Evaluation of Material Supply Strategies in Matrix Manufacturing Systems

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Abstract. Today's productions are driven by increasing variants, uncertainty of variants' distribution as well as volume and shorter innovation cycles.
A matrix manufacturing system aims to tackle these challenges. This new system concept consists of independent and flexibly linked process modules, which have no uniform cycle time and no fixed product order sequence in the system.
However, new challenges arise from this system setup. The changes in the structure have an impact on logistics. In research, there are only a few investigations regarding the consequences to logistics, especially to material supply. Common and new innovative supply strategies are used without knowing their suitability to the new system. The applicability of kanban, single product supply or kitting basket supply differs to the usage in a line assembly. A systematic derivation of suitability in the new context is missing.
The paper fills the gap of research in the outlined field. Firstly, changes and characteristics through the new structure which occur as challenges to the material supply are investigated. These are e.g. the flexibility of order and process sequences. In a second step, the material supply strategies are evaluated according to strategic requirements. As a result, each material supply strategy's suitability is evaluated for usage in matrix manufacturing systems.
The paper concludes with a derivation of guidelines for the planning and selection of a material supply strategy.

Keywords: Material supply, supply strategies, matrix manufacturing system.

1 Introduction

Today's markets are driven by the individualization of products and a high dynamic of demand [1]. The number of variants is constantly increasing, coupled with a decrease of each variant's volume [1, 2]. Hence, market predictions are not easy. To meet the external market requirements, firms and production facilities need to provide internal changeability and scalability. The production system's changeability consists of flexibility, reconfigurability and changeover ability [3]. The "matrix manufacturing system" (MMS) provides the structure and logic to realize the requested changeability. The system, structured in the abstract form of a matrix, consists of flexibly linked process modules with independent cycle times. Product routes through the production are not determined a priori but short-term driven through real-time capacity demand and supply of multiple suitable process modules. Existing research focuses on designing and planning these systems [4, 5], whereas only few authors engage in the planning of material supply [6, 7]. Since a stable material supply is a main enabler of a properly working production system, changes influencing the material supply need to be investigated.

2 State of the Art

2.1 Material supply

Material supply is defined by REFA [8] as the task of providing the required material, in the right kind and amount, to the right time and to the right point of use, to enable the further processing. It consists of several dimensions like storage and container policy, internal supply chain design, definition of material amount, transport and routing and further dimensions [9, 10]. A material supply strategy combines forms of multiple dimension. Common used strategies in practice are: combined order supply, total order supply, partial order supply, single product supply, periodic supplying, kanban, multiple container supply and handheld storage supply [9, 11]. Furthermore, in the automotive sector the concept of a kitting part system is used. In an upstream logistic area, a kitting part with parts demanded by multiple process modules is commissioned and added to the product on a certain process module. Each process takes its required parts of the kitting and uses them for its value creation. In the context of MMS, Popp [6] has introduced a concept of a new material supply strategy. It consists of a mobile storage box including a picking tool. The storage box gets filled with multiple parts which need to be supplied to a certain point of use with a high degree of certainty (but still some uncertainty). After moving to the point of use, the tool picks the needed part just in time and provides it to the worker. Not needed parts are restored in the warehouse. The strategy is called bar concept supply and offers a high degree of flexibility.
For choosing a feasible material supply strategy several approaches exist [9, 10, 12–14]. To select a strategy several analyses investigate e.g. the material demand, part-value, manufacturing structure and space. Still, in practice, choosing a material supply strategy is often done intuitively and without deeper analysis [15, 16].

2.2 Matrix Manufacturing System

A MMS consists of flexibly linked, but physically uncoupled process modules. It has characteristics of a workshop fabrication, but individual process modules are combined in a process flow structure which is required by the products' structure. Kern [17] outlines general characteristics which describe the system (Table 1, row "General"). E.g., the system offers a high flexibility of assembling similar but different products, it is easy to reconfigurate and offers a continuous scalability. These characteristics describe the high changeability of the system.

Table 1. General characteristics based on [14] and operational characteristics of a MMS

Characteristics		Forms
General	Movement (objects)	Products
	Process module (PM)	Modular/Matrix
	Coupling of PM	Uncoupled
	Distance of PM	Medium
	Order of processes	Variable
	Synchronous movement	No
	Batch size	One
	Division of labor	High
	Qualification level	Medium
	Lead time	Low
	Flexibility/changeability	High
	Robustness	Medium
	Volume of parts	High
	Variances of parts	High
Operational	Work distribution	Flexible
	Product assignment to PM	Short-term/ad-hoc
	Task-sequence	Flexible
	Order-sequence	Flexible
	Amount of product-/order-flows	Multiple
	Flow direction	For- and backward
	Process module's cycle time per product	Flexible
	Determination of system's configuration	Mid-term

In addition to the general characteristics outlined by Kern, there are further characteristics of the system, which occur in operation. Firstly, there is no fixed relation between source and sink [18]. An ad-hoc production control assigns a product to its next point of operation. A deterministic prediction of the next sink is, thus, impossible. The assignment depends on the restrictions of the priority graph, the process modules' abilities, the current capacity utilization and the operation status of the system. In conclusion, the task sequence is flexible and not fixed, like in a dedicated manufacturing line [19]. Secondly, through the individual and ad-hoc decisions of choosing a new sink, there is no overall defined cycle time, which is similar to each process module [5]. Therefore, the sequence of different orders might change inside the system [20]. Furthermore, there are multiple product and order flows in one matrix system [20]. The flow's direction is mostly forward, but can be backward in a loop as well. Through reconfigurations of the system [19] the newly outlined characteristics, like a flexible

product flow, change with system parameters. Also, when adding a new process module or changing a product, the system behaves differently.
In conclusion, a MMS offers new degrees of freedom during operations. This challenges the planning and control of the system and affects not only the manufacturing structure itself but also the material supply.

3 Material supply in the context of MMS

3.1 Challenges to material supply

Through the new degrees of freedom within the new system and differences to known manufacturing systems, new challenges to the material supply arise. Six main challenges and their consequences can be identified and are shown in Table 2. They arise through the characteristics of the new structure and organization. [17, 18, 21]
Regarding the material supply, the overall challenge is uncertainty. The uncertainty refers to the location, volume and time. In addition, anchors like a defined product and order sequence do not exist, as e.g. in a dedicated manufacturing line. Further, the system is confronted with an increased number of articles in volume and variants, and with a continuously changing system. In addition, the MMS system itself and each system's element bases on a stochastic behavior, which effects depending process like the material supply. The material supply has to readjust its strategies to this changing and stochastic system.

Table 2. Challenges and consequences to the material supply through the MMS

Challenges to mat. supply	Consequences
Uncertainty of point of use	Risk of shortages
Uncertainty of demand quantity	Risk of shortages
Uncertainty of time of use	Just in time (JIT) delivery is impossible
No fixed product and order sequence	Combined order supply is not feasible & demand summarizing of products is uncertain
Increased quantity and variance	The existing supply area is fixed and stocking policy might be changed
Reconfiguration of the system	No long-term supply strategy is feasible, as system's and workstations' demand are changing, as well

3.2 Methodology of evaluating the suitability

According to the literature [11, 22] and the identified challenges, ten criteria are chosen to evaluate the suitability of material supply strategies in MMS (Fig. 1). Each of the strategies mentioned in chapter 2 perform on a scale between one and five in each criterion. Additionally, the MMS requires performance in each criterion. For each criterion of each strategy a delta between the required and achieved performance arises. [11]

This approach is adopted from Richter [11]. The strategies' assessments and set requirements are done through a literature review [6, 7, 11, 19] and the authors' discussion.

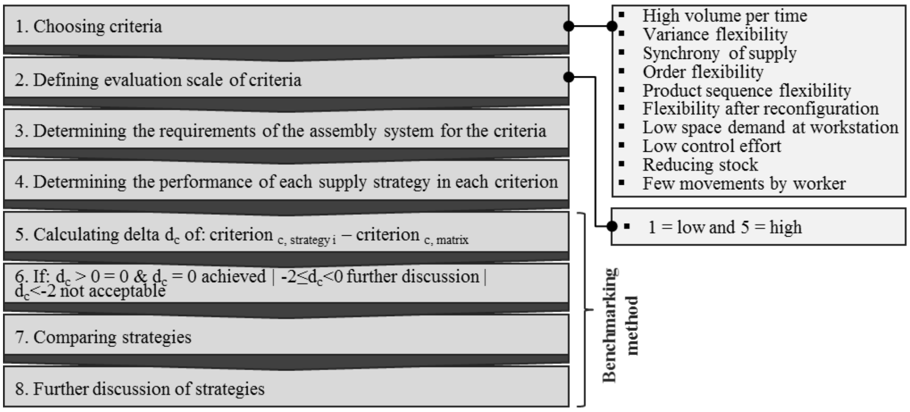

Fig. 1. Chosen method

Different methods exist to evaluate the results [23]. Methods adding multiple results to one number, like building an average, are not sufficient in this case. Well performing criteria cannot compensate a failing criterion. A multi-perspective evaluation is needed which takes all criteria and individual results under investigation. Still, an analytic and numerical evaluation is preferable, as it facilitates the objectivity and comparison.
In conclusion, the benchmark method is chosen, comparing each strategy's performance to the given requirements. The performance is the individual comparison between a strategy's assessment and the requirements. Therefore, the delta of assessment minus requirement is taken. An over performing delta greater than zero is equal to zero since there is no additional benefit in practice. A negative delta is no final excluding indicator in the evaluation. Thus, additional to the analytic calculation, the strategy is interpreted to close the gap between the numerical evaluation of a complex strategy and the authors' evaluation.
The requirements of the MMS are driven by its characteristics presented in Table 1.

3.3 Evaluations

Table 3 shows the result of the evaluation. The deltas are outlined in grey. No strategy achieves the desired requirements in all criteria. Only three strategies have no criterion's delta of less than 2. These strategies are: partial order supply, kitting part system supply and bar concept supply. Furthermore, only the named ones achieve a benchmark greater 80%.

Table 3. Requirements and performance of different strategies

	MMS: Requirements	Performance of each strategy									
		combined order supply	total order supply	partial order supply	single product supply	periodic supply	KANBAN	multiple container supply	handheld stortage supply	kitting part system supply	bar concept supply
High volume per time	4	3	4	5	2	3	4	5	5	2	3
Variance flexibility	4	2	3	4	5	2	2	2	4	5	5
Order flexibility	5	3	3	4	5	2	3	3	4	5	4
Product sequence flexibility	5	1	1	1	3	1	3	3	5	5	5
Synchrony of supply	4	3	5	5	5	4	3	3	2	5	4
Flexibility after reconfiguration	5	2	4	4	4	2	2	1	4	5	4
Low space demand	4	3	2	3	1	4	5	5	4	4	2
Low control effort	3	2	4	4	3	4	5	5	4	3	2
Reducing stock	4	4	4	4	4	3	2	1	2	3	3
Few movements by worker	4	4	4	4	4	4	4	4	1	5	4
Benchmark	100%	62%	74%	81%	79%	67%	71%	67%	79%	93%	81%

Legend: **delta equal or greater 0** | **delta between 0 and -2** | **delta minor -2**

The **combined order supply** is one of the less suitable strategies. Through summarizing different orders, it is inflexible to reconfigurations. In ad-hoc and short-term situations the strategy is less capable to respond in the required time. It needs a high degree of control effort to compromise the challenge of many variances and mid-term reconfigurations of the system. To the requirements of a MMS, it is not suitable. The **total and partial order supply** are characterized by focusing on a (partial) order. This does not suit the batch size of one in matrix systems and makes the strategy mostly unsuitable. The benefits of synchrony of supply, low control effort and few movements by the worker do not have an effect. Additionally, both differ in flexibility and low space demand to the desired value. The strategies are only suitable, if the defined batches are greater than one. The most suitable strategy is the **kitting part system supply**. It offers all desired values except the high volume per time. This is caused by the high effort in picking all parts. By using this strategy, all degrees of freedom of flexibility in variance, order, reconfiguration and assignment to a process module are given. Only the efforts and additional space demand in the previous order picking area are a disadvantage to the strategy. The newly introduced strategy of the **bar concept supply** achieves a benchmark of 83% by offering a synchronized supply of varying parts. Through the opportunity of restoring unneeded material it is quite flexible but needs control effort by predicting the needed material. Furthermore, through its design it requires space for commissioning at the process module and, finally, unneeded material requires space as well. The strategy is more suitable than an order supply, if unpredictability of multiple variants is high, ad-hoc assignments are certain and sufficient supply space at the process module is given. To the contrary, the **single product supply** is defined by a low supply volume, which can be only compromised by a higher space demand. The suitability of the strategy depends on the amount of processes that a process module can carry out. By many conducted processes and a feasible time to supply, the strategy can be suitable, as it supplies many parts at one time. It is like a less mobile and less flexible kitting part system supply. The **periodic supply** offers the benefit of low control effort and space demand. Normally, in the required time frame the supplies are synchronized as well. However, through its periodical perspective its flexibility to changes is low and thus less suitable to the character of the matrix system. The high volume strategies,

kanban and **multiple container supply**, can supply a high volume per time, but do not offer the flexibility to changes in the reconfigurations, in orders or variants. Only by increasing the stocks of every variant changes can be ignored. A quite flexible strategy is the **handheld storage supply**. By possessing stock apart from the individual process modules it can set up stock – and consequently flexibility – which can be used by multiple process modules. This increases the movements of the worker and leads to lower productivity, which makes the strategy less suitable for a matrix manufacturing system.

4 Findings

Across all investigated strategies, none of the strategies fully fulfills all desired requirements of the MMS. Only three strategies exist which perform within promising ranges. Still each strategy has advantages and disadvantages which go even beyond the assessment. The high volume strategies are less flexible to products with a high degree of variants, whereby flexible strategies are not applicable to all material, as they consume a lot of effort and resources. To manage the conflict, following dedicated guidelines arise for planning the material supply strategy: a. the selection of a supply strategy has to be done for each article (-group) individually; b. the selection depends on a multi-perspective consideration, including e.g. costs and space (of resources); c. the uncertainty of demand in MMS in terms of time, quantity and location must be taken into account; d. a planning approach should adopt to changes in the system's configuration.

5 Conclusions & Outlook

The paper investigates the suitability and performance of different material supply strategies in the context of MMS. Through the arising uncertainty within the system, the loss of a fixed order sequence and the batch size one, many strategies are affected and less suitable. Furthermore, the uncertainty and short reaction times are challenging existing approaches. As outlined in the findings, a new planning approach is needed. Furthermore, new supply strategies must be developed to cope with the matrix system's requirements. The strategies' assessment and evaluation is supported by a literature review and a discussion. Through rising importance and knowledge gain of MMS, new insights can be achieved and may extend the outlined approach. The assessment and evaluation offer first indications for further consideration.

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