refuelled elsewhere in the depot (right). Photographed by author.

The solution this project aimed to deliver reflects the original brief set out by the sponsoring firm. Whilst there were stakeholder insights contributed by the author of this study that suggested alternative problems that could be addressed and provided evidence of the extent of the severity of chosen challenge their impact was limited in affecting the direction of the project. However, some of this knowledge was incorporated into how the prototype experiments were conducted and contributed to discussions and plans for additional componentry. The causes for this will be explored in this case study.

The following results show how the artifacts created during the development of the engineering system reflected the needs of those who interacted with them and how this was indicative of the prototyping strategy used by the project. The artifacts include physical prototypes as well as the diagrams and illustrations used to further the development process. Figure 7-2 illustrates how this process of developing the engineering system combined a linear progression from the initial project brief to the technical specifications which would detail how the system would need to be manufactured. The iterative cycle involving the selection and testing of alternative components would only be pursued if the performance of

the chosen part was deemed to be insufficient and would warrant a change. With each change and development of the components that occurred with the test rigs, the system assembly CAD model would be updated. This model also included how the liquid and solid processing components would integrate together, how the train toilet connected to the system and how the system would be housed in a structure that could be installed onto the underside of a specific train carriage.

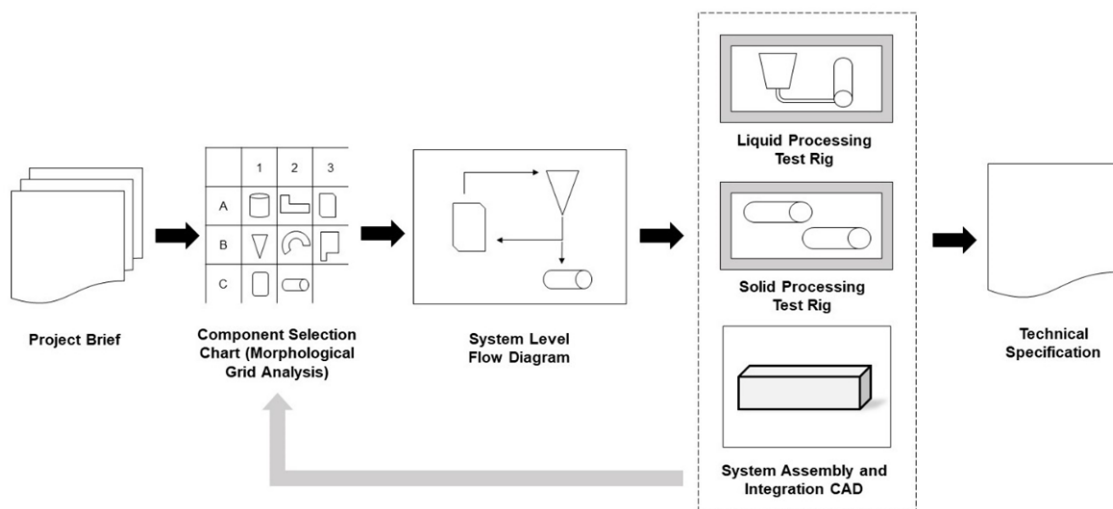


Figure 7-2 The engineering system development project prototyping strategy.
Drawn by author.

7.2 Illustrating a common goal

The extent the project produced diagrams, illustrations and physical prototypes that met the needs of all those who interacted with them was varied. Whilst the opportunities to engage external interests were few, much can be learnt by the extent the approaches used could have supported the creation of these artifacts to reflect their interests. Through examining how the needs of the organisations and the teams within the project influenced the outputs of the development effort, we can identify the extent methods involved contributed to limiting the level of external influence.

The project's first artifact to be shared between both organisations was the system flow level diagram shown in Figure 7-3. This diagram was created by the academic institution to explain to the sponsoring firm how they were going to develop the system showing the readily available parts, shown as images, and the parts that had to be manufactured, shown as text, which would be the responsibility of the sponsoring firm. The parts that had to be produced were primarily for processing the solid fraction of the wastewater whilst the parts for the liquids, whilst involving off-the-shelf filters, had to be adapted to suit the unique characteristics of passenger wastewater and how it would transit through them and around the system. When the diagram was produced, it was perceived to have a positive impact as explained by the system integrator (P3):

“...at the point before this diagram everything was oh I’m going to do this and I’m going to do that ... when you’ve got no boundary or constraint ... you could go anywhere in that void and so by getting [the sub-system developers] to [create the system level flow diagram] it sort of cemented the idea that this was what we were going to aim for and we could slightly adjust this ... it gives the visual aid that everyone can see”

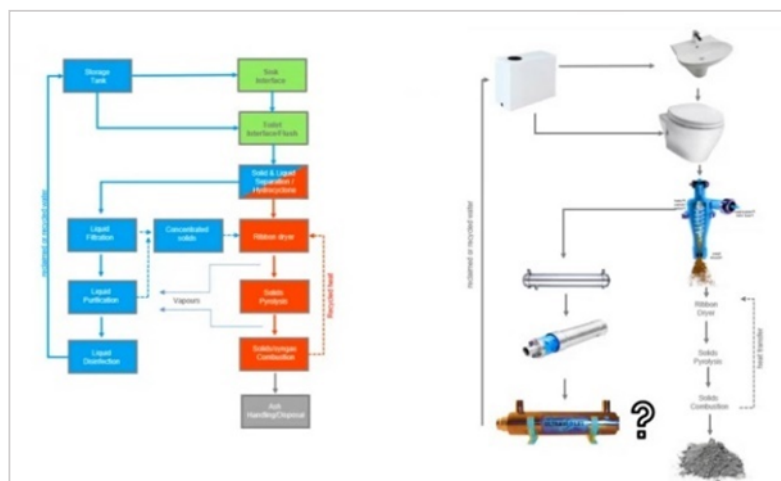


Figure 7-3 The system-level flow diagram of the engineering system. Created by project team.

However, given the role of the individual quoted was to integrate a complex set of components in a dynamic operating environment the creation of this diagram could be seen to be of significant benefit to this aim. When discussing the development process with the project's sponsor (P4) a different assessment of the value was offered:

"... we've got an idea, here's some diagrams, here's some pictures, here's an animation, people will say; oh that looks good, when can we see it, when can we try it? Ah well. So the interest then sort of stalls at that point. Now we can say it's on a train ... we believe that will move it up a notch into being a real product and the next questions we'll face is okay when could it be available?"

This view emphasised a greater importance of producing physical demonstratable artifacts than ones that were illustrative and communicative. As a result, a difference in where the values of prototyping lay began to emerge between the sponsoring firm and the academic institution. Without a shared appreciation in achieving alignment as inferred by the system integrator's comments, the outputs of prototyping activities could fail to represent common interests. This became apparent when discussing why the diagram had not been updated to reflect the need for new components, explained by solid processing sub-system developer (P1):

"... we all had our own ideas on [developing a part to remove foreign objects] ... but then the project was passed so fast we did not think about this, actually we just started focusing on [our own] processing units."

This indicates that forming consensus was considered a time-consuming task that could not be achieved at the required pace of the project. In addition to the lack of value that the sponsoring firm felt was brought to the project by them, this would result in the diagram being deprioritised after the initial success of solidifying the direction of the project. However, despite there being a degree of uncertainty regarding the quality of the water and the potential for water reclaimed from the solid faction to be processed, as signified by the thin blue lines connected the sides and the question mark placed next to the UV disinfection component, this diagram remained largely unchanged throughout the project.

The lack of updates could be explained owing to the unresolved functionalities being located towards the final stages of the treatment process and as such could have been considered to lack priority. However, despite the original aim of the project's process being to create an entire demonstratable system and then swap out parts to optimize it, the diagram instead contextualised where focus would be placed. This concerned sourcing and building parts to achieve the first stages of solid-liquid separation and thermal treatment. Although efforts would still be made to apply the swapping out of off-the-shelf components approach where possible, the diagram did not need to be updated as these capabilities, but not the exact parts depicted, remained the same throughout the project.

The production of this diagram has shown one example from the case that had initially shown a level of success in meeting the needs of a range of audiences. Given that the method in which it was created supported a range of inputs, using similar approaches with future versions of the diagram could have contributed to furthering the level of involvement in the project as this diagram could act a conduit for such interests. However, as the artifact was a diagram and not a demonstratable prototype, the approach used would need to be transferred to this other form in order to maintain the interest of the sponsoring firm. As indicated by the quote from this organisation, outputs were seen as a means of encouraging further commitment to the technology from potential procurement interests rather than as a means to collect information and align goals as had been achieved by the system-level flow diagram.

7.3 Effects of system decomposition

As the project progressed, the approach towards creating outputs changed as a result of the focus being placed on each part of the system and the constraints introduced by the building of the demonstrator. Owing to this decomposition of the system, subsequent drawings and component test rigs would be created for the processing of the solid fractions and the retained liquid of the wastewater individually. This would be accomplished by incorporating the constraints of the demonstrator in parallel to developing the components' internal capabilities to function to enable effective treatment. By doing so, a tension would form as to

the purpose of these artifacts; whether they were to support demonstration or experimentation in the pursuit of a new wastewater processing technology.

In contrast to the system-level flow diagram, the diagrams were produced on an ad hoc basis, interacted with informally and used a range of tools to create, such as virtual whiteboards and hand written annotations on print-outs, as shown in Figure 7-4, enabling the teams to explore their respective system areas in greater detail. However, by doing so the artifacts were only intended for the teams involved in each side of the system thereby excluding the other technical interests and the involvement of the sponsoring firm and system integrator. As both processes were intrinsically connected, when the liquid side would separate out the liquids and the solids, assumptions were made as to the amount of liquid that could remain within the solid fractions. Moreover, transferring liquids recovered by the solid processing to the liquid side represented further evidence of how the two sides were intended to be integrated. These assumptions, however, were unable to be addressed as a result of the two sides of the systems remaining isolated throughout the project.

A more immediate implication of the internal processes being isolated from other stages of the system affected the liquid processing research which began with a recreation of a gravity-flush toilet system to begin testing the efficacy of a solid-liquid separation component. Trains in the target market no longer use this type of toilet instead opting for a vacuum enabled flush. The implications of the influent entering the system under pressure had a severe impact on how these early experiments should be conducted and prompted the first use of the morphological grid analysis component reselection method. As indicated by the picture used in the initial flow diagram, Figure 7-3, the toilet was assumed to function in a similar manner to domestic lavatories, further reflecting the shortcomings of this artifact to demonstrate the knowledge of those who interacted with it who had an awareness of this fact. However, the sponsoring firm was able to source the correct type of toilet which was then used as an integral part of future component and system prototyping.

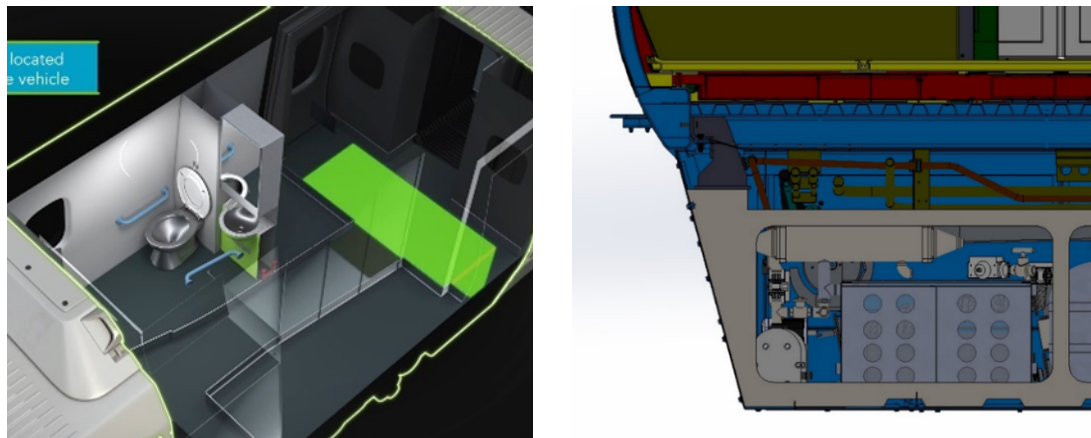


Figure 7-5 Illustrations depicting the position of the system, left, as a marketing video still, right, as the CAD model used for manufacturing purposes. Created by sponsoring firm and project team.

In addition to the required integration of the vacuum toilet, the need to install the system within the dimensional constraints of the underside of the train carriage also prompted a search for components based on their size as the first parts to be tested were chosen without this knowledge. This demonstrated a challenge in finding off-the-shelf components that would prove compatible. Furthermore, the system integrator's influence over the design of the processing component layouts was significant as evident by this exchange during a workshop to discuss alternative components:

System integration developer (P3): *Where you're getting the piping out of the toilet, what angle are you firing it into the top of this [part]?*

Liquid sub-system developer (P2): *At the moment it is very steep ... the angle I'm testing in the laboratory is also [a] very short distance pipe.*

System integration developer (P3): *Because what the train actually [has] is a very shallow angle and it has to go through a 90 degree bend and it comes vertically down into the top of the CET tank.*

Liquid sub-system development supervisor (P5): *We've got two 45 angles in our current set up.*

Liquid sub-system developer (P2): *45 degrees is something the manufacturers recommend for a non-blockage of flow through the pipes. 90 degrees is something that they do not recommend.*

System integration developer (P3): *The problem is particularly how the trains are fit out, we can't adjust that.*

Whilst the CAD drawings of the entire system would reflect the needs of the system integrator to ensure components were being developed to fit, the drawings' constraints manifested their way into how the component test rigs were arranged despite not reflecting the primary needs of the researchers. For example, as shown in Figure 7-6, the test rigs for the prototype components are shown in configurations depicted by the CAD drawings; the liquid processing test rig, shown on the left, depicts the location of the toilet above the system and the width of the solid processing components, shown on the right, were determined by the width of train. These drawings and resulting impact on the test rigs could also be used by the sponsoring firm to track progress and for the academic institution to demonstrate that they were able to meet expectations. As will be explored in the next section, the flexibility for these test rigs to be viewed as representing multiple interests was constrained by the desire for them to prioritise the dimensional constraints of the train. This limited their purpose as being experimental artifacts to aid the development of the fundamental sciences of wastewater treatment and being a representation of the holistic system design process initially intended.



Figure 7-6 The test rigs showing the prototype components for the liquid processing side, left, and the solid fraction processing side, right. Photographed by project team.

Through navigating the constraining demands placed on the researchers to produce working prototypes that support the wastewater treatment experimentation whilst also incorporating the demands for the system to fit within the confines of a train, the artifacts produced began to show a clear departure from the approach taken in the production and sharing of the initial system-level flow diagram. Whilst creating individual drawings and test rigs enabled each team to better represent their specific expertise, the need to incorporate these additional demands potentially limited this affect. This was owing to them being derived not from being able to produce an effective system but one that could fit within a specific size envelope. The decomposition of the system and the lack of a continuously updated diagram that could co-ordinate how both sides of the system would integrate for the purposes of wastewater processing alone further complicated this challenge. As a result, the potential for train-derived requirements to impact the system's treatment performance added a frustration that would be visible in the design of the test rigs and subsequent drawings. As a result, their size and configuration could only be explained in terms of the practicalities of installing the engineering system onto a train.

7.4 Influence of competing internal objectives

As the research teams were both stakeholders in the academic institution, their exposure to the demands for scientific contributions further complicated the ability for the prototyping strategy to be seen as either a commercial or academic pursuit or to define where the overlap lay. Whilst the researchers were willing to attempt to develop a system that could contribute to both contexts, the implications of the need to produce a demonstrator were significant. This was due to the short timeframe confronting the operationally-derived constraints placed on their ability to innovate how we process wastewater. This created further ambiguity as to where their priorities lay and the effectiveness of the outputs as to being seen as both scholarly and practical outputs.

This tension is exemplified by how neither the depiction of how the system would integrate into the train nor the arrangement and sizing of the physical prototype components would reflect the main priority of the wider academic community as explained by the solids processing sub-system developer (P1):

“[the research reviewers] are way more interested in what I get from the analytical instruments, they are way more interested in the analysis of [the system outputs]. Well, at the same time they have been making sure that the prototype is being tested and it's reliable and its operation is ... robust ...”, later adding, “in terms of the operation ... the prototype is doing what we want but it just the scientific side which still needs a heck of a lot of work [such as] the [solid fraction] product analysis ... but this is the difference between industry and academia.”

To address this conflict between interests in the prototyping strategy, whilst committing to the pace at which the project had to proceed, the need for the components to process wastewater specifically from rail passengers was questioned as to being a priority. Instead the use of wastewater from municipal settings or simulant faeces was considered preferable given that these were more readily available. Moreover, the impact of the SARS-CoV-2 pandemic added further rationale for avoiding human wastewater. As explained by the respective researcher (P2):

“... [the project’s supervision] has been pushing me towards getting this pilot scale demonstration to work whether or not you know we test with real train faeces wastewater on the prototype, which will happen at a much later stage ... the immediate action plan for me ... is to get this pilot working first to demonstrate that yes this sort of arrangement technology that we are proposing will eventually be carried forward on trains ...”

However, by considering this approach the test rigs risked becoming less of a scientific object as restricting the use of passenger wastewater could impact the quality of the results. Thereby to avoid this, additional complexity would be created when conducting the experiments as explained by the researcher responsible for the solid treatment process (P1):

“... there might be a chance we make [simulant passenger wastewater] to see if it can mimic the results from [actual passenger wastewater] and feed it into the [thermal processing system] ... which is very difficult I guess, it should be a strict addition of each component within that mixture.”

The importance in using real wastewater, whether from passengers or municipal settings, was further explained by this researcher:

“...Based on [the findings from another project at the centre] ... in terms of knowing that [our proposed thermal treatment process] is now the solution ... if we can combust the product in [a specific manner] ... that’s my only concern that [the wider academic community] says that it’s not combustible it has to be [treated] whereas we’re the only people in the world that are going to combust [a wastewater output in a specific manner] ... and the properties will differ and so if we can ... get the energy out of it, it’s completely neutral ... it’s equal to what we use...”

This evidences a range of needs for the prototypes to serve: it had to be a scientific object that could provide reliable and replicable results, a source of pride for the research team pursuing a different approach to others and, ultimately, a new way of treating wastewater that requires significantly less energy. As the prototypes had a purpose to further a specific field of engineering, the constraints

placed on its development by meeting the practical needs of the rail sector could be seen as responding to a less than optimal application, as the researcher explained:

“...[if installed] on the train [the system] might not be energy efficient because the [faecal] waste volume is very low but if it goes into a household or domestic use for example in Africa where they are using pit latrines ... [resulting in] one place for a community, so the waste volume [generated] is [a lot more] so this process can be [made] energy efficient as well.”

The calorific value of passenger wastewater was an important characteristic for this treatment processes and essential for the prototyped parts to be seen as a means to advance scientific knowledge. Thereby whilst the speed of the project demanded ways of expediting samples to conduct experiments with, if the samples did not accurately reflect the composition of the wastewater that it would be expected to process, the prototypes could fail to be seen in ways they were desired to be by the stakeholders in this particular approach to wastewater treatment. Whilst less pronounced, in discussing this issue with the liquid processing researcher, there was a necessity for passenger wastewater to be sampled for their components to be designed to incorporate the operational needs of the rail industry, as explained (P2):

“...we want to test and see if we can really make the [filters] last long enough and not have to give them a chemical wash more so often because then that would be not very good in terms of maintenance for the railway industry ... and that’s another thing which I don’t really have much knowledge about if the trains would be required to be pulled out of service each time to just to give a cleaning to the [filters] ...” later stating, *“...[the sponsoring firm] was keen to have ... a system that wouldn’t be as heavy on maintenance ... so this definitely has been a point stressed time and again from [the sponsoring firm]...”*

The use of other types of wastewater could therefore impact the accuracy at which the frequency of maintenance would be required. Engineering a filter maintenance capability that was economical and easy-to-use could support the prototypes in their interaction by train service operators concerned with this

aspect. This could demonstrate a flexibility in how the prototypes could be seen as both experimental and a means to address the specific needs of an industry.

However, less clear as to how to demonstrate a capability to a specific stakeholder were the system's ability to meet the requirements of those responsible for testing the quality of the water as further explained by the researcher (P2):

"...the regulations are so diverse and ambiguous at times ... that confuses you and you do not really know which line of treatment you should prefer ... for discharge but being on the safer side and disinfecting the water because it goes into the natural environment. So, things like these guide the regulations and every regulating body does not have the same guiding set of rules..."

The specific nature of the regulations would factor in how the water would be collected, treated and reused within the passenger's immediate vicinity. As guidance was lacking as to how this can be done, firstly to a known standard and secondly in a safe manner, demonstrating or depicting this being adhered to reflected a challenge in how presenting the system as being safe to operate could be achieved.

In attempting to align scientific goals with the potential impact it could bring to the rail industry, the researchers sought to ensure the prototype engineering system could be viewed as an academic contribution to knowledge, a solution that could meet commercial demand and address regulatory ambiguities. However, this required access to wastewater samples and industry knowledge that could add further complexity to the project and potential delays. This would test the commitment the research teams had to ensuring the systems would be viewed as being aligned with industry needs and expectations. As a result, the project adopted a comprise by experimenting with a variety of wastewaters and feedstock and reducing the recycled water quality to be achieved. This aimed to resolve the issue as to whether the water would be safe for hand-basin use, flushing or discharge, the latter being considered during the final stages of the case study, so to ensure the demonstrator could be built and installed on time.

7.5 Engineering for the realities of operational environments

In supporting efforts to align with industry constraints, beyond the immediate concern of the size of the train, the insights gathered by the author in prior studies achieved some impact. Through interviewing senior managers from the rail industry it became clear that the wastewater was both significantly different to what you would expect from municipal sources. This was as a result of there not being any kitchen, laundry or bathroom greywater and the behaviour of passengers resulting in different concentrations of wastewater depending on the nature of the service and the presence of foreign objects caused by accidents or misuse. With these insights, the project team explored ways of collecting samples from the rail context rather than municipal settings to use during their experiments.

Demonstrating that the system could process wastewater from passengers would also result in this being visually apparent in the form of components that could handle the unique challenges caused by passenger behaviour, as explained by the solid processing sub-system developer (P1):

“... one of the foreign objects that I’ve observed with more frequency is anti-bacterial wipes and that does not degrade in the [vacuum toilet discharge] so it does not disintegrate it just comes into the system and so the motors that I have ... are not enough to generate to withstand the torques generated by those wipes in the [internal parts of the system]. Now, in order to overcome this challenge we might need motors with more power or we need a type of macerator...” later adding, *“... even one is going to be damaging to the system.”*

Whilst this could have led to the creation of parts designed specifically for this concern, the direction taken was to continue with wastewater from other sources, simulant feedstock for the solid side of the processing system or to manually remove these foreign objects. As a result this would explain the absence of any aspect of the system’s drawings and prototyped parts that would reflect the knowledge of the train service operators in terms of the causes of blockages that they need to address. Moreover, depending on the power source of the train, the

contents could change owing to how CET tanks services are scheduled in relation to other operating tasks, as explained by the sponsoring firm (P4):

“... because diesels have to come in every day for refuelling anyway carrying out the CET operation is not a major burden because the train has to come in anyway. For [electric trains] the only reason they’re being returned to depots on a daily basis is for toilet servicing...”

This would indicate that samples collected from electric trains could be indicative of longer durations of residence resulting in additional accumulation of solids and decomposition. However, this additional understanding of passenger wastewater would have required further resources and planning as explained by the sub-system developer (P1):

“...there should be a sort of framework for the sampling ... it’s been very difficult for us to arrange sample collection ... there’s a guy who collects and brings it for us but he does not [record] which type of train ...” later adding, *“... we needed more thorough investigation of the types of trains, the frequency of depot visits...”*

As a result the tool that was created, shown to the left in Figure 7-7, to collect samples could be seen to fail to meet the needs of some of those who interacted with it. Owing to the lack of detail of the samples it collects and the additional time and costs required to operate it, it results in being an artifact that could be seen to be largely detrimental to the aims of many who encounter it. However, the implications of designing for the operational realities beyond ensuring the system would physically fit under a train became apparent as a result of the wastewater samples collected from the depots using this tool as explained further (P1):

“...so far [the solid fraction from the wastewater samples] we’ve collected [from the trains] it’s not as much as what we considered for the design outsizing of our tubes ... so we’re guessing that our sizing is even more than what’s currently being generated on the train it can handle and accommodate way more volumes but it’s not happening on the train.”

Therefore, whilst the tool discovered more problems than it solved, it presented an economical way of reflecting the interests of the operators. Although, given

the lack of resources offered in its use, this potentially could have been an indication that whilst it was created with them in mind it did not reflect a significant priority from their perspective.



Figure 7-7 The collection of wastewater samples at a train depot working with a train operating company (left) and the project being promoted at an industry trade show (right). Photographed by project team.

However, using the artifacts as a means to discover new knowledge and by extension incorporate the interests of salient stakeholders responsible for adopting the system was revealed to be one of the driving motivations for developing the entire system so that it could be installed onto a train as explained by the sponsoring firm (P4):

“...we’ve got devices to measure [the power consumption of the system] ... we need to get more information as to how power is distributed on trains ... we found actually we’re taking our DC from the battery and so if when the train’s parked and [the system] is left on it’s draining the battery ... you only find these things out when you put it on the train ... and this is only one particular [type of train] you’ve got diesel multiple units, you’ve got electric multiple units, I don’t know how they generate the power and how it’s distributed ...”

How the outputs of the project could be used to engage stakeholders in the operating environment reflected an additional aim to achieving demonstrable

performance, however, incorporating findings of prior engagement proved challenging. This was evident by how the type of train service could affect the characteristics of the wastewater and the actual design of the components to treat them. However, how this would be incorporated into the manufacturability of the system proved challenging as made apparent by the intentions of the solid sub-system developer (P1) when explaining design decisions with the system integrator (P3):

System integration developer (P3): *... does the [thermal treatment component] need to be [a multiple part] design like this, what was the basis for it?*

Solid sub-system developer (P1): *...[the author of this study] told me he had an interview with one of the [national] operators and he has mentioned that they have a big challenge with the long journey trains on which the toilets CETs fill up very fast ... I was thinking about accommodating short journey trains and long journey at the same time with one [thermal treatment component with multiple parts], however, I think a single [part] can accommodate both of them...*

System integration developer (P3): *On that basis if through the testing it showed you didn't need [multiple internal parts] you could reduce it down to a single one?*

Solid sub-system developer (P1): *Yeah*

System integration developer (P3): *... If the [thermal treatment component] became a single [internal part] that is the same as [another thermal processing component] ... you'd only need to produce this part four times, you'd produce that part twice and you'd produce what would be shorter tube once ... that would reduce the number of parts you'd have to manufacture...*

Solid sub-system developer (P1): *...the volume is very [alternating] so on a train that has less people defecating on the toilets, I'm afraid that the materials would be spread along the tubes and then they will reside in the gap between the [internal part] and the [outer part] and so no material would be conveyed into the [thermal treatment component] until it gets very full...*

This phase of the project suggests potential implications from the interview study of Chapter 6 could have been realised if it were able to have incorporated a greater extent of external knowledge. The diagrams and artifacts produced could have potentially shown how an awareness of the technical demands and constraints that existed onboard the trains and in the wastewater tanks were being addressed. However, as explained by the developer of the solid processing side of the system the speed of the project reduced the time available to make such accommodations. If an alternative approach were taken this could have aided in producing outputs that could be more likely be accepted by the stakeholders in the industry as they could potentially have been able to see their concerns mirrored in the specific components developed for the system.

7.6 Integrating stakeholder needs

Whilst potential was shown for the project's artifacts to reflect the needs of stakeholders, the source of their input was limited to the insights provided by the author's earlier studies, specifically from Chapter 6, and documentation, from water and emission regulators. As such if these developments were pursued and stakeholders were able to engage with the artifacts directly the extent to which they would see and understand their needs being met could provide significant validation to the prototyping strategy used. However, in their present form during the project, if these engagements took place, findings from these prior studies suggest that due to their needs being absent from the design of the system, such as to prevent blockages, this could reduce whether the solution would be considered desirable in their operational contexts.

Although visits to the laboratories, or sharing progress through other means, did not occur during the period of this case study, so to elicit industry feedback with an explicit referencing to the project, in contrast to the study of Chapter 6, the project was promoted during rail sector trade shows that facilitated to a degree this external engagement. This offered the opportunity to observe how the project was being depicted to commercial audiences. However, these specific types of opportunities were few due to the impacts of the pandemic preventing in-person events from occurring. For one of the events, shown on the right in Figure 7-7, a

poster was displayed with an illustration of trains next to stop signs and exclamation marks with the following tagline written by the sponsoring firm:

“Are you losing money while your trains are otherwise engaged? [Project name] Keeping trains regular.”

The event also played a video of the system being compared to current solutions attempting to convince viewers of the operational impediments emptying CET tanks can cause to train operators. This video was later redone during the project from a 2D animation style to a 3D animation style, shown on the left in Figure 7-5, whilst the content remained the same, albeit with greater detail given to how the system appeared and would function. This latter version accurately depicted the arrangement of the system as developed during the project, featuring the recognisable parts of both the solid and liquid treatment functionality. However, during the events the author did not receive any feedback regarding the illustration, tagline or video that could support whether the solution would meet the industry's needs. This could have been an indication of the extent of interest or the lack of understanding of the apparent issue the system was attending to address by the visitors to the stand.

As the prototyping strategy focused exclusively on one potential solution, driven by the objective to build a system that could be installed onto a train, activities that would allow for other concepts to be tested and iterated upon would be at odds with this objective. This could be due to how they may have resulted in solutions that would not be in this “plug and play” form and as such the data collected during the case did not contain evidence of this occurring. In reference to the prior studies, specifically Chapter 5, discoveries that indicated that alternative framings could lead to significantly different forms of solutions, and potentially address salient needs unmet by the approach taken, were unable to be exploited. Where iteration, instead, occurred was at the component level, using the adapted morphological grid analysis approach, to identify, test and replace parts from a predetermined selection of possible candidates based on specific functionality. This was the primary purpose of the workshops held during the project. However, through conversations with the research teams, such

approach was described as challenging to embrace, beyond the lack of suitable parts, due to the lack of opportunity to scientifically assess why a component failed and what would be required for it to succeed.

As a result, the prototyping strategy would be limited in incorporating substantially new framings that occurred at the system level, i.e. beyond installing a unit on a train to process passenger wastewater and address the challenges of operators caused by the collection of wastewater and supplying freshwater. Nor could the strategy achieve this at the wider operational environment level, including interventions in the depot and or wastewater infrastructure to address the opportunities across the rail sector in how they manage all forms of wastewater and freshwater usage. Such changes to a project's direction could introduce a lack of internal support from stakeholders in available project capabilities as the solution could fail to utilise these skills or provide sufficient evidence within the available time to support a change in focus.

However, this prototyping strategy could have potentially been applied to any of these alternative framings and produced prototypes that could have succeeded in demonstrating an alignment with the interests of its industry stakeholders. In these cases, such a project would have been based on an evidenced understanding of the needs for a specific solution which would be evident in how the desired outcome emerged through stakeholder analysis and engagement prior to the project commencing. When insights began to emerge through the studies conducted by this author it became apparent that there were other outcomes that could hold greater potential, however, the strategy was limited in its ability to adapt to these findings.

Furthermore, the chosen prototyping strategy could have been seen as preferable given the increasingly restrictive access to the project requested by the project sponsor. Should greater engagement have been supported, the effects of the pandemic and the potential delays in producing prototypes, which could have been caused by material shortages due to the UK's exit from the EU, could have contributed to limiting these opportunities, although this was not referred to during the interviews or discussed with the author as a participant in

the project. However, this reflects how the adoption of a particular strategy could be the result of either the preferences of the organisations involved or the socio-economic implications beyond their control.

The confidence the organisations leading the project had in pursuing the framing they chose could be explained by the sponsoring firm's background in manufacturing CET tanks and their desire to exploit existing knowledge. This concerned how to fabricate metal components and "plug and play" their new solution so to easily replace existing tanks. The expertise of the academic organisation was also heavily indicative of the types of systems they would be capable of developing and as such the chosen framing can be understood if the desired outcome for both was to further and exploit their own capabilities. The prototype strategy was unlikely to have been chosen so that other desirable outcomes could be considered. This was evident by the extent the activities and artifacts involved limited how stakeholder input could be incorporated, despite their interests and the potential implications on the design of the system being known. The resulting prototype, therefore, displayed significant expertise in wastewater treatment and metal fabrication. However, as a reflection of the demands of the industry to which it would serve it could be considered to require greater engagement and integration of its stakeholders. This could help ensure the engineering system succeeds at meeting expected levels of adoption as a result of addressing their challenges in the most innovative way whilst being manufactured to the highest standard.

7.7 Summary of key findings

To understand whether and how engineering system development responds to the needs of its stakeholders, a case study was conducted of a project during its earliest stages starting at TRL 1. The key findings are first listed below, before being expanded upon, outlining how and why the extent was limited:

- The use of a project process that focuses on enabling components to change is unlikely to be able to adapt to changes required of the purpose of the system itself.

- A means to discuss the design of a system can help align internal stakeholder interests, however, this requires continued updating and inclusion of external interests to effectively reflect their needs.
- The decomposition of a system during the start of a project can deprioritise responding to the requirements for new capabilities or addressing improvements for the entire system.
- Evidence of external stakeholder needs requires significant internal support so to ensure their implications are fully realised.
- Stakeholder involvement could prove to have greater implications on a system's design beyond enabling access to an operating environment.
- A timely completion of a project and a commitment to a particular field of science can reduce the likelihood of responding to external interests if they require additional or alternative technical capabilities.
- Prioritising manufacturability and integration whilst fundamental science is still being pursued can result in conflicting aims for the prototypes and reduce the opportunities for additional input from external stakeholders.
- Promotional material for a system may prove less effective than directly engaging with stakeholders so to assess interest in the system.
- Measuring progress based on technical achievements alone can overlook the extent the system is better reflecting the needs of stakeholders in its intended operating environment.

The single case, concerning a rail passenger wastewater treatment system, initially demonstrated conditions that could make the case atypical or extreme. These atypical elements concerned the level of expertise and resources available. As such, projects that involved less of these could potentially have struggled to reach the same results. However, as the findings demonstrated, the nature of the case proved more in line with that expected from prior studies in literature.

Why the project pursued approaches towards development that were known, albeit in different product contexts, to limit stakeholder involvement could be

explained by how the project was heavily influenced by specific interests. As evident by the sponsoring company's need for a working prototype and the academic institution's focus on new treatment processes and using existing components where possible, the opportunity for wider stakeholder input was limited as this appeared not to be necessary for these approaches. Although the creation of a system diagram evidenced multiple interests, producing a shared artifact, this was achieved only by the internal teams and individuals involved in advancing the technical capabilities. Moreover, the shift towards producing prototypes and drawings that reflected fewer interests became more evident as the project progressed.

The decomposition of the system into isolated components and sub-systems for each team to develop led to further challenges in responding to the needs of the operating environment. This was due to the operational focus being placed specifically on the size constraints which complicated how the novel treatment processes were being made to work and how the team could respond to other needs. Furthermore, as the teams began to focus on delivering technical advancements in their respective areas, how they would affect each other's treatment processes, split between solid and liquid respectively, became less apparent and difficult to determine. The priority being placed on how each side would instead fit rather than work together therefore shifted the focus away from considering the implications of the findings from the wider stakeholder context on the design and purpose of the system.

Attempting to navigate the immediate academic and commercial needs of the project introduced further factors limiting the opportunities for external stakeholder engagement. Although the awareness of external interests included findings from prior studies, the collection of wastewater samples from the operating environment, that revealed problematic foreign objects, and potentially relevant regulations and standards, responding to these inputs proved to contrast with some of the objectives of the developers producing the system. As the system could, potentially, process any type of wastewater and operate in any type of environment this was a source of tension throughout the project. This occurred

between the need to develop a new treatment process and one that was suitable for the specific demands and constraints for how it would be applied to the rail sector.

The priority placed on manufacturability, committing to technical capabilities of the system and a short timeframe, significantly restricted the development decisions of the team. As such, alternative or additional functionalities to address the needs that were known not to have been factored in at the start of the project were unable to be considered. Although the sponsoring firm led engagement of stakeholders through artefacts publicising the potential commercial benefits of the system, these were unable to provide a substantial opportunity for stakeholders to either support or challenge the assumptions made as to their needs. Furthermore, the impact of the SARS-CoV-2 pandemic and the UK's exit from the EU could also have played a part in reducing the opportunities for greater stakeholder engagement and responsiveness during the project, however, there was little evidence to suggest these played a role.

The study revealed that this project could be viewed as a success as there was little evidence of the desire to increase the flexibility and inclusivity of the project processes. This success would stem from the technical achievements that were made rather than the knowledge that the system was aligned with the needs of the industry, a known challenge in transforming technical development practices. This phenomenon has now been shown to occur despite a project's capability to collect, analyse and disseminate stakeholder insights concerning what could constitute a successful engineering system if the development methods are not intentionally chosen, or adapted, to integrate them.

8 DISCUSSION

8.1 Introduction

This chapter presents a discussion on the findings of the prior studies through a series of contributions to knowledge. These further our understanding of the factors that could affect an engineering system aligning with the needs of the industry in which it will operate. This lack of alignment has been identified as a contributing factor for new products to fail to reach expected levels of adoption, due to a lack of understanding of stakeholders in a market (e.g. Cooper, 2019). However, studies that explore why this occurs and the methods that can be applied to reduce the likelihood of this outcome have tended to focus on products that do not have the technical complexity and diversity of stakeholders as that of engineering systems, such as consumer products. When compared to other forms of CoPS, stakeholder engagement has been shown to have positive impacts on complex infrastructure projects (e.g. Lehtinen, Aaltonen and Rajala, 2019). As for small-scale engineering sub-system CoPS, these are yet to be studied as to how they address additional challenges in achieving similar supportive outcomes due to their market orientation and lack of specific stakeholders, such as end-users or the general public.

To address these differences, the following contributions involve methods that have been adapted so to be more exploratory. They demonstrate effectiveness in engineering system development so to enable researchers and practitioners, firstly, to understand the complexity of their stakeholder landscapes. Secondly, these contributions help explore the problems that can be evidenced to be salient and, lastly, they show how engagement could be conducted during a project to address the possible causes of misaligning technical capabilities with stakeholder needs. This especially concerns cases whereby the system contains a high degree of innovation and therefore potential equivocality as to the nature of problems to be addressed and the effectiveness of their solutions. The implications for practice are then discussed so that these contributions could be

applied to support the development of engineering systems in general and passenger wastewater processing technology in particular.

This transferability is derived from the similarities of the case with other cases a reader may be researching (Piekkari and Welch, 2018), such as similar stakeholders, approaches to new product development processes or the technologies involved. As such, the results chapters themselves could form a contribution owing to how the studies could be interpreted differently due to the specific interests of future researchers. However, in order to offer a means to guide this transferability, the following contributions could be utilised by scholars studying similar phenomena who are looking to apply experimental designs using multiple cases. The conclusion in Chapter 9 lists several factors to support this effort in case study sampling. In contributing a definition for engineering system stakeholders, the application of stakeholder theory can be expanded to increase its relevance in this context which could form the basis for these further studies. As such, the contributions also concern how the results from each chapter were arrived at. This demonstrates how these methods, that are either adapted or applied in new contexts, could be applied further in a similar manner, as well as the findings themselves, which could be seen to be generalisable to an extent to support future passenger wastewater system development research. How contributions to knowledge have been formed by answering each research question, and the chapters that contain the results that support them, are summarised in Table 8-1.

Research Questions	Contributions to Knowledge	Relates to Chapter
<i>RQ 1. Who are the stakeholders involved in the adoption of the engineering system in this research context and</i>	Proposed method for identification of stakeholders using a literature review	Chapter 4
	Defining the term “engineering system stakeholder”	Chapter 4

<i>how do they relate to its development?</i>	Demonstrating the effectiveness of problem framing with a document analysis	Chapter 5
<i>RQ 2. How can stakeholder input influence engineering system development, and how is the value of that input understood and captured through the engagement methods applied?</i>	Demonstrating the effectiveness of requirement elicitation with semi-structured interviewing	Chapter 6
	Proposed quality criterion for requirement “alignment”	Chapter 6
	Proposed TRL level “zero” for establishing stakeholder support for a system through identifying desired outcomes	Chapter 7
<i>RQ 3. What are the challenges and opportunities for advancing stakeholder engagement during engineering system development?</i>	Proposed adoption of the boundary object concept to address limitations of prototyping strategies in responding to stakeholder needs	Chapter 7
	Practical implications of the above contributions to knowledge	Chapter 8

Table 8-1 Research questions and their corresponding contributions to knowledge derived from the results of specific chapters.

8.2 The system, the sector and the complex product or system (CoPS) category

Whilst the engineering system explored in this thesis demonstrated characteristics of being a CoPS, there was also evidence that supported how certain engineering systems could be a unique form of CoPS in comparison to larger-scale infrastructure-related innovations. As theorised by Hobday and Davies (2008), CoPS are categorised by high levels of innovation and the involvement of multiple organisations that contribute specific expertise. In the case of engineering systems that exhibit these characteristics, the implications of the radical nature of the innovation, whereby there is no prior generation to improve upon, nor established markets, could explain the challenges in identifying the identities and needs of potentially affected stakeholders. Such conditions would be unlikely to occur in infrastructure-related contexts given the established nature of their stakeholders. This furthers our understanding of how disruptive innovation in engineering systems, as studied by Dedehayir, Nokelainen and Mäkinen (2014), differs to mass-manufactured goods by suggesting that it is not only the maturity of the technology that needs to be established to a higher degree but the relationships with these non-technical interests in parallel to the development of the engineering system itself. For radical CoPS innovation, this may require identifying the needs of the stakeholders that could be affected by, and affect, its development even though their relationships, and potentially their roles themselves, are yet to be established. As a result, this case explored in throughout this thesis could be used to explain the challenges small-scale engineering sub-system CoPS project initiators face in building supportive stakeholder landscapes.

As for whether findings of this thesis can contribute to understanding if the development of engineering systems is capable of adopting NPD processes applied to mass-manufactured goods, and stakeholder analysis methods used in relation to larger infrastructure CoPS, how the central case relates to other cases of engineering system development could provide an answer. Whilst the case was initially considered to have an atypical element to it due to the stakeholder research that was conducted, and the involvement of two organisations with a

high degree of expertise, the case concluded reflecting known organisational challenges in adopting these product development approaches, whereby technical development efforts fail to be sufficiently underpinned by an understanding of market needs (e.g. Cooper, 2019; Markham, 2002). The initial expectations of the case were to provide evidence as to the unknown challenges in succeeding with them once adopted. As such, the resulting case could be considered common rather than atypical as initially considered if compared to existing literature.

A more common case that reflected expected norms would be unlikely to reveal how and why stakeholder engagement can be effective and can be maintained whilst prototyping, for example. Whilst the case study was initially thought to be potentially demonstrative of this uncommon phenomena of succeeding in this effort, the influence of the methods and approaches towards technical development observed proved to challenge this initial interpretation. This, therefore, reflected the known challenges in NPD literature whereby non-technical and external interests are less considered during the earliest stages of a project. As a result, the following contributions support gaining an understanding as to why this can prove challenging to overcome rather than why a engineering system was able to incorporate stakeholder insights and how this could be applied in further research and in practice. If this were the case, this could have also shown how an atypical case could also have been considered an exemplar (Flyvbjerg, 2006).

Without the findings from the document analysis and the interview study, a conclusion could be drawn that engaging stakeholders during a project's front-end would not support the early TRL activities. The wider transport sector's lack of references to operators and other commercial stakeholders revealed during the review support this assumption. However, even though the latter findings that challenged this occurred early in the case, and could have potentially affected the project, the case itself exhibited a common approach to TRL use. This was due to the focus on achieving TRLs as they were defined, rather than respond to the implications from this stakeholder research. An atypical case, therefore, could

have demonstrated how the TRL framework can be applied whilst supporting the need for greater involvement of non-technical interests.

As such, the extent to which this thesis offers generalisable findings from developing an engineering system with stakeholder engagement could be limited by the factors that may influence this practice in any engineering system context, factors of which are listed in the conclusion in Chapter 9. The following contributions to knowledge will support further study into addressing these factors. However, by themselves, these contributions further our understanding of engineering system development practice by addressing the methodological and theoretical gaps in supporting stakeholder engagement in becoming as established in literature as it is in the context of mass-manufactured products, software or larger-scale engineering projects.

Collectively, these contributions advance our understanding of engineering system development projects by evidencing how technical capabilities can be engineered whilst the interests of stakeholders are being shown to support other solutions or framings of the problem. These contributions advance our ability to ensure salient stakeholders are identified and their needs are elicited in a manner such that practitioners can respond to any differences between them and the needs that are assumed to support a proposed solution. These contributions extend the application of methods from other forms of product development projects and demonstrate their applicability to this context despite the lack of an end-user role. Furthermore, these contributions extend the application of theory involving how prototypes of engineering systems are conceptualised and how and why different types of stakeholders influence them to affect the development of the engineering system.

8.2.1 A method for stakeholder identification

To study an entirely new engineering system within a specific operational environment could require overcoming a lack knowledge of who the salient stakeholders are in its development, adoption or operation. This reflects the conditions of an engineering system being the first of its kind within an industry and as such prior knowledge of these stakeholders and what their roles and

relationships are could be uncertain. In contrast to consumer goods, which have established stakeholder roles regardless of the novelty of the product, such as that of an end-user, the related roles and responsibilities of an engineering system could be unique to the system and industry itself. This could be due to the technology involved, its commercial and operational purpose and regulatory implications affecting multiple organisations.

The identification method applied in the stakeholder analysis in Chapter 4 incorporates the Hobday (1998) definition of CoPS so to identify its complex organisational surroundings. Using the sources of these identifications, analysis can be conducted as to their potential interest and influence over the solution at any part of its maturation to inform the desirability of the engineering system or inform further research involving these stakeholders. However, a comprehensive analysis of stakeholder characteristics may be limited by insufficient evidence that can support claims of urgency or legitimacy, for example, as modelled by Mitchell, Agle and Wood (1997) to support identification. As such the adapted review method demonstrated in Chapter 4 contributes primarily to expanding the identification aspect of stakeholder analysis methodologies, by focusing on how to reveal the organisation type and region and inferring their interests and influence.

As a formalised addition to identifying stakeholders, by adapting a systematic literature review, the approach interprets articles as cases of stakeholder activity (Denyer and Tranfield, 2009; Watson et al., 2018), offering an alternative to starting with an approximation of who the stakeholders are and then, if required, snowballing to collect additional identities (e.g. Bryson, 2004). This method also addresses the potential inaccuracies of using predetermined roles, as the stakeholder landscape could be significantly novel or specialist for generalised descriptions to be applicable (e.g. Martín, Reinhardt and Gurtner, 2016).

As such, extant approaches to identification could be more suited to studies that build on established stakeholder landscapes in fields that have known interests and influences, as is evident in land-use development studies (Borrini-Feyerabend and Brown, 1997; Reed and Curzon, 2015) and could support the

larger-scale forms of infrastructure-related CoPS. This approach was used for the specific region focused on by the case central to studies in the 5th, 6th and 7th chapters through the application of an onion diagram method proposed by Alexander and Robertson (2004) that consisted of predetermined roles, albeit ones that were modelled on software development. However, for the purposes of understanding a wider industrial context, as was the aim in Chapter 4, the use of snowballing through document analyses and interviews could lack suitability should the research also involve analysing how different applications reflect different stakeholder landscapes. For example, as shown by this thesis, this could be in terms of different transport modes or regions, hence the decision to adapt a systematic literature review method that would provide this level of comprehensiveness.

In relation to existing calls for methods that focus on identification, adapting a literature review offers an alternative approach contrasting the need to identify stakeholders with a known role and responsibility, reflecting the software development context, to meet an objective that requires specific types of responses during engagement. These approaches reveal how the study of requirement engineering adopts a positivist view supporting how stakeholder identification could lead to assigning roles to preferable subjects (Pacheco and Garcia, 2012) rather than identifying individuals and organisations first and then their roles, of which this proposed method demonstrates. Through enabling identities to emerge from the publications that concern a specific engineering system, further analysis can be conducted that draws on a constructivist approach, more commonly referred to during methods for participation (Reed et al., 2009), into the initial identification stage. This approach aims to ensure the resulting stakeholder landscapes are formed by the people and organisations that populate them rather than by focusing on finding suitable individuals to fill predetermined roles, a challenge when both may not yet be known in great detail.

The lack of certainty as to stakeholder identities at the start of an engineering system project can be further compounded by an equivocalness of the stakeholder term itself. As proposed by Miles (2017) the stakeholder term and theory is contested; “who is a stakeholder?” is a question that does not have a

definitive answer shared by all scholars. This is due to the nature of the studies that involve stakeholder analysis and the specific attention paid to their roles, responsibilities and relationships having a specific research aim, therefore a stakeholder could be identified in a variety of ways. For the purpose of this thesis, who would be affected by or affect the creation of a new engineering system was the criteria to be analysed as a stakeholder and as such a goal to identify specific types of identities with specific types of relationships and characteristics was not the intention. However, existing knowledge of these stakeholders could suggest that the landscape is actually known and as such an extensive and comprehensive identification study may not be required thereby supporting a narrower view of which stakeholders to then study.

As an exploratory method, the adapted literature review method proposed by this thesis can be applied with descriptive, instrumental or normative justifications (Donaldson and Preston, 1995) for the study of stakeholders in an engineering system that involves radical innovation. The delimiting scope being that all stakeholders identified will have a relationship to this type of system, that these identities would be that of organisations rather than individuals and that there will be sufficient commonality to group organisations. Once identified the method can then apply the thematic analysis techniques used across literature to explore how these stakeholders affect or are affected by the engineering system.

The method proved successful in reviewing a diverse body of literature that could form a source for comprehensive stakeholder identification. Through demonstrating that the same types of organisations could appear across different applications of an engineering system, this method supported the grounds for comparison between significantly different literature domains and types of publications. As such, through exploring how passenger wastewater is managed, regulated and studied, specific applications of the same technological process were found to receive greater research and development attention than others. This enabled an analysis of how the same roles in different settings affected or were affected by an engineering system. These findings could justify the decisions for further research and where a NPD project could focus on meeting the needs of a specific operating context. However, such a review is dependent

on these stakeholder roles, and the engineering system they affect or are affected by, being sufficiently similar across industries. A lack of similarity could result in challenges and opportunities for engineering system development being limited to specific applications. Furthermore, equal volumes of literature of these comparable applications would be preferable so to understand how their different operating contexts affect them. Although, as demonstrated by this thesis, this difference in volumes can form a finding in itself.

8.2.2 Defining the term engineering system stakeholder

In responding to claims that to further stakeholder theory, greater emphasis needs to be placed on how scholars are using the term and its theoretical implications in relation to their field (Miles, 2017). The following definition is proposed for an engineering system stakeholder and implies its theoretical normatively-inspired instrumental justification:

An organisation which could be affected by an engineering system's market introduction and/or be able to affect its prior and ongoing development and the extent of its adoption as a result of its commercial, operational, including technological, and/or regulatory implications.

This definition was derived from each type of organisation identified within the studies of this thesis and aims to encapsulate the comprehensive variety of interests and the extent and the natures of influence that emerged, whether positive, negative or neutral. The definition adapts the Freeman (1984) stakeholder definition by contextualising it within the organisational objective of producing an engineering system and ensuring it meets expected levels of adoption. This activity could be affected by either private or public organisations and as such studies that apply this definition would be exploring how engineering systems are affected by, or can cause affect to, a variety of stakeholders. This contrasts an approach to research that could use a narrower definition of the term to analyse how a specific organisation affects or is affected by an engineering

system. In doing so, these studies could exclude the potentially greater influences of other interests.

The importance of the word *could* in both being able to cause affect or be affected is due to how a stakeholder may not be affected by the engineering system but could affect its development, adoption or operation. This is evident by roles played by regulators in the development of passenger wastewater engineering systems, and vice versa. Furthermore, the lack of a predetermined interest or a known *stake* reflects how these organisations may be unaware of developments but could still affect the organisation that had developed the engineering system when they become aware of their stake. For example, by supporting or inhibiting its adoption reflects the characteristics of uncertainty and dynamism known to occur in a stakeholder landscape (Aaltonen and Kujala, 2016).

The flexibility in defining the relationship between the engineering system and each stakeholder allows for situations where this may change over time, in terms of being supportive, for example, and could include multiple types of interests. This was evident in the commercial, operational and regulatory stakes held by transport service providers in the adoption of passenger wastewater systems and their gradual diminishment of support for installing them as seen in the marine and rail sectors reflected in the results of Chapter 4 and Chapter 5. As such, this term offers a means of defining stakeholders that encourages scholars and managers alike to consider the diversity of stakeholder roles and potential uncertainty in their relationships towards a new engineering system that could influence its success in reaching expected levels of adoption.

8.2.3 Exploring engineering system problems

In referring to the results in Chapter 5 and Chapter 6, this thesis demonstrated the extent of the difference between a “presented” problem derived from a project brief and a “discovered” problem derived from stakeholder documents and interviews. Getzels’ claim that finding problems could be “more significant accomplishment than the production of solutions to presented problems” (1979, p.170) reflects the potential implications of addressing the discovered problems in these chapters. Through applying the frame creation model (Dorst, 2015) and

conducting semi-structured interviewing, discovering these problems can also form an instrumental justification for stakeholder analysis. Aiming to achieve an alignment between the purpose of an engineering system and stakeholder needs can not only reveal the differences between these problems but also the formulation of requirements so to increase the level of interest in a solution.

This approach has shown how problem exploration methods in engineering practice that focus on a specific technical challenge could be overlooking salient sources of knowledge that can inform an understanding of the problem itself. As detailed by Murray (2019) engineering practice can often involve examining the same information but in greater detail or from different technical perspectives, a process reflected in the industry standard 5 Whys root cause analysis technique (Public Affairs Division, 2003) which could explain the approaches taken during the case study in Chapter 7. This contribution has shown that this analysis could benefit from the frame creation model using a comprehensive approach to synthesising documented information to significantly evolve a problem's definition. This concerns both how the problem is understood and the types of solutions that could be proposed.

Referring back to the wider context of the case study and how the solution to remove toilets by operators could have been arrived at through using a root-cause analysis method: to eliminate problems caused by providing toilet facilities on board trains, remove the toilets. However, this obvious solution demonstrates how the problem was both narrowly defined and the exploration process involved lacked external and salient additional knowledge. For example, by removing the toilets this would restrict the use of the service by those who considered them essential, which, if known or responded to, could have enabled the operators to arrive at a different understanding of the problem and eventual solutions. Similarly, other insights that were discovered later, such as the prevalence of blockages and foreign objectives, also supported reframing the problem to be addressed. By failing to do so could then introduce further paradoxes that otherwise would not have been necessary to resolve, such as having to affect train operations and passenger behaviour so that the system would not cause further problems.

In applying stakeholder-centred problem exploration methods, a contribution has also been made to the analytical logic used in engineering practice. Whereby existing methods rely on inductive analysis to propose potential explanations as to how a solution could lead to an observable outcome or could lead to a clearly defined intended result, the frame creation model method would instead identify desirable outcomes and synthesise derived solutions through abduction. This method caters for this additional knowledge that is collected rather than formulating technical specifications of solutions that may not be grounded in data explaining how their outcomes would be preferable.

An abductive approach, however, contrasts the tendency for an immediacy of solution development evident in existing engineering practices according to literature (Murray et al., 2019) and shown in the approach witnessed during the case study. This preference to use inductive or deductive logics to focus on a solution suggests that there could be some fundamental cultural challenges in adopting this approach in both academic and industrial settings. This can be inferred by the lack of studies that apply abductive reasoning to engineering practice and the infancy of the problem exploration field itself (Studer et al., 2017). However, whilst these logics are essential for later stage development, the success of these outcomes are dependent on the problem being defined in such a way that if solved would address the most significant concern. As this outcome needs to be determined beforehand, i.e. how the system will solve a problem and why, it cannot be arrived at through deduction or induction. An outcome arrived at through deduction requires an understanding of the inputs, such as the proposed system in operation, whilst an outcome needs to already occur for an explanation to be proposed through induction, activities that would therefore form these later stages of development focusing on refinement.

Whilst pursuing problem exploration through framing would require further research to validate if the proposed solution actually provides this outcome, these subsequent steps would call on the inductive and deductive methods demonstrated in literature as being widely used. However, now that the problem has been thoroughly analysed as being defined in a manner that, if solved, could provide the most benefit, this further development could produce a significantly

more impactful solution. This approach also addresses the difficulties in using inductive and deductive methods when the desired outcome lacks clarity. This could be a result of the solution being technically highly innovative and so prior knowledge is lacking to inform inductive or deductive research. Through hypothetically framing the problem using available evidence of a problematic situation that is intended to be addressed, this clarity has been shown to increase, as evident in Chapter 5. As a result the proposed solution presented in that chapter could develop with greater alignment between what is needed and what will be developed, ensuring that assumptions of its commercial value, operational benefits and regulatory risks are validated.

Applying this approach to problem exploration contributes to furthering an understanding of how the “fuzzy front-end” of innovation (Khurana and Rosenthal, 1998) could be executed and with a focus on an engineering-intensive environment. These methods helped address the challenges in ensuring a project commences with influence from both technology-orientated and market-orientated interests, as called for by Cooper and Sommer (2018). Overcoming the lack of the latter has been evidenced as being instrumental for successful front end activities as studied by Eling and Herstatt (2017). Applying the frame creation model in Chapter 5 which incorporated the analysis of documents and texts from industry, government and media sources, and later analysing transcripts from interviews in Chapter 6, ensured the widest scope of external input could be collected to support this aim.

However, the thesis has shown that awareness of these interests may not be enough to influence the direction of a project should they provide evidence of needs unmet or support alternative conceptualisation. Whilst literature has identified how organisations succeed in navigating the fuzziness through having access to external knowledge, how this knowledge is shared within the organisation through “boundary spanning” behaviours of individuals has also been theorised to be beneficial (Reid and de Brentani, 2012). Due to the lack of equivalent conditions during the project, as a participant-observer, the author was not expected to influence the direction of the project at the conceptual level, rather identify potential regulatory risks that the solution could enable operators to

overcome, as such the need for this approach was not immediately clear at the start of the project. This reflects a phenomena that has received little attention; how is the need for extensive exploration of a problem determined and how to ensure the confidence in a proposed solution is grounded in such analysis. If the latter is evident without the former then the former could be unlikely to occur nor would external knowledge be expected to be widely shared and acted upon.

When access to this external environment became limited and the involvement of the team in learning from the insights reduced, laboratory work, predicated by the presented problem, detailed in the project brief extracts in Chapter 3, became prioritised as evidenced in the case study of Chapter 7. This exploratory knowledge acquisition activity could be then be interpreted as reflecting the “turbulence” described by Safayeni et al. (2008) that could impact short-term project performance, justifying why the definition of the problem remained constant throughout the project so to maintain momentum. As such why the fuzzy front-end may not be seen as beneficial, rather a potential distraction, refers back to the need to study the culture of a project and how value can be placed on exploratory approaches towards understanding the nature of the problem being addressed.

Other concerns such as managing intellectual property (Ellwood, Williams and Egan, 2022) and control over the perception of the project (Schrage, 1996) by the organisations leading the project could have also become potential moderating factors over the author’s ability to further explore the problem. This could explain the hesitancy in supporting the pursuit of fuzzy front-end activities. In practice, it appears that significant oversight may be needed over the information that is brought into a project as a result of sharing information that is generated within it, such as the definition of problems and proposed solutions. Adopting a new framing of the problem could have resulted in challenges in how the project would balance conveying confidence in its solution whilst justifying changes in how the problem was being described, for example.

Overcoming inhibitory practices protecting commercial perception and intellectual property is an aspect that has yet to receive much scholarly attention in

engineering system contexts. In referring to how one multi-national organisation achieves this in relation to consumer products, the use of a separate brand name to test problem frames and solution forms for home appliances enables them to mitigate against failed exploratory products impacting the reputation of the company (Power, 2014). However, such an approach could prove challenging to apply to engineering system contexts due to the significantly higher levels of technical uncertainties and safety risks involved. As such, whilst organisational stakeholders may have similar stakes to those developing consumer goods, how problems can be more flexibly explored could require greater transparency. This could occur between those involved in developing and eventually operating the potential solution with the knowledge that the problem is also simultaneously being explored.

8.2.4 Communicating with stakeholders

To study how exploring a problem can aid the development of a project team's understanding of the industrial challenges its engineering system is intended to address, this thesis has contributed to the study of requirement elicitation techniques. By demonstrating the effectiveness of using a semi-structured interview approach, contributions have been made in validating the extent of an engineering system problem frame, further refining existing requirements and eliciting new requirements that would be unmet by the chosen development direction. This contribution specifically addresses the need for requirement techniques that incorporate the complex multi-organisational realities of engineering system development (Hobday, 2000). Moreover, the implications of the type of engineering pursued being considerably more diverse in application than software, the dominant focus of requirement engineering, as argued by Agouridas et al. (2006), is also addressed. This methodological contribution provides an empirical study of the implications of combining requirement-focused enquiry with human-centred approaches commonly found in design practice, rather than engineering, demonstrating how a similar approach proposed by Hehn et al. (2020) can be applied.

However, much could be learnt from stakeholders prior to conducting interviews with them. As was evident in the findings of the document analysis in Chapter 5 and that which could be inferred by the stakeholder identification by literature review in Chapter 4, validating the problem frame and assessing the extent of interest in passenger wastewater systems was shown to be achieved with a certain degree of empirical depth. The subsequent interview study in Chapter 6 provided actual empirical evidence in support of these findings and provided further insight that was lacking from these publications. However, texts were the only sources of certain requirements, such as industry standards and water regulations, and the frequent mentioning of particular publications in the identification study helped to emphasise the influence certain stakeholders could have in this manner. This was evident with, for example, the International Maritime Organisation (IMO) through their MARPOL Convention 73/78 Annex IV discharge regulation being widely referred to as a primary rationale for developing treatment processes for cruise ship and river boat applications as revealed in Chapter 4.

The lack of regulatory texts to inform requirements, such as the qualities of solids and emissions for the proposed system in the case study, however, could be addressed by the subsequent interviewing. Although, as was evident in the interview study of Chapter 6, such knowledge could also remain unknown but its acquisition could be seen to be sought by the regulatory agency, as evident in the discussion of possible permits or exemptions for an unknown hazard. As such, requirement elicitation efforts were found to be limited by this reality that not all knowledge currently exists to be elicited, a potentially under researched phenomenon unique to highly innovative physical engineering systems. In an effort to address this, the development of the wastewater sample collector could be seen as an example of how requirements could be “co-elicited”. The case study demonstrated that the characteristics of the wastewater, whilst assumed to be significantly different to municipal sources, could not be elicited at the level of detail from extant literature, documentation or interviewees suitable for the engineering of treatment systems, such as the for production of simulants. As such, the knowledge gained through characterising the samples, and through

exploratory and collaborative research in general, would be novel to both the project team and the stakeholders involved.

As requirement engineering study is driven by ways of meeting quality criteria, these criteria have been shown to be addressable by the interview approach taken. For example, “traceability”, so to maintain the link between the stakeholders engaged and their role, responsibilities and the statements they contribute that support a specific requirement, was demonstrated by how the study can contribute to achieving “grounded” requirements by quoting specific stakeholders (Würfel, Lutz and Diehl, 2016). Furthermore, the prior stakeholder identification studies, including the literature review and the following document analysis, in Chapter 4 and Chapter 5, contributed to addressing the “completeness” of requirements, contributing to the gap in methods identified by Pacheco and Garcia (2012). The approach to sampling adopted for the interview study in Chapter 6 interpreted completeness as creating a comprehensive and diverse appreciation of salient needs. This reflects the successful cases shown by the breadth of participation in ACSI and HELCOM, the initiatives that brought together stakeholders in the Alaskan Coast and Baltic Sea respectively, reviewed in Chapter 4. However, this approach contrasts Pacheco and Garcia’s (2012) interpretation of completeness as seen from a technical detail perspective, whereby techniques that are shown to be thorough in examining established needs, such as structured interviewing, are considered preferable for this aim (Coulin and Zowghi, 2005). As the case study in Chapter 7 involved a greater uncertainty as to these needs and required capabilities than a conventional software project, achieving completeness could be viewed as a means to ensure the resulting solution would reflect as much knowledge that could be acquired. This contrasts an approach towards completeness that concerns what is known to be acquirable, adding further emphasis to the importance of this criterion as interpreted in the review by Khan et al. (2022).

8.2.5 Proposing an additional quality criterion for requirements

As both problems and solutions can be explored simultaneously during a semi-structured approach to elicitation, the extent an understanding of a problem and

the capabilities of a solution align within a requirement should be a salient criterion to form an assessment of their quality. Incorporating “alignment” as a quality criterion builds on the findings of Burnay et al. (2020) and their definitions of quality stemming from the individuals themselves, such as a respondent’s creativity, objectivity and steadiness, rather than specifically how their responses relate to the need of the solution being developed. By adding a contextualising criteria relevant to both problem and solution, for example, in referring to the responses given in the interview study in Chapter 6, the requirement *when the type of train service changes, or in the event of a change in the concentration of freshwater, the system should be able to handle different loads and compositions of wastewater, so that the type of service or amount of liquid fraction does not impact its performance* could be considered aligned as this need was in scope with the aim of the project this study contributed to. Furthermore, the requirement is steady and traceable, as it would be unlikely to change and the requirement could be traced to specific stakeholders. The extent that this requirement is aligned could also suggest priorities for future development. This would ensure that the system can process the expected variety of passenger wastewater volumes and chemical characterisations. If the project teams assumed the amount of wastewater and compositions to be more consistent then this would result in a lack of alignment. This would occur between the activities of the project and that which could lead to an engineering system that would prove reliable and safe, thereby supporting a change to these activities.

However, whilst increasing alignment would reflect commonality with managing other criteria, how an organisation ought to respond to a misaligned requirement reflects a potentially differing approach to managing other lower qualities. This is because this could be indicative of a gap between the needs of the stakeholders and the technical development capabilities of the organisation and their proposed solution. Therefore, remedying this outcome could prove more complex in comparison to addressing the technical incompleteness of a requirement, for example, through follow-on structured interviewing of persons with domain expertise (Dick, Hull and Jackson, 2017). As demonstrated by the findings of the interview study of Chapter 6, regarding the approach taken by the project to

address blockages contrasting the requirements to avoid them, statements that were not in scope of the project could be considered misaligned but would require significant change to the direction of the technical capabilities of the system. However, as they reflected saliency towards the needs of the stakeholders, if they were not addressed the project's output could be in jeopardy of failing to ensure the engineering system meets expected levels of adoption.

As such the elicitation method applied in Chapter 6 and this contribution to quality could support practitioner decision-making as to whether to attempt to align with unmet stakeholder needs. Alternatively, a focus could be given to a specific set furthering the use of a stakeholder analysis to identify the most interested and powerful. By providing visibility to decision-makers of misaligned requirements, which could otherwise be overlooked if more structured approaches to elicitation are applied, potential areas of future misalignment could surface. In referring to the case study in Chapter 7, and the findings in Chapter 5 and Chapter 6, a degree of impending misalignment between the project team and the needs of the system's stakeholders could be seen on multiple fronts. However, as the evidence in the earlier chapters demonstrates the types of solutions that could prove more aligned, such as ones that can avoid toilet blockages, future developments of the system could address this concern by incorporating such functionality if not prioritising it as the main purpose of the solution.

8.2.6 Proposing an initial technology readiness level

Findings from the review of stakeholder theory, engineering system NPD practice and the studies of a specific project have indicated a salient activity of technology development is yet to be adequately formalised. As is evident with the readiness level frameworks, monitoring maturity provides a means to assess progress and ensure expected outputs are delivered prior to commencing latter stages, whether this is in the form of the established TRLs or the more specific variants. However, achieving a maturity of stakeholder awareness and analysis for the purposes of validating a proposed solution or technological direction does not specifically feature in any of these technology-orientated readiness levels. Whilst stakeholders are the focus of the societal readiness level (Innovation Fund

Denmark, 2018), from the perspective of the general public and its relation to technology, how to integrate this framework with the TRL and others could prove challenging due to their significantly different areas of focus. As what is expected at each level could be incomparable, integrating readiness levels is further complicated by the need to form consistent understandings of what output should be expected of each stage across multiple projects. This discussion proposes an initial TRL stage that is dedicated to this purpose that would encapsulate the activities of the fuzzy front-end and help to ensure the activities of the subsequent levels progress with a validated understanding of their alignment to external, and internal, interests. The proposed level, Technology Readiness Level Zero (TRL 0), is defined as:

TRL 0: Stakeholder Support for Desired Outcome Established

This definition synthesises instrumental justifications for applying stakeholder theory to create supportive stakeholder relationships (Donaldson and Preston, 1995) with the abductive approach to problem framing driven by identifying desired outcomes (Dorst, 2015). Its proposed description:

Stakeholders in the scientific research context are identified and engaged with so to evaluate the extent of alignment between their desired outcomes. An outcome that is desired and shared by both internal and external stakeholders is sought. This outcome refers to intermediary stages of development as well as how the technology is to be applied once operational and proven.

Proposing a single level rather than a variation of the existing framework reflects findings of the current use of the TRL as being widespread, as such its continued use could be supported, and to avoid the challenges in integrating such a variation. However, the TRL itself can encounter difficulties stemming from

organisational frictions regarding how to ensure levels are accurately assessed and review outcomes are utilised (Olechowski et al., 2020). As such, this could be overcome by a level that supports stakeholder engagement so to understand the desired outcomes of each internal interest. The aim would be to form a consensus as to the direction of the project, such as by forming a shared framing or vision for the project, and the implications for the expectations of each TRL output. Concurrently, or beforehand, this outcome would be informed by, and aligned with, the needs of those responsible for adopting the solution and supporting its development during the latter TRLs. The use of semi-structured interviewing and problem framing should be a central activity that enables this TRL to achieve useful outputs. However, as stakeholder interest and influence could be dynamic and uncertain as theorised by Aaltonen and Kujala (2016), whether this level is assessed and conducted once or continuously and iteratively in conjunction with each TRL stage calls for further study as to how this factor affects the effectiveness of its implementation.

The extent the activities of the TRL 0 were evident in the case study and could form the basis of more intentional activities appeared in several ways. In considering the development of the test rigs, the progressions through the TRLs, if assessed, for both the solid and liquid processing sub-systems appeared to diverge. This could have been due to the differing priorities of the researchers and supervisors themselves to manage the rates of progression and when to begin processing real wastewater, however, a lack of a means to ensure outputs from one formed the inputs of the other was also apparent. By implementing the TRL 0 further at the start of a project, prior to commencing the construction of the test rigs, coordination could have been increased, building on from the success of the initial system-level flow diagram. This would have been a desired outcome of both teams, so to ensure ways of remaining in alignment, i.e. the inputs of one would be, or be informed by, the outputs of the other so to ensure a desirable level of water reduction in the solids, for example.

In another form, as a participant-observer, the author contributing the findings of the interview study demonstrates TRL 0 being conducted in parallel with the later

stages as they progressed. This approach would aim to support maintaining alignment between internal and external interests and to attempt to address the inherent limitations of linear progression through iterative validation of each output. However, as will be explored in the next section, the extent to which a prototyping strategy is able to incorporate initial and ongoing findings from the wider stakeholder landscape could also determine how successful a TRL 0 implementation could be and any attempts to increase, or maintain, alignment.

8.2.7 Towards prototyping strategies for engineering systems with stakeholder engagement

Findings from the case study in the prior chapter have contributed to furthering the conceptualisation of how stakeholders' interests could be incorporated throughout the continued production of physical artifacts. These findings support how, as boundary objects, technical drawings (e.g. Henderson, 1991) and prototypes (e.g. Rhinow, Köppen and Meinel, 2012) face challenges in maintaining "interpretive flexibility" by building upon how this aspect can be both expanded or narrowed across illustrative and constructed artifacts. Whether it be a diagram or equipment used for experiments, such as the wastewater sample collector, a trade show event poster or a rig for testing prototype components, each artifact indicated how the types and method used to create them had implications for the extent these boundaries remained effective in conveying meaning to each respective stakeholder. For example, the CAD model and illustration of the system integrated into the train's structure conveyed the interests of the sponsoring firm and the system integrator. These were further reflected in the sizes of the prototype components. This boundary would remain consistent across all instantiations of physical artifacts and depictions of the engineering system. If they failed to reflect how the system would form part of the train, such as the diagrams produced by each research team, the objects, if interacted with, could be less likely to be interpreted as signifying this interest was being addressed. The implications of boundaries needing to exist across multiple forms of objects represents an additional complexity to the study of engineering systems that are affected by and can affect multiple stakeholders.

With this multi-form boundary object appreciation, the findings further supported how engineering system NPD projects can produce dynamic artifacts that change overtime, rather than be intentionally static. This contrasts the nature of museum exhibits which were originally conceptualised as boundary objects by Star and Griesemer (1989). As such, this finding supports the theorization that boundary objects can also be considered “epistemic” as proposed by Ewenstein and Whyte (2009) as they will embody increasing amounts of knowledge with each modification made to them.

However, when the objects become static or fail to depict the changes in other objects such as the case conducted by Carlile (2002), whereby updated drawings were essential to convey progress in reducing the number of parts in an assembly, the objects begin to lose the integrity of their boundaries. This was shown in the case study of Chapter 7 in the form of the system level flow diagram, albeit as a result of a gradual disengagement of its creators rather than the inherent difficulties of keeping it updated. The adoption of virtual whiteboards, however, was indicative of the latter challenge being addressed in the context of the development of individual components. The lack of wider involvement was evident in the condition of the system level flow diagram towards the end of the case study as it had not been updated. The need for additional steps that could avoid blockages from occurring and how the quality of water would be assured so to be reused as indicated by the chosen parts were not depicted. As a result, if this drawing was interacted with by any stakeholder during this period it would struggle to accurately illustrate the team’s awareness of these concerns nor how other interests were affecting its development.

Furthermore, this temporal aspect was evident in how boundaries could gradually become more dominant. The increasing constraints of the operational environment being introduced into the experiments impacted how test rigs would be constructed, the components they would use, rendering others redundant, such as the toilet and solid-liquid separation parts. This was also evident in how the maximum sizes, preferred configurations and manufacturability had to be factored into the prototypes. Whilst some of these constraints were incorporated

into the initial design and selection of components, these needs became increasingly more influential in directing their continued development, a dimension of boundary object conceptualisation that has also seldom been studied revealing its relevance in the context of managing stakeholder influence.

Whilst the findings offer limited support for what constitutes a successful boundary object in the development of engineering systems, there were indications that this could be a result of artefacts being produced with the most flexibility in their interpretation, reflecting extant studies. By considering the needs of those interacting with them, similar results could be achieved, for example, as evidenced by the collaborative effort in an agriculture project studied by Klerkx et al. (2012) that attempted to unite a group disparate local, governmental and commercial interests. The boundary objects in the passenger wastewater system project of this thesis demonstrated success in this regard but primarily within groups of shared interests, such as the teams responsible for each side of the system, rather than across, or beyond, the organisations involved. However, one example of multi-organisational boundaries concerned the equipment that was created to collect samples. This enabled the research to proceed with greater accuracy as to the composition of the wastewater the system would need to treat, thereby maintaining boundaries in evidencing science-led engineering. This equipment could also have been seen by the train operating company as evidence their needs were being integrated into the system. As the project would involve treating their specific type of wastewater, they would therefore be established as a new boundary.

The extent boundary objects are able to achieve being understood and reflect the needs of those they address could also be determined by the processes used to create them. Whether to support an organisational culture or as a reflection of unintentional limitations, for example, concerning the inflexibilities of digital tools for spontaneous and collaborative interaction (Henderson, 1991), an explanation for why boundary objects fail could be given by the chosen file format, physical materials and access constraints. As evident by this case study, the extent to which a boundary object could intentionally strengthen or weaken certain sources

of influence from those who interact with them appeared to be an intentional management approach. The culture of the organisations involved would influence the ways in which the objects were created; for example, the use of particular methods that did not invite interaction could be considered as part of the norms of restricting the ability for decisions to be made and to control the direction of a project. For example, this was reflected by the test rigs being designed to be interacted with only by each team developing them, whereby lower fidelity prototypes could have potentially invited wider participation and reflect a more inclusive culture of engagement.

This analysis contributes to prototyping literature evidence that stakeholder engagement during testing for technical performance, as detailed by Camburn et al. (2017), and to meet operational and regulatory constraints are not mutually exclusive. This supports the approach proposed by BenMahmoud-Jouini and Midler (2020), whereby prototypes could be created for specific audiences; ones that enable the technical research to progress for predominantly internal interests, and ones that explain how this is being achieved for external interests such as future operators and regulators. The challenge would then be to ensure alignment between the versions created in tandem, so that both are accurate representations of the current state of technical development. Moreover, insights gathered by the non-technical prototype would need to inform technical decisions and vice versa. Such an approach could increase the influence of stakeholder insights that do not directly support the technical direction of an engineering system NPD project through the creation of prototypes of alternative solutions.

Whilst this approach could have potentially resolved the inflexibility in the prototyping strategy chosen in the case study, how the strategy would be implemented would also need to be addressed. Instead of a planned and sequential process, iterative and adaptive facilitation of the prototyping process, whereby prototypes are produced using incredibly low-fidelity techniques that are used by both the technical developers and the external interests (McGowan, Bakula and Castner, 2017), could prove instrumental. The importance of educating those who will be interacting with them to understand the value lies in

the concept rather than the execution, or that a specific hypothesis is being tested that does not relate to the visual appearance, could sustain this approach and address concerns about perception and confidentiality. However, as demonstrated in the case study in Chapter 7, this approach would contrast with the desire to present an outward display of capability, such as the realistic animation of the system and the polished trade show presence. This evidences how this practice observed by Schrage (1996) still remains a potential obstacle limiting opportunities to gather insights from stakeholders who could interact with such artifacts.

Whilst in literature Agile methods are encouraged as a means to remedy this through higher frequency testing of gradually increasing fidelities of prototypes (de Borba, Trabasso and Pessôa, 2019), the dominant application of this approach to consumer and digital contexts reflects a significant gap in knowledge as to how this can be executed across engineering system contexts. This study has contributed to this field by evidencing that this may only be part of the challenge, given that this approach was not attempted in this case, but rather the established build it fully first and then demonstrate it approach. Therefore, how to adapt prototyping strategies in literature to this context would be reliant on projects effectively identifying the comprehensive nature of engineering system stakeholders and elicit requirements that are analysed to align with their needs so that we are then able to cater for the iterative development processes, such as through a dedicated TRL stage. However, by adopting the boundary object concept to any artifact that is produced, regardless of the development approach, prototyping decisions could be taken by the individual researchers themselves as to how the prototypes and drawings could better communicate with audiences beyond their immediate teams. Once this approach is considered more desirable, producing “protocepts”, as proposed by Cooper and Sommer (2016) that emphasise the underlying concept, could then be pursued. This could ensure both technical capabilities and commercial, operational or regulatory-focused concepts are developing in tandem demonstrating how Agile prototyping can be adapted to engineering systems.

8.3 Implications for practice

The following sections propose how these findings can address the challenges of adopting a normatively-inspired instrumental approach towards stakeholder engagement during an engineering system development in practice. The implications concern both the specific nature of the engineering system explored in the case study and possible ways in which these findings can be transferred to other contexts; through practical methods and interventions to project processes.

8.3.1 Developing a passenger wastewater system for the transport sector

The development of engineering systems, that share a common purpose across similar industrial applications, could benefit from being informed as to how their respective stakeholders differ. This would concern their approaches towards how these engineering systems are operated, regulated and in contributing towards the overall commercial performance of their respective industries. If a technology is in its earliest stages of development, this awareness could contribute to identifying an application that has a more supportive environment. For example, in reference to the central case of this thesis, the review in Chapter 4 found that an wastewater system developed for the aviation could benefit from being aligned with their sustainability initiatives and that the system's research teams could receive adequate access to their facilities or operating data. Alternatively, a technological starting point could be derived from understanding the challenges currently faced, in a specific application, that could contribute to increasing adoption if addressed. Here developing systems that are cost effective and reliable to operate could address the needs of seaport and train depot operators respectively if they seek to construct their own treatment facilities. In the cases of seaports, the treatment processes would need to process wastewater with high volumes of salinity and, in both cases, emerging contaminants of concern.

However, applications that are shown to be more widely published than others may not necessarily equate to greater industrial interest. This was evident in the review in Chapter 4 showing how publishing was dependent on the role public bodies play in providing funding and regulatory support. The involvement of

transport operators in sustaining this research, as shown by enabling access to their facilities, vessels, and vehicles, could be a more reliable indicator. The lack of this occurring was due to the development of the systems proceeding with little involvement of those who would be immediate beneficiaries but would be essential for determining the extent to which they positively affect their operations. Therefore, stakeholders more directly involved in the development of passenger wastewater systems may have little influence over its developmental direction, whereas those that do, such as shown by these public bodies, may have little involvement in its development. This is a particular concern involving systems in the sea travel sector which have received significant interest from both public and academic stakeholders but have demonstrated little sustained interest originating from commercial stakeholders involved in their operation. Identifying how the treatment of passenger wastewater could result in improved profitability, for example, could serve as means to address the apparent need for regulatory incentives.

However, in other applications public sector influence has been shown, in reference to the findings of the document analysis in Chapter 5, to extend beyond the norms of improving operational environments. For example, in the case of the UK rail sector, government agencies and departments played a role in potentially disincentivising system development due to what could appear to be lax governance through the use of the D2 exemption, despite the adverse working conditions caused for trackside workers. Understanding how a passenger wastewater system may affect influential stakeholders in determining policy can add further insight into the potential for new systems to be widely adopted when their political implications are addressed. The use of regulatory frameworks to affect an engineering system's adoption in response to the influences from the industry and local communities has been shown to prioritise the former over the latter. Although whilst the D2 exemption issued by the UK government prioritised industry, in Chapter 4, cruise ship legislation introduced by the Alaskan government restricted operations without such systems, thereby prioritising local coastal communities.

Identifying regions and applications, whereby the same stakeholders have both significant involvement and influence, would be ideal for the development of passenger wastewater systems. However, they proved to be few, although campaign groups that advocated for changes in operational practices could be considered an exception. An example of their influence shown in Chapter 4 was their impact in increasing the adoption of wastewater systems onboard cruise ships along the Alaskan coast and in the Baltic Sea. However, the success of advocacy could be regionally dependent, as seen with the case of the trade union in the UK in Chapter 5 being unable to influence policy-makers to end track discharge. Furthermore, whilst airport operators had a prior commitment to sustainable practices, as shown in Chapter 4, this stakeholder could be considered to be both highly involved and influential but provide limited support for specific research. As a result of their alignment with research projects initiated by academic institutions into the effectiveness of their existing wastewater recycling systems this may not extend to the development of entirely new technology. As for the academic institutions themselves, further shown in that chapter, their extent of involvement and influence can range significantly, from laboratory-based explorations into fundamental science, using simulants, through to actively researching the operational environment to inform regulations, as a reflection of their connection to public bodies such as funding agencies and government programmes, all influenced by region. Other stakeholders, such as national standard organisations and independent laboratories, appeared to be supportive of, rather than leading, this effort. Gaining this understanding of the level of influence and interest, and where this interest is focused, of stakeholders in the processing of passenger wastewater will contribute to practitioners identifying partners in their region who could prove instrumental in advancing their technology.

The pursuit of engineering new treatment processes is just one of the practices that could be affected by these implications in gaining an in-depth understanding of stakeholder landscapes as shown through the use of the adapted literature review method in Chapter 4. Policy-makers could infer potential relevance in how a sector can be regulated more consistently as well. They could ensure, for

example, seaports are equipped with the means to collect wastewater from vessels, and that vessels have the necessary tanks to retain it and airports recycle a minimum amount of wastewater and continue to improve upon their L/passenger index. The governance of train and depot operators could align with either of these modes. Moreover, lessons could be learnt from the approach taken by the UK government that failed to support the adoption of such systems by the rail sector which could lead to the questioning of the benefits of their regulatory approach, as detailed in Chapter 5.

As a form of CoPS, the development of passenger wastewater systems will most likely need the support from multiple organisations encompassing public and private interests. Combining international governmental collaboration to harmonise regulations with efforts to increase awareness of freshwater depletion and wastewater valorisation in the transport sector could contribute to this effort. Exemplar initiatives such as HELCOM and ASCI could provide the framework for non-sea travel modes to follow. However, so to contribute to achieving a faster adoption of the required engineering system and regulatory compliance, if the latter exists, represents an opportunity for private operators of airports and airlines to build upon recent advancements. This could demonstrate that such initiatives need not be government-led and that public funding support and further research could be targeted at smaller operators, a stakeholder that was missing in the reports and studies focusing on airports.

8.3.2 Applying “Technology Readiness Level Zero”

How a comprehensive stakeholder analysis and subsequent engagement could occur during a NPD project can be determined by how TRL 0 is pursued. As a singular stage, the level could embody the fuzzy front-end with the specific aim to identify opportunities and develop a concept that is aligned with the relevant stakeholders’ desired outcomes at the start of a project, contributing to incorporating Khurana and Rosenthal’s (1998) fuzzy front-end activities into the TRL framework. By doing so, this would enable TRL 1’s observations of basic principles to be informed by an appreciation of the outcomes desired by stakeholders in a particular scientific context; reflecting conventional front end

innovation practice and answering a call as to how conducting fundamental science could incorporate “opportunity identification” (Eling and Herstatt, 2017).

Alternatively, the level could be revisited continuously throughout the project to ensure alignment is being maintained whilst navigating the uncertainties and equivocality inherent in significantly innovative projects. As stakeholders may not yet have the knowledge to provide definitive answers as to their needs, they could require ongoing engagement as they learn more about the challenges they are facing whilst the project identifies desirable technical capabilities. This approach appears to be supported by the speculative statements given during the interview study in Chapter 6, as to how to improve the rail sector’s wastewater operations, and the activities in Chapter 7, concerning the exploratory characterization of passenger wastewater.

Revisiting TRL 0 could also be described as an iterative approach reflecting the dynamic product development NPD variation whereby the product concept is proposed to be continuously matured as well as the product itself (Ottosson, 2004). As such the intensity of iterations could reflect the extent of innovation, illustrated in Figure 8-1. The more knowledge that may exist outside of the organisation the greater the need to continually engage the stakeholder landscape which could potentially ensure such knowledge is acquired. This also reflects how the incorporation of Agile methods is proposed to advance NPD Stage-Gate processes whereby iteration between external and internal interests could be planned in accordance with the level of uncertainty in needs and requirements (Cooper and Sommer, 2016). Less innovative projects could therefore require fewer revisits to TRL 0 as an incremental improvement is sought.

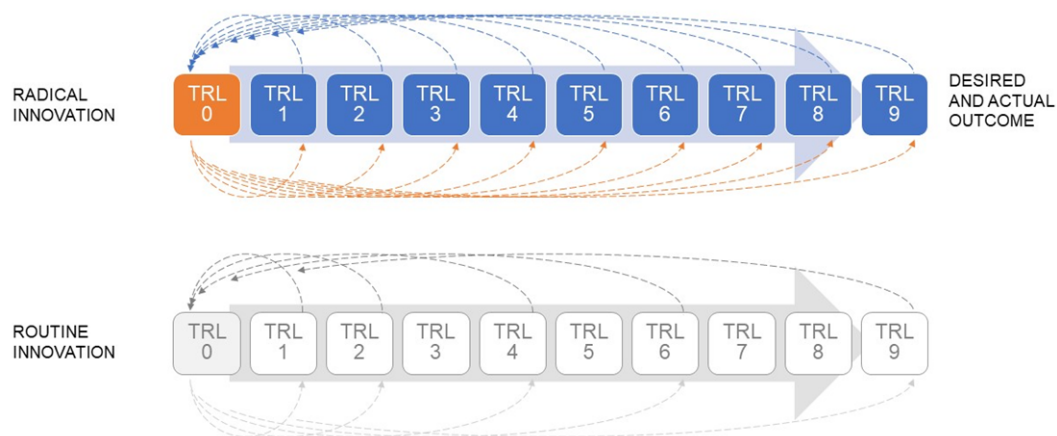


Figure 8-1 Iterating between TRL 0 and subsequent TRLs, or conducting a singular TRL 0, could depend on the extent of innovation with the aim remaining to ensure the outcome is desired by both internal and external stakeholders. Drawn by author.

8.3.3 Principles for implementing TRL 0

To aid the activities that would be undertaken whilst pursuing TRL 0, a set of principles is detailed that adapts the stakeholder integration model developed in the context of medical devices. Martín, Reinhardt and Gurtner's (2016) "Identify, Interact and Integrate" model broadly captures the necessary capabilities required for successful involvement of stakeholders that lead to positive outcomes for all organisations involved. However, due to the model's emphasis on barriers and success factors, the practical implications in terms of methodological approaches to development are not significantly considered. Furthermore, because of the body of literature that contributed to its synthesis exclusively drew on medical device development, the complexities of an engineering system, in terms of stakeholder diversity and product capabilities, was not central to the model and as such does not directly address these concerns. The following principles describe the importance of ensuring awareness of the stakeholder landscape throughout a project. So that any new

roles and changes to existing ones are detected, a continuous analysis of the desired outcomes and the stakeholder landscape is proposed so to increase the effectiveness in identifying whether these outcomes align with the most salient interests. The development of a prototyping strategy that ensures stakeholder needs guide the technical decisions that are taken during the project could be aided by adhering to the following principles:

1. Identify the stakeholder landscape surrounding the engineering system
2. Engage the most salient stakeholders that could be affected by its operation
3. Collaborate using a prototyping strategy focused on reflecting their needs

Applying these principles during the TRL 0 stage, or throughout each of its iterations in conjunction with each latter level, could ensure that the stakeholder landscapes are fully populated and reflect the current state of influences and interests. Any further analysis of the needs of the industry, its regulators and any affected societal concerns could be made with the findings produced from adhering to these principles. Incorporating semi-structured interviews during engagements will help practitioners and scholars alike remain cognizant of the different priorities and interests of stakeholders, including themselves. Maintaining this approach whilst stakeholders interact with prototypes and other developmental artifacts could ensure the greatest amount of external knowledge is accessible during the project. Once these insights are gathered, signs of potential misalignment between the desired outcomes of these stakeholders and the organisations leading the project could be responded to by the latter with greater confidence as to how further technical development would lead to delivering a more successful engineering system.

8.3.4 Applying a stakeholder-engaged prototyping strategy

As an example of an early stage NPD project, the engineering system case study demonstrated limited success in stakeholder involvement, however, the causes

could be inferred so to provide the following recommendations with practical implications:

- Keeping shared technical diagrams up-to-date
- Creating diagrams that illustrate the industrial operation as validated by external stakeholder interests
- Adopting digital tools and practices that support both internal and external interaction
- Ensuring constraints are justified by the desired outcome determined by external stakeholder interests
- Justifying a change in development direction as a result of the implications of stakeholder-elicited constraints
- Surfacing differences between internal interests so to contribute to aligning and sharing development priorities
- “Co-eliciting” requirements for novel technical capabilities from operational environments through collection and testing with stakeholder expertise
- Ensuring prototypes or visualisations are understood by external stakeholders as to how they contribute to developing, rather than demonstrating, a desired outcome

These recommendations distil the findings of the case in Chapter 7 that indicated how stakeholder involvement from both internal and external perspectives was affected by the methods to produce the various artifacts during the prototyping strategy. A number of these pointers, if actioned during this case, could potentially have aided internal cohesion and maintained a shared understanding of the goals for the project. One example from the above recommendations *surfacing differences between internal interests so to contribute to aligning and sharing development priorities* could have supported the creation of prototypes that were effective research tools for wastewater treatment and could also further explore the needs of the rail sector. This could have aided overcoming the conflicting

aims of the prototyping strategy to both contribute to fundamental science and reflect a commercial application.

Whilst these pointers focus on creating a comprehensive stakeholder engagement approach, rather than prioritising speed, in the production of a demonstrator, if executed successfully, this could potentially lead to a quicker time-to-market. This would be the result of avoiding costly reworks and the resulting delays of incorporating stakeholder demands that could have been known earlier in the project. This could be caused by early opportunities to highlight the potential for this to occur being missed, thereby failing in incorporating the recommendation *ensuring constraints are justified by the desired outcome determined by external stakeholder interests*. If costly and complicated technical constraints are pursued that might not be in the interests of these stakeholders, then this could be a significant cause for why a project may need to later readdress these decisions. The findings in Chapter 6 indicated that the emphasis placed on keeping the system within a certain size limit, detailed in Chapter 7, could be one such constraint that if achieved would not address the issues that were revealed to be of a higher priority. Moreover, nor would such constraint be necessary if the system were to be installed on the ground or made mobile such as being installed onto a truck or trailer.

These recommendations aim to contribute ways of demonstrating how implications from this case build on those from literature, which support the early alignment of technical capabilities with stakeholder needs (e.g. Agouridas et al., 2006). This could be achieved through the way prototypes and related artifacts are made and the purposes they embody beyond the immediate technical challenges that they can address.

9 CONCLUSION

This thesis aims to contribute to our understanding of whether and how engaging stakeholders during the development of an engineering system might better align its technical capabilities with the needs and constraints of its industrial operation. This has been achieved by examining a case of the development of a passenger wastewater system through a range of studies. These studies provided insights into the breadth of organisations involved in its development and the methods that could be applied to support its eventual adoption. In using the case of a passenger wastewater system for trains as a focus, its operating environment has been contextualised to offer a comparison with other cases of passenger wastewater system development in other transport modes. This has then served as a means to analyse how and why the specific stakeholders in this case could support, hinder or lack interest in the adoption of such an engineering system. How the teams then involved in its creation affect the extent alignment can occur between the needs it will address and its capabilities, through the technical development techniques applied, was then studied. These findings informed the responses to the research questions introduced by this thesis which are now addressed in the following sections. The responses start with a focus on the specific engineering system explored before considering broader implications.

9.1 RQ 1. Who are the stakeholders involved in the adoption of the engineering system in this research context and how do they relate to its development?

The first part of this question's answer focuses on the specific findings from the passenger wastewater system studies concerning the wider industry and the UK rail context. The second part of this answer then summarises the contributions to knowledge that could be applied more widely to the development of other types of engineering systems, specifically those that could be considered to have sufficient innovation and organisational involvement to be categorised as a CoPS.

9.1.1 Findings from the studies of passenger wastewater systems

The range of literature and documents analysed in Chapter 4 and Chapter 5 respectively revealed that an expansive approach towards sampling was required in order to identify salient interests in passenger wastewater system adoption. As the theoretical justification for the study of stakeholders in this thesis is both normatively-inspired, to encourage greater access to development processes, and instrumental, so to lead to greater adoption of the system, this supports this inclusion of a diversity of salient stakeholders. Whilst they may not be directly involved in development or operation, they could be able to affect, or be affected by, these systems. As such stakeholders from commercial, operational and regulatory, as well from political and social, contexts have featured as part of these findings. How these stakeholders relate to passenger wastewater systems has been explored in terms of the evidence that demonstrates their saliency in determining whether the systems' development is aligning with the needs of an industry.

As detailed in the implications for practice in Chapter 8, utilising the identities and relationships of stakeholder organisations in passenger wastewater systems could prove instrumental in determining its developmental direction. As these could evidence where the interests and influences can be found, with public and academic organisations, as detailed in Chapter 4, demonstrating the greatest involvement. The different purposes for passenger wastewater system research revealed in that chapter offer an insight into what these stakeholders are supporting and how, such as the characterization of wastewater or the impacts on commercial operations. These findings infer who the most influential stakeholders are and how they are involved in passenger wastewater system development, adoption and operation, detailed extensively in Appendix J, suggesting where future development efforts could be focused.

As the application chosen by the project of the case study had few academic or trade publications to be informed by, the identification method applied in Chapter 4 was unable to provide significant grounds for comparison between it and other transport modes and regions. However, whilst this could imply where

development work should focus so to build upon prior research, the value in researching these under researched areas was shown in Chapter 5. As shown in that chapter, choosing to then analyse documents sourced directly from, and in relation to, stakeholders of the mode, and region, concerning the case study was to identify why it has received much less scholarly, and commercial, attention. In doing so the findings identified who the leading stakeholders were so to contribute to a speculative analysis of their interest, power and relationships, detailed in A-C appendices, and how they have affected, or been affected by, the development of potential systems in this mode of transport.

To explain why the overall interest in this type of engineering system could be considered to be low, we can consider the regional impacts a transport mode can have. Being able to draw on the combined influence of multiple public, and academic, organisations in operating environments that capture the public interest, such as the ideal of pollution-free oceans, could result in a new technology receiving greater attention. Modes that do not experience these conditions, such as domestic rail networks of which this research context refers, could struggle to benefit from the same level of interest. This could be due to the absence of comparable stakeholder roles supporting international coordination, such as through bodies like the IMO and HELCOM. Other factors, such as a lack of a commitment to sustainability, whilst suggested as a priority in Chapter 5, but failed to be a significant motivator in Chapter 6, could also contribute to a reduction in interest in such systems, despite this being a globally shared concern, contrasting the findings of the aviation sector's approach as shown in Chapter 4.

The differences between the extent each transport mode adopts a similar technology could also explain how stakeholders with similar roles and responsibilities display significantly different levels of influence. Measured by how they could impact the decisions leading to the adoption of a wastewater system, this difference was evident between local communities. In UK areas near railways and stations they appeared to have less influence than those along the Alaskan coast affected by the same practice of discharging untreated passenger

wastewater, detailed in Chapter 5 and Chapter 4 respectively. Despite the lack of influence, this answer maintains that the former are still stakeholders whose needs should be allowed to affect the development of the engineering system.

A further difference in how stakeholders relate to the passenger wastewater systems was shown by how the public sector, in UK rail operating context, was not entirely responsible for them, owing to the specification, procurement, leasing and operating roles occurring over a range of public and private organisations. As such, the sharing of responsibilities, coupled with a lack of historic support for similar systems, would make identifying opportunities for new passenger wastewater systems with empirical evidence challenging. This was indicated by the number of participants who declined or were unable to take part in the interviews, detailed in Appendix H. This in itself could act to further signal how toilet facilities and other wastewater or related freshwater operations could be of greater interest. As such these stakeholders could be seen to be encouraging the development and eventual adoption of these other solutions.

9.1.2 Contributions for the development processes of future engineering systems

Conducting a literature review for the purposes of stakeholder identification, and forming a preliminary analysis of influence and interest, enabled an appreciation of the extent the challenge an engineering system aims to address is established across similar industrial contexts, as shown in Chapter 4. Depending on the research interests of the researcher, these findings could be applied in a variety of ways. However, whilst the method does not rely on prior knowledge of stakeholders in a given engineering system, possessing knowledge of how its functionality is similar to others, and for there to be comparable grounds, determines how suitable this method is for other types of systems, along with a suitable volume of literature concerning the systems' various applications.

With a corpus of literature comprising a specific technical capability, applying the proposed definition of an engineering system stakeholder, detailed in the prior chapter, to identify organisations in the bodies of the texts, the acknowledgements and affiliations sections, a comprehensive landscape of

stakeholders can be constructed. Capturing the topics of the articles, with any evidence that suggests the nature of the interest from the texts themselves, for example, whether potentially supportive or obstructive, will add further understanding to how these stakeholders could affect the development and/or uptake of the engineering system. Reviewing why and how these organisations are involved in these engineering systems reflects how the method supports the aims of existing literature review methods to form the basis for further research. Alternatively, this could be so to address a specific knowledge gap that could be beneficial for informing the direction of technical development.

Gaps in the literature itself could indicate a lack of knowledge of a particular application or a lack of interest from stakeholders that have shown interest in other areas. Justifying further research into areas that are poorly represented by the corpus could be to understand why a lack of interest is apparent. This could be achieved by the application of a document analysis that collects texts directly from the stakeholder's own sources and contexts as was the approach taken in Chapter 5. This grey literature can then be used to construct problem frames that seek to identify the extent this system would actually address similar challenges. Alternatively, industrial, governmental or social factors could be creating a significantly different environment resulting in challenges that need to otherwise be addressed. This could then help explain how the same type of stakeholder present in other applications of the engineering system has different levels of interest or influence. As such, this comprehensive understanding of the stakeholders will support the extent of the desirability of the framing of a presented problem to be evaluated by a new engineering system NPD project.

9.2 RQ 2. How can stakeholder input influence engineering system development, and how is the value of that input understood and captured through the engagement methods applied?

This question is answered using the same format as the prior question with the first part focusing on the specific findings from the studies of the passenger wastewater system research and the second part exploring the wider

contributions to knowledge this answer could have on the development of innovative and complex engineering systems.

9.2.1 Findings from the studies of passenger wastewater systems

Throughout the studies of this thesis stakeholder input has been analysed in a range of forms covering statements of professional opinion, operating preferences, domain knowledge and elicited requirements or criteria for meeting standards or complying with regulations. When input was from the stakeholders within the project examined in the case study in Chapter 7, statements focused on technical capabilities and approaches towards achieving them from both academic and commercial perspectives. The extent and nature of influence of this input from all results chapters could be measured by the changes in the direction of the development of the engineering system, either in terms of technical capabilities or more fundamentally in terms of the problems it will address.

In the cases of passenger wastewater system development reviewed using articles from across the transport sector in Chapter 4, stakeholder input from local communities, government bodies and academic institutions was shown to be instrumental in encouraging this effort. However, there was also evidence of singular interests and established industry practices also affecting the commitment to develop such systems. For example, the IMO and airport operators both had the capabilities to further sustainable and responsible wastewater treatment practices. Publishing regulations and industry-wide reports reflected how they could provide input into the global initiative to research and engineer such systems. This contrasts with the publications analysed from the UK rail sector, that revealed the lack of comparable international public body, such as the IMO, and how a commitment to wastewater processing was not featured as a priority by the industry itself. The reported emphasis on the costs and operational complexities of doing so appeared to discourage adoption, as evident in the documents and statements offered by sector representatives in trade and government positions. However, as shown in Chapter 7, the lack of documented evidence that demonstrated the sector was supportive of such

systems did not significantly affect the project tasked with developing such a system, although this could have played a role in emphasising physical constraints derived from its installation rather than from the benefits of the system itself.

The inputs gathered from the interview study in Chapter 6 demonstrated significant potential to influence the direction of the project as a result of the method used to explore the initial framing of the problem. This method enabled evidence to be collected that supported findings from the document analysis in Chapter 5 without needing to directly question them as they emerged without prompting. Such findings could have led to a change in the nature of the system if addressed, such as a focus on eliminating toilet blockages and improving the reliability of the design of the washroom. This reflects the value of eliciting requirements in this manner by avoiding the bias of only focusing on an assumed need and solution. Furthermore, inputs from documents and other texts that are chosen based on their relevance to these stakeholders, rather than the proposed solution, could also contribute to overcoming this bias. By incorporating system capabilities that were out-of-scope, the project could address the primary causes of toilets being locked-out-of-use; that being blockages, mechanical faults and damage or the primary causes for wastewater and freshwater challenges; that being the cleaning of trains and the runoff from train depots. These problems appeared to be a greater concern than avoiding the need to discharge CET tanks at a depot or any other related wastewater processing operation.

Whilst the choice of interview method had the potential to ensure a proposed engineering system would develop in alignment with the needs of salient stakeholders, the value of the responses that were indicative of their needs was unable to be fully realised. As their input was not primarily supportive, in which requirements elicited could be acted upon within the original scope, the underlying concept of the system could need revisiting. A misalignment between the aims of the project and these external needs therefore arose which, during the duration of the case study, lacked signs of being effectively resolved. However, whilst a number of reasons relating to the way prototypes were created

and managed could offer an explanation, this engagement method in which stakeholder input was collected and analysed has shown that such findings can be unbiased towards an initial understanding of a problem and the perceived need for a specific type of solution.

Stakeholder input can therefore communicate what may need to be addressed in order for the engineering system to be considered more likely that it will reach expected levels of adoption. A project that pursued engagement without an application in mind for a new wastewater treatment technology could potentially have explored in greater detail the needs that did surface. However, owing to how this project placed priority on the rail sector, in particular installing a system onboard the train itself, and wastewater from passengers reduced the potential that such alternatives would be considered.

9.2.2 Contributions for the development processes of future engineering systems

Through applying a semi-structured approach to requirement elicitation, the development of engineering systems can benefit from data that is potentially free from the influence of the stakeholders directly responsible for executing the project, as shown in Chapter 6. For efforts that concern significant levels of innovation, the lack of certainty, equivocalness of need and desirability of concepts could all act to obscure the extent a problem is validated by those that are thought to be affected by it. By enabling these individuals to guide questioning and to offer insights that either confirm or contrast the presented problem frame, a semi-structured approach could overcome the challenges in eliciting requirements that will more likely lead to functionality that supports the adoption of an engineering system.

Once requirements are formulated from these responses to semi-structured interviewing they could then be assessed for their quality. In particular, adopting the alignment quality criterion, proposed in the prior chapter, could help surface where a project team may have incorrectly assumed a need or constraint and contribute to development decisions to address where misalignment occurs. This could be either through reconceptualising the solution itself, incorporating new

design considerations or eliminating the proposed functionality if evident to lack interest. Using a structured interviewing approach, however, could reduce the potential to elicit requirements that could be misaligned due to the predetermined focus on particular needs and functionality set by the interviewee. As such, whilst the responses could result in significant technical detail, the underlying need could lack validation and prevent an accurate assessment of alignment. Therefore, increasing the structure of an interview once this validation has been achieved, so to elicit more finely detailed requirements, would contribute to ensuring both the needs of the internal teams for specific technical insights and the external interests to communicate their expectations and demands could be met.

However, for the requirement elicitation method to be effective, the influence the findings themselves have on the direction of a project would need to be maintained. Stakeholders should feel that they are being listened to and that the opportunity to offer alternative ideas and concepts would be present, should their needs diverge from those leading the development. As such, the proposed TRL 0 stage as a singular activity or procedural addition to ongoing readiness level maturity reviews could act as a means to formalise semi-structured interviewing and the resulting analysis and integration of the data collected. Moreover, the continued alignment of system functionality with industry demand could provide a much needed technical dimension to guiding the interview themes and follow up questions during subsequent engagements as the project's technology matures. Furthermore, by incorporating internal stakeholder input into the questions asked, increasing all quality criteria of the requirements elicited could also be supported. This could reduce the likelihood that what is required to produce a reliable and safe engineering system is not underemphasised in the pursuit of identifying what is required for a significant problem to be solved thereby ensuring the value of both internal and external input are treated equally.

9.3 RQ 3. What are the challenges and opportunities for advancing stakeholder engagement during engineering system development?

There were several challenges and opportunities for advancing stakeholder engagement practice and theory that emerged whilst researching for this thesis. The most significant challenges came from the specific nature of the system being developed whereby a lack of knowledge and interest became evident during the engagement of salient stakeholders in its intended operating environment. As a result, these stakeholders could have been considered to lack willingness to engage with such a project as they may not have prioritised its potential, appreciate the opportunity to influence alternative development directions, or consider the risks in sharing in intellectual property to be too great. This impact on participation was further enhanced by the restrictions placed on this research by the sponsoring firm, reflecting the commercial sensitivities of the activity. Being able to parse the causes of a lack of interest would be the first hurdle to overcome when developing novel technology as it could be grounded in legitimate risks preventing interest from being acted upon or signal weak demand for the underlying concept and proposed benefits.

Once a stakeholder landscape has been comprehensively identified, where supportive interest has been found could be threatened by the instabilities within the industry itself as economic and regulatory relationships change, new organisations form and new policies are enacted. In the background of the central case of this thesis, the rail sector was going through such a transformation with unknown outcomes as to the exact relationships between train operators, the government and the provision of infrastructure. This is in addition to the already ambiguous positions taken by both public and private sector interests that kept delaying eventual phasing out of discharging untreated passenger wastewater. Developing engineering systems in such dynamic environments could understandably put stakeholder engagement efforts under pressure to evidence alignment.

Whilst these challenges could be shared with other forms of CoPS in the pursuit of complex construction projects, there is the added commercial element of identifying multiple customers and their commonalities that could support a low-volume manufacturing of a highly innovative engineering system. This output would need to prove viable in meeting expected production quantities and levels of adoption thereby emphasising the need for stakeholder engagement to be a cost-effective pursuit. This could be restricted by potentially smaller budgets and narrower timeframes, as evidenced by the case study of this thesis. This draws in the challenges evident in the development of mass-manufactured goods and the need for affordable yet conducive prototyping strategies that can elicit needs and ensure the most promising solutions are chosen for further development.

The opportunities for this research to propose methods that address gaps in knowledge regarding the development of such types of engineering systems, that align with stakeholder needs, were present due to this system being a first-of-a-kind. Whilst a project that had the capability to respond to findings could have introduced further opportunities, such as through the development of prototyping techniques and dedicated project stages, the proposed document and interview analysis methods questioned whether these would be essential to reach some form of understanding of the system's potential. The effectiveness of these methods suggest that engineering systems can receive validation without the need for costly demonstrators of prolonged and intensive engagement. Moreover, the amount of insight that could be gained by stakeholder identification was sufficient to form an understanding as to the reasons for why the rail sector may lack interest in such a system. This was further supported by the document analysis of Chapter 5 and then empirically evidenced in the interview study in Chapter 6. However, beyond adopting just a descriptive approach towards analysing stakeholders to reveal a lack of interest, how to then adapt a project's activities would call on these proposed advances in technical development techniques and approaches towards project structure.

However, as a result of the approach taken to prototype this system, detailed in Chapter 7, broader stakeholder interest was not seen as a necessary condition

for continued development. This was possibly due to the interests of both the sponsoring firm and academic researchers prioritising their own areas of expertise, such as wastewater processing and manufacturability. With the adoption of the boundary object concept for prototyping and visualisation, this would have proved problematic as the artifacts would have had to succeed in demonstrating that they were reflecting the needs of stakeholders in the operating environment as well to be successful. This reflects an ongoing organisational cultural challenge that is well studied in terms of firms struggling to implement fuzzy front-end practices involving iterative and exploratory initial stages to projects. How successful cases concerning other product types translate to engineering system development specifically, however, calls for studies to research how this can be achieved so to instigate comprehensive and responsive stakeholder engagement.

9.4 Limitations and future research

There were several factors that proved challenging to overcome affecting the research environment of the preceding studies. This concerned how passenger wastewater system development and operations in the rail sector lacked significant attention in comparison to other applications and the less than supportive state of the industry in the UK for addressing concerns stemming from their operation. Moreover, the approaches taken by the central organisations in the case study developing a system resulted in few opportunities for further engagement. As a result, the studies in this thesis present a phenomena of how and why developing engineering systems can affect stakeholder engagement rather than the initially intended how and why stakeholder engagement affects engineering system development.

To address the limitation as to how these findings could prove relevant to this latter aim, the scope of the stakeholder analysis expanded to encompass the entire transport sector. This was needed to understand why the problem was not being rigorously addressed and to learn from stakeholders as to where their priorities lay. This enabled this research to adapt to a context that was different to that which had initially been expected. Whilst the initial motivation of the aim

was to understand how engagement can support alignment between a system and its stakeholders, the aim began to shift towards understanding the affects engagement can have on the understanding of a system's problem framing and how alignment may prove challenging to achieve. As a result, these findings support understanding potential ways in which engagement could affect the development of engineering systems rather than provide empirical evidence of this fact.

Moreover, although the case study at the centre of the thesis was initially considered to be an atypical example owing to the presence of an academic institution and an engineering and manufacturing company both of which had significant expertise, the case could instead be considered common as previously discussed. The case could be therefore considered to reflect a phenomenon that is the norm rather than the exception. In retrospect, prioritising the study of the organisations involved in the project rather than the stakeholders in the intended operating environment could have contributed to understanding the extent to which they differed to those found in exemplar cases in literature. This highlights that pursuing case study research in an effort to further advance academic fields could be limited by the extent of dissemination of these prior contributions and that assumptions could be made that overlook this factor when sampling for further study. As such the shift in aim was justified by the reality that the pace of change in practice may differ to that of the dissemination of academic findings. This in itself has demonstrated how literature can benefit from empirical evidence to support realigning its areas of study to the needs of industry whilst providing contributions to the development of theory. As such, a limitation in conducting qualitative research has been made apparent by the extent sampling of cases and individuals can succeed in being purposive when a research context contains significant novelty with few extant studies to inform this approach.

However, if interpreted as a common case, the transferability of the findings could be more widely relevant as there could be more opportunities to conduct case studies that feature the same technical approaches towards developing engineering systems. As such, the focus of these further studies could concern

the possible factors observed that may affect stakeholder engagement, derived from the case study in Chapter 7 and listed in Table 9-2. Similar cases could be compared, for example, on the basis of the extent the pace of a project affected the ability to be influenced by and to support stakeholder engagement. However, conducting multiple case studies of real-world phenomena concerning the development of engineering systems that are highly innovative could prove challenging due to their potential rarity and the resulting limitations on purposive sampling. As such, simulated pedagogical or professional workplace experiments could contribute to furthering an understanding of these factors.

Possible factors	Future research questions
The speed of the project	How does the pace of a project affect the intensity and influence of stakeholder engagement?
The mechanisms for disseminating external knowledge	What activities and deliverables support sharing knowledge from stakeholder engagement?
The extent of innovation	Does the level of innovation pursued affect the extent of stakeholder engagement?
The resources of the project	Does a project need a dedicated role to manage stakeholder engagement?
The CoPS-specific implications of innovation	What are the demands placed on stakeholder engagement to co-develop a solution?
The decision to restrict access to a project, including to IP, individuals and facilities	How can stakeholder engagement be pursued in projects with restricted access?

The experience or knowledge of prior projects	How does the prior projects of organisations involved affect stakeholder engagement?
The effects of tensions, conflicts and ambiguities as to the aims of a project	How do internal uncertainties and equivocalness affect stakeholder engagement?
The size of the organisations involved	How does the size of an organisation affect stakeholder engagement?
The role of academic and commercial objectives	How can stakeholder engagement outcomes contribute to both academic and commercial interests?
The use of physical demonstrators produced to a high material and functional standard	Does the extent of development of a prototype affect stakeholder engagement approaches and outcomes?

Table 9-1 Areas of future research and possible factors to inform qualitative study into the development of engineering systems with stakeholder engagement.

Implementing TRL 0 in these studies could support formalising the fuzzy front-end as a catalyst for organisations to support stakeholder engagement. The factors listed in Table 9-1 could guide exploration into how different projects manage the relationship between the TRL 0 and the remaining framework; for example, should it be conducted once or iteratively and for what reasons? Moreover, the TRL 0 could succeed in ensuring visibility of stakeholder identities and their desired outcomes for the project. How it then affects where basic principles are then observed in meeting TRL 1, or more broadly the overall technological direction of the project, could further help identify implications for practice as to how to manage the outputs of TRL 0. Such outputs could be descriptive; to identify whether there is sufficient interest in a project prior to

pursuing TRL 1 or the TRL 0 could be used instrumentally; to ensure the project would stand the best chance of crossing the “valley of death”. Multiple case study research designs could therefore explore how different applications of the TRL 0 resulted in different levels of stakeholder engagement and whether and how they affected the eventual level of adoption of the engineering system.

Alternatively, a greater focus could be given to the creation of stakeholder landscapes, identifying the comprehensive range of interests in an emerging engineering system. This could include how academic stakeholders in the form of journals and conferences are also playing a role in demonstrating influence in furthering particular topic themes. With the results from these studies, recommendations for TRL 1 activities could be grounded in either conventional knowledge gap justifications or integrated into existing stakeholder interests that could indicate potential support for the maturation of TRL 1 outputs. Future research could also pursue the development of prototyping techniques that directly address the challenge of eliciting feedback during the creation of a product that is not designed for an end-user. Ultimately, understanding what practices potentially restrict qualitative data from being generated during a project may be a more fundamental question to answer before exploring how these findings could be then integrated into an engineering system’s technical capabilities.

9.5 Conclusion

Stakeholder engagement during engineering system development shows promise in helping to deliver successful solutions. Focusing on the problems that continue to plague global commitments to a sustainable and equitable future could prove to be the greatest opportunity for this approach. Where radical innovation and complex societal environments intersect, the need to ensure that technical capabilities are developing in line with a diversity of priorities and values could be as essential as identifying all the engineering constraints and demands that a solution will be subjected to in its operational life. However, without a means to incorporate stakeholders that may not have an interest or understanding of the technical aspects of these products, but whose needs could

translate into actionable requirements, this goal could continue to prove elusive. As such, the future of engineering system development projects will need to incorporate the research and management capabilities to gain an awareness of stakeholder identities, relationships and existing industry practices and ensure influence is given to the most salient. These projects will need the capabilities to also collect, analyse and formulate requirements that centre around their needs and prioritise outcomes that are desired by all. This will help ensure that development activities can demonstrate how they are aligning with the needs that will deliver this future.

The most significant challenge could be in achieving this transformation in our understanding of the required project capabilities to deliver engineering systems that can be considered successful. This thesis has used a definition of success that in itself may not be widely shared within this context. If an engineering system achieves significant breakthroughs in technical performance but fails to be adopted by those intended to benefit from it, then, using the definition chosen by this thesis, the system would be considered a failure and as a result the development processes that led to that breakthrough would need to change. This could prove difficult to achieve if such technology continues to develop with the success criteria, and the same decisions on resources and expertise, being derived from its technical advancements. The suggestion that future needs that are unknown today could be the beneficiaries of such technology could maintain this momentum. However, given the known challenges that exist today, and the known needs that are not being met, whether this is a responsible approach towards engineering system development is debatable. As such, the opportunity for stakeholder engagement to affect engineering system development could be in demonstrating how to achieve the best of both worlds; for problems that can be comprehensively researched and framed and for solutions to address them in radically innovative ways.

This thesis has demonstrated how an engineering system exists within a complex social context as much as a technical one. Through the literature review of stakeholders in all applications of a passenger wastewater system, the

documents that are published by and in relation to stakeholders in a specific type and their own responses and activities collected through interviewing and conducting a case study, this complexity came to light. By doing so, stakeholder theory has been applied to an under researched field and its relevance to boundary object conceptualisation has contributed to furthering how prototypes can be theorised when considering those that will interact with them. In contributing to practice, how the findings from these studies can better align an engineering system's capabilities with the needs of its stakeholders was shown to be dependent on the influence given to such insights and the techniques applied to developing these capabilities. Moreover, this thesis has shown that through applying qualitative methods, a project could lead to substantial departures from what the solution, or potentially the operating context itself, was thought to be, as a result of deeper understanding of the problem through the adoption of abductive reasoning to arrive at alternative framings. Ensuring an engineering system project initiates with sufficient validation of its problem could reduce the likelihood of this occurring. However, in cases of radical innovation, such certainty could prove difficult to ascertain. As such, the implications of adopting a commitment to aligning an engineering system with the needs of the stakeholders in its eventual operation could therefore be to maintain a responsive and iterative approach to each capability and with each stakeholder. To achieve such a transformation would require transitioning away from linear and sequential project processes currently pursued and towards approaches more often applied to software and consumer goods. Through the development of prototyping and requirement elicitation techniques grounded in the theoretical advances demonstrated by this thesis, the challenges that are unique to engineering system NPD projects, such as who to prototype with and how, could be addressed so to ensure how we engineer does limit what we engineer.

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APPENDICES

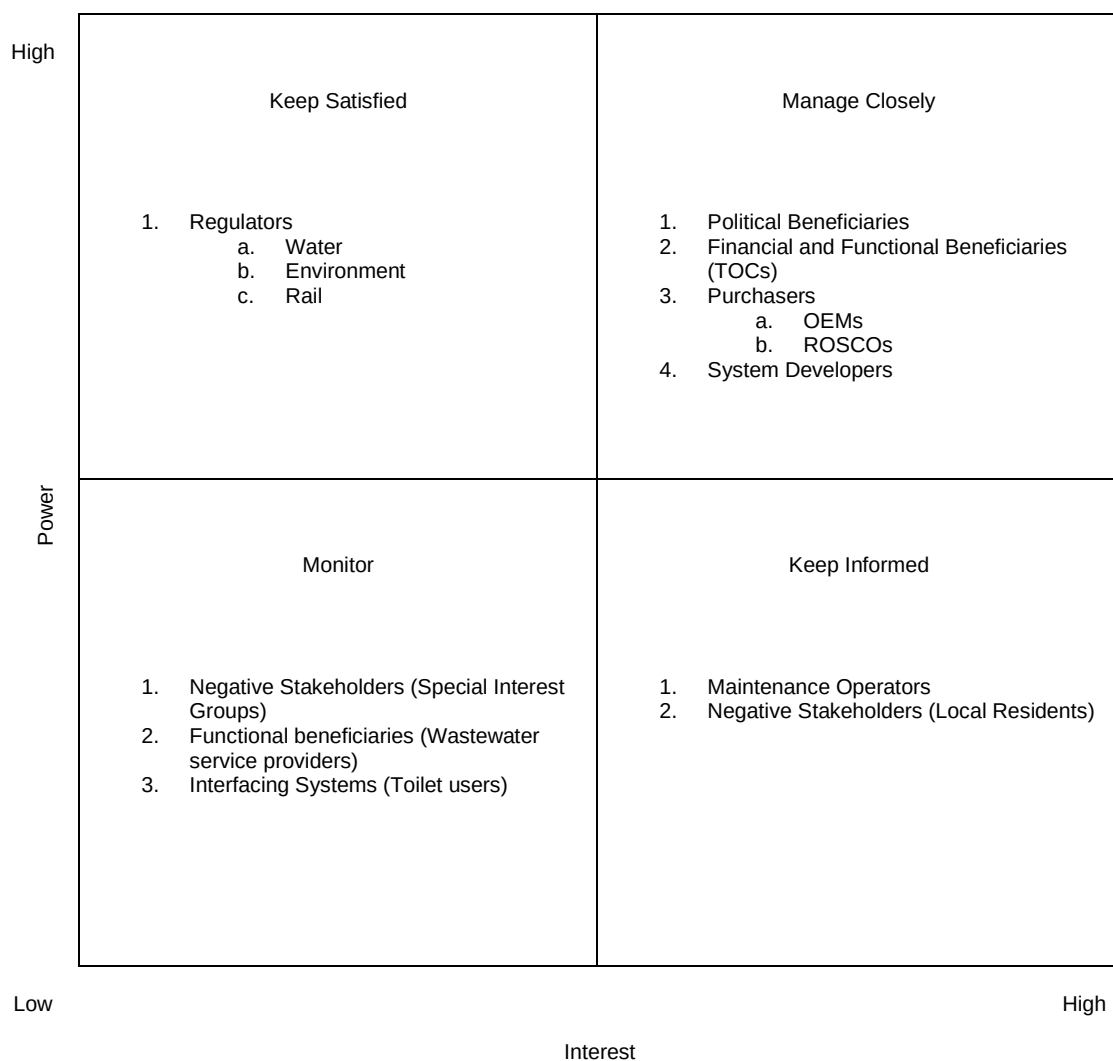
Appendix A : Tabulated stakeholder onion diagram

Derived from the stakeholder identification method proposed by Alexander and Robertson (2004) that involves predetermined “slots” to help guide this effort. As shown not all slots were relevant and not all roles yet existed. The method was developed in a software context and as such did not reflect specifically a physical engineering system in operation.

Circle	Slot	Role
The System (innermost circle)	Normal operator	<ul style="list-style-type: none"> Not applicable
	Help desk	<ul style="list-style-type: none"> Not applicable
	Maintenance operator	<ul style="list-style-type: none"> Servicing providers (cleaning and emptying/replenishing) Maintenance and repair providers Control system monitors
The Containing System	Functional beneficiary	<ul style="list-style-type: none"> Rolling stock servicing schedulers (Train Operating Companies, TOCs) Passenger satisfaction monitors Wastewater service providers
	Purchaser	<ul style="list-style-type: none"> Rolling stock original equipment manufacturer (OEM) Train service franchisee (TOC) Rolling stock leasing company (ROSCO)
	Interfacing system	<ul style="list-style-type: none"> Train toilet user By-product processing (role to be established)
Wider Environment (outermost circle)	Financial beneficiary	<ul style="list-style-type: none"> System manufacturer Train service franchisee (TOC)
	Political beneficiary	<ul style="list-style-type: none"> Franchisee awarding body (Government department)
	Developer	<ul style="list-style-type: none"> Project sponsors (System manufacturer and academic institution)
	Negative stakeholder	<ul style="list-style-type: none"> Local residents (to depots and railways) Rail heritage groups Environmental groups
	Regulator	<ul style="list-style-type: none"> Environment inspectors Rail safety inspectors Water safety inspectors

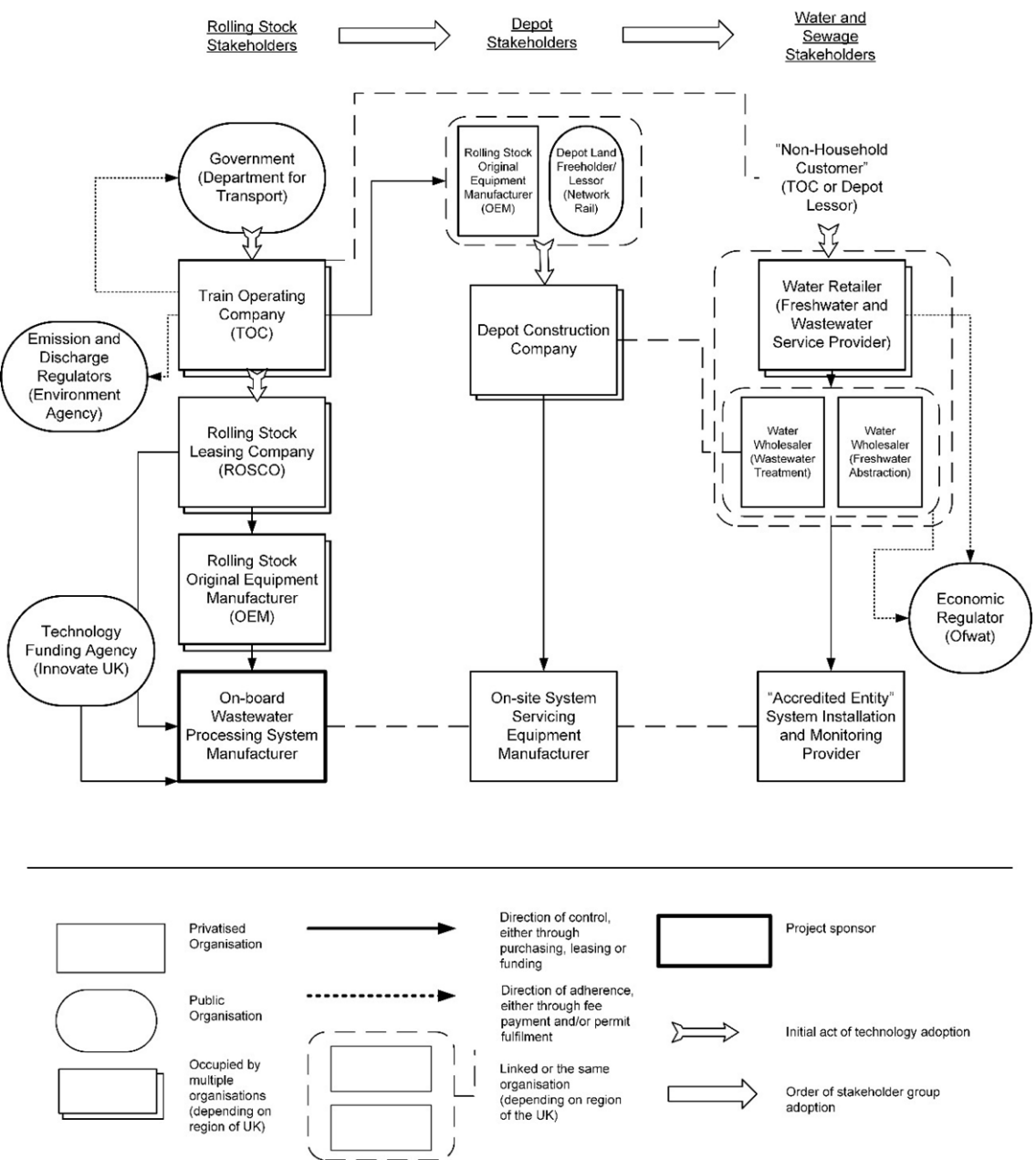
Appendix B : Power-interest grid analysis results

This analysis of stakeholder's power and interest in the adoption of the passenger wastewater system was derived from the findings of the initial document analysis in Chapter 5. These result reflect an optimistic view of the potential positions of the stakeholders, especially in the top right quadrant. Evidence collected later in Chapter 6 suggested these stakeholders may have less interest than initially estimated.



Appendix C : Stakeholder mapping diagram

Diagram showing how the rail and water sectors could relate once the case study's engineering system is in operation, derived from the initial findings of the document analysis in Chapter 5.



Appendix D : Frame Creation Model

The Frame Creation Model process applied during the document analysis study in Chapter 5 extracted from Dorst, K. (2015) 'Frame Creation and Design in the Expanded Field', *She Ji*, Autumn(1) Elsevier Ltd, p. 26.

1. <i>Archaeology</i>	<i>Analysing the history of the problem owner & the initial problem formulation</i>
2. <i>Paradox</i>	<i>Analysing the problem situation: what makes this hard?</i>
3. <i>Context</i>	<i>Analysing the inner circle of stakeholders</i>
4. <i>Field</i>	<i>Exploring the broader field</i>
5. <i>Themes</i>	<i>Investigating the themes that emerge in the broader field</i>
6. <i>Frames</i>	<i>Identifying patterns between themes to create frames</i>
7. <i>Futures</i>	<i>Exploring the possible outcomes and value propositions for the various stakeholders</i>
8. <i>Transformation</i>	<i>Investigating changes in stakeholders' strategies and practices required for implementation</i>
9. <i>Integration</i>	<i>Drawing lessons from the new approach & identify new opportunities within the network</i>

Appendix E : Interview guide

This interview guide was used as a reference during the interview sessions conducted for Chapter 6. Depending on the responses given to the questions that explored the themes, the follow-up questions would be asked. These questions would only be asked if they were relevant to these initial responses.

Order	Theme	Follow-up Questions
1st	The challenges of operating and maintaining wastewater systems and the impact on costs and reliability associated with fleet performance.	<ul style="list-style-type: none"> • In your view, who are the key supply chain stakeholders? • In your view, does wastewater processing have any significant impact on a rolling stock's other functions? (i.e. the environment, operating costs, service reliability, passenger comfort etc.)
2nd	Any examples of success or failure in integrating new systems into rolling stock and infrastructure (i.e. depots) that could potentially translate into wastewater system development.	<ul style="list-style-type: none"> • Could you describe any recent improvements you feel are particularly (un)successful concerning system suppliers to rolling stock manufacturers? (For example, being compatible with other systems, being flexible for multiple configurations, including services such installation, maintenance, decommissioning) • Could you describe to what extent data can highlight specific faults in the day-to-day operation of wastewater processing/toilets on-board rolling stock? Any examples of other systems and how have they made an impact?
3rd	Views on rolling stock capabilities that are in the process of being developed to reflect the needs of customers and the industry in the future (wastewater/depots or otherwise).	<ul style="list-style-type: none"> • In your view, what areas of the rolling stock wastewater system sector do you feel, if improved, would have significant impact on train operations? (If prompted: for example, in terms of decarbonisation, operating costs, service reliability, passenger comfort etc.) • Could you comment on any potential challenges there could be in implementing a radically different sanitation system on rolling stock? (If prompted: for example, training, distributions, regulations, maintenance, safety etc.)

Appendix F : Interview consent form

This interview consent form was used prior to conducting each interview in Chapter 6 so to ensure transparency as to the aims of the research and that the required level of anonymity of the participants would be respected during the write-up .

Informed consent form Project SafeWaste

Title of the project:	Understanding the challenges of rolling stock sanitation through conducting stakeholder interviews
Name of the researcher:	Harris Chapman
Researcher's contact details:	Harris.Chapman@cranfield.ac.uk SWEE +44 (0)1234 750111
Participant number:	Click or tap here to enter text.
Date:	Click or tap here to enter text.

About Project SafeWaste

"Cranfield University are working with Garrandale Ltd conducting research into how water supplies and human waste are managed in sidings, depots and on-board trains.

The results of this research will be used to develop more sustainable systems that are simple to service and maintain and that will reduce operating costs and disruption to the railways.

For the research to be of benefit to the rail industry, visiting academics will need to look in detail at when, where and how water is supplied to trains and when, where and how waste is removed from trains. Talking with managers and operatives and taking samples, where necessary."

Statement from Garrandale Ltd

About Cranfield University

Cranfield University is a distinctive, wholly postgraduate university – a forward-thinking institution where world-class research and innovation leads to world-changing solutions. We are a major contributor in the UK and internationally. Key to our success is our collaboration with industry. We undertake research and consultancy for industrial clients, non-government and government organisations. We nurture and develop future leaders in competitive global businesses providing them with the expertise and confidence to face up to the challenges of a constantly changing environment. We have an extensive track record in engineering, linking them with business and commerce. An extensive range of facilities underpins the work undertaken.

Part 1

- The data I provide will be used by Cranfield University for the purpose of research. The data (and any backups) will be stored in securely encrypted areas, only accessible by authorised users in accordance with the UK Data Protection Act 2018.
- Interviews will be recorded and securely stored on the Cranfield University network as audio files. These audio files will be securely deleted as soon as they are no longer required.
- The recordings will be transcribed and saved as text files. These files (and any backups) will also be securely deleted as soon as they are no longer required.
- Anonymised transcripts will be created, by removing or replacing identifiers such as name, age, and location. These anonymised transcripts may be quoted from in support of findings (e.g. in journal articles, conference papers).
- Analytical software will be used to aggregate the results of the research and every reasonable step will be taken to anonymise the data. The aggregated data may be published in support of the research findings.
- The discussions will be audio recorded and transcribed for analysis. The analysis will be only used for this research project and no other purpose.
- Any results in the report to the client will not be available to me for commercial reasons.
- Any commercially sensitive information mentioned by myself will not be included in any transcripts, however, this information must be explicitly identified as such during the interview to ensure this.

Part 2

1. I confirm that I have been informed about this research project and I agree to take part.
2. I wish for my name to be referred to in any report, publication or presentation as:

	Revealed	Anonymised (i.e. 'a senior member of management within the rolling stock leasing sector')
Full Name	☐	☐
Company Name	☐	☐
Job Role	☐	☐

3. **(If identity is stated as anonymous above)** I have been provided with a participant number as shown above. The researcher(s) will record data against my participant number instead of recording my name. The file linking my name to my participant number will be accessible only to the main researchers, and will be securely destroyed after 9 months.

4. I understand that I can withdraw from this project at any stage by informing a member of the research team, for whom contact details have been provided. I also understand that I can withdraw my data for a period of up to **1** month from today, as after this time it will not be possible to identify my individual data from the aggregated results as explained in point 3.

I am happy for my contact details to be passed to Garrandale Ltd once the research is completed:

Yes ☐ / No ☐

I confirm that I have read and understand the information provided on this form and give my consent to taking part in this research.

Participant's Signature		Date:	Click or tap here to enter text.
Participant's Name	Click or tap here to enter text.		
Researcher's Signature		Date:	Click or tap here to enter text.

Appendix G : Interview ethics protocol

This interview ethics protocol details how the interviews in Chapter 6 were arranged and conducted.

How interviewees will be found:

1. An agreed list of potential interviewees will be formulated based on contacts from Garrandale Rail and, if specific areas need to be addressed, Cranfield University researchers may suggest additional interviewees subject to Garrandale's approval. Areas that are currently of interest include individuals who relate to the topic of rolling stock sanitation from:
 - o Department for Transport
 - o Network Rail
 - o Train Operating Companies (TOCs)
 - o Rolling Stock Leasing Companies (ROSCOs)
 - o Equipment Manufacturers
2. Any individuals who are contacted for interviews will be made aware that their participation is entirely voluntary, and if they choose not to participate in the study, their contact information will not be retained or used for any other purpose. Their choice whether or not to participate in the study will have no impact on their relationship with Garrandale Rail (if they have an existing relationship) – we do not believe there are any significant power imbalances between Garrandale and the interviewees which would make this an issue.

Topics to be discussed during interviews:

The purpose of conducting qualitative research is to build a clear picture of the needs of the industry and test underlying assumptions of this research project. As such, questions will not specifically seek to validate this project's approach to developing a solution but will attempt to unearth views that will potentially prove the need for this technology or provide evidence for a need that could be

addressed. The following topics will be delivered in an unstructured manner depending on the background of the interviewee and their interests:

1. The challenges of managing sanitation in the context of other rolling stock functions and depots.
2. Recent developments and success in implementing new solutions on rolling stock and at depots (waste or otherwise).
3. Potential areas that require significant improvement (from the point-of-view of the interviewee).

How confidentiality and informed consent will be dealt with:

1. Garrandale Rail has agreed to be named during interviews, therefore, Garrandale Rail will be aware that they will be mentioned and will be aware to whom. A statement about the project and Garrandale's role will be agreed with Garrandale before the interviews commence.
2. None of Garrandale's commercially sensitive information will be divulged to interviewees without Garrandale's express consent.
3. Nonetheless, all interviewees will be made aware that the research is funded by Garrandale, and that Garrandale has a commercial interest in the research outcomes – this will be part of the informed consent procedure.
4. Garrandale Rail representatives may wish to observe and potentially take part in these interviews (subject to consent of the interviewees).
5. If any commercially sensitive is divulged by interviewees (perhaps unintentionally), we will discuss with the interviewees whether that information should be disclosed to Garrandale (assuming a Garrandale representative is not present). If they do not wish that information to be disclosed, it will be omitted from the data.
6. Although Garrandale will be aware of which individuals will be approached for interviews and (to some extent) whether or not they take part, Garrandale will not have access to the full raw interview data. Anything provided to Garrandale (in the form of direct quotes, summaries, or coded text, for example) will be anonymised as much as

possible, unless interviewees have given their explicit permission to be named and quoted.

7. Notwithstanding the above, it is acknowledged that Garrandale have extensive knowledge of, and links within, the rail sector. Therefore, even where text is anonymised, Garrandale may be able to deduce who provided it. This is unavoidable, and interviewees will be made aware of this through informed consent.
8. An NDA has been signed between Cranfield University and Garrandale Rail therefore formalising the understanding that only information that has been approved by Garrandale Rail will be shared during interviews.
9. A Data Management Plan has been created by this CURES applicant to address the specifics of where interview findings will be stored, how interviewees will be engaged with and what permissions they will be required to give.

How this protocol impacts other areas of research:

1. Given this project forms part of a currently four person team, the likelihood that industry professionals will be contacted by other researchers other than this applicant is high, specifically for advice on technical matters.
2. This protocol will be shared to form the basis of such engagement, however, efforts will be made to ensure the team acts in a coordinated fashion and that relevant information is shared to prevent unnecessary engagement.

Appendix H : Interviewees unable to be involved

List of anonymised organisations who could not take part due to either commercial confidentiality restrictions from the sponsoring firm, no contact information was given or no information was received during the period the research was conducted:

Candidate organisations	Interviewee job role	Interview agenda
Electric Train Operators <ul style="list-style-type: none"> <i>(List contained 4 organisations)</i> 	Equivalent to "Engineering Assurance & Development Manager" or specific to overseeing wastewater management both on board and at depots	<p>The challenges of operating and maintaining wastewater systems and the impact on costs and reliability associated with fleet performance.</p> <p>Any examples of success or failure in integrating new systems into rolling stock and infrastructure (i.e. depots) that could potentially translate into wastewater system development.</p>
Long Distance Train Operators <ul style="list-style-type: none"> <i>(List contained 4 organisations)</i> 	Equivalent to electric operator positions or "Fleet Manager" due to the impact on operations derived from route lengths and depot access	Views on rolling stock capabilities that are in the process of being developed to reflect the needs of customers and the industry in the future (wastewater/depots or otherwise).
Depot Construction Companies <ul style="list-style-type: none"> <i>(List contained 1 organisation)</i> 	"Project Manager" involved in depot construction projects or any technical leads specialising in sewer/mains connections	Provide additional information to expand on the insights drawn from the water sector interviewees

OEM (infrastructure divisions) <ul style="list-style-type: none"> <i>(List contained 2 organisations)</i> 	“Head of Infrastructure” (within the rail divisions)	Following the same format as the train operating companies: Discussing challenges of managing wastewater, specifically constructing sewer connections, then successes or failures of new initiatives then commenting on the future demands of the industry.
Rail and wastewater system component suppliers <ul style="list-style-type: none"> <i>(List contained 2 organisations)</i> 	“Product Manager” of components used in wastewater/rail systems	Following the same format as previous interviews with the aim to uncover whether our assessment of their influence/interest in bringing technology is significantly high or not.

List of anonymised organisations who could not take part due to commercial confidentiality restrictions emanating from themselves:

Candidate organisations	Interviewee job role	Interview agenda
OEM rolling stock manufacturer <ul style="list-style-type: none"> <i>(List contained 1 organisation)</i> 	“Systems Integration Engineer” involved in the design/engineering/servicing of CET systems	Discover the extent of problems associated with CET integration and operation. Identify if there are any requirements for technology to meet and/or improve upon
Rolling Stock Leasing Company <ul style="list-style-type: none"> <i>(List contained 1 organisation)</i> 	“Procurement Manager” involved in retro-fitting/specifying new fleets with CET systems	Discover the motivations behind retro-fitting and if CET system upgrades would be a priority. What operating improvements would be expected of a new wastewater system

Appendix I : Passenger wastewater articles

References for these articles are listed in Chapter 10. Stakeholder identities are named by their organisation type or by the organisation's name if they represent multiple national governments, with the exception of US EPA due to its prevalence within multiple national contexts.

No.	Year	Authors	Transport Mode	Topic Theme	Stakeholders	Region	Article Type
1	(2021)	Ahmed et al.	Air Travel, Sea Travel	Wastewater Composition Characterization	Government Agency, Transportation Service Operator, Non-Profit Organisation, Funding Agency	Oceania, Asia, North America	Journal Article
2	(2016)	AIDA Cruises	Sea Travel	Wastewater Treatment Development	Transportation Service Operator, Non-Profit Organisation, HELCOM, EU	Europe	Trade Article
3	(2021)	Albastaki et al.	Air Travel	Wastewater Composition Characterization	Government Department, WHO Infrastructure Operator	Asia	Journal Article
4	(2006)	American Laundry News	Sea Travel	Management Practice Development	Non-Profit Organisation	North America	Trade Article
5	(2020)	Atilano-Camino et al.	Air Travel, Coach Travel	Wastewater Treatment Development	WHO, Funding Agency	South America	Journal Article
6	(2018)	Backer	Sea Travel	Regulatory Impact on Operations	HELCOM IMO Non-Profit Organisation	Europe	Journal Article
7	(2015)	Badin	Sea Travel	Regulatory Impact on Operations	Engineering System Manufacturer, IMO, Transportation Service Operator	Europe	Trade Article
8	(2010)	Basak et al.	Sea Travel	Operational Impact on the Environment	Private Research Organisation, Government Agency, Government Department	Asia	Journal Article
9	(2019)	Baxter, Srisaeng and Wild	Air Travel	Operational Impact on the Environment	Infrastructure Operator	Europe	Journal Article
10	(2018)	Baxter, Srisaeng and Wild	Air Travel	Operational Impact on the Environment	Government Department, Infrastructure Operator	Asia	Journal Article
11	(2013)	Beavis	Sea Travel	Wastewater Treatment Development	Engineering System Manufacturer, EU	Europe	Trade Article
12	(2018)	Bieliatynskyi, Osipa and Kornienko	Air Travel	Management Practice Development	UNESCO	Europe	Conference Paper
13	(2019c)	Cai et al.	Sea Travel	Wastewater Treatment Development	Government Agency, IMO, Funding Agency	Asia	Journal Article
14	(2019b)	Cai et al.	Sea Travel	Wastewater Treatment Development	IMO Engineering System Manufacturer, Funding Agency,	Asia	Journal Article
15	(2020)	Cai et al.	Sea Travel	Wastewater Treatment Development	IMO, Engineering System Manufacturer, Funding Agency	Asia	Conference Paper

16	(2019d)	Cai et al.	Sea Travel	Wastewater Treatment Development	Government Agency, IMO Funding Agency	Asia	Journal Article
17	(2019a)	Cai et al.	Sea Travel	Wastewater Treatment Development	IMO, Funding Agency	Asia	Journal Article
18	(2009)	Carinci	Air Travel	Management Practice Development	Engineering System Manufacturer, Construction-Related Company	North America	Trade Article
19	(2013)	Carvalho et al.	Air Travel	Management Practice Development	N/A	South America	Journal Article
20	(2020)	Cervený, Miller and Gende	Sea Travel	Management Practice Development	Government Department, Enforcement Agency, Government Department, UNWTO, Transportation Service Operator, UNESCO, Non-Profit Organisation	North America	Journal Article
21	(2011)	Chen et al.	Sea Travel	Wastewater Treatment Development	Enforcement Agency, Engineering System Manufacturer, Funding Agency	Asia	Conference Paper
22	(2009)	Chen et al.	Sea Travel	Wastewater Treatment Development	N/A	Asia	Conference Paper
23	(2012)	Chen et al.	Sea Travel	Wastewater Treatment Development	Government Agency, Engineering System Manufacturer, Government Department	Asia	Conference Paper
24	(2022)	Chen et al.	Sea Travel	Wastewater Treatment Development	IMO US EPA, National Standards Organisation, Funding Agency	Asia	Conference Paper
25	(2021)	Chen et al.	Sea Travel	Wastewater Treatment Development	Funding Agency	Asia	Journal Article
26	(2019)	Chen, Shi and Wang	Sea Travel	Operational Impact on the Environment	Government Agency, National Standards Organisation	Asia	Conference Paper
27	(2019)	Çiçek	Sea Travel	Management Practice Development	IMO, NATO	Asia	Journal Article
28	(2017)	da Paixão Filho et al.	Air Travel	Wastewater Treatment Development	Non-Profit Organisation, Funding Agency	South America	Journal Article
29	(2000)	Del Rosso	Sea Travel	Regulatory Impact on Operations	Transportation Service Operator	North America	Trade Article
30	(2013)	do Couto et al.	Air Travel	Wastewater Treatment Development	WHO, UNESCO, Funding Agency Government-Owned Corporation	South America	Journal Article
31	(2007)	Dokianakis et al.	Sea Travel	Wastewater Treatment Development	Government Agency, IMO	Europe	Journal Article
32	(2003)	Eley and Morehouse	Sea Travel	Wastewater Treatment Development	Private Research Organisation, Government Department, Non-Profit Organisation	North America	Conference Paper
33	(1993)	ENR: Engineering News-Record	Air Travel	Regulatory Impact on Operations	Enforcement Agency, Non-Profit Organisation	North America	Trade Article
34	(2019)	Fan et al.	Sea Travel	Management Practice Development	N/A	Asia	Conference Paper

35	(2004)	Finger	Space Tourism	Wastewater Treatment Development	N/A	North America	Conference Paper
36	(1997)	Gabrieli et al.	Air Travel	Wastewater Composition Characterization	Government Department	Europe	Conference Paper
37	(2004b)	Geiselman	Sea Travel	Regulatory Impact on Operations	Government Department, Non-Profit Organisation	North America	Trade Article
38	(2004c)	Geiselman	Sea Travel	Regulatory Impact on Operations	Government Department, Enforcement Agency, US EPA, Non-Profit Organisation	North America	Trade Article
39	(2004a)	Geiselman	Sea Travel	Regulatory Impact on Operations	Government Department, Non-Profit Organisation	North America	Trade Article
40	(2017)	Grant-Smith and Mayes	Sea Travel	Regulatory Impact on Operations	IMO, Enforcement Agency	Oceania	Journal Article
41	(2020)	Greer, Rakas and Horvath	Air Travel	Operational Impact on the Environment	Non-Profit Organisation, Funding Agency, Infrastructure Operator	North America	Journal Article
42	(1996)	Hawley, Barton and Reader	Sea Travel	Wastewater Treatment Development	IMO	Europe	Conference Paper
43	(2019)	Heß et al.	Air Travel	Wastewater Composition Characterization	Private Research Organisation, Government Department	Europe	Journal Article
44	(2000)	Hydraulics & Pneumatics	Sea Travel	Wastewater Treatment Development	Engineering System Manufacturer, Transportation Service Operator, Enforcement Agency	North America	Trade Article
45	(2010)	Jainchill	Sea Travel	Regulatory Impact on Operations	Non-Profit Organisation, Government Department	North America	Trade Article
46	(2016)	Jarzemskis and Jarzemska	Sea Travel	Management Practice Development	IMO, HELCOM, Transportation Service Operator, EU	Europe	Journal Article
47	(2019)	Jiang et al.	Sea Travel	Wastewater Treatment Development	Funding Agency	Asia	Journal Article
48	(2018)	Jiao and Liu	Sea Travel	Management Practice Development	Government Department, National Standards Organisation, UN, IMO,	Asia	Conference Paper
49	(2002)	Johnson	Sea Travel	Operational Impact on the Environment	US EPA, Government Department	North America	Trade Article
50	(2003a)	Johnson	Sea Travel	Operational Impact on the Environment	Non-Profit Organisation, Transportation Service Operator	North America	Trade Article
51	(2003b)	Johnson	Sea Travel	Operational Impact on the Environment	Non-Profit Organisation	North America	Trade Article
52	(2003)	Keinen et al.	Sea Travel	Operational Impact on the Environment	US EPA, Private Research Organisation, Government Department, Non-Profit Organisation, Transportation Service Operator	North America	Conference Paper
53	(2002)	Klie and Daly	Sea Travel	Wastewater Treatment Development	Engineering System Manufacturer, IMO Government Department, Enforcement Agency, Transportation Service Operator	North America	Journal Article

54	(2017)	Korkmaz et al.	Sea Travel	Wastewater Treatment Development	Government Agency, Funding Agency	Asia	Journal Article
55	(2021)	Kotrikla, Zavantias and Kaloupi	Sea Travel	Management Practice Development	EU, IMO, UNEP	South America	Journal Article
56	(2016)	Krop et al.	Air Travel	Management Practice Development	Funding Agency, US EPA, Private Research Organisation, Infrastructure Operator	North America	Journal Article
57	(2012)	Leung et al.	Air Travel	Operational Impact on the Environment	Government-Owned Corporation, Enforcement Agency, Government Department, OECD	Asia	Journal Article
58	(2017)	Li, Huang and Qu	Sea Travel	Operational Impact on the Environment	Enforcement Agency, Funding Agency	Asia	Journal Article
59	(2020)	Liu and Chu	Sea Travel	Management Practice Development	IMO, Government Department	Asia	Conference Paper
60	(2007)	Liu et al.	Air Travel	Wastewater Treatment Development	Government Department, Engineering System Manufacturer	Asia	Conference Paper
61	(2014)	Liu et al.	Sea Travel	Wastewater Treatment Development	Government Agency, IMO	Asia	Journal Article
62	(2003)	Loehr et al.	Sea Travel	Operational Impact on the Environment	Government Department, US EPA	North America	Conference Paper
63	(2006)	Loehr et al.	Sea Travel	Operational Impact on the Environment	Private Research Organisation, Enforcement Agency, Government Department, US EPA, National Standards Organisation, Transportation Service Operator, Non-Profit Organisation	North America	Journal Article
64	(2010)	Lu and Wang	Rail Travel	Wastewater Treatment Development	Government Department	Asia	Conference Paper
65	(2012)	Ma et al.	Rail Travel	Management Practice Development	Government-Owned Corporation, Government Department, National Standards Organisation	Asia	Conference Paper
66	(2006)	Management of Environmental Quality	Sea Travel	Regulatory Impact on Operations	EU	Europe	Journal Article
67	(2003)	McGee and Loeh	Sea Travel	Operational Impact on the Environment	Government Department, Private Research Organisation, Non-Profit Organisation, Enforcement Agency, FDA, US EPA	North America	Conference Paper
68	(2003)	Mearns et al.	Sea Travel	Operational Impact on the Environment	Enforcement Agency, US EPA, Government Department, Non-Profit Organisation, Private Research Organisation, Transportation Service Operator, Non-Profit Organisation, Private Research Organisation	North America	Conference Paper

69	(2011)	Meng, Lin and Zhong	Sea Travel	Wastewater Treatment Development	Engineering System Manufacturer	Asia	Conference Paper
70	(2003)	Morehouse	Sea Travel	Wastewater Composition Characterization	Government Department, US EPA, Enforcement Agency, Government-Owned Corporation	North America	Conference Paper
71	(2003)	Morehouse and Koch	Sea Travel	Operational Impact on the Environment	Government Department, Transportation Service Operator, Enforcement Agency, IMO, US EPA, Transportation Service Operator, Non-Profit Organisation	North America	Conference Paper
72	(2014)	Moreno-Andrade et al.	Air Travel, Coach Travel	Wastewater Treatment Development	Funding Agency	South America	Journal Article
73	(2004)	O'Rourke	Sea Travel	Regulatory Impact on Operations	Non-Profit Organisation, Transportation Service Operator, Government Department	North America	Trade Article
74	(2017)	Onwuegbuc hunam et al.	Sea Travel	Operational Impact on the Environment	Infrastructure Operator, IMO, UN, Government-Owned Corporation, Enforcement Agency	Africa	Journal Article
75	(2019)	Parks et al.	Sea Travel	Operational Impact on the Environment	Non-Profit Organisation, Enforcement Agency, IMO, US EPA	North America	Journal Article
76	(2014)	Passos, von Sperling and Ribeiro	Air Travel	Wastewater Composition Characterization	Government-Owned Corporation	South America	Journal Article
77	(2016)	Perić	Sea Travel	Management Practice Development	IMO	Europe	Journal Article
78	(2000)	Peters, Günther and Vossenkaul	Sea Travel	Wastewater Treatment Development	Private Research Organisation, Engineering System Manufacturer	Europe	Journal Article
79	(2020)	Pickett et al.	Space Tourism	Management Practice Development	Government Agency, ISO, Funding Agency, Infrastructure Operator	North America	Journal Article
80	(2004)	Prior	Sea Travel	Regulatory Impact on Operations	Government Department, Transportation Service Operator, Non-Profit Organisation	North America	Trade Article
81	(2004)	Process Engineering	Air Travel	Management Practice Development	Infrastructure Operator, Engineering System Manufacturer	Europe	Trade Article
82	(1997)	Reader, Barton and Hawley	Sea Travel	Wastewater Treatment Development	EU, IMO, Funding Agency, Construction-Related Company	North America, Europe	Conference Paper
83	(2005a)	Renstrom	Sea Travel	Regulatory Impact on Operations	Non-Profit Organisation, IMO, US EPA, IMO, EU, Engineering System Manufacturer, Transportation Service Operator	North America	Trade Article

84	(2005b)	Renstrom	Sea Travel	Regulatory Impact on Operations	Government Department, Enforcement Agency, US EPA,	North America	Trade Article
85	(2018)	Reshnyak et al.	Sea Travel	Management Practice Development	N/A	Europe	Conference Paper
86	(2013)	Ribeiro et al.	Air Travel	Operational Impact on the Environment	Government Department, US EPA, National Standards Organisation, Enforcement Agency, Government-Owned Corporation, Funding Agency	South America	Journal Article
87	(2020)	Şahin and Vardar	Sea Travel	Operational Impact on the Environment	US EPA, IMO, HELCOM, Transportation Service Operator	Asia	Journal Article
88	(2009)	Schoenburg	Sea Travel	Operational Impact on the Environment	WWF, IMO, EU	Europe	Trade Article
89	(2022)	Schumüller, Weichgrebe and Köster	Sea Travel	Wastewater Treatment Development	Non-Profit Organisation, IMO, Transportation Service Operator, Government Department, US EPA, Private Research Organisation, Non-Profit Organisation	Europe	Trade Article
90	(1991)	Sekoulov, Figueroa and Oles	Air Travel	Wastewater Treatment Development	WHO, FDA	Europe	Journal Article
91	(2012)	Shi et al.	Sea Travel	Wastewater Treatment Development	IMO	Asia	Conference Paper
92	(1997)	Shieh, Baric and Sobsey	Air Travel	Wastewater Composition Characterization	WHO Enforcement Agency, Infrastructure Operator	North America	Journal Article
93	(2011)	Sun	Sea Travel	Wastewater Treatment Development	N/A	Asia	Conference Paper
94	(2010b)	Sun et al.	Sea Travel	Wastewater Treatment Development	DNV, Engineering System Manufacturer, National Standards Organisation, ISO, Funding Agency	Europe	Journal Article
95	(2010a)	Sun et al.	Sea Travel	Wastewater Treatment Development	DNV, Engineering System Manufacturer, IMO	Europe	Journal Article
96	(2000)	Szumilas et al.	Sea Travel	Regulatory Impact on Operations	IMO, HELCOM	Europe	Journal Article
97	(2009)	Thomas and Muirhead	Space Tourism	Wastewater Treatment Development	Government Agency	North America	Journal Article
98	(2010)	Thomas, Weislogel and Klaus	Space Tourism	Wastewater Treatment Development	Government Agency	North America	Journal Article
99	(2019)	Tina, Vice and Nikola	Sea Travel	Operational Impact on the Environment	IMO	Europe	Journal Article
100	(2002)	Tobin	Sea Travel	Regulatory Impact on Operations	Government Department	North America	Trade Article
101	(2003)	Tobin	Sea Travel	Regulatory Impact on Operations	Non-Profit Organisation, Transportation Service Operator	Europe	Trade Article

102	(2008)	Travel Agent	Sea Travel	Regulatory Impact on Operations	Government Department, Non-Profit Organisation, Transportation Service Operator	North America	Trade Article
103	(2001)	Travel Weekly	Sea Travel	Management Practice Development	Transportation Service Operator	North America	Trade Article
104	(2000)	Tricia	Sea Travel	Operational Impact on the Environment	Non-Profit Organisation, Enforcement Agency, Government Department, Transportation Service Operator, US EPA, Non-Profit Organisation	North America	Trade Article
105	(2011)	Tunney	Sea Travel	Regulatory Impact on Operations	Government Department,	North America	Trade Article
106	(2011)	Ulniković et al.	Sea Travel	Management Practice Development	Infrastructure Operator, IMO, EU, Government Department	Europe	Journal Article
107	(2021)	Underground Construction	Air Travel	Management Practice Development	Government Department, Infrastructure Operator, Transportation Service Operator	North America	Trade Article
108	(2020)	Vaneckhaut e and Fazli	Sea Travel	Management Practice Development	IMO, US EPA, HELCOM, Infrastructure Operator, Funding Agency	Europe	Journal Article
109	(2020)	Vicente-Cera et al.	Sea Travel	Management Practice Development	IMO, Government Department, Transportation Service Operator	Europe	Journal Article
110	(2019)	Vicente-Cera et al.	Sea Travel	Wastewater Composition Characterization	IMO, US EPA, Government Department	Europe	Journal Article
111	(2020)	Vujičić et al.	Sea Travel	Management Practice Development	IMO DNV	Europe	Journal Article
112	(2012)	Wang et al.	Rail Travel	Wastewater Treatment Development	Government-Owned Corporation, Funding Agency	Asia	Conference Paper
113	(2019)	Wang, Li and Xiao	Sea Travel	Management Practice Development	Non-Profit Organisation, IMO, Funding Agency	North America, Asia	Journal Article
114	(2016)	Wang, Lu and Zhang	Sea Travel	Operational Impact on the Environment	Government Agency, US EPA, Funding Agency	Asia	Journal Article
115	(2015)	Wärtsilä Corporation	Sea Travel	Regulatory Impact on Operations	IMO, Transportation Service Operator, Engineering System Manufacturer	Europe	Trade Article
116	(2005)	Waste News	Sea Travel	Regulatory Impact on Operations	US EPA	North America	Trade Article
117	(2020)	Wei et al.	Rail Travel	Wastewater Treatment Development	Funding Agency	Asia	Journal Article
118	(2016)	Westhof, Köster and Reich	Sea Travel	Wastewater Composition Characterization	IMO National Standards Organisation, Government Department	Europe	Journal Article
119	(2018)	Wilewska-Bien and Anderberg	Sea Travel	Management Practice Development	IMO, Non-Profit Organisation, EU	Europe	Journal Article
120	(2019)	Wilewska-Bien et al.	Sea Travel	Operational Impact on the Environment	IMO, HELCOM, EU, Funding Agency, Private Research Organisation	Europe	Journal Article

121	(2016)	Wilewska-Bien, Granhag and Andersson	Sea Travel	Regulatory Impact on Operations	IMO, EU, HELCOM	Europe	Journal Article
122	(2008)	Xia et al.	Space Tourism	Wastewater Treatment Development	Government Agency	North America	Conference Paper
123	(2019)	Xin and Gao	Sea Travel	Management Practice Development	Government Agency	Asia	Conference Paper
124	(2013)	Xu et al.	Air Travel	Management Practice Development	Enforcement Agency, National Standards Organisation, Funding Agency	Asia	Journal Article
125	(2011)	Xu et al.	Air Travel	Wastewater Composition Characterization	Enforcement Agency, WHO National Standards Organisation, Funding Agency	Asia	Journal Article
126	(2015)	Yang, Shao and Zhu	Sea Travel	Management Practice Development	N/A	Asia	Journal Article
127	(2019)	Yao, He and Chen	Air Travel	Management Practice Development	Enforcement Agency, Funding Agency, Government-Owned Corporation	Asia	Journal Article
128	(2014)	Zeng et al.	Sea Travel	Operational Impact on the Environment	N/A	Asia	Conference Paper
129	(2011)	Zhang and Xu	Sea Travel	Wastewater Treatment Development	N/A	Asia	Conference Paper
130	(2011)	Zhang and Zuo	Sea Travel	Operational Impact on the Environment	Construction-Related Company, Funding Agency	Asia	Conference Paper
131	(2020b)	Zhang et al.	Sea Travel	Wastewater Treatment Development	Government Agency, IMO, Funding Agency	Asia	Journal Article
132	(2020a)	Zhang et al.	Sea Travel	Wastewater Treatment Development	Construction-Related Company, Engineering System Manufacturer, IMO, Funding Agency	Asia	Conference Paper
133	(2005)	Zhou, Dai and Lei	Space Tourism	Wastewater Treatment Development	N/A	Asia	Conference Paper
134	(2016)	Zhu, He and Wang	Sea Travel	Wastewater Treatment Development	IMO, Engineering System Manufacturer, Funding Agency	Asia	Journal Article
135	(2015)	Zhu, He and Wang	Sea Travel	Wastewater Treatment Development	N/A	Asia	Conference Paper

Appendix J : Stakeholders and their interests in the development and operation of passenger wastewater systems

This chart details the 5 stakeholder groups, their constituent sub-groups and the interests inferred by the topics of the articles reviewed in Chapter 4 that each group was either affiliated to, mentioned in the body of the text or acknowledged by. The largest sub-groups are examined further in Chapter 4 in relation to each specific transport mode.



Appendix K : Stakeholder live document

This spreadsheet was used to share insights from interviewees with the team and sponsoring firm during the case study. Comments were added by the project team supervisors.

Stakeholder Insights - Passenger Wastewater System Development Project

Phase 1 2019-2021

Last Updated: 15/07/2021

Researcher: Harris Chapman

Supervisor: Dr Heather Smith

Second Supervisor: Prof. Leon Williams

ID and Quote Number	Quote	Interviewee	Interview Date	Insight	Scope Coding	Comments
101.01	"Some of the bio-reactor systems that are in use require something called an acid wash every couple of months or so and there may be a role for specialist waste handling companies to get involved in the disposal of that acid wash. As I understand it, acid cannot be flushed into the normal sewer system."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Opportunity to ensure (Passenger Wastewater System Development Project) does not require specialist equipment and processes to maintain.	Near term design consideration	
101.02	"We leave it to the train operator to put in place proper working methods and proper technologies to comply with all the European and national standards when it comes to train sanitation systems."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	(Passenger Wastewater System Development Project) system should comply with standards and regulations by design without the need for external monitoring.	Near term design consideration	

101.03	"The success for this project (Project SafeWaste) would be the train operator question developing their own solutions that best suit their needs for their own stock and the passenger services they operate."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	System should be adaptable to the specific requirements of the operational environment.	Near term design consideration	
101.04	"...one of those requirements is that whenever the train has a toilet has to be accessible to people in a wheelchair..."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Opportunity to explore how the system can be more reliable than current systems to meet the needs of disabled passengers.	Out of scope - not related to current wastewater focus	
101.05	"It will be the train operator's responsibility to ensure the bio-toilets fitted to their trains are working properly..."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Requirement to ensure TOCs can detect faults in the system	Future design consideration with expansion of scope	
101.06	"We know there is an issue with certain heritage stock that the sheer design of the train doesn't easily allow for the fitting of CET tanks and so they are looking to use a direct discharge toilet"	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Possibility of considering constraints relating to retrofitting heritage stock	Future design consideration with expansion of scope	
101.07	"...if the system you're thinking of has some discharges, and the discharges meet the Environment Agency standards for bathing water then yeah it could work but then I think the trick will be making sure that they do..."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Requirement to conform to EU regulations on bathing water quality and provide guarantee of conformity (during use and in lab conditions?)	In scope of current development	Again, we will evaluate the quality of the water to be achieved as part of the testing in the coming year but we will first focus on reaching the required quality for

						reuse rather than discharge.
101.08	"...it would interesting to know how your system is designed to ... react if someone did try to flush something they shouldn't down the toilet ..."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Requirement to ensure objects that are flushed down the toilet don't create the same problems as current systems	Future design consideration with expansion of scope	
101.09	"...if you're looking to introduce this onto a train that runs into Scotland or runs into Wales not only will have to meet UK legislation but also the Welsh and Scottish legislation..."	Rolling Stock Policy Manager, Passenger Services, (UK Government)	17/05/2019	Possibility to ensure system conforms to legislation across all UK environment agencies	Near term design consideration	
102.01	"...the latest thinking is to try and ensure a circular economy where resources are reused or recovered as far as possible..."	Environment and Business Senior Advisor (UK Government)	06/06/2019	An expectation to demonstrate the value of reusing waste	Future design consideration with expansion of scope	
102.02	"...you've also got public perception ... in a policy and regulatory setting and that means ... (for) ... the environment as a stakeholder the public provides that voice."	Environment and Business Senior Advisor (UK Government)	06/06/2019	Opportunity to enable operators to provide an environmentally-friendly solution to reflect public demand	Future design consideration with expansion of scope	
102.03	"...waste regulation is a devolved area of policy and therefore it is for the Scottish government and the Welsh government to determine which policies they wish to pursue..."	Environment and Business Senior Advisor (UK Government)	06/06/2019	Requirement to ensure (Passenger Wastewater System Development Project) meets the standards of England, Scotland and Wales	Near term design consideration	
102.04	"...In terms of the compliance with European legislation the current situation is that ... they must comply with the Waste Framework Directive..."	Environment and Business Senior Advisor (UK Government)	06/06/2019	Requirement to ensure (Passenger Wastewater System Development Project) meets EU standards	Near term design consideration	

102.05	<p>“...The washing machine produces a wastewater which ... has micro-plastics and micro-fibres in it and that will carry through to the sludge onto land ... a lot of the heavy metals which were a concern from industrial wastewaters have diminished ... maybe there are organics and persistent organic pollution which are found in industrial wastewaters ... and then there is road runoff ... there is rubber particles from the tyres, clearly oils are a potential and also farm runoff which also goes into the same system often and you may have pesticides and other substances that maybe a concern ... anti-biotic issues and anti-microbial resistance is an issue of concern, something which this chemical investigation programme is looking into ...I would imagine there is very little focus on rail companies and the generation of waste by rail operators and I think this would probably be wrapped up in a more general approach to the question of contaminates...”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	<p>Opportunity to inform stakeholders of the similarities and differences of wastewater generated on rolling stock to that of domestic, industrial, agricultural or other infrastructure sources</p>	Out of scope - not related to current wastewater focus	
102.06	<p>“We’re facing ... climate change reducing the amounts of available water in the environment, changing the nature of rainfall and also the increasing population, in the south-east in particular, creating a situation where people may not actually have enough water to supply our needs in the future, we’re looking at a twenty five, fifty year timeframe for that unless we act.”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	<p>Opportunity to demonstrate how the system could would reduce water stress</p>	In scope of current development	
102.07	<p>“...we’ve got the sludge use for agriculture regulations but that’s really for large scale sewage treatment works ... how would you do any regulation for those activities (using waste generated from rolling stock) it’s difficult to say.”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	<p>Opportunity to demonstrate the lack of regulation currently aimed at wastewater standards on board rolling stock</p>	Out of scope - not related to current wastewater focus	

102.08	<p>“...If you were looking instead at (thermal treatment) or some other heat-based treatment ... what are the aerial emissions the treatment unit generates? You'd have to look at primarily the quality of the solid fraction that is left, the bio-char or similar... there's been some research into bio-solids quality because the heat processes ... varies so much according to inputs and the temperature at which the unit is operated those variables will have a significant impact on the potential contaminates that may end up in your bio-char...”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	Known limitations to (thermal treatment) technology can be addressed by (Passenger Wastewater System Development Project)	In scope of current development	
102.09	<p>“...There are potential gains in that you could end up with a valuable bio-char which could potentially be used as a soil enhancer ... The water industry is not invested in that sort of ((thermal treatment)) technology because it is so energy intensive ... are the economics different if you're looking at a smaller scale unit?...”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	Benefits of (thermal treatment) technology can be communicated to operators looking to create valuable waste by-products	Near term design consideration	
102.1	<p>“...we won't regulate as long as you meet the standards or meet these criteria and we might turn that in the future into an exception if the risks is considered to be sufficiently low. Failing that, if we can't confer to regulatory position or we are not satisfied that a regulatory position is appropriate then it would be a permitting requirement...”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	Opportunity to ensure the system will benefit from exemptions (i.e. D2)	Near term design consideration	
102.11	<p>“...keep the waste as simple as possible and to understand your waste and characterise it as best as possible, that way you stay out of any significant regulatory hurdles...”</p>	Environment and Business Senior Advisor (UK Government)	06/06/2019	Requirement to ensure (Passenger Wastewater System Development Project) can monitor and control waste contaminates throughout the system	Future design consideration with expansion of scope	
103.01	<p>• Fleet scale and age makes introduction of new technology challenging especially retrofitting</p>	Rail Safety Standards Advisor (Non-Profit)	28/01/2020	Requirement to identify how age and scale of fleets will impact the system	Future design consideration with expansion of scope	

103.02	<ul style="list-style-type: none"> • Risk adverse <ul style="list-style-type: none"> o The rail industry is not known to be a first mover in adopting new technology § Unlikely for a 737 MAX event <ul style="list-style-type: none"> o Technology needs to be established or heavily tested o Global issue 	Rail Safety Standards Advisor (Non-Profit)	28/01/2020	Requirement to demonstrate the system has been rigorously tested and gain trust of rail industry	Near term design consideration	
103.03	<ul style="list-style-type: none"> • Influence <ul style="list-style-type: none"> o Legislation responsible for the uptake of new technology § Enforcement the next challenge <ul style="list-style-type: none"> o Unions representing depot and track workers pressured the withdrawal of direct discharge § Toilet paper would stick to the underside of carriages making maintenance difficult § Discharge would spray track side workers • Concern of Hepatitis-C and AIDS <ul style="list-style-type: none"> o Passengers had little impact on this decision § HOWEVER the introduction of recycled water on-board could change this, especially if there are health risks § Should passengers be made aware? o Operators should be responsible for the upkeep of water quality in recycling systems 	Rail Safety Standards Advisor (Non-Profit)	28/01/2020	Opportunity to explore how system operators can communicate the low-risk nature of the outputs to employees and passengers	Future design consideration with expansion of scope	
103.04	<ul style="list-style-type: none"> • Machinery <ul style="list-style-type: none"> o Control systems used for track machinery (i.e. cranes that can travel on rail to build and maintain rail infrastructure) were significantly more advanced than rolling stock systems – ‘Rated Capacity Indicators’ § Rolling stock brakes are more advanced than machinery brakes <ul style="list-style-type: none"> o Safety was the main motivator for this technology development due to events when machinery would tip over or off the tracks o Control systems were also required to enable machinery to be more functional and suitable for rail environments § Being able to do more appears to be a motivator given the space and access constraints that aren't present on conventional construction sites 	Rail Safety Standards Advisor (Non-Profit)	28/01/2020	Opportunity to explore how the system could solve other operator challenges (i.e. using new water techniques as a sand replacement for rail traction)	Future design consideration with expansion of scope	

103.05	<ul style="list-style-type: none"> • Infrastructure o Knock-on effects of rail technology introduction can impact rolling stock: § Failure to electrify railways in the UK meant trains that should have been retired were kept in service that did not conform to toilet standards 	Rail Safety Standards Advisor (Non-Profit)	28/01/2020	Opportunity to explore the relationship between the system and current infrastructure to identify risks/strengths	Future design consideration with expansion of scope	
201.01	"...we don't really deal with anyone else right now, it's something we are looking into in the future, we are looking at different potential (wastewater system) suppliers..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Opportunity to further engage with (Global OEM) as a potential customer	Out of scope - not related to current wastewater focus	
201.02	"...with the exception of the change in the TSI ... that's resulted in huge projects ... looking into designs in order to meet full requirements within that standard ..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure (Passenger Wastewater System Development Project) is compliant with current and future standards	Near term design consideration	
201.03	"You'd like to think that most companies have that future technology aspect, where they're actively looking to improve their technologies ... it's going to be quite costly in a sense for them to do it. However ... that's not to say we can't work alongside them ... they're ... going to be taking a lot of risk financially to the business if you know because you got to make sure people want the product."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Opportunity to further engage with (Global OEM) as a partner to ensure system meets their needs	Out of scope - not related to current wastewater focus	
201.04	"...When they changed the regulations on what you can dispose onto the track I think everyone kind of got caught out ..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure (Passenger Wastewater System Development Project) is compliant with current and future standards to speed up integration	Near term design consideration	
201.05	"...I think we've started looking into a company that is developing a chemical bio-reactor toilet ... which essentially removes a lot of that process."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to compare (Passenger Wastewater System Development Project) with 'competing' systems	Future design consideration with expansion of scope	

201.06	"...when it cants, when there's 65% range maybe in your wastewater tank, what will happen when you get a severe enough cant it can send a sensor high and give a false indication which then locks your toilets out and sends an email directly to the customer saying this tank is full, toilet is now locked out of use ... send it to get de-tankled. But that may not be the case and then what we're doing then is sending a train again out-of-service to a facility to conduct what may not need to be done until the following day."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure sensors used in the system are not adversely affected by the rolling stock's operating environment and that false readings do not lead to costly and unnecessary servicing	Future design consideration with expansion of scope	
201.07	"... (CET tanks are) designed that way because it provides balance ... so we use it ... to balance the bogies out ... so it's quite important that they are there, if we were to remove them we would have to replace that weight."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure the weight of the system matches current requirements	Near term design consideration	
201.08	"...If a product gets developed that is proven to be environmentally friendly means that we can dispose of waste safely (on tracks) ... it's a massive benefit to maintenance costs and saving yourself a lot more money in the long run. As long as the maintenance required to change ... whether it's a chemical reaction ... is kept to a similar level or below the current maintenance costings for how we do it right now."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure cost of operating the system is equal or below current systems	Near term design consideration	We will have a clearer idea of the cost of the system once we have tested the integrated system and demonstrated the application so I would expect to only be able to answer that question confidently towards the end of the project in 1-2 years time.
201.09	"...The problem with new technology is that we almost need it to be reliable from the get go so for a new system we could be a little bit nervous about implementing to begin with as there's no reliability data to fall back on..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure the system has been rigorously tested with a proven track record	Out of scope - not related to current wastewater focus	
201.1	"... The only issues we've really had are sensor issues and capacity is obviously big limitation, I think those are the two issues we see from our end, if we could	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Opportunity to communicate the benefits of the system to overcome current challenges	In scope of current development	

	control then in a better fashion..."			(relating to sensor issues)		
201.11	"Procurement probably play the biggest part in all this ... it's up to them to tell us what they think is out there in terms of market value which will mean we have an outstanding product in the end."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure procurement stakeholders are familiar with the system	Near term design consideration	
201.12	"...keeping the train up in service as much as possible, it's no good developing a system if needs to sit down for 5 hours to go through an entire process..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure the system does not require lengthy servicing periods	Out of scope - not related to current wastewater focus	
201.13	"...they're a big no-no really when you're developing a product if you have single-point failure... you want to stay away from a system that's got too many "this is a safety critical fault" or "this is a fault that requires urgent attention" ..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure (Passenger Wastewater System Development Project) system contains redundancy or is capable of issuing predictive maintenance notices	Future design consideration with expansion of scope	
201.14	"... understanding the relationships so making sure it can integrate with the train but it's not networked in, that way if you lose one you lose all four..."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure (Passenger Wastewater System Development Project) systems can operate in isolation and aren't impacted by failures in other systems	Future design consideration with expansion of scope	
201.15	"...historically commuter trains struggle a bit more in terms of capacities ... people like to put things down toilets that aren't meant to go down again ... we'd have wet wipes ... blocked for a week because it had someone chuck a nappy down."	System Integration Engineer, CET Tanks (OEM)	08/07/2019	Requirement to ensure (Passenger Wastewater System Development Project) can prevent or mitigate the risks of blockages and can meet the demands of commuters trains equally as well as other services	Future design consideration with expansion of scope	

202.01	<ul style="list-style-type: none"> • Mass <ul style="list-style-type: none"> o (Global OEM)' is looking to reduce the mass of their rolling stock § The use of new materials § Reducing the mass of the toilet systems <ul style="list-style-type: none"> o Reducing the mass of a train reduces the energy required to move and stop it o Reducing the size of the freshwater tank and waste tank can help § However, compared to mass savings from reducing the weight of the rolling stock structure (cabins, bogies), tanks are not significant 	System Development Engineer (OEM)	28/01/2020	Requirement to ensure the mass of the system does not exceed current mass of CET	Near term design consideration	
202.02	<p>§ Customers prefer opting for larger tanks due to:</p> <ul style="list-style-type: none"> • Industry norms • Potential for reducing the need to empty and replenish them as frequently • HOWEVER: Freshwater tanks NEED to be emptied every two days to preserve water quality; larger tanks that are never emptied fully and are constantly refilled can lead to contamination: 8% of tanks fail (Germany, TBC) • (Global OEM) is powerless to prevent customers from choosing the wrong tank size: <ul style="list-style-type: none"> o If the specs state that they need a certain size then they have to deliver otherwise they will lose to another OEM or an OEM can sue the operator for accepting a bid that does not conform to the requirements 	System Development Engineer (OEM)	28/01/2020	Opportunity to explore how the system can provide freshwater over the two day limit for current tanks (and maintain quality)	Near term design consideration	
202.03	<ul style="list-style-type: none"> • Data <ul style="list-style-type: none"> o (Global OEM) is installing monitoring systems on their trains to collect data to inform future system requirements even if current operators do not fully use them: § Suggests similar approach Tesla is taking to enabling their cars to self-drive through collecting data for when this is legal <ul style="list-style-type: none"> o 'Landside' operations can benefit from 'predictive maintenance' as a result of these systems informing them when to empty and fill tanks due to actual volumes § Mind set issue: some operators are more interested than others 	System Development Engineer (OEM)	28/01/2020	Opportunity to gather data from train toilets to measure exact usage to inform system volumes and frequencies	Near term design consideration	

202.04	<ul style="list-style-type: none"> Current systems/in development <ul style="list-style-type: none"> Recycling greywater Emphasis on reducing the mass required by the freshwater tank Currently in use on the ICE 4 trains <ul style="list-style-type: none"> Recycling water from black water (very early stage development) 	System Development Engineer (OEM)	28/01/2020	Opportunity to explore/integrate (Global OEM) current and future wastewater rail technology	Near term design consideration	
202.05	<ul style="list-style-type: none"> Water usage <ul style="list-style-type: none"> (Global OEM) has tested the exact amount of water required to flush the toilets to provide sufficient transfer of waste (Global OEM) has tested the exact amount of water required to clean hands (pressure and duration of the tap) 	System Development Engineer (OEM)	28/01/2020	Opportunity to optimize current hand-basin and flush water usage	Near term design consideration	
202.06	<ul style="list-style-type: none"> Built to last <ul style="list-style-type: none"> Rail industry looks to produce products that can last 30 years and do not reflect short-term obsolescence found in other industries However, this reflects the way in which maintenance is provided: <ul style="list-style-type: none"> If provided by the OEM that built the train they'll most likely prefer longer term components (no market for selling parts) Potentially cheaper if the train is not bought with maintenance regime and the incentive for reliability and cost reduction is not there 	System Development Engineer (OEM)	28/01/2020	Requirement to ensure the system can be serviced for the 30 years to meet industry norms	Future design consideration with expansion of scope	
202.07	<ul style="list-style-type: none"> New standard <ul style="list-style-type: none"> (Global OEM) wants the new standard to ensure OEMs are not undercut by others and can be relied upon by operators as the authority for the correct toilet specifications Relates to USE 563 (TBC) 	System Development Engineer (OEM)	28/01/2020	Opportunity to incorporate the new CEN standards into the system (or identify ways in which it can reflect required standards)	Future design consideration with expansion of scope	
301.01	"...we invest financially but we've got the technical backup as well so we're there to improve the fleets whereas some of the new people coming to market are just finance companies so they are totally relying on people like (Global OEM) and (Global OEM) to be build and maintain."	Procurement Manager (ROSCO)	07/08/2019	Opportunity to ensure (Passenger Wastewater System Development Project) system can be serviced by different ROSCO, OEM and TOC resources	Out of scope - not related to current wastewater focus	

301.02	<p>"...every unit that's gone into works there's a subtle difference on the actual dimensions ... the drawings tell you one thing ... but when it usually comes in there are subtle differences which can cause a problem... Short of surveying every train, it's difficult, because if you survey one or two, you got your drawing, your assumption is that's correct, I guess the risk is that if you go out and produce 'x' amount of units and you come to fit them and they don't all fit... obviously it's probably impossible to survey every single unit it's just something to be aware of."</p>	Procurement Manager (ROSCO)	07/08/2019	Requirement to ensure (Passenger Wastewater System Development Project) system can be adapted to various dimensional constraints	Out of scope - not related to current wastewater focus	
301.03	<p>" ... A lot of the trains, I know the (train operator) ones, have sensors fitted ... where GPS, when it comes to a point in that part of the track ... then it takes all the waste out, probably in the middle of nowhere where people go ... rather than straight outside a station."</p>	Procurement Manager (ROSCO)	07/08/2019	Opportunity to consider the use of GPS systems should safe discharge be a feature of (Passenger Wastewater System Development Project)'s system	Future design consideration with expansion of scope	
301.04	<p>"... With CET tanks you get terrible smells coming out of them if they're not emptied... I'm a customer as well I used the train every day, sometimes it's a disgusting smell."</p>	Procurement Manager (ROSCO)	07/08/2019	Requirement to ensure (Passenger Wastewater System Development Project) does not exceed odour of current normal levels	Near term design consideration	
301.05	<p>"There's mobile services, which I know they've used ... there was a CET discharge facility on the depot ... I know not everyone has that luxury ... I know a lot of people have to use mobile services... you can only do it when you're back at the depot ... if they can't get back to the sidings and they're back in traffic the next day, the toilet's locked out of use..."</p>	Procurement Manager (ROSCO)	07/08/2019	Requirement to ensure any servicing equipment that may be used for the (Passenger Wastewater System Development Project) system is mobile	Near term design consideration	

301.06	"...where the pipework's not been up to the required standard and waste has been seeping out of them ... in the early days when we first fitted them you're going to have teething problems ... we've had other issues, with the water, when you wash your hands, the heat being too hot ..."	Procurement Manager (ROSCO)	07/08/2019	Requirement to rigorously test the system to ensure few problems occur during the implementation	Near term design consideration	
301.07	"Now we're looking at Bluetooth technology rather than strip a vehicle to run the cables through we can maybe use Bluetooth equipment ... easy to slot in and take out."	Procurement Manager (ROSCO)	07/08/2019	Requirement to consider installation methods that do not require significant impact to the rolling stock's structure	Near term design consideration	
301.08	"To reduce the pence for mile we're currently looking at ... for certain fleets at the minute, where we can push out maintenance ... if you're not doing the jobs as regularly that reduces costs. We've looked at taking weight as the Network (Rail) will charge for weight as well ... that will reduce the operating costs as well ..."	Procurement Manager (ROSCO)	07/08/2019	Opportunities to explore how (Passenger Wastewater System Development Project) could reduce the frequency of current servicing and the reduction of rolling stock weight to reduce Network Rail charges	Out of scope - not related to current wastewater focus	
301.09	"... You could have a toilet that's locked out of use ten times but it could be for ten different reasons ... which in my experience the operator will have on the depot on their localised maintenance system, we wouldn't have access to that much detail ... we don't necessarily see all the data that the operators are producing every day from their own systems. They tend to share more if there is a problem, obviously."	Procurement Manager (ROSCO)	07/08/2019	Opportunities to explore how to ensure operators and lessors have the same level of insights into the performance of the (Passenger Wastewater System Development Project) system	Out of scope - not related to current wastewater focus	
301.1	"... one of the issues we're having with the older fleets is that we're putting all this extra kit on it, they were designed to be able to take x amount of weight so we are on the extreme of some of them, mechanically and electrically as well. New systems we're putting on we're draining the electricity as well so it's one thing we have to be careful of when we're looking at new things because there's only so	Procurement Manager (ROSCO)	07/08/2019	Requirement to ensure (Passenger Wastewater System Development Project) system stays within the limits of power consumption and weight restrictions of the carriage	Near term design consideration	

	much power we can generate from certain units."					
401.01	"If you've got an electric train it is a very different situation (to a diesel train)... the most frequent thing you would do with it is send it for its toilets to be either both filled and emptied ... So actually a lot of the operational planning around electric vehicles can be about emptying the toilet."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to work with electric train operators to ensure system is compatible with their specific requirements	In scope of current development	
401.02	"...we haven't retro fitted CET tanks... There are a few cases where we have, but what we have done we have replaced the train, got a new train, that is how it has largely been applied. There are a few cases where we have retro fitted it."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to assess the differences in requirements for retrofitting vs integrating onto new trains	Near term design consideration	
401.03	"...we started operating trains out of Stourbridge ... We had to put in toilet emptying facilities there. It was particularly problematic because there wasn't a mains drainage connection to the site... So initially we actually had to empty the toilets into another tank that was then emptied by a tanker every day. After a few years of doing that we got fed up and actually put in a proper mains connect... It's just the cost ... You have got the cost of getting a load of pipes laid in the ground and the design and the hassle of getting all the diggers in..."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to communicate the benefits of decentralised wastewater systems	In scope of current development	

401.04	<p>"... (at) a new facility at Banbury ... It came out ... once we had built the facility that the local drainage network was almost at capacity. So we've had to put in place ... a lot of storage capacity on the site, mainly for rainwater, because that tends to be the dominant design criteria for drainage is surface water ... we actually pump out waste water overnight when the local drainage network can cope because it hasn't got the household waste and drainage requirement on it... we have a long debate with Thames Water about how to manage that situation... I think in all likelihood we would connect into the drainage network anyway and then have a big argument with them. Because realistically there is no other way of treating your waste unless you want to build your own waste water management plant, which would be very expensive."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to engage with water utility companies to assess the impact of wastewater drainage from rolling stock	In scope of current development	
401.05	<p>"...the local waste water authority may expect you to contribute to the cost of upgrading the local facilities"</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Communicate a hidden cost in investing in growing fleets that use CET systems	Future design consideration with expansion of scope	
401.06	<p>"So in terms of, typically you go through a concept design, then you go to a detailed design, then you try and fit, make sure it works and you would apply that and roll it out across your fleet. It is the kind of stages that we would go through for major change. That will also be accompanied by a kind of safety validation process called the common safety method where you typically if it's deemed to be what's known as a significant change you would do a (hazard ?) identification right at the start and then as you move through the design phase concept into detailed design and then once you have done your trial you would do some validation testing that would demonstrate the change you have made, if your (vertical ?) was safe or compliant with standards</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to meet rail standards of developing new designs for fleet systems	In scope of current development	

	and then you would draw it out across your fleet."					
401.07	<p>"...there is a growing market tendency in train maintenance for maintenance to be a separate, to be carried out by a company that is different from the operator. A lot of the new trains, the train maintenance provider is the company that built the train, as opposed to people who operate it. So in that sort of market, probably the person making the change is likely to be the train builder and because they also maintain the train they will have an interest from that perspective... The suppliers like doing maintenance because it's more profitable for them. It provides a steady income stream compared to building a new train."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to ensure train manufacturers are capable of maintaining the system (along with operators and maintainers) if integrated into new trains	Near term design consideration	
401.08	<p>"...if you are retro fitting a system, typically on a mainline train, the system once it's installed on the train, it becomes the property of the train owner and then the maintainer has an interest in obviously maintaining it ... it isn't as simple as it sounds sometimes. Obviously the supplier has an interest if they are supplying a whole system."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to explore who should be responsible for maintaining the system if it is retrofitted to existing trains	Out of scope - not related to current wastewater focus	

401.09	<p>"...there is always a data exchange going on between the operator and the maintainer ... we are having data exchange all the time over how the train is being used, so we know how many miles it has done for example ... Obviously in the background we've got fairly large maintenance systems that are tracking defects and also planned maintenance (inaudible) so that we know what work is coming up, what our priorities are in terms of repair. So we can tell you how many toilet defects for example we have got right now."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement for system to be compatible with current monitoring systems	Near term design consideration	
401.1	<p>"It is being organised through the rail delivery group ... every four weeks a select group of train operators report how many days they've not had toilets working and the brief reason of why that is the case ... one of the dominant reasons that is typically is because the CET tank has not been emptied. So nine train operators ... typically toilet non-availability across those nine operators is three per cent. The reasons for non-availability tanking, which is either the waste tank is full or there is no fresh water, is 32% of the reasons, and 68% is for other factors such as blockage, locks, toilet door locks, toilet doors failing, tap not working, toilet not flushing... if you looked at toilets across the network that were not working on trains 1% of that would be due to CET or no fresh water, so not able to empty them. The waste tank is full or unable to empty it... Why would it be? We haven't got the train to the right, a location where we can do it."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to explore other reasons for toilet non-availability	Near term design consideration	This insight contains two actions; a yellow status for exploring reasons for toilet system related non-availability and a grey status for toilet cubicle related reasons (i.e. door faults)

401.11	<p>"... Train toilet usage is kind of aligned to distance of services. So if you operate long distance services your toilets get used much more heavily than if you operate journeys of say less than an hour because a lot of people can hold it for a journey less than an hour and will just go in the station or when they get to their destination. If they are on a train for two or three hours they will probably need to go at least once."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to understand the wastewater differences between types of train services (and how they may differ to non-train sources)	In scope of current development	We have so far taken only two samples but with hopefully access to a second depot in the near future we can increase the frequency of sampling and obtain answers for this. I am assuming that the sampling campaign will last until June 2020 to obtain a significant and representative number of samples.
401.12	<p>"... if we have ... got two toilets on a four car train, if we lose one of the toilets due to a technical defect obviously the remaining toilet is much more heavily used and therefore as a consequence its tank and its fresh water gets used much more quicker and then the toilet tank will get full. I suspect that occurs on particularly long distance operators, although they would tend to have more toilets on their train."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to understand worst case scenario in wastewater quantities and engage with long-distance train operators	In scope of current development	From a treatment process point of view, we are already evaluating the technologies for ranges of wastewater flows/volumes so we will have a clear idea of what's achievable for the system. As part of the testing we will continue working on this for at least another year. However, we are not currently able to obtain actual data from trains in terms of volumes generated.

401.13	"I think there will be increasing pressure from regulators to have reliable working toilets on trains... there is a PRM deadline at the end of this year and I think after that point there will be regulatory emphasis on having working on train toilets."	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to understand the implications in making the system meet future reliability regulations	Near term design consideration	
401.14	"The thing about a toilet, on-train toilet is not just the actual toilet you have got to keep working, you have got to keep the door system working, so water, obviously empty the toilet tank. What we tend to find is that the design integrity of the door system is worse than that of the toilet."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to understand the impacts of other component failures on the use of the system	Out of scope - not related to current wastewater focus	
401.15	"So, right now there's no, there's no legal limit, but there is a kind of guideline of six days. We think that a regulator will start from the start of next year come down on that six day thing, but it is actually trying to sometimes fix some of these defects within six days. It is quite difficult because they can require quite complex, difficult repairs. Particularly the door systems, if you have got to fit a new door, or fit a new door mechanism that would take you quite a bit of time. And you may not have the spare parts, even in the UK to do it."	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to guarantee system can be fixed within 6 days to meet potential reliability regulations	Future design consideration with expansion of scope	
401.16	"We could send you all our toilet defect data for a period of time ... we don't mind supplying data, but in this particular instance we know it is very sensitive in the public domain so we wouldn't want it to be well known that it is from us."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to analyse dataset of toilet defects	Future design consideration with expansion of scope	

401.17	<p>"We are pretty sure that most of our sensors don't work, but we generally don't care... in our case the fact that the sensor's failed doesn't lock the toilet out of use, some train designs if the sensor says the CET tank is full it will lock the toilet out of use ... We do know other operators who are very sensitive to it... It depends on how you manage your toilets. Probably if you are an EMU electric train operator it is more useful ... because emptying your toilet is a determining factor on how you plan on doing your maintenance. For us as a diesel train operator the dominant factor is the fuel and it is much more frequently ... but not much more ... more frequently that you deal with fuel than you would necessarily deal with the toilet... some toilets the way that the vacuum toilet works is the vacuum is formed in an evacuator module. That is actually within the toilet tank so if the tank overfills it fills up the evacuator module, which then permanently damages it... We altered all our toilet designs to get rid of this particular flaw and actually what happens in our case is when the CET tank fills up if it overfills it just spills out, but a pee onto the track, well that's not really a great problem."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to provide optional outcomes for when the system is at capacity	Future design consideration with expansion of scope	
401.18	<p>"The fresh water tank is always bigger than the CET tank because the water you use for stuff like handwashing doesn't go into the CET tank. That goes straight down onto the track normally... it would be quite easy to design it so that the handwashing water went in the CET tank, but largely we haven't done that."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to ensure system doesn't rely on hand basin water if it is to be retro fitted without altering plumbing	In scope of current development	Clarify with (project sponsor) to what extent this quote is indicative of all services As mentioned above we look into the impact of flows/volumes on the technologies but from water saving/recycling point of view, we will want to include the hand wash water.

401.19	"Largely the problem with fresh water tanks tend to occur if you have a tap defect that it just effectively draining the water out the tank. It tends to be a consequence of something else."	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to ensure system can function with tap leakage	In scope of current development	Noted that system will ensure any water from a leaking tap will not be wasted (reliant on reuse/recycling functionality) Yes, this is covered by testing and system will actually help recover the water from leaking tap
401.2	"...as an industry we are challenged to be prepared to upgrade for disabled people and an aged population probably earlier than other transport modes so perhaps we can offer transport for an aging population. We are better positioned for it than some other transport modes, but there is still a long way to go until we can make that happen."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to communicate the importance of reliable wastewater systems for an ageing population	Out of scope - not related to current wastewater focus	
401.21	"...we have got to be aware as an industry at both the national government level we need to take on the Unions and actually have technology available that will do that for us... people don't want to spend their lives emptying toilets. If I talked to my son and said, now then I want you to spend the next 40 years emptying train toilets, I think I know what response I will get from him. And actually I don't think that people in the future will want to do that type of work. I think we will struggle to employ people to do that type of work, particularly when you say oh yes and also I want you to do it at night in the freezing cold."	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to engage with unions to offer a constructive means to retrain and reemploy workers displaced by the system	Out of scope - not related to current wastewater focus	
401.22	"...once you have got robotic systems for connecting any type of hose to a train that will either take fluid off a train or put a fluid on it becomes quite an attractive proposition, particularly to people like us who have to deal with re-fuelling trains, because all of	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to explore how any emptying or replenishing of the system can use robotics	Out of scope - not related to current wastewater focus	

	sudden you do lots of tasks at once."					
401.23	"Automated cleaning of trains would be brilliant, but it is a much more difficult task to automate."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to communicate how the system contributes to automation	Out of scope - not related to current wastewater focus	
401.24	"I think ((Passenger Wastewater System Development Project)) is a good technology for rail. It eliminates the need for the tanks and tank emptying so it is good from that perspective. Potentially it makes sidings simpler and easier to operate and build. But you have got to remember we don't do that very often anyway."	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to explore if the system can have a wider impact	Future design consideration with expansion of scope	
401.25	"... You still need to keep the fresh water tank topped up. So unless you can recycle water, which may be an option, it doesn't eliminate the need for the fluid tasks, the frequent fluid tasks. If you can re-use the water it would do ultimately..."	Engineering Assurance & Development Director (TOC)	30/08/2019	Requirement to recycle water to eliminate/reduce the need for fresh water replenishment	In scope of current development	Water will always need to be topped up. Fresh water consumption can only be reduced significantly if both toilet flushing and hand washing can be reused. The system will not eliminate the need to refill the fresh water tank but can reduce the frequency significantly. Again this is being assessed as part of the testing which will estimate the maximum recovery rate.

401.26	<p>"They have probably got a case (to install bioreactors) because they are an electric train operator... It is much easier in sidings to put fresh water filling in for filling up the tank, for filling up the trains than it is to put in all the drainage for emptying them. So they have probably got a case where they are looking at building additional sidings or they have got existing sidings that don't have toilet emptying facilities, but they can fill up with water... We've certainly got sidings like that ourselves... They are fully equipped for water replenishment, they are not equipped for emptying. That is partly historic because when you dumped everything on the track all you needed in your sidings was fresh water filling points."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to communicate the system delivers the same (and more) benefit derived from bioreactors (i.e. can enable sidings without drainage to be used more frequently)	In scope of current development	
401.27	<p>"It would jet clean the top of the rail with very, very high pressure water jet. But of course you use lots of water, so we used to have tanks on site that would hold very large water volumes that we then pump onto the train, but most depots don't have that problem. In fact we have no longer got the trains, so we have no longer got the problem either, but in one instance Thames Water actually thought that there was a leak on their distribution network so shut the depot down because we were using so much water."</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to engage with water utility companies to explore the impacts of regular depot fresh water use	Out of scope - not related to current wastewater focus	
401.28	<p>"The nice thing about water is it is relatively cheap, so we use lots of it. Typically on depots if they have got the train wash is your biggest consumer of water. It far exceeds the tanking requirement with the water, fresh water tank requirements. For us as an operator we know that our single biggest consumer of water across our entire estate is our train wash... You can recycle the water and there are train washes that do that, in fact (project sponsor) I suspect supply one if you wanted more information. (project sponsor) make train washers so if you wanted</p>	Engineering Assurance & Development Director (TOC)	30/08/2019	Opportunity to learn from train wash wastewater management processes	Future design consideration with expansion of scope	

	more information, talk to them."					
402.01	"...the law we've got in the TSI from 2010 now to have sealed toilets in the train without waste emission on the tracks, in fact, so operating department decided to not implement toilets on the commuter trains but we implement toilets on ... regional trains and mainline trains..."	System Development Engineer (Train Operator)	28/01/2020	Opportunity to explore how the system could enable commuter trains that don't have toilets to have them	Future design consideration with expansion of scope	
402.02	"...we've got two options for waste, toilet waste we can store it and remove it to send it to sewage treatment in the depot or you can treat on board and release this waste on the track after treatment and the water quality must be according as basin waters quality."	System Development Engineer (Train Operator)	28/01/2020	Requirement for any discharge to be hand basin water quality (bathing or drinking?)	In scope of current development	
402.03	"...it has great financial issues ... because when we need to collect, you know train in the depot regularly just 20 toilets tanks, it is really more difficult to operate than the train without toilets where your train can be parked anywhere and there's no reason to take it to the depot for such maintenance operation."	System Development Engineer (Train Operator)	28/01/2020	Requirement to ensure system can provide the same operational/financial benefits as a train without toilets	In scope of current development	
402.04	"...we always consider that the train starts its life running on the line, but on life for rolling stock which maybe in 30 or 40 years, it may change or it will evolve from a service to another service where toilets should be requested..."	System Development Engineer (Train Operator)	28/01/2020	Opportunity to communicate that the system will enable rolling stock to be used on more services (that require toilets)	Out of scope - not related to current wastewater focus	

402.05	"...even though ... we command to implement toilets but (the procurement) choose to not implement it and for these commuter trains, they decided to re-install toilets on the platforms ... More in the station of the ground than the rolling stock but in our main city we've got ... two operators ... in fact all operating department of those trains decided to remove it... we're all under pressure to reduce our costs and one lever to reduce this cost was to move the toilets from the train and to move it to the station and that's big price on that one hand, than certainly lower one because operate the toilet in the station to me it's cheaper than toilet on the train, on train service needed to operate it, to clean it, to keep it clean it's costly."	System Development Engineer (Train Operator)	28/01/2020	Current solution to providing toilet facilities to passengers is through installing them at stations instead, possible alternative system use to enable decentralised stations	Out of scope - not related to current wastewater focus	
402.06	"we make a kind of survey but what happened in other countries, when you hear about one of your neighbours that have decided on the small regional trains to not implement toilet and after a few years due to passengers complain on a court, the court force the train company, the operating company to implement toilets on trains where it had been not designed to put it."	System Development Engineer (Train Operator)	28/01/2020	Risk involved in removing toilets: passengers can take operators to court, reason for using this system instead	In scope of current development	
402.07	"... Sometimes some people do what they need to do on the train and it's now a cleaning issues because when you've got toilets on trains it is in the contract, we have as train operating company with the cleaning staff who used to clean the toilets but when someone has done something wrong on the train there is not expected someone has done something on the train... So, cleaning company staff say no we are not going to clean because it is not in our contract to clean such stuff... And maintenance department don't want to clean or cleaning responsible don't want to	System Development Engineer (Train Operator)	28/01/2020	Removing toilets from trains will not remove the need to use them: outcome creates problems for cleaning contracts that do not cater for human waste	In scope of current development	

	clean and we've got a dirty train."					
402.1	"... when we consider the philosophy of the TSI documents we are dealing with lots of new requirements and new functionalities in trains to help accessibility of passengers, disabled people on board. In fact, to me it's nonsense to not install toilets on trains because you can need the toilet in a hurry, specifically when you are disabled passenger..."	System Development Engineer (Train Operator)	28/01/2020	Opportunity to highlight the importance of toilets to services without them from a disabled passenger point-of-view	In scope of current development	
402.11	"In fact, when you are not operating toilets on your train your train is cheaper, it's not so expensive and it's cheaper to operate because there's lots of service and maintenance expense need to clean the toilets it says, and actually that choice it has great influence specifically since the toilets are momentarily sealed or with onboard treatment systems."	System Development Engineer (Train Operator)	28/01/2020	Financial benefits of running services without toilets is a significant incentive. OPEX needs to be comparable.	Future design consideration with expansion of scope	
402.13	"... there's more toilets available in airport than toilets available in aircraft ... you've got, there's about 180 passengers in train with the same amount of passenger on a mainline train you have most of time four to five toilets, on Airbus you've got only three or sometimes two depending of the choice of the company..."	System Development Engineer (Train Operator)	28/01/2020	Air travel uses a different ratio of toilets to passengers, opportunity to explore rail ratio of toilets to passengers	Future design consideration with expansion of scope	

402.14	"... the three functions with low reliability are passenger access doors, air-conditioning system and toilets and the one with the worst influence on passenger satisfaction specifically on mainline trains are toilets... And the operating department, marketing department for mainline trains they've got greatest expectation of passenger satisfaction on the toilet service and it's really, really, hard because the available product we've got on the market are not really reliable."	System Development Engineer (Train Operator)	28/01/2020	Toilets have the lowest reliability and highest cause of dissatisfaction amongst passengers, demonstrating the impact on both operating and marketing departments	Out of scope - not related to current wastewater focus	
402.15	"... one of the highest difficulty we've got today is the capacity of the system in the railway, rolling stock environment is the capacity of the system to move the human waste from the toilet bowl when it has been left to the tank where it is stored which is for emptying in the depot ... you've got as the toilets on the train as the only passenger area accessible where you are totally hidden in the toilets you can do what you want in the toilet, it's really funny to see what passengers can throw through the toilets."	System Development Engineer (Train Operator)	28/01/2020	Behaviour of passengers exploiting the privacy of toilets to damage current systems, opportunity to address this	Out of scope - not related to current wastewater focus	
402.16	"...there's lots of technical issues on the train design that has an influence on the toilet system, for example it is now mandatory for all rolling stocks that the wheelchair users may have direct access in autonomy without any help from outside inside the train, so it means that with the kind of train platform we've got, we need to have low floor at the low end of the platform it's 550 millimetres above the rail level, that means that the floor of the train is low and the toilet tank to collect the waste must be, it's impossible any more to put it below the first floor because there is only the rail below so as there's no place anymore most of toilets are above the toilet allocation level, that means actually to move a product, the waste, to throw it into the tank and that kind of design doesn't help to have reliable toilets."	System Development Engineer (Train Operator)	28/01/2020	As a result of catering for disabled passenger access, train floors with this operator are much lower, resulting in only 550 mm of space for underfloor toilet systems	Near term design consideration	

402.17	"... one way we developed to reduce the volume of water stored in the train is re-use of the water that had been previously used to wash the hands of the passenger, we use it to rinse the toilet bowl for the next passenger... it helps to reduce the weight of the tanks in the train, on mainline trains ... it is really important that more weight of the train and, of course, the energy consumption of trains is something we really, really want to reduce and reducing the weight is interesting to reduce energy consumption..."	System Development Engineer (Train Operator)	28/01/2020	Requirement to ensure current savings of weight and energy consumption are provided with new system	Near term design consideration	
402.18	"... the technology you rely installing because everything needs to manage something with the product you are not really able to manage because in fact the passenger can throw what they want in toilet."	System Development Engineer (Train Operator)	28/01/2020	Requirement to enable the system to respond to any foreign objects disposed of by the passengers	Future design consideration with expansion of scope	
402.19	"... there's specificity on toilet waste we collect from the toilets on the trains, is that the concentrations are sort of different from the one, any classical sewage treatment system used to see ... when you are at home when you are flushing the toilet you will throw more or less three litres with 0.2 litres of urine, faeces, if needed, but in any case the dilution is really different than the one we've got on trains, on trains in fact, you've got immediately a mix really highly concentrated in urine and any classical way to clean ... needs to deal with something really difficult to process because according my experience ... some analysis in the past when you collect the waste in your tank it's immediately used as a PH really high with the urine concentration incredible and as soon as it's mixed with water and through to the waste water tank the chemical content is really tricky to deal... It's an issue because it's never been our strategy to make our own water treatment in our depot so we used to deal with contract with the owners of the cities ... even it is diluted in the city water	System Development Engineer (Train Operator)	28/01/2020	Rolling stock and domestic wastewater are significantly different, urine concentration is much higher, pH values are much higher, can cause challenges for municipal wastewater treatment facilities	In scope of current development	

	it is difficult... I've got the feeling the urine concentration is much higher than the one you can have at home."					
402.2	"... when you are dealing with bioreactor technology you need to balance with the waste and you need to have as stable as possible waste concentration with a balance mixed with urine and carbon products and if you've got too much urine it's toxic to the bacteria that some are able to work with urine so to me it's, it's absolutely difficult to manage... this concentration is really, really tricky and the ratio in between is something really specific and for now I don't know how to deal to have such a system that instead of using a tank something processing to send to the track ... it would be very interesting for us to not stop the train to empty it in the depot."	System Development Engineer (Train Operator)	28/01/2020	Opportunity to communicate the shortcomings of bioreactor technology requiring unrealistic ratios of wastewater contents to protect the bacteria (however, ability to safely discharge on track and not at depot is of interest)	In scope of current development	

402.21	"... the content of the waste to me is about 2% of faeces, 48% of urine, I should say 2% in weight of toilet paper and of course about 48% of water and, in fact, in that case when we are recycling the water from the tap we've got this dilution and most of time when we are not recycling this water is going directly to the track when it's not recycled..."	System Development Engineer (Train Operator)	28/01/2020	Wastewater profile reported to be present in this operator's tanks, 2% faeces, 2% toilet paper, 48% urine, 48% water	In scope of current development	
402.22	"... two years ago I made the exercise we still had half of the toilets throwing on the track but this 50% of the rolling stock are operating more or less 20% of the track, so it's difficult to know exact overview..."	System Development Engineer (Train Operator)	28/01/2020	Significant number of trains in France still discharge directly onto the tracks without processing	In scope of current development	
402.23	"... supply of bioreactor technology is interesting investment if you're able to increase the time between two maintenance operation... technically it is always interesting for an operator to say, ok, my trains are in service and I will catch it only every three, four, seven, ten days..."	System Development Engineer (Train Operator)	28/01/2020	Requirement to ensure system achieves same reduction in depot visits as bioreactor	Near term design consideration	
402.24	"... the mainline fleet in the past we had safety inspection on bogies and wheels on everything as a lower frequency than the emptying of toilets so it was not a problem to combine the emptying of the toilets with the safety inspection, the wheels and the bogies... But as they made huge improvement on bogies, to collect data, to check everything and they know that the maintenance frequency is now longer than the maintenance interval of tanks. So, now we are thinking about how we can increase that bigger tank or treatment technology that helps..."	System Development Engineer (Train Operator)	28/01/2020	Tank emptying is becoming more isolated due to the reduction in depot visits due to the reliability of other systems that used to be maintained during the same visits - new system will need to meet the same level of intervention frequencies	In scope of current development	

402.25	<p>"... it's a balance between the procurement price and the maintenance price during the life time and on toilet systems one part of the price is the emptying operation, other price is maintenance of the system and the emptying is directly linked to the frequency, you've got the energy which has a great influence and, of course, from the tank resulting in without any maintenance ... just not big issue with the tanks, you need to replace and seal somewhere, some floating levels from times to times but there is not a maintenance problem with such equipment. When you want to deal with treatment technology you need to consider that you are going to win money on the emptying operation but what about maintenance? The bioreactor technology, you've got collect the waste, you've got a filter, you need to clean the filter regularly, you've got a transfer system, you need to keep it in service, you've got sensors, you need to clean regularly, you've got heating system to clean the waste at the end of the process with regular maintenance operation..."</p>	System Development Engineer (Train Operator)	28/01/2020	<p>Complexity of servicing bioreactors increases OPEX compared to the simpler CET requirements - OPEX of system would have to be comparable to CET</p>	Near term design consideration	
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402.26	<p>"... really depends of the infrastructure you've got on the ground because emptying operation is really expensive when you need to move the train to a specific track to empty, it's really expensive when you've got not powerful equipment, it's really tricky when your depot are overcrowded and it's impossible to move any train to put it on the right track to empty it, vital knowledge you are new train operator and you are starting from nothing it's really interesting to consider the bioreactor technology because if you need to buy everything, of course, it will be interesting to empty your system every 60 days instead of every three days because every three days you need to manage all the operations of the train around this emptying operation, with bioreactor you've got sensors you know exactly when it will be full and you can manage it when you want, at night or during weekend or when the train will go back naturally to the depot for other reasons..."</p>	System Development Engineer (Train Operator)	28/01/2020	<p>Location-dependent facilities required for CET servicing systems make bioreactors more appealing to operators who do not have these (system will need to have same benefits)</p>	Near term design consideration	
402.27	<p>"... when you are big operators, when you have got everywhere with very old technology with tanks and when you need to empty every three days you have that huge number of tracks and it's incredibly costly to maintain that equipment to empty it, but you've got it and as you've got it, the interest is much lower to implement bioreactor technology because everything is managed to send the trains to the emptying operation..."</p>	System Development Engineer (Train Operator)	28/01/2020	<p>...unlike existing operators with the infrastructure already in place (i.e. system servicing requirements could replace/retrofit existing equipment)</p>	Near term design consideration	

402.28	<p>"... when you've got the treatment, for example, the frequency is about three days on a mainline train, if you use the same kind of volume and weight to implement the bioreactor you will go to about 45 to 60 days, so ... because the emptying operation of bioreactor technology takes longer time than conventional one ... technique really is more complicated with the same weight ... so perhaps the price is divided by 12. This one (CET system) there is no energy consumption onboard, this bioreactor when you need it to eat all of the waste you are throwing through the track, there's an energy consumption and ... the travels of the waste along the water treatment system is about two days, it means that if you've got the volume of two days in the system it means that the average weight of your equipment is higher than the one you've got here, so it increase weight in your train."</p>	System Development Engineer (Train Operator)	28/01/2020	Requirement to ensure the system achieves the same processing time as bioreactors (2 days)	In scope of current development	
402.29	<p>"... That means that even if you just look at the price of the emptying operation you can consider that you are earning money and at the end it's not so clear, for us it's not so clear that's why we are not pushing so strongly on that. Perhaps in future because I hope that in future improvement of technology or new things are more other way to treat water should arise, if we can reduce the volume, reduce the energy consumption, reduce the amount of liquid request to clean it perhaps consider it differently but for now the technology is to me not much or enough to have really strong figure to say ok, it's this technology is cheaper than the previous one..."</p>	System Development Engineer (Train Operator)	28/01/2020	Difficulty in calculating the overall savings in using the bioreactor vs. CET reduces interest, opportunity to communicate system benefits with greater clarity	Future design consideration with expansion of scope	

402.3	"... what we want for future is to really increase the reliability of the transfer of the waste from the toilet to the tank because today it's a mess honestly. It's incredibly costly ... impact on passenger satisfaction is really direct ... no one has enough money to invest on long term period on the toilet bowl technology..."	System Development Engineer (Train Operator)	28/01/2020	Significant interest in reducing the impacts of items that are not supposed to be flushed down the toilet	Future design consideration with expansion of scope	
402.31	"... And in fact at the very beginning one of the issue we have was the capacity of the retention tank but as we are re-using for about ten years, the last train we bought, we are recycling the grey water, it allows us to reduce the drinkable water and to increase retention... the suppliers, they will tell you that you win about 50% in reality it's not 50% ... between 30 and 35%..."	System Development Engineer (Train Operator)	28/01/2020	Importance of ensuring system can provide same level of current water savings through grey water recycling	Near term design consideration	
402.32	"... chemical content of the toilet paper is important to consider because we use a lot of, we reused paper and sometimes I know that in the past we made some measurements to find various specific products and ... after the toilet paper put in the water and we were getting the analysis we find exactly the same products... if you wanted to change the brand of the toilet paper you use in your trains, in France as we know the toilet paper has a great influence on the reliability of the toilet, we've got a national process to say ok when we are dealing with the contract with the toilet paper supplier ... we proceed in laboratory some fresh tests to check if it's able to compare it as the previous one to be sure that it's able to be used on trains... some are compatible with bioreactors and some not."	System Development Engineer (Train Operator)	28/01/2020	Requirement to understand the characterization of toilet paper types	In scope of current development	
501.01	"...one thing you need to do for your risk assessment around what is going to be the impact on the stakeholder so it can be for the users, but also for the people who are cleaning the system."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Requirement to conduct a risk assessment of the system in operation and to include both end-users and operators	Near term design consideration	

501.02	"...I would think that actually the treatment inside the train you probably reduce the end issue, or the risk associated with public health because there is nobody trying to pump the waste water from the train tank to another tank..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to demonstrate that this system is safer than current CET due to eliminating direct contact to waste during pipe fitting	In scope of current development	
501.03	"...Really high risk ... if your system is not working there will be people probably with on the train, let's say Novo virus ... or flu, or whatever it is and if your system doesn't remove these pathogens then people ... some people still clean their teeth in a train toilet... I don't know why, but ... if you put non-potable water then people that will say I don't care I am just going to drink it, so if you were going to use this for cleaning then you will need to go to potable ... at least..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Requirement to ensure pathogens are removed to ensure water can still be safely consumed due to current passenger behaviours	In scope of current development	
501.04	"... Yeah, toilet flushing you would need a low technology because there wouldn't be a lot of contact between the people and the water ... maybe you realise that the end product you need to ... assess what risk you will have if someone is ingesting it, touching it or breathing it, in both the non-potable water used for usage and as you said the faecal matter of the waste..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to recycle water used for flushing to lower standard than handwashing due to associated risks	In scope of current development	
501.05	"... at the moment I am in the same position ... as a water company we don't want the responsibility of it because there is a maintenance cost and developers don't want to be responsible for it because once the development is sold then they have no reason to stay in the development or to be addressed to the development. Then it would depend on the users, which are the people. The people buying the property might not want to pay for the maintenance. So, in your case I would say the rail company, or whoever is maintaining the trains, would be responsible for maintaining the system. I am guessing they already have to maintain the toilet,	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Identify who would be responsible/willing to maintain the system due to specialist skills involved and standards required beyond either rail or water sector waste management	Future design consideration with expansion of scope	

	so if a toilet is broken they have to maintain it anyway..."					
501.06	"... you can add solar panels on your roof, so the energy company has nothing to do with it, unless you have a big solar panel production, but three solar panels ... have no say on what I am doing with the electricity. It would be the same for your case, it is a private company that decided to do some water recycling and as long as they meet the WRAS guidelines for multiple re-use then water company has nothing to say..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Responsibility for company maintaining water standards for the system to meet WRAS guidelines	Future design consideration with expansion of scope	
501.07	"... If they want to do that they need to do a risk assessment to understand what are the current risks in the source of non-potable re-use. What they need to reach is a water quality and if it is for hand washing it will be potable water quality ..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Responsibility for company maintaining water standards to conduct risk assessments for the system	Future design consideration with expansion of scope	
501.08	"...there is not a lot of, or there is a few technology that can remove the blood but I am not sure..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to ensure blood can be removed whilst recycling water	Near term design consideration	

501.09	"...So, there would be then a treatment that are able to mitigate some of the risk and then you will have non-barrier treatment, so it might be signage, if it is only for toilet the fact that there is no stagnant water in the toilet is one of the [barrier] which means that nobody can touch it or drink it..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to explore how signage for passengers/ maintenance workers can impact system use	Near term design consideration	
501.1	"... For me we are more working with suppliers and because we know what can treat water and waste water ... it is quite easy because we know ... what is going to work and what is not going to work ... Arup, Acorn probably ... they will have the capacity to understand the process technology required for the type of water."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to find partners for rail companies that can provide the wastewater management expertise	Future design consideration with expansion of scope	
501.11	"...(biggest barrier to the rail sector) is likely to be the cost, because implementing this is going to cost far more than just have a tank that you empty and ... you fill with water... Because what you are speaking about is like in each train to have like, if there is one toilet per carriage, and you have a 12 carriage train ... therefore is 12 decentralised system. ... and the smaller in the system the higher the cost is to operate."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to demonstrate how the system's lower OPEX will justify a much higher CAPEX	Future design consideration with expansion of scope	
501.12	"... there is some treatment that once they are there if they are well maintained it can be quite cheap to operate. There will be an added cost, chemical cost, again depending on which	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to specify treatment processes that will ensure operating cost is low	In scope of current development	

	treatment is within the train..."					
501.13	"... Some treatments might not be available for train because you need some kind of ventilation... I never heard about this kind of process in a train I would say. And they probably have a (large) footprint, so I don't know, they might have to re-design ... I don't know if you have finished to de-block the toilet ..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Requirement to redevelop current treatment to fit rolling stock constraints (lack of size and ventilation)	In scope of current development	
501.14	"Another barrier to your system is the train company, or the one that operates the train, might be scared of what happens in reputation if, let's say, a full carriage become ill after using the toilet. So it is things, reputational barrier is one as well."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Requirement to consider reputational concerns of TOCs/ROSCOs	Near term design consideration	
501.15	"In terms of regulation, there is no regulation to do what you are doing, so they are probably going to have to meet one. There is no regulation, so one of the barriers is how far will you go in the treatment to mitigate your risk and to make sure that you are not going overboard, so you put so much treatment that is so expensive."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to explore cost/benefit of adhering to regulations not currently applied to the system	In scope of current development	
501.16	"And there was as well, the supply reliability. So, if in the future there is a cut in supply because there is no water for people then kind of always have a minimum water... depending on which category we are in terms of drought. So the first thing is irrigation and then because you know when there is a hose pipe ban people can't clean their car for example, well it might be, I don't know if it is applied to commercial premises as well where they can't clean trains..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to consider the benefits of the system providing more reliable water supply in times of drought	Out of scope - not related to current wastewater focus	

501.17	"...when there is rain then a lot of our sewers are over capacity already so when there is a new development then there is an area where you can't put any more sewage into the sewer. I don't think there is a ban in that case, though, I think we have no choice. What happens is ... the sewer if it is too full we will open the sewer outfalls on the Thames or on any rivers so it goes straight to the river without being treated. And we don't want that..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Current approach to managing over-capacity of drainage is to discharge directly into the Thames river. System could demonstrate how it would avoid this.	Out of scope - not related to current wastewater focus	
501.18	"... I wouldn't recommend it to black water recycling because it would cost much more than the potable ... unless they are in an area where they think that there will be not enough water supply, but yeah. At the moment there is no legislation on black water recycling in the UK, so this is quite a big barrier..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Blackwater recycling is not recommended due to cost of treatment and lack of legislation unless water stress is a significant concern	In scope of current development	
501.19	"If you take the case of Old Ford, so the regulatory barrier is where there is no regulation. So what we have done is we took the US EPA guidelines ... and then once we had these guidelines we looked at our drinking water guidelines and some of the US guidelines were more stringent than the potable ones, so for the ones that the US guidelines were stringent we used the potable guidelines, the UK ones, and finally we spoke with customers."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to consider both US EPA regulations and UK potable regulations for reuse quality guidelines due to no direct regulation	In scope of current development	
501.2	"...The granular activated carbon was really for colour removal because the toilet (bowl) are white ceramic and that (outputs) by your reactor is slightly yellow and the last thing you want is people going to the toilet and see a slightly yellow water just before going to the toilet."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to consider whether the colour of the water will require further treatment	Near term design consideration	

501.21	"The question is how do you manipulate the solids to ensure that the workers, or the employees, not getting ill from that... technology is never, in water at least, I would say it is not a barrier. There is always a way to do stuff and to make it safe. It is finding the balance between the amount of technology that you use it is the risk you are taking and I don't think train company would like to take any risk so I would say we would probably end up with quite an expensive technology."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to explore how much risk vs. cost will determine the treatment provided by the system to meet rail concerns	Future design consideration with expansion of scope	
501.22	"...sometimes just education, if people, so there is some countries ... people know that you shouldn't drink non-potable reuse, but because in the UK it is not widely implemented then people don't understand that yet."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Using non-potable water for handwashing will pose a risk due to UK passengers' likelihood to ingest it	In scope of current development	
501.23	"... I would say the train probably in Australia would be more likely to have a better system than doing it in the UK... because in Australia you have (non-potable water reuse) everywhere. So in Australia you have potable and non-potable system, where in the UK you don't have that..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Other markets, such as Australia, may have different passenger behaviours preventing non-potable water ingestion	Out of scope - not related to current wastewater focus	
501.24	"... let's say that all your trains are going to the same place every day, then you probably are likely to have a certain amount of solids but if it is like a different station then you will always end up with a small amount and just by transporting this quantity you may end up with a higher carbon footprint and cost than if you just dispose it to somewhere else... When you do a technology you look at what is the impact on terms of public health, what are the environmental impact and what are the costs and then you need to balance to make sure that you are in the right place, rather than trying to do something to save water, but at the end you are going to have a big impact on other things far more than anything else."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to calculate the total carbon footprint of the operation, including logistics of waste disposal, and any other public health impacts	Future design consideration with expansion of scope	

501.25	"... There is a cost to discharge solids, either to landfill or to the land for fertilizer... waste water sludge trading in Europe. They are starting to reduce that because of microplastic."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	System waste could be an agricultural product if it does not contain microplastics	Near term design consideration	
501.26	"... we are sending ash from incinerator we are sending them to a company that do concrete block and this is used for the construction of housing... We are speaking maybe like 20 tons a day or something like this..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	System waste could be a construction material, if supplied in sufficient quantities	Near term design consideration	
501.27	"... ash to landfill for example they would need a EA permit..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	System waste to landfill will require an EA permit	Near term design consideration	
501.28	"... we are looking at how we can reduce the water consumption of big users and yeah I don't know what, we have quite a lot of train depots in London, the Thames Barrier, it would be good to understand how this can be reduced..."	Project Manager, Water Reuse (Water Wholesaler)	12/12/2019	Opportunity to demonstrate to Thames Water how the system can reduce water consumption	Out of scope - not related to current wastewater focus	
502.01	"How do we, as an organisation, meet the challenges of becoming a net zero carbon emittance by 2030...we are partners in four EU programs at the moment, all really in that resource recovery, circular economy space... We are of the view that in order to become net zero carbon requires a whole range of things from energy use and energy generation and transport..."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Reducing carbon emissions to zero by 2030 is top priority leads to reducing energy use and increasing energy generation from wastewater. Nutrient recovery less of a priority. Could our system help generate energy?	Out of scope - not related to current wastewater focus	Out-of-scope: system unlikely to be carbon neutral (if powered by diesel engine produced electric/fossil fuel derived power)
502.02	"...all our sludge is anaerobically digested because that is an important element for us to produce as much energy as we can, but that does mean that we are sending tankers around all the little works and bringing the sludge... there is a lot of sludge tankered around the region."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Currently, focus is on energy recovery and so sludge is transported by tanker to larger works from smaller ones to enable this due to them not being able to anaerobically digest. Could our system help?	Out of scope - not related to current wastewater focus	Out-of-scope: application of technology for small-scale municipal treatment works requires a different wastewater feedstock

502.03	"...you have got to meet really tight phosphorus limits or really tight ammonia limits it is more difficult and historically we haven't had to, but the water framework directive if the watercourse that is being discharged to is sensitive then that requires some quite high levels of treatment..."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Water Framework Directive is increasing pressure to reduce phosphorus and ammonia in wastewater. Could our system help?	Out of scope - not related to current wastewater focus	Responding to WFD by diverting ammonia and phosphorus to solids collection
502.04	"...a number of emerging contaminants that might be regulated, so heavy metals, micro organics, well not microplastics at the moment, but there is a long list of things that we might have to remove from the waste water in the future. It is difficult anyway, but it is doubly difficult in the small works with a fairly passive treatment technology."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Small decentralized works will struggle to remove hazardous substances in the future with passive technology. Could our system meet that need?	Out of scope - not related to current wastewater focus	Out-of-scope: application of technology for small-scale municipal treatment works uses a different wastewater feedstock
502.05	"...would be a wonderful model to be able to re-use the water and take the heat and almost be off grid and supply benefit to the local community... to do that in a way that is consistent with the sort of low maintenance and low operator visit requirements is difficult... co-locate waste water treatment works with industry that needs water, that needs heat, because the challenge is often if you are ... geographically quite remote ... it makes it a bit harder to get that water and that heat to where it is needed."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Opportunity for any recovery/reuse to be used within the areas of the processing; possible exploration into the benefits of the outputs for depot neighbourhoods	Out of scope - not related to current wastewater focus	Demonstrated with the system: using recycled water from the hand-basin for hand-basin use
502.06	"...big industry they want volume, and sure that is not to say you couldn't pick up from multiple small works and send it, but it becomes logistically a bit more complex."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Low volume/high distribution of outputs from our system would make it less appealing to industry	Out of scope - not related to current wastewater focus	...Establishing markets for solid output out-of-scope; unlikely due to low volume and distributed sources

502.07	<p>"You have to manage the flow, which is complex... emerging substances of concern, pharmaceutical residues, antimicrobial resistance, microplastics, PFAS, these really, really slow to break down fluorinated substances. They are coming from industry, they are coming from domestic properties, the sort of source control element of that is something we are determined to try and... have more influence on... definitely is one of the challenges that we face, less control on the input and yet we are required to, rightly so, have standards on the output, which means really what happens is you build big treatment works with lots of safety factor in there because you have to be able to deal with the sort of worse case. So, if you could get better at controlling that input then you could build a much tighter waste water treatment plant, in size and process, and it would be easier to operate."</p>	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	<p>Lack of control of input results in over processing so to ensure any hazardous substances can be dealt with. More control over inputs could result in more effective/efficient treatment plants. Benefit of the control of input in our system?</p>	Out of scope - not related to current wastewater focus	Out-of-scope: train wastewater unlikely to be a source of hazardous substances to the same degree as domestic
502.08	<p>"Monday... we can afford to we can put out more ammonia or more phosphorous today ... we ... need to produce almost a pure water that needs to go into the river today ... today we want to produce cellulose, because there's loads of value in cellulose, or maybe Tuesday bioplastics ... Or today we are really focussing in on producing as much biomethane as we can or hydrogen...tailor your process is flexible enough that you can yeah operate it to achieve those different outputs..."</p>	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	<p>Being able to control the quality and type of output by controlling the processes so to meet requirements (change ammonia/phosphorus levels, focus on cellulose or bioplastics, biomethane or hydrogen)</p>	Out of scope - not related to current wastewater focus	Out-of-scope

502.09	"...there are some quite big advances being made now on the sensor technology and measuring things as you say real time, but equally on the sort of data analytics side... to start doing clever things like having smart networks so you can store water in the network but you can also, depending on the treatment capacity of a particular works you can say right there is a spare 10 per cent treatment capacity in works X so we will divert more flow to works X and take some of the load off works Y to ensure that you are fully optimised on a systems level rather than just on a works by works basis."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Using sensors to relieve pressure across the entire sewerage network by directing flows; could trains be part of this network?	Out of scope - not related to current wastewater focus	Sewer network impact is an ongoing topic of stakeholder research
502.1	"...a lot of those barriers are not actually technical barriers, so the technologies are there to be able to recover these things. It's policy and regulation, so how to get something that at the moment is viewed as a waste to end of waste and a product, because unless it is a product it is going to be quite hard to sell, or at least it is going to be hard to sell at the cost that you need to sell it at in order to pay back on the investment you've made. So there is definitely challenges there... also then public perception about using products that may have been recovered from waste..."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Commercial, regulatory and perception barriers concerning waste as a valuable product could hinder uptake and pricing	Out of scope - not related to current wastewater focus	Establishing markets for solid output out-of-scope; unlikely due to low volume (and low value?) and distributed sources
502.11	"...you will have higher levels of ammonia and nutrients in there (train wastewater), so it is good from that perspective, so it is stronger and that is an advantage... things to recover are the nutrients and energy and there may be opportunities to recover cellulose as well..."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Train wastewater could have higher levels of ammonia, nutrients, cellulose and energy recovery than other wastewaters	Future design consideration with expansion of scope	Characterisation reflects lab research
502.12	"...you might have the opportunity to potentially recover more at a centralised facility cause you are not going to have all the anaerobic digestion and all the other stuff on a train, but yeah, whether the downside of transporting it to a works more than offsets the sort of resource that you	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Benefit of using a centralised system; you can incorporate anaerobic digestion due to size constraints, however, could be offset by the logistics required to	Out of scope - not related to current wastewater focus	Chosen solid processing technology produces energy, out-of-scope to consider anaerobic digestion

	could recover from it. I am not sure."			transport train wastewater		
502.13	"...I suppose it is possible that you could have some small scale energy recovery system that you could use on the train, but what I am not sure about is whether that would give you much benefit and advantage because you are on a train with overhead electricity supply I suppose and if the grid is green, and it is going that way, isn't it, whether there is much benefit and advantage in generating your own energy ... might be difficult at a smaller scale I suspect."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Use the system to generate energy for the train? Would it be possible or deliver any significant benefit?	Out of scope - not related to current wastewater focus	Out-of-scope for other uses of energy produced, currently used only for the operation of the solid processing
502.14	"...having some degree of treatment not on the train but specifically for the train waste where you ... would need a number of...treatment hubs around on the network... you would discharge from the train to a holding tank on the little, I say little, it might not be little, on the treatment works goes through the treatment process and then is discharged to the environment or re-used... It is just a case then of the logistics, isn't it, of the trains discharging to this centralised treatment facility... That might be a better model."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Idea to split treatment between the train and a centralised hub to prevent unnecessary processing at traditional wastewater treatment plants	Out of scope - not related to current wastewater focus	Out-of-scope
502.15	"...there are a number of operating companies out there that will operate the waste water treatment plants and maybe even own the treatment plant. That is a commercial model that exists I think as well. It may be, well I can imagine the train companies won't want to be owned as an operator necessarily of a treatment plant. Maybe they will be the owner but not the operator. That would be a route too."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	If infrastructure/g round equipment is required for the system who will own it? In this scenario of a centralised hub specifically for train wastewater processing or for the decentralised depot approach	Out of scope - not related to current wastewater focus	In particular solid disposal and filter cleaning. OPEX-related issue: out-of-scope

502.16	"...If there is no pain on discharging it onto the tracks then why would they look to change. I suppose ... it is when regulation forces them..."	Technical Lead, Treatment and Abstraction (Water Wholesaler)	27/11/2020	Lack of regulation could prevent operators from ending track discharge unless made aware of hidden benefits of doing so	Out of scope - not related to current wastewater focus	Ongoing stakeholder research supports this view
601.01	"... whenever we bid for a large tender we would be more expensive because we were doing water efficiency and therefore we wouldn't win."	Managing Director (Water Retailer)	19/08/2020	Water efficiency services in tenders are not attractive to large commercial water users due to immediate increase in costs.	Out of scope - not related to current wastewater focus	...Out-of-scope: aim of the project is not to product cheaper water (rather cheaper operations of trains due to movements)
601.02	"... it is not the vibrant market they expected. About I think it's 15% of people have switched so far. The majority don't even know about the market."	Managing Director (Water Retailer)	19/08/2020	The opportunity for train operators to switch water suppliers might not be well known	Out of scope - not related to current wastewater focus	...Could support (project sponsor)'s marketing
601.03	"... if you're looking at technologies that would apply across the whole market that becomes difficult with England, Scotland, Wales and Northern Ireland. Northern Ireland there is no market, Wales it's only above 50 mega litres a year and it's dominated by Welsh Water, England there's a market, Scotland there's a market but they're separate...It would be easier in a country where you didn't have a market. I mean for instance it might be worth talking to Northern Irish water because they're state owned and there's none of this shenanigans there."	Managing Director (Water Retailer)	19/08/2020	The UK market for water services is fragmented across each country thereby making routes to markets potentially different. The Northern Irish market could be simplest due to being state owned.	Out of scope - not related to current wastewater focus	...Supports (project sponsor)'s interest in European markets
601.04	"... water is going to become scarcer in the future and I think that insurance companies and others are going to say well hang on a minute, what exactly are you doing to mitigate your water use?"	Managing Director (Water Retailer)	19/08/2020	Potential future impact on insurance costs for companies not reducing water consumption to reduce risk of supply shortages	Out of scope - not related to current wastewater focus	Out-of-scope: OPEX-related but could potential aid marketing the system if it related to lower insurance

601.05	"...when trains are topped up and stations there are not, there aren't any non-return valves on the top of them so quite often they just overflow and water just pours onto the track."	Managing Director (Water Retailer)	19/08/2020	Current water usage in depots leads to wastage; the implementation of non-return valves could prevent freshwater spillage when refilling tanks	Out of scope - not related to current wastewater focus	Out-of-scope: other train operations can be a source of water reduction
601.06	"...OFWAT hoped that we would see metering of sewerage but most people don't understand trade effluent so not very much work has been done in that area... In terms of metering sewerage it's very expensive so no one's even bothering... because it's complex and because the rules for sewerage versus trade effluent vary from wholesaler to wholesaler and are ridiculously complicated and are quite often wrong people don't like to look at this that much."	Managing Director (Water Retailer)	19/08/2020	Difficulties in metering sewerage results in a gap in understanding how much money can be saved through reuse/recovery	Out of scope - not related to current wastewater focus	Out-of-scope: metering sewerage is an opportunity to measure cost reduction in avoiding the need to use sewers
601.07	"...large opportunities for circular economy, water recycling, you should be looking at heat and nutrient recovery from these plants... OFWAT are keen for a market in bio-solids."	Managing Director (Water Retailer)	19/08/2020	Potential support from Ofwat for companies producing bio-solids	Out of scope - not related to current wastewater focus	Could support (project sponsor)'s marketing
601.08	"...OFWAT haven't used our licences to promote water efficiency. It's all about the cheapest operator... don't hold your breath waiting for policy to sort this."	Managing Director (Water Retailer)	19/08/2020	Price sensitivity reduces appeal of costly efficiency drives; should our system aim to reduce the cost of water? (i.e. through reuse)	Out of scope - not related to current wastewater focus	Out-of-scope: aim of the project is not to product cheaper water (rather cheaper operations of trains due to movements)
601.09	"...how are we going to get it? If it's ash from loads and loads of different trains then you still have to go to the depot and then you have to load it onto lorries for us and we have to package it and we have to sell it."	Managing Director (Water Retailer)	19/08/2020	Distributed nature of system will lead to the challenge of collecting ash for commercial use	Out of scope - not related to current wastewater focus	Out-of-scope: OPEX-related concern
601.1	"...I'm sure that on German trains it's all perfectly fine but the Brits tend to flush loads of stuff down the train toilet unfortunately. Even if it says don't."	Managing Director (Water Retailer)	19/08/2020	Challenge of encouraging passengers not to flush wrong items down toilet!	Future design consideration with expansion of scope	Out-of-scope: other than incorporating passenger behaviour through filtration

601.11	"...I think the difficulty is that you've got so many different train companies and so many different retailers you're not going to be in the position where it's one retailer servicing all of the train companies buying into your thing and saying 'oh yeah that will be great' and also all the contracts change. And all the contracts are tied in."	Managing Director (Water Retailer)	19/08/2020	Fragmented nature of UK train operators means no large single customer; a reason for looking at other markets	Out of scope - not related to current wastewater focus	Supports (project sponsor)'s interest in European markets
701.01	"...companies really have to look at the water footprint and try to reclaim as much as possible... so that you can re-use it the certain process in your factory then that's all beneficial for the company itself but also for the environment."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Perception of the 'water footprint' could raise awareness of the importance of reducing consumption and increasing reuse	Out of scope - not related to current wastewater focus	Total water footprint of the entire lifecycle of the product is out-of-scope, however, low water usage/recycling capabilities reduce this in-service
701.02	"...the nano size particles it is something that is new to us in the last maybe five years, maybe a little bit longer, we really have a focus now on these particles and these particles are coming from for example the pharmaceutical industry discharging certain elements to our water bodies and in the end it ends up in our system, in the water system. It's not healthy and so we have to do something about it."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Nano particles are a growing concern in wastewater filtration effectiveness	Future design consideration with expansion of scope	Chosen filtration technology will address this
701.03	"...is the human that is buying water ... maybe not able, but is he willing to pay for this kind of treatment (recycling wastewater to potable water) and that is a political thing. It is sometimes very difficult, so technology wise it is doable... but then there is a certain cost involved that is the next discussion that you have to address, who is paying for it. In the end it will be the taxpayer I think, but we have to address it also for the future."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	The cost of recycling water to drinking standard could be subsidised by governments due to the higher price making it unaffordable	Out of scope - not related to current wastewater focus	Out-of-scope

701.04	<p>"...And then there is another big thing to address is the way people are looking at it so if you tell people that they are using or drinking reclaimed water that was first in their sewer system that it went through many, many treatment steps and now it is very clean again and people can drink it, it's a very difficult discussion, people will not really like it... I know only one and that is Singapore ... These countries they have to do things like this because they rely a lot on their neighbours like Malaysia for a drinking water supply... but if you tell people in the UK or here in Holland that they have to drink the sewerage water it is difficult... if you are an inhabitant of Singapore and we don't like these ideas then I think you have a problem. Here in Europe you can raise your voice and say this is not what we want and the Government what are we going to do, but it is not how it works in Singapore."</p>	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	<p>If water is recycled for hand basins and is labelled as drinking water with its origins this could prove unpopular. Further research into how this practice became successful beyond political/cultural reasons in Singapore could encourage acceptance</p>	Future design consideration with expansion of scope	...Passenger acceptance is being delt with through plans to separate toilet from hand-basin wastewater streams so that recycled water only comes from the hand-basin
701.05	<p>"...if you look at the companies that also rely on fresh water supply from drinking water companies, but also can use water from a borehole... you use the water twice or maybe three times. It's not so much extra cost, so that is a different approach that these companies ... have limited access to water so they can just increase the same way they increase their production, or there is legislation and they have to and become more stringent so they have to look at all ways to treat their waste water... they ... can use it in our plant, as cooling water or to clean a loading dock, the trucks... they will use it also in the marketing to show the world OK we are a very green company and we take care of the environment, blah, blah, blah, but it is the way we have to go..."</p>	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	<p>Benefits of recycling water are numerous within industrial settings; avoiding fines, eliminating cost of sourcing freshwater, used for cleaning, cooling and marketing by giving a green image</p>	Out of scope - not related to current wastewater focus	Supports (project sponsor)'s marketing efforts to promote the benefits of water recycling

701.06	"...Poland for example ... are asking the European Union for money to... catch up... like Germany, France, UK, Holland, Belgium ... with water treatment... So water in a way is not restricted by borders."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Countries with less developed wastewater systems could require more financial support to implement them.	Out of scope - not related to current wastewater focus	Out-of-scope
701.07	"...we look at individual cases. So companies they want ... a solution and that's what we do but we are not looking at a macro level to provide solutions to solve problems for Europe for example, that is impossible..."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Filtration technology is designed for specific purposes; companies rather than countries indicating limitations; how does this apply to trains with variable/unknown wastewater characteristics ?	Near term design consideration	Reflects current approach to using samples of actual wastewater from trains to determine filtration processes
701.08	"...vessels, cruise ships, and oil tankers ... when they go to another sea or another port they sometimes have to discharge this (ballast) water. In the past they just pumped it out of the vessel and then maybe took some new water in, but they cannot do anymore... many strange things can happen over there with sea life or just the environment... I don't think it is there yet, the legislation, but it's coming, and then we will also see that many of the owners of vessels in some way they have to take care of it and they have to install technologies to treat the water. "	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Maritime example of water processing of ballast discharge; possible example for trains; the implications of environmental impacts of discharging untreated water that can carry organisms across borders	Out of scope - not related to current wastewater focus	Could impact solids discharge/disposal more due to regulatory frameworks prioritising governing water discharge (in Europe). Disposing ash/sludge may have cross-border regulatory constraints.

701.1	"...So the ceramic membrane itself is not really an item that needs a lot of attention or maintenance, so it can last very long. The process is well designed and built. It can run for a very long time before anybody has to pay attention... there is a pump and there will be maybe some valves and in the end those are the items that need maintenance maybe once every year... We also have systems in the industry that needs let's say a check every two days or maintenance every week because of the harsh conditions. I don't think on the trains with this waste water treatment it is a very harsh condition, so the membranes itself it is not a tough condition for the membranes itself, maybe the pumps need it, but it depends also on what the people put in these toilets of course."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Operational assessment of maintenance frequencies required and the specifying of valves and pumps that have the least required attention (ceramic membranes are robust)	Out of scope - not related to current wastewater focus	Low maintenance components will be specified to meet/exceed the expected membrane service frequency
701.11	"...if things end up in the water that should not be there then you will have the possibility of blockage in either a pump or a valve or in the membranes itself. So you have to look at maybe pre-filtration, a lot of filter unit and take out larger particles or even products and yeah it's not, the fluids itself is not harmful to the components you use... wet napkins to use them as little or as less as possible, but they all end up in a sewer system and then they end up in pumps, etc., etc., blocking pumps. This is something that you have to take into account when you do a design..."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Blockage risk assessment of each component and ensure adequate pre-filtration (e.g. removal of wet wipes)	Future design consideration with expansion of scope	Foreign objects will be prevented from entering the water side of the system and (possibly diverted to the solid processing side to be further filtered).
701.12	"...the train that will also be part of it to maybe change the behaviour of the travellers. I am thinking in a plane, in an airplane, you are also not allowed to throw everything into the toilet of the airplane itself. They also have this infographic telling you I think that maybe wet toilet paper, wet napkins, you cannot throw in these systems ... It can also be a sector where you can maybe have some information from how they	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Signage solutions to encourage behaviour change regarding passengers blocking toilets could be borrowed from aviation	Future design consideration with expansion of scope	Passenger acceptance is being delt with through plans to separate toilet from hand-basin wastewater streams so that recycled water only comes from the hand-basin

	deal with it in airplanes, because they store all the toilet water..."					
701.9	"...I can imagine that, especially here in Europe, you try to focus on more centralised systems so when a train enters a station it can discharge its water to a tank and from this tank the water treatment is done, because otherwise you will have water treatment systems on every train, so more decentralised, as in general this will drive cost up if you have the larger centralised systems that make more sense if you look at cost... I think it makes sense to have more centralised systems because if every train needs its own water treatment system, also if you look at maintenance for example, or if you have to replace something, then it will become more like a model that you see for airplanes, so engines on airplanes they also need maintenance from time to time. If you look at these logistic operations it is huge, there is a lot of cost involved there."	Managing Director (Wastewater Filter Manufacturer)	21/12/2020	Potential higher cost involved in operating decentralised vs centralised systems due to both initial installation of multiples and ongoing maintenance (from the point-of-view of accessing systems that are not centralised leads to logistical costs)	Out of scope - not related to current wastewater focus	Out-of-scope
702.01	"...other bits of technologies that are out there that are going to possibly overtake the bioreactor toilet, cheaper than the bioreactor toilet, easier to fit, easier to maintain."	Project Manager (Train Equipment Distributor)	23/02/2021	Currently distributors are looking for systems that are less challenging to operate than the bioreactor	In scope of current development	
702.02	"...As a depot manager speed is the essence... Trains come into a depot at anywhere between 11 o'clock and two o'clock in the morning and are departing between three o'clock and six o'clock the next day so we have a very	Project Manager (Train Equipment Distributor)	23/02/2021	Ensuring systems can be cleaned and maintained during existing depot schedule	Near term design consideration	

	small window of opportunity."					
702.03	"... condition-based monitoring takes more of a higher level. If you know that all the tanks on the train are a quarter full and the usual is quarter to half for a full day then you know you haven't got to put that through the CET plant... They mainly all just go straight onto the CET points... It's a waste, it is a waste of time and effort if you're only emptying less than a quarter of a tank... you can save probably the best part of 40 minutes in the train movements on a depot if you knew exactly where those toilets were."	Project Manager (Train Equipment Distributor)	23/02/2021	Currently, CETs are emptied without any knowledge of whether they need to be due to lack of sensor data, leads to trains being moved around/to depots unnecessarily	Out of scope - not related to current wastewater focus	
702.04	"... look at what's happened with the bioreactor toilets ... There's only one toilet on every five cars because basically they're a commuter type train. Commuter trains never have, you know short commuter distances never had toilets... But why have they chosen the bioreactor? Well probably because most of the locations where those trains end up at night don't have a CET tank emptying facility."	Project Manager (Train Equipment Distributor)	23/02/2021	If operators can't access depots with CET facilities then onboard processing makes sense or if the toilet is rarely used like on commuter services	In scope of current development	
702.05	"... if your recycled water was equal to your used water and everything else then you know close the system but the amount of water produced for urine and everything else is that equal to what the requirements of what the system are to carry out the flushing mechanism."	Project Manager (Train Equipment Distributor)	23/02/2021	Making onboard recycling work: the amount used must equal the amount generated: how can this be ensured/calculated?	Near term design consideration	

702.05	"... unfortunately as time has gone on toilet usage on trains has declined... The female population would rather use a toilet at home than a toilet outside of home... Whereas you know probably back in the 60s, 70s, maybe early 80s hygiene was probably not as high on people's agenda but you've only got to see the current with the Covid that is, that will make people even more aware of those sort of things."	Project Manager (Train Equipment Distributor)	23/02/2021	General decline in toilet use due to changes in preferences and now COVID - could this be the end of the train toilet??	Out of scope - not related to current wastewater focus	
702.06	"... I was with the (project sponsor) guys and they were showing it (the bioreactor system) me because they were tied in with Protec at that point in time and we looked at it and it was massive, looked extremely complex... If something is complex it's got more avenues to go wrong. It shouldn't have but it does and I'm at this point of sort of saying yeah it's great but we don't know enough about it and it's longevity."	Project Manager (Train Equipment Distributor)	23/02/2021	Apparent complexity of any new system can create concern over maintainability	In scope of current development	
702.07		Project Manager (Train Equipment Distributor)	23/02/2021	Reducing the weight of the train via reducing water/wastewater retention/tanking could lead to performance/cost improvements	In scope of current development	
702.08	"...wait until the track a track worker gets doused in a whole load of water off a train and the unions get hold of it. Hang on you said this thing wasn't going to happen."	Project Manager (Train Equipment Distributor)	23/02/2021	Any discharge could still be viewed as negative if track side workers are exposed to it	Future design consideration with expansion of scope	
702.09	"...the ScotRail guys came back to us and said it takes them about three-and-a-half hours."	Project Manager (Train Equipment Distributor)	23/02/2021	The time it takes to clean a bioreactor system is 3.5 hours (which is not ideal)	Near term design consideration	

801.01	"...whenever things needs to be changed with regards to infrastructure in particular there is quite a lot of hoops and things that you need to go through like getting landlord's consent... So it is making sure that the design of the depot is actually fit for purpose and it matches requirements and legislation and things and works the right way from the beginning..."	Environment Manager, Train Depots (OEM)	13/01/2021	Emphasise on ensuring depots are designed correctly from the start as oppose to retrofitting; due to complexity associated with ownership of infrastructure	Out of scope - not related to current wastewater focus	
801.02	"...we have quite a lot of construction projects on the go at the moment that relate to drainage design... ultimately the things that we are trying to do are improving drainage systems ..."	Environment Manager, Train Depots (OEM)	13/01/2021	Current focus is on drainage systems	Out of scope - not related to current wastewater focus	
801.03	"...the water wholesalers there definitely has to be a balance in terms of the consultations we do with them ... if we want to do an additional activity on site is it even going to be approved ... or are they going to look at the big residential development next door and say actually no, the sewers ... not just ... capacity related, but there is also the flooding element as well. Are they going to be happy with us bringing additional water down into the system, how is it going to impact them... basically being implied that we are at the top capacity of what we could do if we wanted to do any more it might not get through, but so far we haven't had any pushback from them..."	Environment Manager, Train Depots (OEM)	13/01/2021	Potential sewer capacity constraints, although this has not yet been reported, due to nearby residential/commercial needs	In scope of current development	
801.04	"... That has never been raised as an issue in terms of the amount of water we pull from the mains... It is more the issues ... with what we are putting into the sewers. You know the flow rates, the volume we put (in and the) hours, what time we put it in, that type of thing."	Environment Manager, Train Depots (OEM)	13/01/2021	Reducing wastewater more of an importance than freshwater	In scope of current development	
801.05	"One is cost, the cost to the business, and the second one is the fact that we have an environmental management system in place and there has always been a drive for continuous	Environment Manager, Train Depots (OEM)	13/01/2021	Cost is the primary driver to managing water consumption, "environmental management system" is a	Out of scope - not related to current wastewater focus	

	improvement and to reduce resource usage as we can."			secondary factor but important		
801.06	"For water for some unknown reason ... there are only two settings and you can only choose two different volumes. So every time a water tank is filled there is always hundreds of litres that overflows and is going into the drains for no reason whatsoever."	Environment Manager, Train Depots (OEM)	13/01/2021	Freshwater is wasted due to unavoidable spillages as a result of limitations in the refilling process	Out of scope - not related to current wastewater focus	
801.07	"all of those things (referring to replenishing consumables, i.e. screen-wash, sand, fuel, water) mixed together you know if you have little drips and drops ... From a water quality perspective is how do we ... improve the way we manage our hoses ... chlorinated water to sterilise them and but in practice it is quite a difficult thing to do because you have got human factors, people leaving hoses on the floor, you know people are using like potentially dirty gloves ... how can we ... engineer all of those issues out so that we don't have to worry about the human factor anymore"	Environment Manager, Train Depots (OEM)	13/01/2021	Source separation of wastewater a challenge due to leakages and spills as a result of relying on humans: automated systems less likely to result in this?	Out of scope - not related to current wastewater focus	
801.08	"...We have an external consultation in that comes and does regular monitoring, so we monitor, obviously from each network and water quality because we have to."	Environment Manager, Train Depots (OEM)	13/01/2021	Currently, water quality is measured by an external consultant	Near term design consideration	
801.09	"...our catering water it all goes through a UV system and then through a water filter before it gets anywhere..."	Environment Manager, Train Depots (OEM)	13/01/2021	Catering water is UV treated and filtered	Future design consideration with expansion of scope	
801.1	"We ended up having to do those manual hand cleans in areas where we might not have done them, purely because of the drainage design, to remain compliant... that changes the complete flow of the way that the depot works because of where you have to do your activity"	Environment Manager, Train Depots (OEM)	13/01/2021	Current drainage systems are limited to what they can handle having knock-on effects to depot operations	Out of scope - not related to current wastewater focus	

801.11	"...when it comes to the toilet side of things that has all been designed in because you know it would be part of the service so you know exactly where you are going to be doing the fuelling and your tanking, that is already well established and well defined. But equally as I have mentioned about the importance of depot design we have ended up in situations where ... we have had to do manual cleaning on service banks because it is the only place that has the right drainage beneath it..."	Environment Manager, Train Depots (OEM)	13/01/2021	CET facilities are readily available at this company's sites, however, drainage locations are not, resulting in trains being moved so that detergents and diesel are not disposed of incorrectly	Out of scope - not related to current wastewater focus	
801.12	"...the issues come as well if the site infrastructure has a fault it will break down and then from a business continuity perspective it is making sure that those suppliers, those maintainers can come to site you know within the call out times and get things running again."	Environment Manager, Train Depots (OEM)	13/01/2021	If the system can be fixed can (project sponsor) or a contract be on call?	Future design consideration with expansion of scope	
801.13	"...we have to chlorinate the tanks for our trains and that process can result in quite a lot of water, waste water, because you have to like empty the tank,, then re-fill it, then empty it out and wash it again to get it back into a place where it is usable. So that can be quite a high volume of waste water that is also going down into the same place as other processes."	Environment Manager, Train Depots (OEM)	13/01/2021	Currently, washing tanks during the chlorination process requires significant amounts of water; can this be avoided?	Out of scope - not related to current wastewater focus	
801.14	"...could sampling be designed to make it so that we don't need to chlorinate the tanks all the time. Could something be designed to make sure that those tanks are sterile all the time. I don't know whether it is like a coating or something that helps to keep bacterial growth down, but what it could be and then you wouldn't need to worry necessarily about that element of maintenance"	Environment Manager, Train Depots (OEM)	13/01/2021	Tank materials and design to ensure water remains contaminate free	Out of scope - not related to current wastewater focus	

801.15	"... Could extra equipment be added onto the CET infrastructure that means the risk of things being put on the ground or risks of leaks and spills and wear and tear, cos you get wear and tear of all the hoses ... can something be designed to make it that those hoses don't need to be replaced so often. I think there are improvements actually needed to all of that really."	Environment Manager, Train Depots (OEM)	13/01/2021	Wear and tear of equipment and the need for replacements; can the system be designed with longevity?	Out of scope - not related to current wastewater focus	
801.16	"...a water reclaim system on a carriage wash pump it is a really dirty system and really difficult to manage from a water quality perspective. So we found that it has taken quite a lot of work and resource and monitoring to keep it where it should be to extent that you know saving that water doesn't outweigh the benefits of just making a once through system."	Environment Manager, Train Depots (OEM)	13/01/2021	Comparing the cost of recycling vs. mains water usage has indicated prohibitive costs due to monitoring expenses	Out of scope - not related to current wastewater focus	
801.17	"...you need to cater for there are designs on some of our systems where if the water hasn't moved for like four hours there is something in place to circulate it to make sure that the water quality stays good..."	Environment Manager, Train Depots (OEM)	13/01/2021	Circulating freshwater is currently done to reduce contamination	Future design consideration with expansion of scope	
801.18	"... I wonder just what that impact is on like interceptors you might have in place. If you are pushing this volume through and you are including your storm water as well is that going to have a knock on impact on the efficiency of interceptors, are they going to have enough time to do what they need to do in each tank before it goes off."	Environment Manager, Train Depots (OEM)	13/01/2021	Could onsite processing reduce the strain on current systems (flowrates impacting interceptors efficiencies)	Out of scope - not related to current wastewater focus	

801.19	"...putting in treatment plants for example has been floated as an idea ... to avoid having to do it on civil works ... But the issue is, as you know, once your depot is built it is built and quite often they are kind of sandwiched into really tight spaces, aren't they, you know in between a commercial zone or residential area so wherever it is. So if you do make these changes and improvements when it comes to the water authority, where do you actually put them and how easy is it then to, in terms of the operation through the life of the contracts or whatever you are doing, how do you make sure it is easy for them to be maintained."	Environment Manager, Train Depots (OEM)	13/01/2021	Processing wastewater onsite has been considered, however, space constraints and impacts on existing infrastructure operations/contracts need to be addressed further	Out of scope - not related to current wastewater focus	
901.01	"... we heavily rely on ... mobile clean out systems which generally because the railway is often, railway depots are often rail locked, that is the way that waste gets recovered through pumping systems... most of our sites don't currently have CET so you need to recover directly from the train rather from a ground source which the suppliers are most familiar with."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Currently use mobile pumps to empty CETs. Can be dangerous/logistically challenging due to accessing the trains.	Out of scope - not related to current wastewater focus	
901.02	"...Different to the train operators because they, most of them are getting new depots with CET recovery, effluent recovery built into the ground. But yeah it's certainly a challenge for ourselves and the freight operators because they are like us and currently going through a process of fitting toilets."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Freight operators as well as rail maintenance fleet operators share similar problems in terms of needing to retrofit depots with CET emptying facilities	Near term design consideration	
901.03	"Incinerator style toilets are used in some of the areas rather than CET so that's another slight variant where you have to collect the ash versus a fluid product... there was an issue around the heat because they heat and burn the produce, often when the vehicle is turned off and that's something that we can't do."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Incinerator toilets have been trailed, however, the system needed to be left on when the train was unattended which wasn't possible	Out of scope - not related to current wastewater focus	

901.04	"...the vast majority of our fleet are fitted with CET toilet solutions... Very expensive, high management and maintenance interaction, not very pleasant as well and when they're all blocked is when you end up; and this was from the train operators when there were blockages with the systems because it's fluid you end up having to re-lay carpets, seats, deep cleaning because it just gets everywhere... So that's the secondary problems with using fluid based systems."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Aware of blockages being a major problem with CET systems	Future design consideration with expansion of scope	
901.05	"So the only thing we can discharge to track is clean water and even then that creates a problem because our trains run near to SSSI sites... So if you discharge too much clean water you can still pollute water courses... It's being drawn through from the Environment Agency because if you, if you discharge large amounts of fresh water into areas of scientific interest then you can affect the biodiversity in that area. So we try, we try not to, we try not to discharge to the track anything and we have machines that do discharge water to the track to apply adhesion modifiers. So we are actively trying to reduce that wherever possible."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Current regulations prohibit the discharge of any level of water quality (including bathing water) due to biodiversity/scientific interest/environment agency concern	Future design consideration with expansion of scope	
901.06	"We have a relatively small quantity however we have to carry more but because we don't go back to a depot every 12 hours which is what most of the train operators do."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Rail fleet operator uses CET system with much lower emptying frequencies than other operators	Near term design consideration	
901.07	"So if there was a product that could come off that was bagged or packaged in a way that it's not going to spill, not going to go anywhere, that we can just put in the general waste then that would be so much easier for us to manage."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Ideal system that turns wastewater solids into waste that can be disposed of via landfill (general waste)	In scope of current development	

901.08	"...I think we definitely use over a million litres of water a year in our depots because we spray, we use water to clean the rail head to aid adhesion... we're very concerned about the amount of water that we use... if there was a solution which would reuse the water for whatever service and remove the material away from it to make it safe then that would be a, that would be a perfect solution for us."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Reduction in water usage a focus when cleaning rails; possibly to capture/recycle/reuse	Out of scope - not related to current wastewater focus	
901.09	"... we do the thing called monsoon washing so we have a high capacity shower that washes the ballasts and the trains to get rid of the ballast dust particles you know respiratory silicone, crystalised silicone... So the best that we have available at the minute is where we use ground sourced water recovery and then that goes into a tank, we filter it and then pump that into wash. It goes back into the, we're using the ground as the filter."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Water treatment filtering applicability silicone dust contaminates. Currently use ground source water recovery process.	Out of scope - not related to current wastewater focus	
901.1	"... Ribbleshead Viaduct ... there's no power or water or waste to the signalling centre so they are developing a self-contained cabin which recycles water ... we do have cabins in locations which are completely disconnected from anything, miles away including mobile signal."	Fleet and Engineering Director, Railway Maintenance (UK Government)	12/03/2021	Need for decentralised treatment system to be installed for remote railway buildings	Future design consideration with expansion of scope	