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Matrix Fusion Factory

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Abstract

The current trend in mass personalization is making it ever-more important to achieve a smooth transition towards a more flexible production process to keep up with global competition. IFF has therefore developed the concept of the Matrix Fusion Factory (MFF). MFF fuses the standardized coordinate system developed by IFF with the real factory, thus linking physical factories with their digital images. It is based on modularized, mobile machines capable of configuring and positioning themselves according to the tasks and context concerned. The necessary information, such as machine areas or work instructions, is gathered practically in realtime depending on location, time, order and equipment, and made available within the factory in a context-based manner.
In the MFF, this information is considered as being part of the physical factory. This allows the impact of the available information on the production system to be identified and simulated and, the availability of information to be adjusted. This mutual dependence between the physical and the digital factory can only be achieved through fusion. The end-result is a digital-physical factory that enables efficient and flexible value-adding processes in modularized mobile factories.

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Keywords: factory organisation, digital shadow, digitization, production optimization, cyber physical production system

1. Introduction

Due to rising product individualization and shorter product lifecycles, the processing industry is faced with constant change, particularly in the field of manufacturing [1, 2]. This external market complexity can only be countered with

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an equally high degree of internal company complexity [1, 3]. The degree of internal complexity must be high enough to enable effective operation. However, to allow efficient operation, it must remain manageable [1].

Throughout the history of manufacturing, managing internal complexity or the ability to manage it, i.e. adding value efficiently, has always been and will always remain a decisive factor when it comes to successful business operations [4]. In the early years of manufacturing engineering, with Taylorism complexity was minimized in favor of efficiency [5]. The underlying linear description logic with specified order flows defined in advance, as well as all the resulting worksteps, workplaces and work contents, is still applicable today, despite the latest modifications [1, 2]. Thanks to the relatively rigid synchronized chain and separation of value-adding processes from non-value adding processes on the one hand, and differentiating between logistics and production means on the other, the linear structure can be clearly described. This makes the manufacturing system relatively easy to plan and control. However, this simplicity caused by these pre-defined work steps, places and contents restricts the potential to make the manufacturing system more adaptable and efficient [6].

The goal of the fourth industrial (r)evolution of realizing lot size 1 production at the same cost as mass-production can, however, only be achieved by making value-adding processes more flexible while simultaneously improving efficiency [7, p. 111]. For this reason, it does not appear to make sense to adhere to the line structure for the future production of mass personalized products in lot size 1 in the mid-term. [1]

Therefore, the flexibility required for future production can only be achieved through a change in paradigm, similar to the attempt made in the eighties to manufacture in boxes. Since today's methods of logically describing value-adding were unavailable at that time, the increased internal complexity resulting from breaking up this structure led to much poorer efficiency and effectivity [8]. As opposed to the attempt made back then, today we now have powerful IT systems [9] which enable production to be made more flexible without impairing the cost-effectiveness of the manufacturing system or product quality. Moving away from mixed-model line assembly, fixed cycles as well as defined work contents and places will, in the same way as manufacturing in boxes, not only significantly increase flexibility but also complexity. In the future, the challenge for manufacturing companies will be in managing the production flexibility required without losing out on efficiency and effectiveness due to increased internal complexity, as was the case in the eighties.

Over the next few years, the manufacturing industry must achieve three main tasks: (1) Development of company-specific modeling concepts for internal and external complexity. (2) Development and construction of tools to describe, measure, manage and control complexity corridors and (3) Development of business models to manage complexity efficiently in order to construct new, more adaptable, highly-flexible and efficient manufacturing systems.

Based on this, with the matrix fusion factory, IFF has developed a concept for a mass personalization manufacturing system that focuses on flexibility and efficiency.

2. Structure (elements) of the matrix fusion factory

To the same extent that product requirements are changing, manufacturing systems also need to adapt constantly [1]. In an extreme case, this means that the manufacturing system must have processes, work contents, production steps and technologies available which may only ever be needed one single time to manufacture one single product.

A prerequisite for the cost-effective mass production of personalized products is therefore a factory which adapts to each of the products being manufactured. Depending on the individuality of the product concerned, this may concern all levels of the Stuttgart business model [2]. Adaption must take place continuously, from the process right through to the production network. The manufacturing system must therefore be made flexible enough to allow a new level of adaptability to be attained.

2.1. Fluidized order flow

With lot size 1 production, it can be assumed that the diversity of production processes rises significantly [4]. If machines are connected inflexibly, the utilization rate of the various machines and the overall system falls. This is because workpieces move past processing machines in an untreated condition while the machines are unable to processes any other workpieces. A first step towards an adaptable manufacturing system for personalized production is therefore to flexibly decouple machines which are not needed for each product. It must be possible to flexibly connect individual machines and equipment which are only required occasionally for the manufacturing system without the rest of the system missing a cycle or losing the time required to process a workpiece. This breaks up the fixed chain of production. [10]

In further consequence, better machine utilization and a more efficient manufacturing system can only be achieved by fluidizing the order flow and dispensing with fixed cycles [10]. The capacity of all machines can only be increased if orders take individual routes through the production system. These routes must be planned and executed in realtime according to the production steps required and the capacities currently available. This enables machines and equipment to be used to capacity by different products at the same time. As a result, all machines and equipment in the entire manufacturing system are decoupled. Since the amount of time required by a machine to process different products varies, the production-wide cycle must be dispensed with. Otherwise, workpieces and machines would be waiting for workpieces that are still being processed.

2.2. Optimizing utilization through flexible technical integration

By considering utilization at the technical functional level of the machines and equipment, the order flow can be further parallelized. Consequently, a machine is understood as being a temporary group of technical functional modules. Seen from this perspective, machines are made up of different compatible, configurable modules that are capable of defined technical processes. Thus, a machine can be optimally adjusted to a given order while, at the same time, other technical functions which are currently not required can be used for other orders.

Value-adding in the MFF is therefore based on modularized, mobilized machines capable of reconfiguring and moving around autonomously - or allow themselves to be configured and moved – as required by each order. In the MFF, a differentiation is made between mobilized and mobile machines and modules. In this context, mobilized means that a machine moves of its own accord, whereas mobile may mean either that it moves of its own accord or that it is moved by external means. In the same way, modularized components are understood as autonomous modules with the ability to describe themselves, whereas modular components are not autonomous and unable to describe themselves. In consequence, the machines in the MFF are composed of different mobile and mobilized modules which perform different production processes.

2.3. Improving efficiency through logistic value-adding

Efficiency can be further improved through using the necessary logistic assignments to add value. By mobilizing machines and equipment, workpieces can be processed during transport. This cuts the amount of production time that is not used to add value, or increases utilization and shortens throughput times.

The superior controller calculates and coordinates routes and processing times for the mobilized machines to reduce the time spent moving from one place to another without adding value. Thus, production means are classified according to their degree of wastage, which depends on the state of mobility and the task to be performed (see Table 1). Mobility states are grouped into immobile, mobile and intermittently mobile. The degree of wastage is determined by the task in conjunction with the state of mobility. For example, an immobile machine waiting for the next workpiece contributes less towards value-adding than a machine that is moving in an unladen state. Despite not adding any value, it is nevertheless actively shortening the time till the next value-adding process and therefore has a lower degree of wastage. The degree of wastage does not consider the waste incurred by the respective manufacturing process.

Table 1. Degrees of wastage and achievable quality

Mobility state	Activity	Degree of wastage	Achievable quality
Immobile	Waiting	--	+++
	Setting-up	-	
	Manufacturing	+	
Mobile	Unladen journey	-	+
	Transport	0	
	Setting-up	+	
	Manufacturing	+++	
Intermittently mobile	Manufacturing	++	++

2.4. Managing complexity by fusing the factory coordinate system with the physical factory (matrix fusion)

The so improved flexibility and efficiency results in a much higher level of complexity and a greater need to align all entities making up the manufacturing system. This calls for a new approach to production planning and control that parallelizes the order flow and enables products to be manufactured with the right quality at the right time and at the right price.

To control the manufacturing system in realtime and be able to make the correct decisions about the order flow, the entire production process must be mapped as completely as possible in near-realtime. This is achieved by tracking processes inside the factory in realtime. Through continuous tracking, the factory models created can be continuously adapted to the real situation and decisions simulated in advance based on the realtime data recorded.

The first step towards realtime control was already taken when the standardized factory coordinate system was developed. The coordinate system allows the complete manufacturing system to be mapped almost in realtime. The factory coordinate system merges the digital image of the factory (digital shadow) with the real production process practically in realtime and independent of scale. To achieve this, diverse data acquisition systems are grouped into a classification system on the basis of the degree of accuracy required; depending on the degree of resolution, the data collected is then merged chronologically in a standardized coordinate system according to time. [11]

A further step is to determine which information is needed by the manufacturing system at which point in time, in which scope, by which people and machines, at which places and in which degree of detail so that the respective order is met at the right time, with the right quality and at the right price. For lot size 1 production, it is essential to predict the effects of information supply and availability on value-adding in order to manufacture goods cost-effectively. This particularly applies when using modularized and mobilized machines to add value.

To simulate and predict the effects on value adding, the functioning principles of the physical and digital manufacturing system first need to be understood, as well as the way they interact. In an adaptable factory, the way in which the manufacturing system functions changes constantly according to multi-criterial target figures, the layout and the orders being processed. New decisions must be made time and again about which information will have the desired positive effect on the manufacturing system to add value. In addition, it also has to be known when and where it could be needed, as well as in which form it must be made available to the manufacturing system in order to achieve the desired effect. This means that the manufacturing system must be in a constant learning state in order to evaluate the effects on value adding in dependence on the given variables at a given point in time.

With regard to people, not only does a machine operator, for example, have to know which machine he currently has to operate and where the machine will presumably be located when he starts work, but also know his work contents and worksteps involved, as well as how to operate the respective machine, including the variable machine areas. The scope, depth and form of the information required must also be clarified, as well as the effects of varying these parameters on value-adding.

To understand the impact on value-adding due to information supply (which is always understood in the following as including the various parameters of when, where, what, who, how, how many, in which depth and to what extent), it is essential to record how the manufacturing system reacts to the information supplied. In this way, the different ways in which the various entities of the manufacturing system react can be linked to the various changing parameters. This enables the subsequent effects on value-adding to be ascertained, as well as predictions to be made about the supply of information in the future. This results in a control loop formed by the supply of information, reactions recorded, determination of the effects of the various reactions on different parameters, determination of how value-adding is affected, as well as a forecast of future reactions and the derivation of optimum information supply methods. In this context, it is crucial that the supply and receipt of information are not identical. This especially concerns the differences in the perception of information between the supply side and receiving side. If the effects of the supply of information need to be predicted, not only must the supply of information be recorded from different perspectives, but also its receipt, or the time or place when/where the information is perceived. The perspective supplying the information perceives the information from the digital part of the factory where the information was generated and mode of supply determined. The receiving perspective becomes aware of the information supplied in the physical part of the factory where the information is perceived, and certain actions based on this perception are then initiated.

Therefore, it is not sufficient to file the information and its mode of supply in the digital shadow and just record the physical effects of the supply. This is because it cannot be assured how the information in the physical part of the manufacturing system was perceived or received. Its effects on the manufacturing system can only be determined if the supplied information is also recorded by the receiving side and thus perceived as being part of the physical factory.

It thus follows that the information supplied and its mode of supply must also be recorded in realtime and transferred as part of the physical factory to a digital model. Based on this model, the effects of information currently available in the manufacturing system can be determined and documented and its effects on the added-value predicted. The acquisition of digital information combined with real objects as one real-digital object and its subsequent (return) transfer to the digital world require a loop in which the digital and physical perception of the supplied information are constantly compared with one another. Consequently, the instructions for action derived from the digital shadow, as well as the information and where, when and how it is delivered must be understood as being part of the physical manufacturing system and transformed back into the standardized coordinate system. (see Fig. 1)

This concept leads to the understanding that, in an extreme case, the physical and digital factory represent the same digital-physical object which, depending on the perspective (digital or physical), assumes varying characteristics. Thus, the supply of information forms the core of the digital-physical factory because it exists in both worlds at the same time. The differences in its characteristics in the digital or physical factory solely depend on the perspective. This results in a fusion of the physical production process with the digital model of the factory and thus in a holistic cyber-physical manufacturing system.

Unlike given models like the digital shadow, MFF does not just describe the actual state of the physical entities of the production system but adds time, location and position data, and specifies the accuracy of this characterization for each single object [11]. MFF also extends this concept on the information level and additionally files which information in which detail and in which form are allocated to which entity at which time and place. This allows to evaluate the reaction of single entities and the entire production system to the information provided. The information flow may

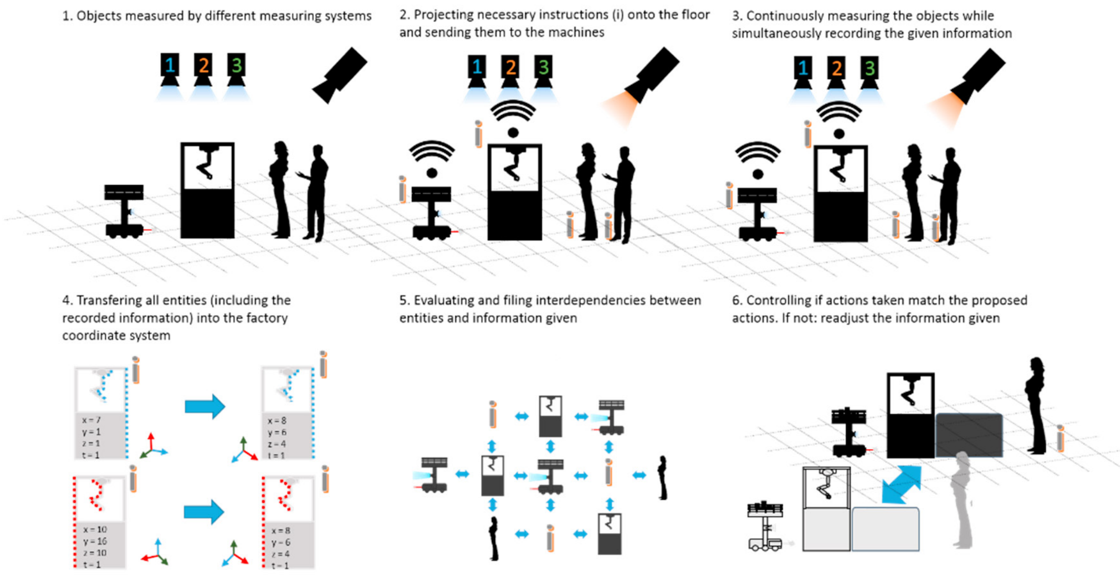

Fig. 1. Procedure for Matrix-Fusion.

be designed in such a way that each entity will receive the information needed in the form and detail needed at the right point in time and place and thus value adding will be optimized

This fusion of the physical factory with the standardized coordinate system, “matrix fusion”, enables the manufacturing system to draw conclusions about how the digital-physical factory will function in a similar situation in the future. “Matrix fusion” also enables the production system to influence value-adding and improve it by generating and supplying the necessary information. This allows decisions to be made in realtime, as well as effects to be predicted and improvements to be made. Future processes can only be improved if the entire virtual-physical manufacturing system is understood as a whole and optimized from the point of view of a higher goal.

Therefore, the MFF considers the digital and physical factory as being different forms of the digital-physical factory. The concept of matrix fusion allows the complexity of an adaptable factory to be managed, as well as the potential of modular and mobile manufacturing systems to improve flexibility and efficiency exploited.

3. Implementation in the IFF learning factory

With the IFF multi-scalar factory acquisition system [11], all the entities of the manufacturing system in the advanced Industrial Engineering learning factory aIE are merged to create a standardized factory coordinate system. The demonstrators are restricted to value-adding AGVs capable of performing assembly tasks during transport processes with the aid of assembly workers. Workers and AGVs are recorded by an optical detection system and transferred to the standardized coordinate system. Based on a current order for an end-product to be processed, specific instructions for action regarding assembly tasks, as well as the supply of material and logistics information, are projected by a beamer directly onto the shopfloor ceiling or workplace. Alternatively, depending on the number of addressees, this information can be sent instead to augmented reality glasses worn by the people concerned. These instructions for action include information about AGV routes, the routes taken by the AGVs and workers (projected by the beamer to avoid collisions with other people on the shopfloor), as well as information about machine areas moving in time with AGVs and specific instructions for the machine operators. By supplying the information, virtual instructions for action become part of the physical factory and have lasting impact on the manufacturing system. Thanks to the optical factory acquisition system, both instructions for action as well as the progress based on them can not only be tracked in realtime but also changed as required. This allows the advantages of matrix fusion to be directly demonstrated in individual process steps. This concept is currently used in trainings for high-level executives and managers. Because practical relevance is important in education and especially in learning factories [12], the MFF is being connected to real manufacturing ecosystems to demonstrate the effects on real production data.

4. Conclusion

In the MFF information is considered a part of the real factory. It is registered according to time and location and transferred into the digital coordinate system. This allows to identify and simulate the impact of the available information on the production system and, if necessary, to readjust the availability of information. Because of this, MFF fuses the standardized coordinate system with the real factory and terminates the separation of physical factories and their digital images. The resulting mutual dependence on the real and the digital factory requires their fusion resulting in a digital-physical factory and allows for efficient and flexible value-adding processes of modularized mobile factories.

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