HANDLING PRODUCT VARIETY IN A MIXED-PRODUCT ASSEMBLY LINE: A CASE STUDY

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Abstract

In today's fast-changing global market, using mixed-product assembly lines (MPALs) and mixed-model assembly lines (MMALs) allows manufacturing companies to be flexible and to maintain their competitive edge through product variety. Balancing and sequencing issues have been recognized as the main challenges of MPALs and MMALs, but other practical needs of MPALs remain unclear. Recognizing the practical needs of MPALs helps in identifying related requirements for product design, leading to products that closely align with the MPAL concept. The objective of this paper is to offer an industrial perspective on the needs of MPALs and to identify its requirements vis-à-vis product design. To achieve this objective, a single real-time case study in a heavy-vehicle-manufacturing company has been performed. The results from this industrial case study suggest that in order to handle product variety in MPALs and to reduce the related complexity, certain dimensions of flexibility need to be created in the assembly system, and requirements related to product design should be considered simultaneously in order to support assembly processes.

Keywords: Mixed-product assembly line, Flexibility, Requirements, Product design, Complexity.

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1 INTRODUCTION

As a result of the paradigm shift from mass production to mass customisation, the variety offered by consumer-product manufacturers has increased significantly over the past several decades (Hu et al., 2011). In this transition, intense competition in the global market and the fast-developing needs of customers have propelled manufacturing companies towards producing highly customised products in greater variety. As a key stage in the manufacturing process, assembly is used to create variety in products. Variety can be achieved at different stages of product realization, during design, fabrication, assembly, at the stage of sales, or through adjustment during the usage phase (Hu et al., 2011). In order to transition to mass customisation and to foster flexibility, at the assembly stage, this common characteristic of assembly stage has directed manufacturing companies to develop mixed-model assembly lines (MMALs) and mixed-product assembly lines (MPALs). In the last decade, some manufacturers have made product diversity their priority and have operated MPALs to meet variable demands from customers and to become more competitive in their industry (Lin and Chu, 2013). Given that product diversity is a key factor for most manufacturing industries, MPALs that are flexible and reconfigurable for different product models have recently received significant attention from manufacturers (Lin and Chu, 2013). Flexibility in assembly system stems from the major dimensions of volume, mix and new product namely, the assembly system's responsiveness and adaptability to market fluctuations and its capacity to produce different products (Asadi et al., 2015). As variety increases, the assembly and supply processes can become very complex (Hu et al., 2008). Thus, dealing with the needs associated with product variety in an MPAL can be considered as a challenge inherent to flexible assembly systems (see Figure 1).

To focus on the needs of an MPAL, distinguishing between it and the similar in-use concept of the MMAL is essential. The former has often been categorised under the latter and has therefore, regardless of its crucial importance for today's manufacturing companies, attracted less attention independently. Bearing that in mind, a considerable amount of research has focused on balancing and sequencing problems as the two most prominent challenges of MMALs. The vast majority of these studies propose mathematical solutions for particular cases without a sharp focus on practical applications in industry, see, e.g., (Merengo et al., 1999; Vilarinho and Simaria, 2002; Haq et al., 2006; Xu and Xiao, 2009). Hence, a wide gap has grown between developed scientific solutions for challenges in MMALs and MPALs and the approaches practised in industry. In spite of the enormous academic efforts in assembly-line balancing and sequencing, mathematical algorithms were used only by small percentage of companies during the 1970s and 1980s, and this gap has widened recently (Boysen et al., 2007). The three main reasons behind this shortage are that researchers have thus far not considered the ''true'' real-world problems; when the problems were covered, they could not be solved to satisfaction; and scientific results could not be transferred to practical applications (Boysen et al., 2007). The importance of close-to-practice research on MPALs has been mentioned by Lin and Chu (2013). In some industries, the impact of product variety on an assembly system calls for deeper insight into the practical needs of an MPAL. For instance, in the case of automotive-vehicle production, increased product variety has a significant negative impact on performance (quality and productivity) in assembly and parts supply (Hu et al., 2008). Recognising generic needs that arise in

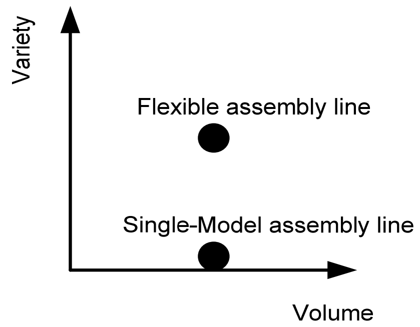

Figure 1. Flexible assembly line vs. single-model assembly line

MPAL helps reduce complexity and increase the system's efficiency. In case of growing variety, the profit may not keep pace due to diminishing returns since the cost and complexity of manufacturing may be increasing; therefore, in order to reap maximal benefits, the product offering and manufacturing systems should be designed jointly (Wang et al., 2011b). Although the prominent role of product variety in increasing the complexity of an MPAL has been emphasised, the requirements of MPAL in terms of product design have not been specifically discussed. Understanding the needs of an MPAL further helps identify these requirements so as to closely align the products with the MPAL's needs.

The objective of this paper is to identify both the generic needs of an MPAL and the requirements it imposes on product design. To fulfil this aim, a case study in a heavy-vehicle-manufacturing company has been performed. The structure of the paper is as follows. First, a brief overview of the existing research on creating variety in assembly lines, flexibility, and complexity in MPALs is presented as the theoretical basis for the case study. Then, the applied research methodology is described, followed by the empirical findings from the case study. Analysis is presented in the discussion, and the paper concludes with several suggestions for future research.

2 THEORETICAL PROPOSITION

2.1 Creating variety in assembly lines

Assembly is one of the most cost-effective approaches to high product variety (Hu et al., 2011). This potential in the assembly approach can be realised in different types of assembly lines namely: mixed-model (MMALs), multi-model, mixed-product (MPALs) and multi-product assembly lines. These four terms have been used in manufacturing literature to refer to the range of products that can be produced on an assembly line. MMALs are increasing in many industrial environments (Haq et al., 2006). Various industries are incorporating MMALs because they bring various benefits; for example, a mixed-model automobile assembly line not only saves investment costs by sharing multiple products on the same line but also absorbs demand fluctuation (Hu et al., 2008).

In an MMAL, different models of a product are produced on a single assembly line. Three main characteristics of MMALs have been highlighted in the research:

- Different models of a parent product with slightly different characteristics are assembled on the same assembly line (Haixu and Bhaba, 1998; Vilarinho and Simaria, 2002; Kim and Jeong, 2007; Rahimi-Vahed et al., 2007; Ullah et al., 2014).
- Small batches are produced, and without relying on large inventories, sudden changes in demand can be responded to promptly (Haixu and Bhaba, 1998; Merengo et al., 1999; Kim and Jeong, 2007; Rahimi-Vahed et al., 2007; Bautista and Cano, 2008).
- The production processes for different product models are similar to the extent that they result in very quick or insignificant set-up times (Merengo et al., 1999; Boysen et al., 2007; Bautista and Cano, 2008; Ullah et al., 2014).

Based on the categorisation offered by Becker and Scholl (2006), however, only three versions of assembly-line balancing problems have been recognised: single-model, mixed-model, and multi-model problems. According to Rekiek et al. (2000), an MPAL is a production line capable of producing a variety of product models (called variants) simultaneously and continuously. Nevertheless, few authors have differentiated between MMALs and MPALs. Lin and Chu (2013) make a sharp distinction between the two based on considerations taken in sequencing problems. There is only one product with multiple models in each production line for mixed-model sequencing problems, whereas there are multiple products with only one model in each production line for mixed-product sequencing problems (Lin and Chu, 2013).

2.2 Flexibility in MPALs

Flexibility is the ability to change or react with little penalty in time, effort, cost, or performance (Upton, 1994). Bengtsson and Olhager (2002) regard *mix flexibility* and *volume* and *new product flexibility* as the major dimensions of flexibility. Flexible assembly can be realised through mixed-model or mixed-product concepts since not only they offer high variety but they also mitigate demand fluctuations (Hu et al., 2008; Wang et al., 2011b). In some cases, multi-model lines are used; these lines can produce batches of different models with quick set-up times; when more flexibility is required, MMALs are used. In these systems, set-up is so quick and cheap that it is possible to produce very small batches (even one-unit batches) in any sequence (Merengo et al., 1999). Different dimensions of manufacturing flexibility have been recognised by different authors through the years, see, e.g., (Browne et al., 1984; Sethi and Sethi, 1990; Shewchuk and Moodie, 1998). Among all these, Sethi and Sethi (1990) identified eleven well-known comprehensive dimensions of manufacturing flexibility; machine flexibility, material handling flexibility, operation flexibility, process flexibility, product flexibility, routing flexibility, volume flexibility, expansion flexibility, control-programme flexibility, production flexibility and market flexibility (see (Sethi and Sethi, 1990) for the definition of each).

2.3 Complexity driven by variety in MPAL

Variety allows manufacturers to satisfy a wide range of customer requirements, but it can also be a major contributing factor to increased complexity in assembly (Samy and ElMaraghy, 2012). Establishing an MPAL that offers a great variety may become a complex task and thus affect performance. Product variety and options have a significant and adverse impact on productivity, labour costs, assembly-line downtime, minor repairs and major re-workings, as well as inventory levels (Sarkis, 1997).

3 RESEARCH METHODOLOGY

3.1 Case-study design

Case studies constitute the preferred research method for closely investigating a phenomenon in its natural context (Yin, 2009). This research paper is based on the findings of a case-study research in the heavy-vehicle-manufacturing industry, supported by a review of the relevant exiting research. In order to reach the objective, the requirements that flexible MPAL places on product design have been investigated. This investigation was conducted during the time the flexible assembly concept was being developed and proved in the case company namely, during the “concept-development” and “pilot-implementation” phases. The major focus on flexibility in the assembly system and on the practical development of an MPAL concept comprises the main motivation for this case study research. It is worth mentioning that two of the authors were closely involved in the case company’s activities focused on the needs and requirements of a flexible MPAL.

Among the twelve product families produced by the case company, four product models from four different product families (A, B, C and D) had been chosen for assembly in a flexible mixed-product assembly system. At the time of this study, each of these four product families was produced in different manufacturing plants with semi-automatic MMALs. In these assembly lines, most of the assembly tasks were performed by the assemblers and only tasks such as material handling and testing were partly automated. The case study covers the time that the flexible mixed-product assembly concept for these four products was developed and proven. The development and implementation activities were led by a cross-functional project team within the case company.

3.2 Data collection and analysis

Good case studies benefit from multiple sources of evidence namely: direct observation, interviews, archival records, documents, participant observation and physical artefacts (Yin, 2011). Focused activities performed by the two authors who were active participants in the case company during the "concept-development" phase of the flexible mixed-product assembly system and its "pilot-implementation" phase, the literature review, semi-structured interviews, in-depth interviews and project documents (e.g. presentations, minutes of meetings, and reports) all served as primary sources of data in the study. A detailed summary of the data sources for this work is presented in Table 1. The longer durations for the workshops imply that those certain occurrences lasted few hours or for a whole day.

Data analysis was performed during and after the data collection as suggested by Merriam (2009). A generic approach to analyse collected qualitative data suggested by Saunders et al. (2012) was followed for the analysis of the data in this work. The taken approach consists of five points:

1. Identifying categories or codes that allow you to comprehend your data
2. Attaching data from disparate sources to appropriate categories or codes to integrate the data
3. Developing categories further to identify relationships and patterns
4. Developing testable propositions
5. Drawing conclusions

To further verify the results, the findings of the study were reported and discussed with the case company on several occasions.

Table 1. Sources of data collection and evidence

Data source	No.	Participants	Duration (min)	Topic of focus
Meetings (concept development)	27	Cross functional project team	30-60	On-going concept development activities, logistic issues, flexible MPAL needs and requirements for product design
Meetings (pilot implementation)	8	Technology platform team, assembly team representatives	30-60	Flexible MPAL requirements for product design
Workshop (concept development)	10	Cross-functional project team	60-480	Flexible MPAL concept development
Workshop (pilot implementation)	2	Technology platform team, assembly team representatives	240-300	Flexible MPAL requirements for product design
Semi-structured interviews	3	Director of process development-assembly and fabrication requirements, engineer-product architecture, senior system-requirements engineer	97 169 90	Flexible MPAL needs and requirements for product design
In-depth interviews	6	MPAL project manager (2), technology platform manager, consultant-system Engineering, coordinator-product architecture, product platform development manager	60 60 50 46 75	
Informal discussions	Several	Case company employees	----------	
Company documents	Full access	----------	----------	General (including the afore mentioned topics)

4 EMPIRICAL FINDINGS

Through the transition from MMALs to MPALs, the case company aimed at achieving high flexibility. According to its market strategies, by reshaping its global manufacturing footprints in this transition, the case company intended to satisfy all the demands for different types of products in each market segment. Moreover, a flexible assembly system capable of producing all four products and increased commonality in assembly operations were expected to decrease the amount of in-use equipment and the number of in-use tools in assembly process. Keeping zero buffer at the line by facilitating one-peace flow, reducing assembly takt times relative to current times (as in the MMAL), and increasing shared assets for the assembly of different products are other key pre-determined characteristics of this flexible assembly concept. The MPAL concept developed by the case company consists of one main assembly line with five assembly zones and two pre-assembly flows with a total of seven pre-assembly zones. A schematic figure of the layout of the main line and pre-assembly lines is presented in Figure 2.

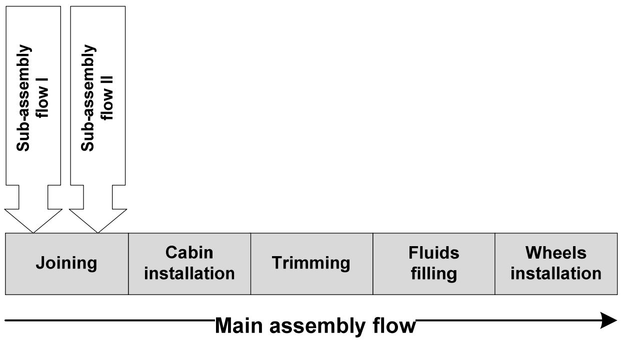

Figure 2. Main assembly line and sub-assembly

4.1 Selection of products for MPAL

Four principles were identified as decisive factors in selecting the four products (A, B, C, and D):

- When the correlation of assembly time, weight, and size for all the products was analysed, the similarities among the four products were more prominent than those among other product families.
- In the most critical operation in the final assembly line, -joining-, the four products followed the same pattern: their upper- and under- carrier structures were horizontally joined together.
- Assembly of all four products covered similar main assembly operations at the vehicle-module level (e.g., attachment of motor, cab, wheels to vehicles).
- Critical assembly tools and equipment (i.e., the most expensive and the heaviest items) could be shared among the products.

4.2 Generic needs of an MPAL

Despite their similarities, handling the variety involved in four different products creates particular needs that must be addressed through an MPAL:

1. The need for continuous change in the product mix, so that the mix for all four products can be changed upon request. This creates the need to readily switch between products in the assembly zones. Consequently, a major need arises to even out the recurring variation in assembly-work content and the type of assembly tasks.
2. The need to facilitate the introduction of new products into the assembly system.
3. The need to handle large volume changes to adapt to seasonal market demands.
4. The need for extra space to accommodate four products from four different product families along a single assembly line.
5. The need to use common equipment, tools, and fixtures to assemble four products of dissimilar size, weight, and design.
6. The need to supply materials in the correct sequence to different assembly zones.

In order to satisfy these needs, technical solutions for assembly processes were proposed for use in the MPAL and supporting operations. These technical solutions consist of a flat assembly base; using an Automated Guided Vehicle (AGV) to allow a continuously moving line; an assembly-line layout divided into assembly zones to facilitate shared assembly tasks among skilled groups of assemblers, to create a standardised wok content, and improved balancing; and standardised reconfigurable equipment and tools, along with a sequenced moving-material supply system on the line to deliver material to each assembly zone.
Moreover, these needs indicate that it is necessary to create different dimensions of flexibility—such as product flexibility, volume flexibility, market flexibility, expansion flexibility, production flexibility, material handling flexibility, and control programme flexibility—in order to accommodate variety in an MPAL.

4.3 MPAL requirements for product design

In addition to the proposed technical solutions for the assembly process, three main categories of requirements that should be realised in product design have also been identified. These are a common assembly sequence for different products, standardised assembly interfaces, and reduced part numbers. Each requirement is expected to reduce the complexity that emerges when product variety is introduced on an assembly line. They assist, further, in satisfying some of the needs of an MPAL mentioned earlier.

4.3.1 A common assembly sequence for different products

Establishing a common assembly sequence to be followed for different products allows the use of common assembly equipment and tools in different zones. It also provides a suitable setting for better balancing approaches based on similar operations common among the products. Product designs should make it possible to deconstruct different products into similar main modules. Therefore, the common assembly sequence is defined based on the similar operations in the similar modules shared by different product families. In this case, when a product is broken down into its smaller building blocks, the highest levels of building blocks, each of which also involves certain functionality, are here called *product module*s. Common assembly sequencing plays an important role in meeting an MPAL's needs regarding introducing a new product, changing the product mix, maintaining an efficient material supply, and deploying different tools and equipment.

4.3.2 Standardised assembly interfaces

From the product-design point of view, the most important interfaces on the products are the physical interfaces that are used in many different product varieties and derive from customer needs. Therefore, the interfaces that are often reused are worth documenting from a product-design point of view. However, from the assembly-process standpoint, the most critical interfaces are those that involve the greatest cost, the most time, and the most equipment in assembly. Designing similar standardised assembly interfaces and similar tooling points across different product families is regarded as a major boost toward satisfying the needs of the MPAL. Designing similar standardised product interfaces that require similar assembly, grasping, and fixture methods also further encourages the use of similar tools and equipment. Creating similar assembly interfaces for different products is thus expected to primarily fulfil the needs of a changing product mix, efficient material supply, and different equipment and tools.

4.3.3 Reduced part numbers

Common parts (e.g. bolts and nuts) across products serve the MPAL's needs by balancing the material-supply frequency and increasing assembly-task quality in each assembly zone. Using similar parts and consequently reducing the number of parts used in assembling different products in different assembly zones has two main impacts: it reduces the need to introduce different parts along the assembly line and consequently decreases the need for extra space. Utilising common parts even when the product mix in the assembly zone is constantly changing, results in greater ease and precision in assemblers' performance. Several needs of an MPAL—namely, an efficient material supply, extra space, different tools and equipment, and volume fluctuations—can be satisfied by use of common parts in products.

5 DISCUSSION AND CONCLUSION

According to earlier research, sometimes the concepts of MPALs and MMALs are not clearly differentiated, see, e.g., (Rekiek et al., 2000; Becker and Scholl, 2006). This may owe to the fact that both concepts share the same key characteristics, which are highly pivotal to balancing and sequencing problems—for instance, having no set-up times and zero inventory on the line. It is worth mentioning that balancing and sequencing issues have been treated as the two main needs of these assembly lines. Therefore, the distinction between the two concepts of MMAL and MPAL in terms of other specific needs have been discussed very little in the existing research. As the findings demonstrate, in keeping no inventory along the line and having no set-up time, the presented MPAL in the case study shares certain basic characteristics with an MMAL. Additionally, through assembly of four different products from distinct product families in the case company, a wide variety is offered. Compared to an MMAL, in which variety covers certain sets of products from the same parent product (Rahimi-Vahed et al., 2007; Ullah et al., 2014), the needs of an MPAL appear to remain at a different level. At this level, the distinctive physical properties of the products play a crucial role and consecutively impose certain requirements on product design and flexibility. The crucial role of a product's physical attributes is reflected in the findings, both in the selection of products for an MPAL concept and in the requirements connected to product design.

The identified six major needs of an MPAL can be met both through technical solutions supporting the assembly processes and by imposing a few main requirements on product designs. The MPAL's needs, its requirements for product design, and the connection of each need to the different dimensions of flexibility are presented in Figure 3. Each requirement's role in fulfilling few immediate needs is also illustrated.

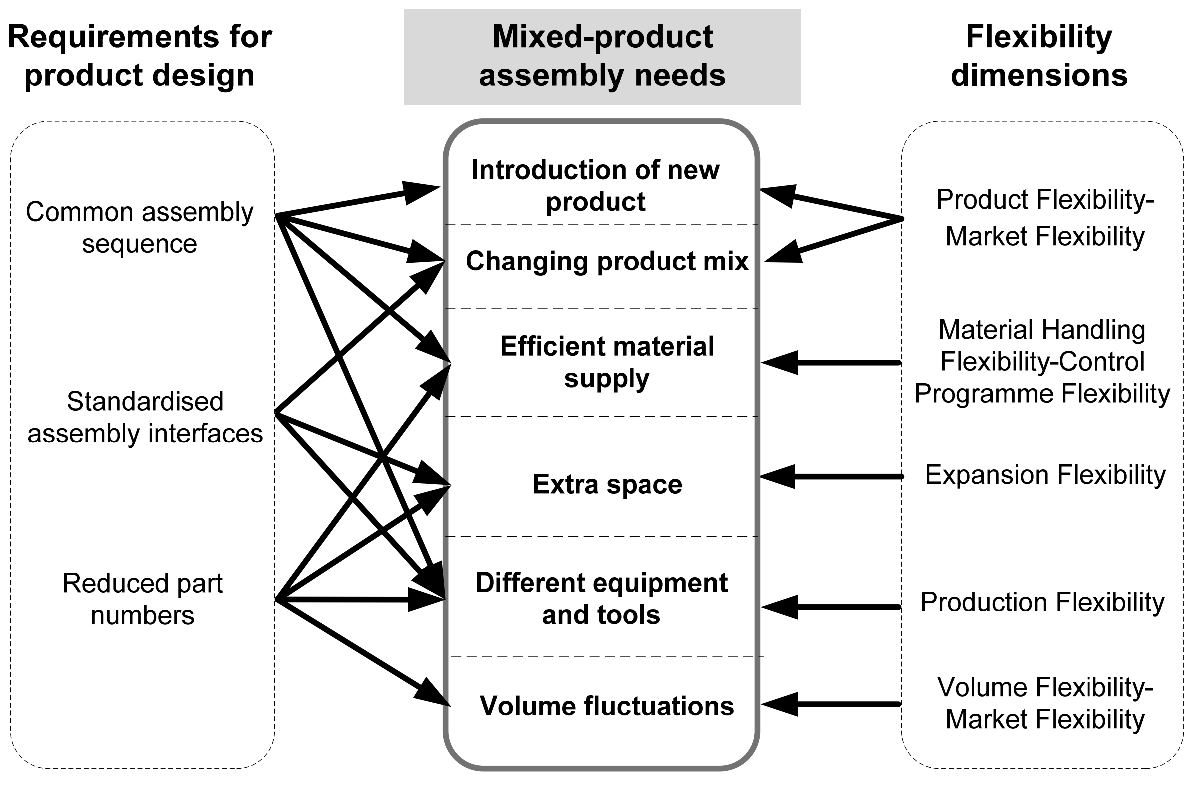

Figure 3. The needs of MPAL in relation to dimensions of flexibility and requirements for product design

As shown in Figure 3, certain needs within an MPAL closely correspond to certain dimensions of flexibility as outlined in the comprehensive categorisation by Sethi and Sethi (1990). Based on this finding, different dimensions of flexibility—such as product flexibility, expansion flexibility, volume flexibility, production flexibility, market flexibility, control programme flexibility, and material handling flexibility—must be created in MPAL to secure the line's overall flexibility. An MPAL offers major dimensions of flexibility (e.g., new product, volume and mix flexibility) and therefore is flexible (Bengtsson and Olhager, 2002; Hu et al., 2008; Wang et al., 2011a). Taking that into account, the overall flexibility at the complete line level relates closely to the system's capacity and productivity. Using technical solutions, such as reconfigurable tools and equipment and reconfigurable material-supply solutions, not only fosters the afore-mentioned dimensions of flexibility, but it also specifically helps increase efficiency and volume flexibility by altering capacity of the line. Furthermore, the ability of the assemblers to be multi-skilled and to perform different types of tasks, labour flexibility as suggested by Koste and Malhotra (2000), was also identified as a pivotal type of flexibility in the semi-automated mixed-product assembly systems.

Product variety constitutes a major contributing factor to increasing complexity in assembly (Sarkis, 1997; Samy and ElMaraghy, 2012). Common assembly sequence for different products, standardised assembly interfaces and reduced part numbers have been identified as the product design requirement in this study. Meeting these requirements can each help address several needs of an MPAL and thus reduce the complexity introduced by a wide variety of products (see Figure 3). Considering these requirements in product design (Figure 3, left), however, against the flexibility needed in the system (Figure 3, right), calls for a certain level of standardisation in product design, as well as in the assembly operations taking place in each assembly zone. Although this standardisation results in reduced operation flexibility in each assembly zone, facilitating the assembly of four products from distinct product families eventually secures overall flexibility for the line (e.g., new product, volume, and mix flexibility). Moreover, the standardisation created by following the same assembly sequence may limit the operation flexibility, as defined by Sethi and Sethi (1990), in each assembly zone. Furthermore, by incorporating similar standardised assembly tasks and parts into different products, satisfying these requirements in the product design also contribute to error proofing in the assembly operations.

The aim of this paper was to identify the major needs of an MPAL and to investigate the requirements that such a system imposes on product design through a case study of a heavy-vehicle-manufacturing company. The findings of this paper stem from a single case study and therefore focus on the needs and requirements involved in establishing a semi-automatic MPAL in that particular industry. Similar research in other industries that deploy different levels of automation might be useful in investigating complementary perspectives. Moreover, in order to further detect the DRIVERS of complexity in performing the assembly tasks in MPAL, future research on assemblers' perspectives regarding complexity in such a system is also required.

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