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Challenges in Flexible Manufacturing Technologies for the Final Assembly in the Commercial Vehicle Industry

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Abstract: Increasing customer demands and product diversity as well as emerging technologies and market trends, such as the establishment of new driveline technologies, like e-mobility or hydrogen, present challenges for manufacturing companies in the commercial vehicle industry. Consequently, companies must strengthen their focus to the aspect of flexibility within their manufacturing processes. This paper contributes to the state of the art in flexible manufacturing technologies research, which enables manufacturing companies to deal with these increasing flexibility requirements. Focussing on the area of final assembly the paper takes a holistic perspective and characterizes the readiness of automotive companies to be able to implement flexible manufacturing technologies. The system ecosystem and the process organization of automotive companies are examined with respect to the requirements of flexible manufacturing. Finally, gaps that hinder the implementation of flexible manufacturing technologies are identified and described, and possible solution concepts for the identified gaps are proposed.

Keywords: business capabilities; final assembly; flexibility; gap analysis; manufacturing

1 INTRODUCTION

The commercial vehicle industry is facing new challenges that are derived from increasing customer demands leading to higher complexity due to the diversity of variants. On the other hand, challenges arise from emerging technologies, such as electromobility and digitalization [1]. Particularly, these developments have a major effect on manufacturing, including manufacturing preparation and process engineering. One way how companies are dealing with these challenges is the introduction of new concepts in the area of flexible manufacturing. This has a great impact on state-of-the-art manufacturing and influences the digital infrastructure and organization of companies.

The challenges an organization is facing can be studied along the capabilities that are required in order to meet the requirements that are imposed by the novel concepts of flexible manufacturing. These so-called business capabilities [2] can be identified for state-of-the-art manufacturing systems, as well as for novel flexible manufacturing systems. In addition to presenting the currently realized as well as the required system capabilities for future manufacturing, the main contribution of this paper is an analysis of the gaps that currently prevent the realization of required novel system capabilities to increase manufacturing flexibility.

The research for this paper was conducted following the scientific method of expert interviews on the one hand, and a case study on the other hand. Regarding the former, qualitative interviews with open-ended questions ensure openness and flexibility. The conducted type of interview is particularly suitable for uncovering unknown findings step by step. In total, seven experts were interviewed: three enterprise architects, two solution architects from two different final assembly plants, as well as two manufacturing engineers. By conducting the interviews with different roles and areas of expertise, it was possible to cover as broad an area of the research topic as possible and to reflect the issue with relevant results from different perspectives. Regarding the case study as a second scientific method, a realistic future scenario is described as a case that is derived from thorough research and study of the domain. It includes a sufficient level of information and detail that can be analysed an interpreted from different perspectives. A case study is a suitable method since the manufacturing system investigated in this paper is not technically implemented yet in any organization, and thus has no real-life environment that can be used for observations and thus for field research.

In the following, Sect. 2 describes the state of the art regarding the conventional truck assembly line. Moreover, the business capability map is introduced for manufacturing operations related business capabilities currently realized. Section 3 presents the elements of a future manufacturing system including its required system capabilities. Section 4 introduces the gaps that were identified and relates them to the required system capabilities. Section 5 evaluates the presented findings, before Sect. 6 concludes the paper with a summary and an outlook on future work. The paper is based on a more extensive scientific work conducted through the application of the mentioned scientific methods at a leading OEM of commercial vehicles [3].

2 STATE OF THE ART

The contribution of this paper is based on the state of the art in the final assembly in the commercial vehicle industry and the business capabilities currently characterizing such assembly systems.

2.1 Final Assembly in Commercial Vehicle Production

The final assembly in the European automotive industry is characterized by customized products and different vehicle-variations on one assembly line. High variation requires a high degree of flexibility, which cannot be provided by automated solutions, thus, manual or only partially mechanised assembly operations are applied, despite high labour costs [4]. Heavy-duty truck manufacturing, as a sub-section of the automotive industry, has even lower volumes and higher customization levels [5].

Final assembly lines are dominated by linearly arranged workstations that are rigidly connected with each other using conveyor technology [6, 7]. A workstation can be described by the assembly operations conducted in it, the number of operators, the available equipment and the materials delivered to the station [7]. The process of allocating assembly operations to the manufacturing resources is called line balancing [8]. Each workstation is designed to conduct a number of specific assembly operations, according to which the required number of operators for each station will be derived. An assembly line can be further characterized by a tact time per station, where a station's total assembly time cannot exceed the tact time [6, 7]. The difference between the total assembly time per station and the tact time is unproductive "idle time". Assembly line balancing has the overall goal to evenly distribute all assembly activities throughout the workstations and minimize idle time [9]. Apart from the tact time, further technical and organisational restrictions, as well as equipment availability and the level of qualification of operators need to be considered [10].

Assembly operations are generally planned on standardized assembly sequences. As a result, operators will complete assembly tasks in a fixed sequence, which needs to be revised and updated by manufacturing engineers regularly due to product changes and changing manufacturing parameters. To this end, not all vehicle configurations require the same order of operations, e.g., a vehicle without a glass roof still needs to pass the corresponding station without any operations conducted here [6].

Regarding material handling, which involves the storage, control, and delivery of production parts for the final assembly, Just-In-Time (JIT) and Just-In-Sequence (JIS) are heavily utilized concepts in the automotive industry. The JIT approach ensures that only the required items in the right quantity are supplied into the production system when needed. The goal is to reduce inventories, and eliminate waste and inconsistencies while increasing productivity. The JIS approach goes further and aims to ensure that the material is delivered in the order in which it will be processed later. For JIT and JIS to be effective, the company must have a very smooth operational system for material handling in place, as any disruptions in the material supply chain can cause a significant impact on the entire system [10].

2.2 The Business Capability Map

Business capabilities refer to the abilities possessed by an organization, individual, or system to perform a fundamental business function. A business capability map provides a structured representation of all business capabilities within the organization to coordinate and align a variety of distinct business capabilities [2]. The business capability map provides a clear definition for each business capability, which is further broken down into IT systems that assist the organization in achieving these capabilities. This section will outline the current business capability map for manufacturing-related business capabilities (see Fig. 1).

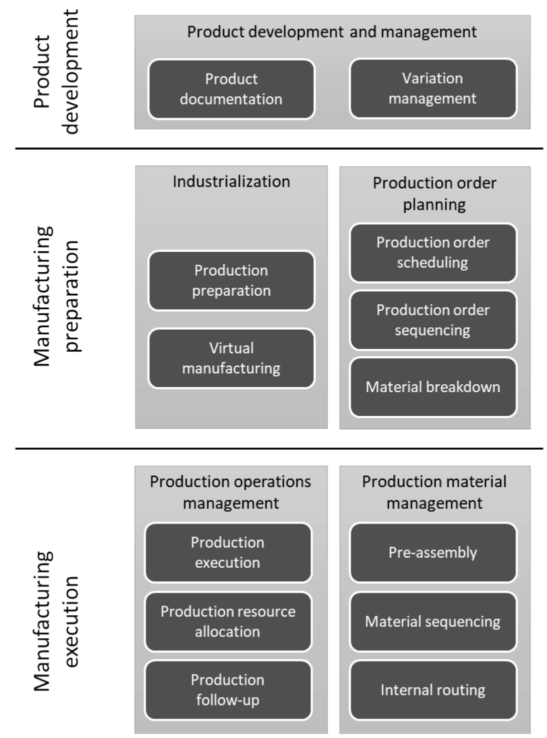

Figure 1 Current business capability map

Product development and management. The capability of developing new products and improvement is a crucial requirement for competitiveness in high-tech industries such as the automotive industry. Product development involves all activities related to the design of the product and its properties, including geometric design of individual components and the product as a whole. The main output of the product development process is the intellectual product, containing the product description along with all associated documentation, specifications, and digital models [11]. *Product development and management* heavily influences manufacturing processes.

Industrialization. After product development, the next phase is referred to as *industrialization* or production planning. Industrialization acts as the interface between product development and manufacturing. It involves planning production processes, providing necessary manufacturing resources, and conducting production tests to verify manufacturing feasibility and optimization [12]. The focus of *industrialization* is on the operational aspects of designing and implementing the manufacturing solution within the production environment. The business capability *industrialization* describes an organization's ability to develop, configure, prepare, verify, and implement the manufacturing solution for developed products.

Production order planning. Efficient processing of customer orders requires the conversion of orders into production orders and planning in terms of time and capacity with available resources. There are several core processes within *production order planning.* Production order scheduling involves converting customer orders into production orders and assigning them to different plants while respecting production capacity constraints, sales forecasts, order prioritization and the model-mix within the plant [13]. Production order sequencing converts scheduled production orders into a detailed production program for a certain period of time. Material requirements planning is relevant for material planning aspects. Overall *production order planning* describes an organization's ability to plan and fulfil customer orders within their manufacturing system.

Production operations management. Also known as shopfloor management, *production operations management* involves coordinating and managing all functions directly within the operational manufacturing execution area. The primary goal is to control production processes efficiently and without any disruptions. However, being able to generate appropriate process deviations to keep the assembly flow running smoothly in case of any disruptions is an important part of *production operations management* area [14]. This business capability describes the organization's ability to efficiently steer manufacturing processes on the execution level as well as collect and use real-time data from the shopfloor for optimization and reporting purposes.

Production material management. The supply of materials to workstations is a core task of the final assembly. Through the implementation of JIT and JIS concepts, materials need to be delivered in the right sequence with respect to its further processing at their point of use [10]. In this context, intralogistics covers the planning, control, implementation, and optimization of the internal flow of goods and materials, including the required information flow. Immediate intralogistics processes within final assembly include pre-assembly and kitting operations, material sequencing, as well as internal routing of materials. This business capability describes the organization's ability to effectively supply the right parts and sub-assemblies in the right quantity, at the right time and the right point of use.

3 FUTURE FLEXIBLE MANUFACTURING SYSTEM

Flexibility in manufacturing refers to the system's ability to adapt to changing market demands and quantities, as well as the required effort for installations and process adjustments [15]. Because of shorter product life cycles, smaller lot sizes as well as increasing product variety and complexity, concepts, which increase manufacturing flexibility gain in importance, are presented in the following. A possible future flexible assembly line is presented, which is used to derive required system capabilities.

3.1 Future Manufacturing Concepts

Flexibility in future manufacturing systems is characterized in the following dimensions [16]. ***Operation flexibility*** denotes the ability of a part or a manufacturing process to be executed in different ways or sequences. ***Process flexibility*** describes the ability of a workstation to quickly produce a variety of products without any major reconfigurations. ***Routing flexibility*** denotes the ability to produce a part by using alternate routes through the system.

Flexible material delivery. Automotive assembly lines are characterized by standardized and rigid assembly sequences, resulting in components always being delivered to the same workstation for their processing [17]. By combining operational flexibility for parts and processes, process flexibility for workstations, and routing flexibility for the material handling system, the concept of flexible material delivery is introduced. It allows workstations to execute different assembly operations through the delivery of different parts. The assembly sequence is not standardized and may vary between production orders. The allocation of assembly operations determines the material delivery points for the required parts. Within JIS-manufacturing, a higher degree of synchronization between process execution and the material handling system is required. Flexible material delivery results in more decision freedom in manufacturing preparation, however through increased levels of complexity in the execution area and for the operators are a consequence.

Plug and Produce. Besides flexible material delivery, the provisioning of production resources such as tooling and equipment need to be considered. The Plug and Produce concept, refers to a technology in which manufacturing devices can be utilized without requiring any modifications to the system or additional registrations to the database [18]. For instance, fastening tools in manual assembly can be utilized in multiple workstation for a variety of assembly operations, without the prior need for readjustments.

Flexible production sequencing. In flexible manufacturing environments, the production of a single final product can be achieved using various sequences of operations [19]. Instead of the rigid assembly line, a production program determines which products need to be processed in which workstations. Hence, the classification of the capabilities of manufacturing assets, such as workstations, equipment and operators is required. Furthermore, a link between product parts based on individual manufacturing related product requirements is essential. The goal is to generate an optimal sequence for operations for each individual production order while avoiding inefficiencies in the production process. However, the standardized assembly sequence and and uniform tact time for the entire assembly line need to be abandoned, resulting in individual assembly sequences, production routes, and tact times for each production order.

Collaborative robotics. Although automation is not common in final assembly systems and over 90% of tasks are still performed by humans, collaborative robots (cobots) are becoming increasingly relevant for the assembly area [20]. Cobots can help to reduce stress and ergonomics issues for human operators, allowing operators to focus on tasks that are more complex. As adaptiveness and situation awareness in robotics continue to improve and cost-effective solutions are established, the importance of cobots for the assembly sector will increase further. Cobots can be utilized flexibly for a variety of assembly operations. Hence, an important prerequisite for their use is their integration into the process engineering methodology.

3.2 The Future Flexible Assembly System

A new final assembly system combining the four flexible manufacturing concepts from Sect. 3.1 is designed with the goal to increase efficiency by enhancing the flexibility of the system while considering new driveline technologies, like e-mobility or hydrogen, in the commercial vehicle industry.

The proposed new concept utilizes flexible assembly work cells, capable of assembling different products in different batch sizes without the need for time-consuming reconfigurations to the work cells. The system incorporates the three principles of a flexible manufacturing system described by Askin et al. [21], specifically, routing flexibility, part volume flexibility and part mix flexibility to allow the system to adapt to changes in volume and type of product. However, since conventional assembly lines are designed for efficiency and can be optimized for speed, the general design of the assembly system was chosen to follow a mix of cellular manufacturing and characteristics of the conventional assembly line.

The presented assembly system replaces workstations with assembly zones and utilizes a mixture of cellular assembly and line manufacturing. High-level product classes are introduced based on manufacturing requirements. Consequently, product-class specific assembly zones are dedicated to specific variants, like conventional, electrical or hydrogen vehicles. Flexible production sequencing is used to ensure that each production order only passes through required assembly zones. To enable routing flexibility, AGVs are used for transportation. Flexibility within the individual assembly zones themselves is ensured through the concepts of flexible material delivery, Plug and Produce and cobots. Both material and equipment as well as cobots are guided by AGVs from central pools or warehouses to their point of use in the assembly zones. Since not every equipment can be moved flexibly between the assembly zones, specific assembly zones are introduced containing stationary equipment for specific operations. Moreover, the concept of a standardized tact time is replaced by dynamic tact times per individual assembly zone derived from the individual workload of production order configurations.

Based on this proposed hypothetical future flexible assembly system, a case study was created. The case study incorporates a realistic manufacturing scenario with different product variations, e.g., driveline technologies, assembly operations and multiple cycles. The goal was to create a feasible and realistic manufacturing scenario for the system, which would highlight the system's abilities in terms of flexibility and efficiency.

3.3 Required System Capabilities

Based on the four flexible manufacturing concepts and the introduced future flexible assembly system four required system capabilities were derived.

Autonomous decision-making. The dynamic and flexible allocation of assembly processes, resources, and production materials is too complex, costly and time consuming to be performed manually. For that reason, autonomous decision-making, with systems making independent manufacturing decisions is required.

Real-time data processing. Based on the dynamic process design, in which the system can adapt to short-term changes, it is fundamental to include real-time data capturing and processing. To enable real-time data processing, an efficient data infrastructure that allows for immediate access to the necessary data and information is necessary. Additionally, relying on manual processes can be too time-consuming, which is why it is necessary to implement a combination with autonomous decision-making.

Software management and maintenance. To implement a flexible assembly system, the development and implementation of new software systems is required. In this context, the essential aspect of the system ecosystem is scalability. It is essential to plan individual systems and the ecosystem with respect to system maintenance, expansion of functionalities and use cases in advance, in order to ensure that the system ecosystem remains flexible and adaptable.

Process methodology. The flexible assembly system requires the adaptation of the organization's way of working. This requires an adaptation of the planning methodology with regard to manufacturing preparation as well as for assembly processes in the execution area. It is important to train responsible individuals in the data-supported way of working of a new system architecture. Manufacturing-related product documentation, simulation-based verifications, and optimization must be integrated into the processes. Overall, the successful implementation of a flexible assembly system requires changes to both process and organization. A key factor is that the prevailing assembly structure is no longer a determining factor.

4 GAPS

Derived from the expert interviews and the case study seven major gaps were identified that represent considerable obstacles for companies in their transformation process towards flexible manufacturing systems. Fig. 2 illustrates the relation of the identified gaps to the required system capabilities as described in the following paragraphs.

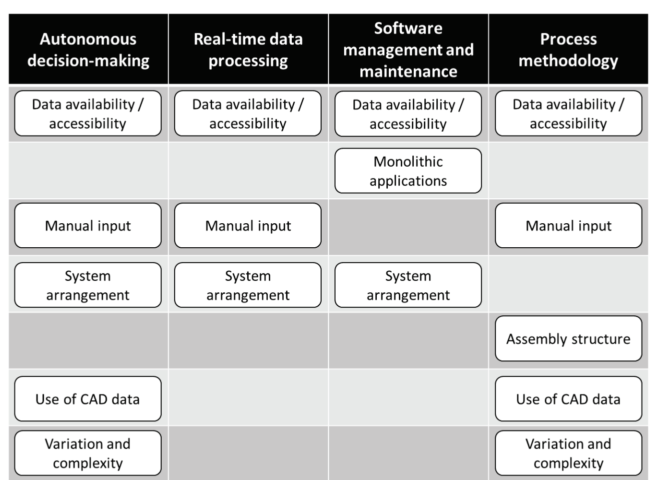

Figure 2 Identified gaps and their relation to required system capabilities

4.1 Data Availability and Accessibility

Data availability refers to the process of data acquisition and storage. It includes organizational decisions of which and how much data to collect. In addition, there are technical factors involved, e.g., data types and storage systems. Data accessibility refers to the provisioning of the relevant data for the respective stakeholders (people, systems, processes) at the time it is required. A major factor that influences data accessibility is the heterogeneity of data due to different sources, including technical issues such as the need for sufficient interfaces between different systems.

In the interviews, it was unveiled, that problems concerning data availability and accessibility become visible, e.g., in the assembly environment. Heterogeneous data sources providing production-relevant product data, and data and information about equipment are an issue. It should be pointed out that even if the data for the operating equipment is created, the information content was found to be insufficient for the decision-making process, e.g., regarding availability of certain tools and an analysis of the degree of utilization.

For ***autonomous decision-making*** the availability and accessibility of all data and information is essential. ***Real-time data processing*** requires direct accessibility of the the relevant data and information, which relies on an effective and efficient data infrastructure. Data accessibility has an important influence on ***software management and maintenance***, as well as ***process methodology***, since the responsible persons must be trained with respect to the data-supported way of working in a new system architecture.

4.2 Monolithic Applications

Monolithic applications are characterized by the fact that they are built as a single proprietary system that combines several business processes. Even though such monoliths can be internally organized in several layers, these layers are typically intertwined and no further decoupling or modularization is done, impeding other application to from fine-grained access to relevant data and functions. The agglomeration of functionality increases dependencies of other applications from different areas. Thus, monoliths have high responsibility for a smooth functioning of the overall system, since problems may affect the entirety.

Often monolithic applications are systems that are internally developed within an organization, and have been growing over many years continuously adding new functionality. This expansion increases complexity, dependencies, and complicate maintainability. Moreover, complexity and lack of transparency hamper further developments, particularly regarding dynamic changes required in flexible manufacturing systems. Criticality not only comes from the required stability of the system due to the risks imposed to depending applications in case of a system failure, but also from the high maintenance costs.

Regarding the required system capabilities, monolithic applications are a main obstacle for ***software management and maintenance***, particularly regarding the extension of the current system ecosystem.

4.3 Manual Input

The interviews revealed, that systems in the manufacturing area, particularly preparation systems, are largely based on manual input by production engineers. Since manual input is often error-prone, incorrect information propagates to other systems causing problems or inefficiencies. For instance, many process planning activities need to be done manually, which includes creation of assembly operations, estimation of assembly times, and determination of use points for material handling. Incorrect or imprecise estimation of assembly times, for example, leads to considerable inefficiencies within assembly line balancing.

Another reason why there is the need for many manual-input-reliant systems is insufficient interfaces and data connections between systems. If a process planning system, for instance, is not connected to a product lifecycle management (PLM) system the data must be provided manually. Additionally, missing data capturing systems, such as sensors that measure assembly operation times on the shopfloor, require manual theoretical estimations.

In future flexible manufacturing systems, the required capability ***autonomous decision-making*** is dependent on structured, high-quality data, which can hardly be provided using manual input processes. In addition, ***real-time data processing*** relies on fast data provisioning that cannot be managed if manual processes are involved. Regarding ***process methodology***, it is important to raise the awareness for the criticality of data created by manual inputs.

4.4 System Arrangement and Data Management Infrastructure

It can be observed that systems are typically arranged in a sequential ordering. This so-called "waterfall structure" bears the disadvantage, that flawed data in an upstream process has an impact on various downstream systems. A reason for this sequential arrangement is the lack of backward connections in the systems. Hence, there is no significant data flow from the shopfloor back to the manufacturing preparation systems. An example for an effect of this “waterfall structure” is if use pointes are specified incorrectly by the logistics engineer, which leads to material being delivered to the wrong zone on the assembly line.

Another gap regarding system arrangement is the data management infrastructure based on periodic batch updates. This means that data is entered into the systems at specific intervals, which prevents real-time use of the data [22].

Regarding the required system capabilities for flexible manufacturing, ***autonomous decision-making*** and ***real-time data processing*** suffer from unavailable real-time data due to data batches and missing backward data channels. The sequential arrangement of systems is also important in terms of ***software management and maintenance***.

4.5 Assembly Structure

The interviews showed that the physical assembly structure is the basis for both manufacturing preparation as well as for execution. The assignment of assembly operations, the determination of the tact time and the allocation of equipment to the stations are examples for important processes, which are based on the assembly structure. As a consequence, IT systems are based upon this structure as well, manifesting the rigid assembly processes within the underlying data infrastructure. For example, intralogistics operates on the basis of predefined material delivery points assigned to workstations, making it difficult to flexibly reorganize assembly processes on the assembly line. Moreover, the production program follows the rigid structure, since each production order is already pre-determined to pass through each station of the assembly line.

The assembly structure is a major obstacle for the implementation of flexible manufacturing technologies, as it dominates both system and process design. The removal of this structure is the initial consequence of the realization of flexible manufacturing technologies. But since, it is currently the standard way of working in the automotive industry and the IT system structure has evolved to fit this way of working, this is incredibly difficult both process- and systemwise.

The rigid assembly structure affects all business capabilities, however the main effect is on the required system capability ***process methodology***, as it is the current basis for all manufacturing preparation and execution activities. The use of flexible manufacturing concepts and the future flexible assembly system renders the current way of working based on a rigid assembly structure infeasible.

4.6 Utilization of CAD-Data

CAD product-data is currently not utilized for manufacturing purposes in either manufacturing preparation or execution. The interviews highlighted that visual simulations and CAD data are only used for certain verifications and validations for specific projects, but not implemented in the operational way of working in processes or systems. This can be classified as unused potential and an obstacle for flexible manufacturing, as visual data is essential for any simulations as well as for operator assistance.

The high product variation and the resulting complex product database is optimized for product development in the product documentation process. This makes the retrieval of correct visual data for the respective production process very difficult and time consuming affecting the company's ability to create and use virtual simulations. The necessary connections between the manufacturing preparation systems and the PLM system containing the CAD-data are not efficient. There is also a lack of clearly defined processes for the operational use of visual data within manufacturing.

In terms of the required system capabilities, the use of CAD-data has a significant impact on ***autonomous decision making***, since visual data is required in the data basis as well. Furthermore, the use of CAD-data needs to be considered within ***process methodology***.

4.7 Increased Variation and Complexity

The increasing product variation and complexity in the commercial vehicle industry represents a challenge for both the system ecosystem and process landscape. The process differences between different driveline technologies are extensive, resulting in increased complexity for both preparation and execution processes. This complexity is difficult to handle with manual-input based systems, and will lead to high inefficiencies on the conventional assembly line. Additionally, cognitive challenges related to handling the complexity of different processes for operators will increase heavily, requiring appropriate adaptations on the shopfloor, such as an effective system for operator assistance.

The increasing product variation and complexity mainly affect the required system capabilities of ***autonomous decision-making*** and ***process methodology.***

5 EVALUATION

The analysis conducted in this paper is evaluated by proposing a concept for a flexible assembly system and reviewing the required system capabilities in this context.

5.1 Solution Concept

5.1.1 Data Standard

One of the basic proposed adaptations concerns data standards, as unstructured data has a high proportion within the manufacturing domain. Due to the high proportion of unstructured data within the manufacturing domain, a suggested solution is to introduce clear data standards that require data in a structured format. For this purpose, process adaptations such as standardized assembly instructions can be implemented to structure the database. However, some data sets cannot be generated in a structured format and as a consequence solid ETL (Extract, Transform, and Load) processes and tools are required. ETL processes involve extracting data from various sources, transforming it into a structured format and integrate it into the target database.

5.1.2 Process Methodology

As the rigid assembly structure does not work with the flexible assembly system, a new planning and process-engineering methodology is required for manufacturing preparation as illustrated in Fig. 3. The proposal is to introduce a generic planning methodology that initially disregards physical factors, such as the number of workstations or the assembly sequence, and focuses on creating assembly operations and instructions only in relation to the components instead. These operations must be well described, with requirements like the required assembly operation time, equipment, and qualifications. Assembly processes are then assigned to assembly zones using an autonomous software solution. Logistics processes are generated automatically based on that allocation.

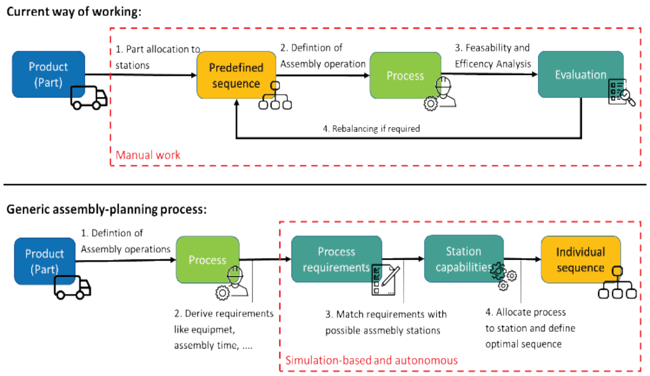

Figure 3 Generic process engineering

With a large number of possible assembly sequences for formulated assembly operations, a constraint-based model can be generated based on characteristics and technical capabilities of individual assembly zones. This model can be used to match the process requirements of assembly operations with assembly zones capabilities, described in the model. Simulations and AI preselect the solution with the best KPIs. The process engineering workload is then limited to generate accurate assembly operations, create and update the assembly system model, and verify simulated solutions. The principle of a generic approach to assembly planning was also discussed by Küber et al. [17].

5.1.3 System-Architecture Adaptation

A conceptual proposal for an adaptation of the system architecture is the transition from monoliths to service-oriented architectures (SOA), which offers easier maintenance of systems and a faster and more effective way to develop and deploy functionalities [23] thus increasing scalability. A specific well-defined implementation of the SOA is the Microservice Architecture (MOA). Microservices can encapsulate business capabilities and allow for a flexible, modular and evolvable architecture [24].

A concrete proposal for a system-architecture adaptation is a variation of the "Advanced Manufacturing Analytics Platform" by Groger et al. [25]. The foundation for the architecture is a model of the manufacturing system containing information about the manufacturing process and serving as the basis for analysis and simulation activities. The architecture consists of three layers:

The ***data integration layer*** is in charge of integrating all relevant data from different sources, and is built upon a manufacturing data warehouse, which integrates manufacturing-relevant execution data, e.g. originating from MES-systems, and operational data from PLM-, process engineering- or ERP-systems. The ***process analysis layer*** is responsible for identifying and managing process insights, which are generated using simulation-based techniques. Data provided by the manufacturing data warehouse is used in a manufacturing mining, manufacturing graph analysis and a manufacturing metrics management component. The ***process optimization layer*** takes care of the actual process optimization. Based on the process insights identified in the process analysis layer, the two techniques of indication-based manufacturing optimization and pattern-based manufacturing optimization are applied to support the process optimization.

5.2 Evaluation

For the evaluation of the proposed concept for the flexible assembly system, the required system capabilities are discussed in the context of the proposed concept adaptations.

Autonomous decision-making. Through the introduction of a data standard and concepts like the Manufacturing Analytics Platform autonomous decision making as well as an efficient database are introduced. The proposed concept is simulation-based and autonomous, reducing the amount of manual work required, and creates the data basis for autonomous systems, ultimately enabling required autonomous technologies in manufacturing preparation.

Real-time data processing. Concepts like the Manufacturing Analytics Platform aim to integrate relevant data from both manufacturing-execution and operational sources to detect deviations and optimize assembly configurations. This architecture concept avoids the sequential arrangement of systems and can be combined with the concept of SOA for faster calculations, creating the basis for a dynamic and fast responsiveness of the flexible assembly system. If the appropriate data capturing technologies are implemented as well, the basis for real-time data processing is given.

Software-management and maintenance. Monolithic architectures are a main obstacle for IT-scalability. Through the introduction of SOA, this problem is solved by providing a modular system architecture that reduces dependencies between individual applications and enables the faster development of new applications. The introduction of data standards has further positive effects on IT-scalability.

Process methodology. The proposed generic assembly-planning methodology enables the implementation of the flexible assembly system within a company's process landscape by allowing assembly planning to be conducted on the basis of the product rather than rigid assembly structures. This leads to more efficient production planning and avoids manual allocation of assembly operations to assembly zones.

6 CONCLUSION

The future of manufacturing is characterized by flexible manufacturing technologies that bring enormous challenges for the commercial vehicle industry. Based on classical business capabilities that constitute the state of the art in manufacturing-related automotive organizations, a future flexible manufacturing system was outlined comprising the concepts of flexible material delivery, Plug and Produce, flexible production sequencing and collaborative robotics. Based on these concepts, a case study for a future flexible assembly system was defined and required system capabilities were identified, namely autonomous decision-making, real-time data processing, software management and maintenance and a new process methodology. Interviews with seven domain experts in the field were conducted to identify the main gaps that need to be overcome by the commercial vehicle industry to realize a future flexible manufacturing environment. In this paper, seven gaps were described and their relations to the required system capabilities were pointed out. A concept for a flexible assembly system was presented as a basis for evaluating the gap analysis.

Despite the inherently limited scope of a case study and expert interviews, both methods were designed in a way that the findings and conclusions are representative for the branch of commercial vehicle industry, and to a large extent also for the automotive industry in general. Future work will be a more detailed conceptualization and finally implementation of the solution concept, as well as studies in related branches.

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