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A framework for the design of a Reconfigurable and Mobile Manufacturing System

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Abstract

Today production systems, plants and supply chains are optimized for a one-site (one implantation) configuration and for mass production. For some products, the shipping costs from the manufacturing site to the end user site can have a significant impact on the total cost of the product. In such a case, the ability to manufacture close to the end user is a valuable alternative. The framework we propose was tested on a real industrial case in the solar energy field. The company producing the solar fields wanted to face the twofold objectives of a reconfigurable manufacturing system able to handle a huge variety of changes: that different geographical sites, a high variability in demand, etc. and a robust mobile system that can move from one manufacturing location to another one without performance loss.

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1. Introduction

In a tense economic and specific industrial context, manufacturing companies raise the question to stay competitive by making customers their foremost concern, by managing their quality, by optimizing their production

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and logistic costs, by managing their energy performance while preserving the interest of each stakeholder. Some concepts such as customization, reconfigurability and flexibility, efficiency and continuous improvement, and wastage prevention have become value drivers over time. Reconfigurable Mobile Manufacturing Systems (RMMS) appear to be levers to satisfy the underlying objectives. Such systems have developed in many industry branches (building industry [1], automobile industry [2], white goods sector ...) and are, most of the time, discussed in the literature in their running phase presenting their features and benefits. Objective here is to address the subject from the design phase and to propose a framework for their design by addressing the decision variables of the system that might be considered to achieve the expected results. Indeed, designing a manufacturing system is a complex task, as the system has to be aligned with the organization's values, mission, vision, the policy and the corporate strategy as well as with production requirements to satisfy the market demand and the requirement of modern societies. Its is thus necessary to address both a set of corporate objectives and a social responsibility and to take several complex decisions respecting several criteria in a constrained environment. To do that, an understanding of the design details is required as the way these impact on the interactions between the different components of the manufacturing system. Mobility and re-configurability have their specific constraints that need to be integrated in the design phase.

After a short state of the art about Reconfigurable and Mobile Manufacturing System, the contribution introduces the RMMS lifecycle and the five checkpoints that need to be addressed to make this kind of system viable. The framework for the design of such a system is depicted in section 3. One illustration of its use in the context of a solar plant design is briefly detailed in section 4, before concluding on the ongoing work.

2. Industrial production system challenges

2.1. From flexible manufacturing systems to mobile and reconfigurable manufacturing system

Manufacturing systems have to cope with more and more market demand fluctuation in terms of quantity and product mix variability. In this context, manufacturing systems having the ability to rapidly adapt to demand changes in an easy way (effortless) and cost effectively is important [3]. Expected characteristics of such systems are their ability to: (1) adapt to lot size changes to satisfy the demand, (2) change their facilities and even, (3) change their location. Reconfigurable Manufacturing Systems were introduced as a means to face the two first previous challenges while Mobile Manufacturing Systems allows to handle the last one. Accordingly, the combination of reconfigurability and mobility is viewed as an enabler to increase the possibility to change and to adapt to altering needs between different locations passing possibly through a warehousing location between two production sites [4].
ElMaraghy defined three kind of manufacturing systems: dedicated manufacturing lines (DML), flexible and reconfigurable manufacturing systems (FMS and RMS) and their objectives in [5] see table 1.
Koren and Shpitalni proposed to compare them according to a list of specific criteria (see Table 2). The comparison shows that in a RMS the machine structure and the system structure are changeable. These changes only concern two possibilities of reconfiguration: the physical level and the logical level. This point of view is confirmed in [6] as authors assumed that component changes and machines/modules/cells/material removal or modification allow capacity scalability and functionality changing. Rösiö [8] proposed to integrate a third dimension: the human dimension.

Table 1. Summary of three manufacturing system paradigms, according to

Systems	Definitions and objectives
Dedicated manufacturing lines (DMLs)	A machining system designed for production of a specific part type at high volume. Cost-effectiveness is the driver achieved through pre-planning and optimization.
Flexible manufacturing systems (FMSs)	A Flexible Manufacturing system is an integrated system of machine modules and material handling equipment under computer control for the automatic random processing of palletized parts. The objective is to cost-effectively manufacture several types of parts, within pre-defined part families that can change over time, with minimum changeover cost, on the same system at the required volume and quality.
Reconfigurable manufacturing systems (RMSs)	A reconfigurable Manufacturing System is designed for rapid change in structure in order to quickly adjust production capacity and functionality, within a part family, in response to changes in market requirements.

The objective is to provide exactly the functionality and capacity that is needed, when it is needed.

Table 2. Comparison of RMS features with dedicated and flexible systems

An example of a column heading	DML	RMS	FMS
System structure	Fixed	Changeable	Changeable
Machine structure	Fixed	Changeable	Fixed
System focus	Part	Part family	Machine
Scalability	No	Yes	Yes
Flexibility	No	Customized	General
Simultaneously operating tools	Yes	Possible	No
Productivity	Very High	High	Low
Cost per part	Low	Medium	Reasonable

In order to perform cost-effective and rapid reconfiguration, the design and operation of RMS must be based on several principles described in [9]. Reconfigurability can be described by a number of abilities defined as RMS core characteristics [10]; reconfigurable or reconfigurability characteristics [7], [8], or else reconfigurability enabler [11]. We choose the term RMS characteristics to qualify these abilities. Among these characteristics mobility appears to: (1) develop new business in case of geographic opportunities, (2) improve efficiency by the workload adjustment to the available capacity, (3) override the economical and technical challenge of transportation in the case where final products are bulky and fragile. MMS have also their own characteristics to consider during the design phase closely connected to operating and strategic needs, to ensure the ability to move the plant from one site to another one. The characteristics are based on the system lifecycle analysis.

2.2. Reconfigurable Mobile Manufacturing System RMMS lifecycle

Stillström [10] considered that three kind of activities have to be done sequentially during the a RMS lifecycle: (1) transportation to go from one site to the other for a new order or to a waiting site between two productions, (2) production to undertake the required production, (3) configuration and reconfiguration to arrange the production modules to satisfy the first production and then to satisfy the others by adding/removing/ replacing equipment. We propose to extend this lifecycle by adding other phases, see Figure 1: Before the first transportation to the effective production site, the presence of transportation infrastructures will have to be checked and otherwise setup. Then, between the transportation to the effective production site and the configuration phase preparation operations are mandatory to unsure the feasibility of the plant running: basically fluid supply, building of living space, etc. All these activities as well as the configuration are included in the factory set up. After the production phase, a diagnosis phase will have to ensure that all production modules will be operational for an upcoming production. Finally, after the diagnosis the plant will be disassembled and transported to the upcoming production site when its is known (scenario A) or otherwise to a storage warehouse (scenario B).

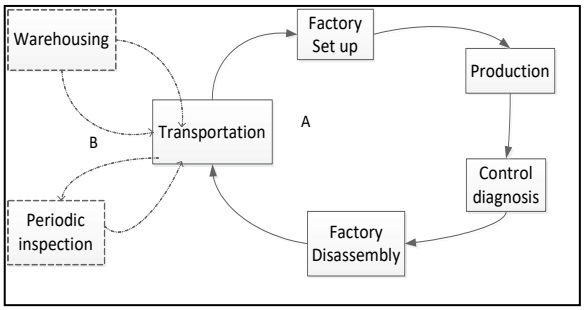

Fig. 1. RRMS Scenarios

It can be interesting to add to the above presented lifecycle a periodic inspection phase regarding the engineering solutions adopted to ensure module mobility. A critical review of the existing literature brings to the fore some crucial issues for research. The main one is that the existing literature on mobile manufacturing systems focuses on local mobility and does not address problems linked to recurrent mobility over long distances. The next section addresses the RRMS key success factors integrating such constraints.

3. Design framework based on five RRMS checkpoints

3.1. Checkpoints to address RRMS viability

A mobile manufacturing system requires a lot of configuration and maintenance operations to adapt its functioning to the expected performance level as every change of location can impact its performance because of the activities the system faces. The system lifecycle analysis is thus of huge importance and leads to RMMS specifications. First: the production system must be **modular**, i.e. each module as to be transportable and operational on site. Each module (weight and volume) has to cope with the module of transportation and its own constraints. By the same way, each module has to be consistent with the accessible energy sources and then has to be quickly and easily able to integrate one with other ones. Second the geographical mobility requires having **appropriate automated process** able to (self) adapt to the local human resource level of competencies, both during the running phase, plant assembly and disassembly. The maintenance operations during this phase should be basic and accessible for low-skilled staff. **Training periods** have to be envisaged to reskill internal staff. Then regarding the geographical constraints, **energy forecasting and supply** is a challenge that will have to be considered for each location. By the same way the **raw material procurement** will represent a challenge Indeed, for one location the choice of a supplier depends among other things on the localization of the production because of the transportation costs. Here as the location change, the selection will have to be reviewed each time. Thus the contract negotiation will be more critical and the contract period shorter.

Module transportation constraints as well as raw material and energy supply procurement constraints or else human resource availability and competencies constraints will make the issue of make or buy a strategic issue whose response will impact the RRMS revenue and profitability. The particular model that illustrates the make or buy challenge is addresses in [13].

3.2. Design framework of a RMMS

The design of a RMMS lies on two steps: the first one concerns the design of a plant able to deliver the required production considering the previous checkpoints to ensure the feasibility of the mobility (figure 2). The second step considers several locations. In this step the challenge is find the best compromise between the different plant reconfigurations linked to the different location considering that each location will have its own strategy.

<u>Manufacturing system for one location</u>

The strategy consists in generating different strategy and evaluating them. The feasibility of the solutions is strongly constrained as many parameters have to be considered coming from the manufacturing system macro and micro-environment. As mentioned in section 2.2, if road or port installations are not present beside the plant installation, additional activities should be undertaken that will cause additional expenses. Same thing for the fluid or living spaces. Even if these additional expenses should not be supported by the plant provider, they may reduce the buyer's incentive to buy the use of the plant for the production even more if the installation is ephemeral. Accordingly, these constraints have to be considered to find solutions that are less mean expensive. The same appears regarding the local working force as the plant can also represent an incentive for the selling if the buyer is a government for example, as it can generate employments if the local population is at least slightly skilled. If not, the three possibilities for the solution provider are: to sell the plant for the production with the working force, to outsource some tasks or to provision subsets. Whatever the solutions, expenses will be generated as other impacts on the raw material and subsets storage capacity or transportation installations, production yields as working times differs as do regulations about employment security, etc.

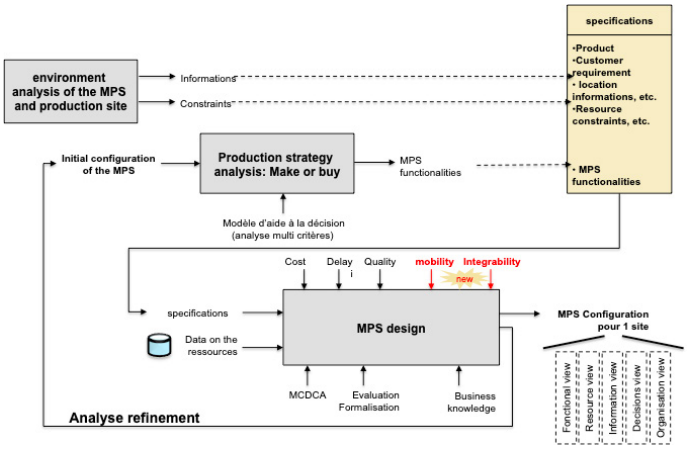

Fig. 2. MPS design framework for one location

Its is here assumed that the analysis of the environment of the manufacturing system will give information and constraints about the location environment and stakeholders requirements. This will lead to specifications concerning the product to deliver, specific customer requirements that can concern incentives for example, information on the plant installation, workforce skills. These specifications or manufacturing system functionalities and the characteristics of the existing and available production modules will be analyzed to see if satisfying configurations exist regarding five criteria: the classical cost, delay and quality and the new one mobility and integrability. Each configuration will be evaluated independently. In case several configurations exist, the configuration adopted will be the best one regarding business knowledge. In case there is no solution, an analysis refinement will be performed to see what is the best strategy between making, buying or subcontracting. That analysis will lead to new MPS functionalities that will launch a new MPS design process. The loop will be launched until a convenient solution is found.

Manufacturing system for n location

The process is quite similar for n location, as for each an analysis of the macro and microenvironment of the system will have to be performed to ensure a local performance level, see figure 3. Aggregation of the local performances of the different locations will give a global performance whose level will have to be aligned with the objectives of the company who design the RMMS and propose the plant.

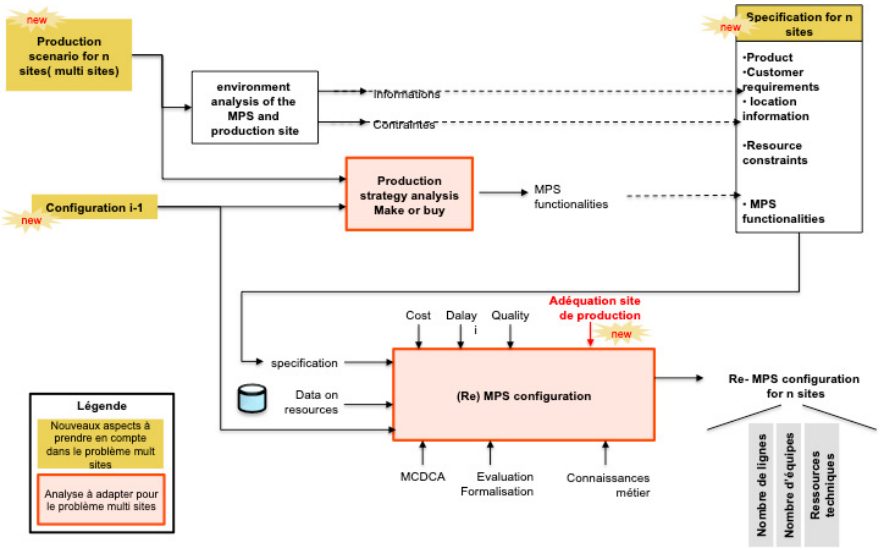

Fig. 3. MPS design framework for n locations

The challenge concerns the classical management of dynamic reconfigurations or multi-criteria optimization. The mobility of the system during the different design phases (preliminary design and detailed project design) can be calculated through mobility index obtained by satisfaction functions, whose aggregation is given by a weighted average.

The whole framework, detailed in [14] was built upon the case of a solar panel plant. The initial constraint was linked to the unability of the solar panel producer to transport them after their production to their installation location because of their size 10 meters long and their fragility. The solution was then to produce them closed to the end user. However, as the required production volume is limited, mobility was envisaged to go to upcoming end user that can be located close or far to the first one: another country with another environment and another strategy. The constraint for each production buyer is to have enough incentives to buy the good solution regarding its specificities and for the plant provider to choose the good strategy between the design of a stationary manufacturing plant with the difficulties to transport the final product or a mobile manufacturing system that requires a lot of investments and has more regulation constraints, being understood that reconfigurability is mandatory to address this king of market.

4. Conclusion

This paper highlights the ins and outs of reconfigurable and mobile manufacturing systems before presenting the life cycle of a RMMS and the checkpoint that can ensure such kind of system viability. The framework for the design of RMMS lay on these checkpoints and on: (1) a refinement of the requirement specification, (2) the determination of make or buy strategy and, (3) some technical solution proposal. To take these decisions, data and criterion are mandatory. Date are mentioned on the figure while criterion are discussed in [12]. Future works concerns the testing of that framework on industrial cases of other domains than the solar energy field as well as the enrichment of the formal model to support decision-making.

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