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Lean assessment tool for workstation design of assembly lines

Micael Teixeira Gonçalves^a, Konstantinos Salonitis^{a,*}^aManufacturing Department, Cranfield University, Cranfield, MK43 0AL, UK* Corresponding author. Tel.: +44 (0)1234 758344. E-mail address: k.salonitis@cranfield.ac.uk**Abstract**

Efficiently designed workstations are essential to provide both flexibility and mass production in an effective way. Unfortunately, it is common to find industrial workstations built without a purposeful design. The design of the workstation, oriented to both users and tasks requirements, allows organisations to increase their production indicators (less time, space and cost) and quality levels. Within the present paper, an assessment tool was developed to address a literature gap regarding the lack of tools to evaluate Workstation Design, particularly in assembly lines. The concept of “Hierarchy of Workstation needs” is introduced for prioritising the requirements to achieve full performance in workstations. The concept is visualised as a pyramid split in four levels to achieve excellence: functionality, effectiveness, efficiency and satisfaction. Seven requirements were identified for Workstation Design, namely: “Health and Safety”, “Work environment, cleanliness and orderliness”, “Waste elimination”, “Inventory and material logistics”, “Flexibility”, “Visual Management” and, lastly, “Quality”. An evaluation model and a tool to assess each requirement was developed based on lean and ergonomic aspects and specific for workstation design, which it is difficult to find in other assessment tools. This model has the form of a checklist that is based on the current best practices in Workstation Design of assembly lines. The assessment tool was validated in an automotive assembly line and based on the results obtained, improvements in the associate working zones, workstation dimensions, storage areas or parts feeding system are introduced to improve “Waste elimination” and “Inventory and material logistics”.

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1. Introduction

Manufacturing organisations need to exhibit flexibility and mass production capabilities for individual customisation in a hyper-efficient way. The development of an effective and efficient manufacturing system is crucial to deal with the market competition. A workstation is among the most important places in a manufacturing environment. Several lean based tools have been developed for the optimization of workstation design. 5S is probably the most widely used one to support continuous improvement. Well-organised working areas are essential for standardised work procedures, which are needed to control the workplace. To perform the required tasks, operators must use different types of equipment, tools and materials. If the necessary resources are not clearly and properly stored, operators lose precious time to find them, increasing thus the non-value added time (waste) [1].

Workstation design thus is a crucial process to ensure effectiveness, customisation, automation and competitiveness in high volume environments, using less time, space, cost and inventory. Taking that into account, workstations play a critical role in manufacturing processes. Lean workstations should be designed with a focus to minimise waste and concentrate operators to critical issues. Unfortunately, it is common to find that industrial workstations have been built ad-hoc without investing effort to achieve a purposeful configuration. It is important that the design of the workstation is done from the inside out and optimise the workstation from the operators’ perspective.

In the current paper, the key aspects to be considered to design an assembly line workstation are proposed, following both lean and ergonomic principles. In order to design leaner and safer workstations, a tool to measure and evaluate them objectively is proposed.

2. Literature review

Studies on lean manufacturing principles and workstation assessment methods have been reviewed and critically analysed to present the importance of an efficient workstation design in a manufacturing plant.

2.1. Workstation Design

Workstation design is responsible for placing materials, tools, equipment, etc., and routing operator movements in the most suitable form. That way, operators can perform their work in an efficient manner [1]. It is essential to ensure effectiveness in an environment of high customisation, automation and competitiveness.

Traditional workstations and lean workstations are inherently different. Traditional workplaces are designed to facilitate the work of material handler, not increase value added by the operator. A lean workstation is designed focused on operator concerns, such as safety and ergonomics, and minimal wasted motion, with the goal to get parts efficiently and find tools quickly. Assembly materials, tools or parts should be strategically positioned to allow the operator to reach it instantaneously, without interfering with operators' safety and comfortability [2].

2.2. Workstation Assessment Tools

There are uncountable lean tools (Strategos Lean Assessment Questionnaire [3], Rapid Plant Assessment [4], etc.) and workstation assessment tools (Kobayashi's 20 Keys [6], Ergonomic Workstation Analysis [7], etc.). However, it is evident that gap in instruments to evaluate the performance of the workstation design in assembly lines exists.

Strategos LAT [3], developed by Quarterman Lee, is used to evaluate nine areas of manufacturing using a Microsoft Excel-based self-assessment questionnaire. Goodson [4] created one of the most well-known and useful plant assessment tools which aims to evaluate if a factory is truly lean in as little as 30 minutes - "Rapid Plant Assessment". Then, this information should influence decisions related to benchmarking, continuous improvement, competitor analysis, and acquisitions. Lean Enterprise Self-Assessment Tool (LESAT) is a questionnaire developed by a team of industry, government and academic members. It is a simple and easy to use guide focused on lean attributes and aligned with business performance planning, which forms the basis for most other lean assessment tools [5]. These lean tools are well-known in the industry but they focus on assessing where the companies are along their lean journey, and not in the evaluation of specific aspects of the workstation.

Kobayashi's 20 Keys [6] is also one of the most used implementation guides to lean manufacturing at shop floor level. Probably because it allows to evaluate particular aspects in the workplace. It is not a model to achieve success, but a pragmatic approach or roadmap based on several years of experience of the author. The main objective of this practical method is to create "*a way to make footholds all the way to the top of the manufacturing mountain*". Despite of being a

fantastic learning tool, it does not take in consideration the safety and comfort of the employees. On the other hand, workstations tools mostly focus on employee safety and ergonomics aspects. Ergonomic Workplace Method (EWM) [7] is one of the most used ergonomic tools in workstations. It assesses health risks of working conditions of a workplace.

These tools are powerful but they do not take into consideration the relations between the operator and his work space [1], [8]. The assessment of workstation design must focus on both lean and ergonomic aspects. Lean assessment tends to reduce the waste in the workstations and ergonomic assessment safeguards employee safety and comfort. This relationship is essential to ensure success, mainly in a long-term period [9].

A good example is the "Workstation Design Navigator", developed by Bergman et al. [9]. The evaluation method used is based on AB Volvo Assessment Tool, inspired by Toyota Production System, and it results in a combination of human factors, materials supply and personnel strategies. This proactive approach assumes that losses should be reduced by solving problems before they occur, which means, supporting design of workplaces. Other tools have been also published, mainly in the automotive industry. Good examples are the "Process Diagnostic Standards Tools", inspired again by Toyota Production System. They allow an objective evaluation, but they are often very restrictive, making them only usable in specific contexts.

3. Hierarchy of workstation needs

To understand what motivates people, Maslow [10] identified five different motivation needs which are often depicted within a pyramid. One of the biggest principles of his theory is that lower level needs should be satisfied to be able to reach higher levels. In the present study, the same principles were applied in workplace environments, and based on that the "Hierarchy of workstations needs" was developed to understand and prioritise the requirements to achieve full performance in workstations.

Functionality, effectiveness, efficiency and satisfaction are the levels before reaching excellence, which are closely related with the tiers of motivation needs proposed by Maslow (Fig. 1). Functionality ensure physical and safety needs of the operators. Effectiveness fulfil their social and relationship needs, such as friendship, love and belonging. Efficiency reflects how the workstation and their associates are seen in the whole facility and if their value is recognised and respected by others – esteem. Finally, satisfaction refers to the achievement of higher goals and full levels of satisfaction – self-actualisation and self-transcendence. Once all levels have been fulfilled, the company and its workstation can achieve the desired level of excellence

According to Granath et al. [11], two main dimensions in workplaces should be distinguished: functionality and usability. *Functionality* refers to the ability to perform a regular function and it is more concerned about features of the workstation (which individually do not make the workstation usable). For improving the functionality dimension, workstations need to be designed based on lean and

ergonomics principles. Such principles might be specific for each industry. They are included in the pyramid as “Physical and safety basic needs”. When these requirements are not met, the workstation cannot function properly and predictively. Typical examples of this are safe and healthy procedures not clearly defined or explained, inappropriate use of the space, unorganised and uncleaned areas, or even high level of unneeded inventory.

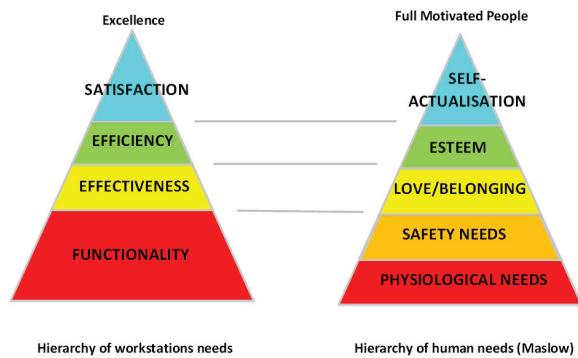


Fig. 1. Hierarchy of workstation needs and Maslow Pyramid

Usability can be defined as the system’s capability to achieve a specified goal in a specified context of use. According to Blaksted et al. [12], it can be divided in 3 consecutive levels: effectiveness, efficiency and satisfaction.

Effectiveness refers to the possibility to provide the desired effect. An organisation, and consequently workstations, will only realise its goals when employees’ social needs are fulfilled [12]. “The Toyota Way” also highlight the importance of social needs in one of its two pillars: “Respect for people”. “Continuous improvement”, the other pillar, captures the set of principles and tools needed for a lean workstation (also described in “The House of Lean”), but respect for people origins the real root of sustained performance [1]. Good examples to these practises are: build and guide working teams, motivation strategies, encourage employee’s participation, set goals, recognise achievements or throw company activities.

Efficiency expresses how the resources are allocated and organised to increase productivity [12]. The relationship between workplaces and whole facility is essential to achieve the lean principles, such as flow, standard work or continuous improvement, and to accomplish robustness, simplicity and transparency. Examples of good practises are: best use of associates skills (aligned with the tasks) clear, shared and ambitious goals, synchronised production, and focus on the entire process and not the end state.

Satisfaction is related with employees’ experiences, feelings and attitudes about the workstation. This satisfaction is fully achieved when there is a total integration and synchronisation within the organisation (systems, peoples, resources, etc.) [12]. One good example is the applicability of the first (and probably the most important) lean principle (“identify customer value”) in this context [1]. Workstations need to look at each other as clients and suppliers, as to provide the best possible product (without defects), at the exact time and with the correct quantity. In order to

accomplish that, they have to be able to solve their issues and perform their activities autonomously (even maintenance and corrective tasks), without interfere with the work of the remaining workstations. This way, they work autonomously and well integrated in the whole system.

Excellence defines the best in terms of quality, cost, time, people and environment performance indicators. It can only be achieved with constantly improvements in all areas of the company and synergetic efforts. It is the place where all companies want to be [6]. As can be seen in Fig. 2, excellence is the final goal of the pyramid.



Fig. 2. Hierarchy of workstation needs

The design of a workstation is an elementary need with impact in the performance of the whole organisation, and therefore it is included in the first level of the model (part of the functionality dimension).

4. Proposed assessment tool

After prioritising the workstation needs, defining the focus of the tool and understanding its importance, an assessment tool to evaluate Workstation Design in assembly lines was developed. It was development in 4 steps:

- 1) Definition of the key requirements of Workstation Design (Assessment categories)
- 2) Propose a method to assess each requirement (Assessment methodology)
- 3) Convert the assessment into a result and define a process to introduce improvements (Performance score system)
- 4) Validate the assessment tool in an industrial context and introduce final adjustments (Case study)

4.1. Assessment categories

The assessment tool evaluates seven key requirements of Workstation Design:

1. Health and Safety
2. Work environment, cleanliness and orderliness
3. Waste elimination
4. Inventory and Material logistics
5. Flexibility
6. Visual Management
7. Quality

Health and Safety: Workstations should be designed with the aim to satisfy individual operator's needs (height, reach, size, etc.) within the context of work [1], [6]. Besides that, factors such as repetition, posture and vibration, contributes to higher rates of injury, and should be reduced by improving the Workstation Design [13].

Work environment, cleanliness and orderliness: Clean and orderly workstations are essential to ensure a safe and efficient flow of products. The lighting levels should be appropriate, the air quality and temperature good and noise levels low. The workstation areas should be clearly marked (inventory, tools, parts, processes, etc.), using visual and intuitive labelling systems [1], [4].

Waste elimination: The use of space must be organized efficiently; inappropriate layouts result in extra material handling which means waste. Simple layouts, visual control, low levels of inventory and efficient material handling (ideally materials are moved only once) are the key to promote value adding activities and continuous flow [1], [3], [4].

Inventory and Material logistics: Inventory is considered to be the "evil" in lean manufacturing. Inventory is however ensuring the correct running of the assembly lines, but excessive inventory should be avoided. Carrying out stock is expensive and it increases material handling [1], [3]. Material logistics (or parts feeding system) play an important role in how the manufacturing plant operates. In an assembly line, they are crucial to ensure flexibility and efficiency [14].

Flexibility: In today's assembly lines, mixed-model production is essential to ensure profit. Flexibility is the key to achieve this without compromising efficiency. Techniques and strategies, such as common parts, casters for easy movement of equipment or adhesive marking, have been developed to mitigate quickly, cheaply and efficiently the impact of this mixed production cycles [1], [4], [15].

Visual Management: Visual management system is a key theme in lean operation and essential to ensure standardisation. They define visual devices as mechanisms that "influence, guide, direct or limit behaviour by making vital information available close to the point of use" [1], [4].

Quality: Manufacturing plants have to strive to continuously improve quality. They have to ensure, for example, the correct scheme to support standardisation, the use of leading technology related to its business and the right environment to boost associate feelings [1], [3], [4].

4.2. Assessment methodology

The assessment tool is based on a checklist of best practices in today's assembly lines. This approach was selected in order to emphasise the importance of each detail in Workstation Design, rather than only classify each category between a determined scale. Furthermore, it provides clear guidelines of what should be done to improve the final results and it allows to evaluate a wide range of competences [16].

The checklist was predominantly based on the following tools:

- Strategos Lean Assessment Questionnaire [3]

- Rapid Plant Assessment [4]
- Kobayashi's 20 Keys [6]
- Ergonomic Workstation Analysis [7]
- Workstation Design Navigator (or AB Volvo Assessment Tool) [9]
- Automotive Process Diagnostic Standards Toll

Moreover, a comprehensive study and some manufacturing plant visits to automotive assembly lines were carried out as to identify the practices in the workstation design of assembly lines. Each practice corresponds to a different item assessed through the checklist, totalling around 150 items (or questions).

The type of response selected was the alternative response ("True" or "False"). It is a strategy easy to construct and mark, and it allows the collection of more objective answer. Nevertheless, many of the evaluated items can be partially achieved, and for this reason an intermediate stage ("Partially True") was added. Furthermore, for mitigating the guess factor, a fourth option was also added ("Not Applicable").

The questionnaire on the assessment tool was circulated to both operators, managers and experts with high knowledge about the production system. That way, the results become more objective and reliable, instead of having the perception of only one associate.

4.3. Performance score system

After each item was marked, the score of each requirement was converted into a scale. Initially the answers were translated in points per Table 1. The "Partially True" was assigned 2 points (below the average) to push companies to completely fulfil each item.

Table 1. Number of points assigned to each answer

	Yes	Partially True	No
Number of Points	5	2	0

Subsequently, the score of each category is transformed into a scale between 0 and 5, as per the Equation 1 and Table 2.

$$\%Points = \frac{\sum Points}{Maximum\ possible\ points} \quad (1)$$

Table 2. Level assigned according to the number of points

%Points	0 - 20%	20 - 40%	40 - 60%	60 - 80%	80-100%
Level	1	2	3	4	5

The 5 levels that describe each requirement of Workstation Design are defined similarly to the "20 Keys Five-Point Evaluation System" created by Kobayashi [6]:

- Level 1: There is no evidence of concern about the need for efficient Workstation Design.
- Level 2: The company understand the importance of Workstation Design but lacks the ability to fulfil the requirement.

- Level 3: The requirement follows the main practices of Workstation Design.
- Level 4: The requirement follows the Workstation Design principles and it is in pair with the rest of the industry.
- Level 5: The requirement is one step ahead of the industry average.

Moreover, the same score strategy is utilised to achieve a global assessment of Workstation Design in the organisation. It takes into consideration the score level obtained in each category. In this way, the company (or the evaluated workstation) is described according the following levels:

- Level 1: There is no evidence of concern about Workstation Design.
- Level 2: Company understands the importance of Workstation Design but lacks the ability to implement
- Level 3: Company follows the main Lean principles of Workstation Design.
- Level 4: Company follows the Lean and Ergonomic Workstation Design principles and it is on pair with the rest of the industry.
- Level 5: Workstation Design is one step ahead of the industry average.

5. Case Study

The assessment tool was applied and validated in a multinational automotive company with headquarters in UK. Automotive industry was selected because assembly lines in this sector is the most common example of assembly lines. During this stage, the tool was presented and filled by an associate and an experienced Operations Manager (responsible for one of the assembly line).

The validation process took into account four different types: interface, construction, content and measurement.

Generally, both respondents argued that the instrument will be able to provide an overall perception of how well the company designs the workstations and guide the introduction of improvements. The following feedback was also gathered:

- *Interface*: it is adjusted, the vocabulary is suitable for all associates, the structure is well defined, and the tool is easy to apply and use.
- *Construction*: it is appropriate and it is linked with the content and measurement system. Nevertheless, too many items need to be performed.
- *Content*: it fits the purpose of the tool. The requirements defined allows an effective judgment of Workstation Design, most of the best practices are identified and a clear guidance for improvements is provided.
- *Measurement system*: it is appropriate, allows an objective analysis and a true assessment of the selected requirements and/or organisation.

The results obtained are shown in Figure 3.

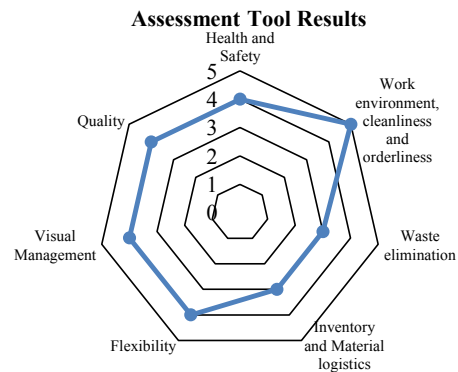


Fig. 3. Results of the assessment tool application in the case study

The company achieved a final level score of 4, which indicates that the company follows the Workstation Design principles and it is on pair with the rest of industry practices. However, as it is a well-referred automotive company, changes should be introduced for improving and be ahead of the remaining industry (level 5).

Based on the results obtained, the key aspects that should be quickly enhanced are “waste elimination” and “inventory and material logistics”. These dimensions scored a result below the sector’s average (level 3).

Regarding the positive points, the results also evidenced an excellent level (level 5) of “work environment, cleanliness and orderliness”. This indicates that a propitious environment is created to ensure the growing of the remaining dimensions.

In order to improve the company performance, mainly in the identified dimensions, improvements were introduced in two areas: workstation dimensions and part feeding system. These improvements result from fulfilment of each item in the checklists, an extensive and comprehensive review of the literature, and benchmarking of the best current practices of the automotive industries.

The improvements in the workstation dimensions were introduced to reduce or eliminate waste within the workstation, namely:

- New associate working zones: based on a model of human dimensions for British people.
- New configuration and re-dimensions of the storage areas: based on the human model developed, lean principles, such as visual management, and centred in the user.
- Standard aisles widths: based on international standards, such as OSHA and British Standards.

Regarding the parts feeding system, improvements were suggested in order to reduce inventory levels and increase material logistic indicators, namely:

- A hybrid solution of for part feeding policy (continuous supply, kanban, kitting or sequencing) based on part characteristics (variety, size, consumption volume and value).
- A decentralised storage configuration.
- A new system to transport parts based on Automated Guided Vehicles (AGV) and Vision Guided Vehicles (VGD).

- Technology systems to guide operator actions, such as, pick-to-light, bar-code scanners, voice-directed, display picking or automatic picking machines.

The set of recommendations are summarised in Figure 4.

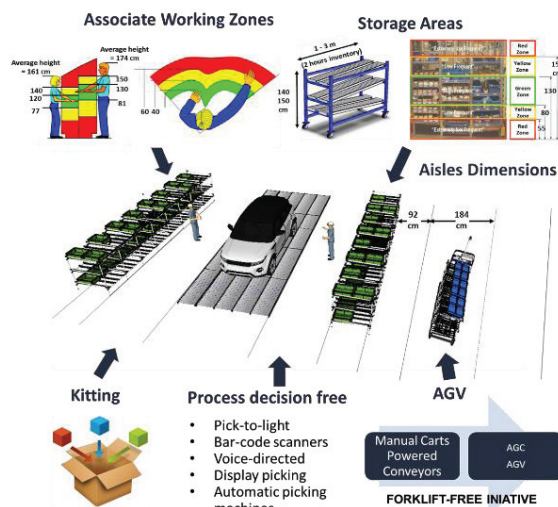


Fig. 4. Set of recommendations to the case study

6. Conclusions and limitations

In the current article, the overall aims of alerting the importance of Workstation Design in multi-product environment and developing an assessment tool to evaluate it in assembly lines were successfully fulfilled.

The process of workstation design plays an important role, in increasing performance and quality indicators in organisations. Nevertheless, design oriented to both users and tasks requirements are not common to find in industrial workstations. The assessment tool developed accounts simultaneously for lean and ergonomic principles, something that has not been found in others assessment tools, mainly for assembly lines.

Based on the concept of “Hierarchy of Workstation needs”, seven key requirements were identified for Workstation Design and they are evaluated in the assessment tool, namely: “Health and Safety”, “Work environment, cleanliness and orderliness”, “Waste elimination”, “Inventory and material logistics”, “Flexibility”, “Visual Management” and, lastly, “Quality”. Each one of these requirements are evaluated using a checklist of best practices in the industry and converted in a 5 level scale.

Finally, the assessment tool was validated in an automotive assembly line and the results indicated two areas of improvement: “Waste elimination” and “Inventory and material logistics”. Based on these results, improvements in the associate working zones, workstation dimensions, storage areas or parts feeding system are introduced.

Four main limitations can be identified in the assessment tool. First, there is no consensus in the literature about what are the key requirements to assess the Workstation Design and

different aspects can be equally important. Second, the assessment method is based on the checklist developed taking into consideration information from others assessment tools and knowledge acquired by the author. In which, some important items which should be assessed may be missing. Third, it is important that the tool circulates between different people of the organisation in order to have reliable results. Finally, all items have the same weight in the score calculations. In reality, specific items have more importance (and potential impact) than others.

In order to improve credibility of the assessment tool, future studies should validate the tool in different companies and different types of industries. Each industry has its own characteristics and it is important to have them articulated with the checklist.

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Gonçalves, Micael T.; Salonitis, Konstantinos

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