Introduction to Material Feeding 4.0: strategic, tactical, and operational impact

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Abstract. Mass customization, the process of producing a low-volume high-variety of products, is changing production environments. In Material Feeding (MF) this means a huge increment in the number of parts, and information, that need to be managed during the different MF activities. If companies want to get high performances from their MF activities, they need to be able to manage these changes in the best manner. Industry 4.0 technologies are introducing new opportunities to help companies in the execution and control of the MF activities. It is important for companies to be able to understand how to implement these technologies in their processes and how to take these opportunities. In order to facilitate this, in this paper the concept of Material Feeding 4.0 (MF 4.0) is presented for the first time, as Material Feeding where the Industry 4.0 technologies are introduced. The impact of the identified technologies is studied at a strategic, tactical and operational level.

Keywords: Material Feeding, Industry 4.0, Assembly System, Strategic, Tactical, Operational.

1 Introduction

The demand for customized products is increasing. A high demand of customized products implies that the production and assembly lines require to be fed with an enormous amount of different parts. Material feeding (MF) describes all the activities that are responsible for the provision of components, parts, equipment, etc. to production and assembly systems when needed [1]. If companies want to satisfy the demand of their customers these activities need to be continuously improved and optimized. In this paper the focus will be in the assembly system (AS). MF, in AS, can be performed in different ways, by storing all parts near the assembly line or pre-processing parts and delivering them when needed [2]. In the last years with the so-called Industry 4.0 revolution, both AS and MF are considering the introduction of the technologies that this revolution is offering in their planning and control processes. However, although other works already exist that try to study the effects of these technologies on the AS, [3, 4], still no work exists about their effects in the planning and control processes of the MF systems. Although in literature the terms Supply Chain 4.0 and Logistics 4.0 have been already discussed with a broader perspective, [5, 6], in this paper we focus on the specific process and set of activities related to MF. The idea is to understand which are the emerging technologies that can be implemented in the MF activities and how their implementation can impact at three levels: strategic, tactical, and operational. The remainder of this paper is structured as follows. Section 2 provides a review of the existing literature concentrating on the MF activities. Section 3 illustrates and discusses the results obtained from the review of the literature. Finally, in Section 4 the paper is shortly summarized.

2 Review of the existing literature

Examples of Industry 4.0 technologies in AS are: Internet of Things (IoT), Big data, Cloud Computing, Augmented Reality, Collaborative Robots, and Additive Manufacturing [3]. These technologies affect the performance of the AS activities. In MF it is not yet defined which emerging technologies can be used. The main activities of MF are transportation, preparation, and material management [7]. Transportation implies the process of moving all the components, parts, from a point A where they are stocked to a point B where they are requested. The preparation implies the processes of handling and repacking parts into load carriers used for the corresponding line feeding policy [7]. Material management instead includes all the process related to the storage of components and products. For the storage of components, two of the possible solutions are the central receiving stores and the supermarkets [8]. An extensive review of the existing literature on the subject has been carried out to see what is possible to find about Industry 4.0 technologies that can have an impact on these three activities. We used Scopus database as search engine limiting the research from January 2006 to March 2020, English as language, and journal and conference papers as sources.

2.1 Transportation

In the planning and control of the transportation activity one of the most important decisions is the choice of the transportation devices. Examples of traditional transportation devices are the forklift, tow train, or feeder line [8]. Thanks to the technology development, new solutions have appeared in the last few years [9]. First the Automatic Guided Vehicles (AGVs), driverless vehicles that follow a fixed path in order to move from a point to another [10], and now Autonomous Mobile Robots (AMRs) are getting more popular due to their flexibility [11]. These mobile robots can move without following a fixed path and use cameras and sophisticated software to identify their surroundings and take the most efficient route to their destination [12]. AGVs and AMRs are platforms in which you can implement different additional equipment/resources such as lifting systems and collaborative robot. They can be used as “workstations” to assemble the products [13] or to move shelves from the warehouse to the AS [11]. Based on how companies decide to use them, they will face different problems in order to optimize the performances. For example, if the AGVs/AMRs are used to move the shelves for the picking operations, an example of a possible problem might be when non-completed shelves have to be moved using AGVs/AMRs that usually move complete shelves. A solution to this problem is presented in [14] where the authors proposed a scheduling method to move the shelves even if they are not complete. In [15] a cloud-based architecture that controls and improves the collaboration of the AMRs is presented. Simulations showed that using this cloud-based architecture gives the opportunity to improve energy efficiency and save costs. AMRs seem to be a very prominent technology in order to improve the transportation activity. This is also thanks to the development of more powerful Data Analytics techniques.

2.2 Preparation

In the preparation activity for AS we can find the picking and kitting process [1]. The process of picking can be described as manually seeking a particular item in storage according to a list, taking that object and putting it into a bin/container the appropriate transport vehicle, and bringing the objects to the required location for processing [16]. The kit preparation process instead supplies AS with kits of components. The kits are prepared at a kit preparation workspace apart from the AS [17]. Picking and kitting operation can be facilitated using a AMRs to transport the necessary components from the warehouse to the AS [11]. AMRs are not used only for the transportation. In the last few years many manufacturers have started to develop mobile robots with various functions [9]. If a collaborative robot is integrated with a mobile robot this can be called collaborative mobile robots [18]. In [18] the collaborative mobile robot is used to perform a part-feeding task. The validity of the solution is granted by the successfully performed tests. Another example of a collaborative robot mounted in a mobile robot is presented in [17]. The collaborative robot sorts the components that have been picked by an operator into a batch of kits. The mobile robot gives the opportunity to the collaborative robot to do its operations moving together with the human operator. This is done safely and relieves the human operator of activities associated with sorting components into kits. Kitting preparation in the context of material supply to AS can be performed utilizing augmented reality (AR) [19]. AR is used in single kit-preparation and in batch preparation. The experiment demonstrates how AR is competitive both in terms of time-efficiency and picking accuracy. AR is used also in picking activities. The main improvements that AR can give to picking operations are the errors reduction and time efficiency [16, 20, 21]. The preparation of the different components and parts to deliver at the AS is a very important activity. A mistake in this activity means a reduction in the performances of the AS. The introduction of AR in this activity is made in order to reduce the probability of making mistakes.

2.3 Material management

Data Analytics techniques, such as data mining algorithms and machine learning algorithm, are becoming more popular and powerful with the advent of Industry 4.0 [22]. These techniques can be used to improve the material management activities of a company. For example, in [23] a machine learning algorithm is proposed to optimize the warehouse storage location allocation. The solution can improve the efficiency of warehouse operations in case of weak correlation between the stock keeping units. Whereas in [24] a positioning big data forecasting model is used in order to predict the trajectory of the mobile robots. This can improve the safety, reliability and stability of the mobile robot navigation. The introduction of mobile robots in the warehouses can mean a change in their design. Mobile robots allow spatial flexibility and expandability. If a warehouse needs more capacity, one simply adds more pods, drives, and stations [11]. In order to manage the inventories of warehouses and ASs it is possible to adopt new smart solutions. Internet of Things (IoT) and Cloud computing can be used to automate inventory systems [25]. An example of a solution that can improve this automation of inventory systems is presented in [26] with the concept of self-optimizing Kanban. Self-optimizing Kanban systems autonomously adjust their capacities as well as the quantity of cards in circulation according to predefined performances. In order to use these systems, it is important to collect all the data of the quantities inside the warehouses in real-time and to use data analytic algorithms to manage the collected data. The data are the most important resource in material management. It is important to know which data need to be collected and how. Once the data are collected, they need to be analyzed in order to obtain valuable information. IoT technologies and Data Analytics techniques will help companies in this MF activity.

3 Material Feeding 4.0

In Figure 1 we see the results obtained from the review of the literature. From the figure we can see that the most adopted technologies in MF activities are: mobile robots, augmented reality, IoT technologies, Cloud Computing and Data Analytics. These are the technologies that can be present in a MF 4.0 system.

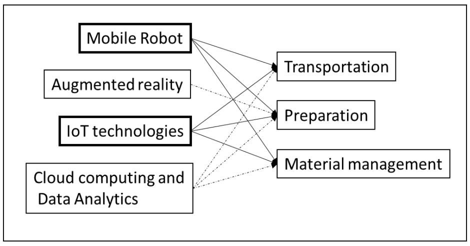

Fig. 1. Industry 4.0 technologies for Material Feeding activities.

Table 1 summarizes where the technologies impact in the different activities at a strategic, tactical, and operational level. The table helps to think about new research challenges that can appear if some of the technologies identified are introduced in the MF system. In order to state the impact of the different technologies at a strategic, tactical, and operational levels in MF 4.0, the scope of every level is shortly explained in the following. Decisions of different levels affect each other and should be considered in an integrated way regarding the intra-organizational decision levels as well as the inter-organizational hierarchy [27]. Due to page restriction, we will use the mobile robots as an example.

Table 1. Decision areas of Material Feeding 4.0. Impact of the different technologies in planning and control.

	Impact level		
Industry 4.0 technology	Strategic	Tactical	Operational
Mobile robots	• Type of mobile robots • Design the guide path system • Warehouse design • Skills to use the system	• Feeding policies • Number of mobile robots • Scheduling of the mobile robots • Human-mobile robot interaction	• Routes of the mobile robots • Control of the system
Augmented reality	• Type of AR devices • Skills to use the AR devices	• Number of workers • Ergonomic of the system	• Real-time information sharing → sequencing of kitting and picking information • Control of the system
IoT technologies	• Type of IoT technologies • Type of containers • Skills to use the IoT technologies	• Number of containers in the warehouses and in the AS • Position of the IoT technologies	• Real-time control of the capacity of the container • Control of the system
Cloud computing and Data Analytics	• Type of Cloud Computing system and/or Data Analytics techniques • Data to storage and analysis • Skills to use these techonologies	• Information to create and share • How to create the information	• Real-time sharing and displaying of the information • Control of the system

3.1 Strategic level in MF 4.0

Strategic decisions are those decisions that have an influence over the years and a long-term impact on the performance of the MF. Once a strategic decision is made, it is very unlikely to be altered in the short term. They are usually taken at the highest levels of management, include a wide range of uncertainties and carry higher levels of risk. In MF 4.0, the most important decision at this level for all the MF 4.0 activities, is the choice of the technologies to adopt. It is possible to decide gradually which are the technologies to implement in the different activities. Which type of mobile robots to buy will influence all the decisions that a company has to face after their purchase. A mobile robot can be used only as a transportation system or it can be integrated with collaborative robot for picking activities [9, 17]. This together with the flexibility of the guidance system of a mobile robot and its dimensions will influence the design of the possible paths and of the warehouses (central receiving stores or the supermarkets) where it will work [10, 12]. The design of the warehouses can be also influenced by the different types of containers that the mobile robots can transport [11]. The investment that a company makes when it decides to buy the mobile robots is not related only to the purchase of the robots. Someone needs to know how to use them. If the mobile robots are introduced in one or more of the MF activities, it is important to know which skills are needed to use them and what is necessary to do in order to best implement them. This can influence the performance given by the mobile robots. For example, if the company decide to not hire new workers that already know how to use them, it is possible that during the first period, their performance will be lower than the expected. This because a certain amount of time is needed to learn how to use them.

3.2 Tactical level in MF 4.0

Tactical decisions are decisions and plans that concern the more detailed implementation of the strategic decisions, usually with a medium-term impact on a company. At the tactical level, the decisions about which are the technologies to implement are already made. For the mobile robots this means that the company has decided which type to buy. At this level, for all the MF 4.0 activities, it is important to prepare the different technologies to be used. The first thing to understand is which are the feeding policies to be adopted [1]. The flexibility of mobile robots can change the application of the feeding policies making one policy more convenient than another. For example, it can be more convenient to prepare kits than move entire pallets. Mobile robots are also more flexible with respect to the transported volumes and they can adapt themselves with the variation of the material flow. The chosen policies can influence the number of mobile robots that the company needs and respect with traditional transportation devices it is possible that new algorithms are necessaries to calculate this number. In the scheduling phase of the mobile robots, the company decides when, where and how a mobile robot should act to perform tasks [10]. A new problem to solve during this phase is which mobile robot to use based on the operations needed to perform [9]. This because there are different types of mobile robots that are going to be implemented based on the activities that they must do. In this phase is important to consider also the ergonomic aspect of the system. In fact, the safety precautions that one has to implement can be different in order to use the different type of mobile robots. These can change from a mobile robot that is used only as transportation system from another that works together with human workers, for example when it is used as a workstation or when it helps the human operator in the preparation of the kits [13, 17].

3.3 Operational level in MF 4.0

Operational decisions are related to day-to-day operations of the companies. They have a short-term horizon as they are taken repetitively. At this level, for all the MF 4.0 activities, it is important to ensure that technology works as best as possible. The vehicle routing problem decides the route a mobile robot should take and the sequence of loads (or jobs) that this vehicle should visit [10]. The routes that a mobile robot can travel are different from those of a traditional transportation devise [8]. The routes change also depending on whether the mobile robots must follow a fixed path or not. Regardless of the technology, at the operational level it is possible to find the control of the system. This will give the opportunity to continuously improve the MF 4.0 system and to avoid that it stops working. Checking the operation of a mobile robot is more difficult and requires new data to be collected and new knowledge. This is because they are not guided by human workers, and if something is not working properly, no one can be aware of it if a proper control system is not implemented. It is important to create new solutions that can control the mobile robots during the execution of their activities [15]. The data collected from the mobile robots need to be analyzed, and once these data become information these need to be understood before then take any decisions. Not understand the information generated by the execution of the different activities from the mobile robots means not being able to understand if the system is working properly. This means having a system that is not working with the desired performance and that is not possible to change it in order to improve them.

4 Conclusion

This paper focused on the individualization of the most common Industry 4.0 technologies that can be used during the execution of the MF activities. The considered MF activities are transportation, preparation, and material management. This gives us the opportunity to introduce the concept of MF 4.0. MF systems where the different activities are done with the help of the new technologies of Industry 4.0. Moreover, we give some suggestions about the decisions that need to be taken in MF 4.0 with respect to a strategic, tactical and operational impact level. This is only an introduction in the topic of MF 4.0. There seems to be a high potential for future works in this research stream. Future research for example should focus on understanding how to measure the performance of the different technologies implemented in the MF 4.0 activities. This is related to another possible work that is understanding which are the data that need to be collected from the MF 4.0 activities and how to collect them. The technologies are becoming always more powerful and user friendly and their introduction will increase in the next few years. It will be important to know in advance which will be possible issues that companies will face when they decide to implement one of these technologies.

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