Reconfigurable manufacturing system design: The case of mobile manufacturing system

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Abstract. Mobile manufacturing is an enabler to increase the possibility to change and to adapt to altering needs, where the geographical position is not fixed. The main idea with the mobile manufacturing concept is to easily and quickly reuse manufacturing capacities between different orders or projects. This paper examines the concept of mobile manufacturing system by addressing issues related to manufacturing system mobility management. Review of reconfigurable manufacturing system is conducted. Issues as reconfigurable manufacturing system design and the make or buy problem in the special context of multi-site environment are discussed.

Keywords: Mobility, RMS, manufacturing system design

1 Introduction

It is becoming increasingly evident that the era of mass production is being replaced by the era of high value added and specific market niches. The key to creating products that can meet the demands of a diversified customer base is a short development cycle yielding low cost and high quality goods in sufficient quantity. This makes flexibility an increasingly important attribute to manufacturing [1]. Manufacturing system must have the ability to be rapidly transformed due to new technologies and demand changes, and also to change their facilities and even their locations. In addition, they are expected to produce instantly high quality while coping with these changes [2].

In the following sections we will discuss the concept of mobile manufacturing,. Next we address issues about reconfigurable manufacturing system like design framework for this type of manufacturing systems and present a case study where this using reconfigurable manufacturing system can be justified.

2 The concept of mobile manufacturing

2.1 A specific need for mobility

Due to excessive production capability and economic globalization, the manufacturing environment becomes turbulent and uncertain. Manufacturing enterprises are forced to reassess their production paradigms, so that a manufacturing system can be designed and operated efficiently in the ever-changing environment [3]. Mobile manufacturing is an enabler to increase the possibility to change, and to adapt to altering needs, where the geographical position is not fixed.

The purpose of the concept is to move manufacturing equipment from a stationary location (the site where the actor that controls and manages the capacity is) to a temporary location (the site where the capacity is used in operation) [4].

There are several reasons for introducing mobile manufacturing systems:

- Mobility is needed to increase flexibility: Upton considered mobility as an operational form of flexibility: "the ability to change product being manufactured quickly, on an on-going basis is the capability which most frequently supports the ability to provide quick response" [5].
- Mobility is needed to improve efficiency: Mobile manufacturing capacity can be used to adjust the manufacturing system to an inconsistent workload. By implementing mobile manufacturing modules that quickly and easily can be used on different production sites, fewer investments are needed in manufacturing equipment. The effectiveness and the quality of the performed work is improved and the overall equipment efficiency is maximized.
- Mobility is needed to reach new markets: Mobility is used as a characteristic in strategic domain to describe manufacturing in a long-term perspective. "By using mobile manufacturing capacity, it is possible to enter geographically new markets while maintaining control of the business. The company could win a new order and produce part of the order in a local country, while a large part of the order could still be manufactured at the company's manufacturing site in [home country]" [4].
- Mobility is needed to reduce the manufacturing cost of the end product: In the case of products with important volume dimensions that are produced in important quantities and should be livered to different geographical locations, shipping costs can dramatically raise the final cost. In this case, Producing close to the client site could be an alternative to reduce the global manufacturing cost. Thereby economy of scale may be considered to split the investment on mobile manufacturing unit.

2.2 Dimensions affecting mobility

Two dimensions can affect mobility: the functionality area and the distance.

Mobility is defined as a form of operational flexibility [5]. Mobility refers to the movement of physical manufacturing resources [4]. There exists at the same time a geographical distance between the temporary and the stationary location in mobile manufacturing, and a technological, organizational, and social distances as well as cultural differences. Those distances and differences are not totally separated from each other, but rather connected. Those distances have been analyzed by Ask and Stillström through case studies. They highlight two forms of distances [4]:

- The geographical distance defined as the distance that can be measured in, for example, kilometers or yard, between the stationary and temporary location.
- The organizational distance corresponding to the distance between departments, functions, or levels. The organizational distance is not as easy to determine as the geographical distance, but it is of huge importance in information handling for example.

2.3 Managing the mobility of manufacturing systems

For one rotation, i.e operating cycle for one temporary location, the main cycle is as has been described by [4]: "*the life cycle starts with configuration of the manufacturing modules to a specific order. Thereafter, the modules are transported to the location where they will be used in production. When the order is finished, the manufacturing modules are transported to home site, or to another location, where they are reconfigured and reused*".

In addition, we should consider other necessary stages. Each of these stages is explained in greater detail below (see Figure 1):

- Factory Set up: the plant is built on the end-user site. Before this stage, site preparation operations are already carried out. The manufacturing system is set up and commissioning operations are performed.
- Diagnosis control: at the end of the production campaign, all resources are controlled and reconfigured to prepare the next production campaign.
- Disassembly: The manufacturing system is disassembled, conditioned, and ready to be shipped to next end user location or to home location.

On another level, when considering operating cycle of mobile manufacturing unit between two rotations we must consider the commercial order book of the firm. Indeed, in the case of several rotations, there are two possible scenarios:

- after the first rotation, the mobile manufacturing system is already reserved to produce on a determined location. In this case, Maintenance operations and necessary modules replacement could be operated at :(1) the end of the first rotation, (2) before producing on the next location or (3) during the transportation stage. For each case, required components supplying, availability of the required operators qualification and delay constraints should be taken into account when deciding or choosing solution.
- Second scenario corresponds to the case when there is no immediate command after the first rotation. In this case, modules of the mobile manufacturing system should be stored for a period. A determined location is already reserved what will enable carrying out the heavy maintenance operations, which corresponds to replacement of machinery for example. Other solution may be the storage mobile manufacturing system modules on the first location. It depends on negotiations between the firm and the first client. In order to enable the realization of maintenance operations required components

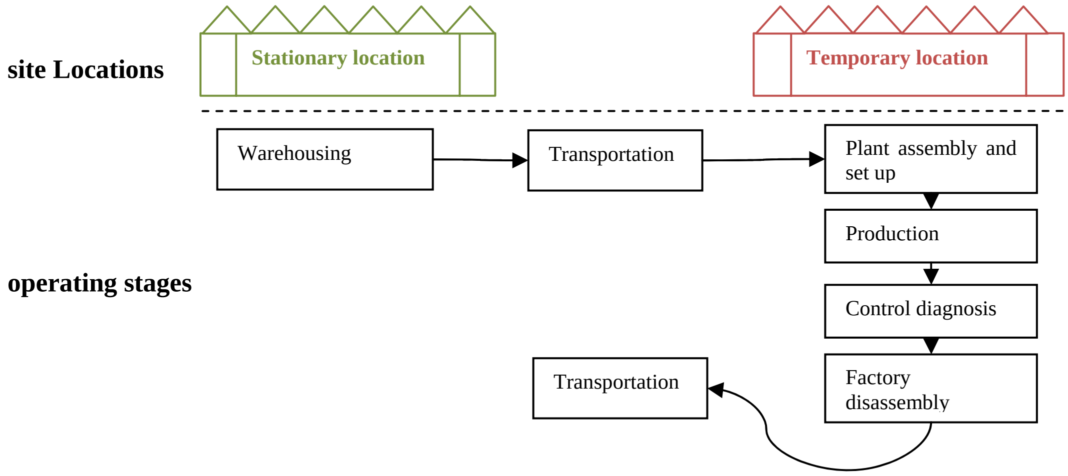

Figure 1: Exploitation stages of a mobile production system, for one rotation

supplying, availability of the required operators qualification and delay constraints should be taken into account when deciding or choosing a solution.

Furthermore, a specific stage corresponding to periodic inspection is required. The need to consider this stage depends strongly on the technical solutions adopted to allow modules mobility. For example, to allow the mobility of a machinery, it is possible to embed the machinery into a container. Due to regulation constraints on marine container shipment, resources must be inspected periodically.

3 Reconfigurable Manufacturing System

Facing a dynamic market demand, manufacturing systems must cope with more and more volume demand fluctuation and product mix variability[7]. In this context, the manufacturing system adaptability becomes more valuable. The demand for a manufacturing system able to cope with changes rapidly and cost effectively is crucial. Reconfigurable Manufacturing Systems (referred to as RMS hereafter) allow changeable functionality and scalable capacity by physically changing the components of the system, by adding, removing or modifying machine modules, machines, manufacturing cells, material handling and/or complete lines".

Table 1: Comparison of RMS features with dedicated and flexible systems

	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

Koren and Shpitalni conduct a comparison between Dedicated manufacturing lines (DML), Flexible Manufacturing System (FMS) and RMS (

) [8].

For Koren [8] RMSs are designed at the outset for rapid change in structure, as well as in hardware and software components, in order to quickly adjust production capacity and functionality within a part family in response to sudden changes in market or regulatory requirements".

3.1 Case study: Solar Energy field manufacturing system

In the Solar Energy Field, shipping costs drive the global manufacturing cost of solar collectors. Actually, shipping costs are expensive due to the wide surface of solar collectors (approximately ten of m²). A solution to reduce the global manufacturing cost is to produce close to the end-user installation site. Moreover, in order to make the production system investment more profitable, it would be wise if the same production system can serve producing many solar fields i.e. if the manufacturing system can move between different production sites.

Furthermore, as the market demand forecast fluctuates between two orders, the product volume and duration to satisfy this demand may vary. The manufacturing system may cope with this variability. Demand variation results in a necessary, cost effectively, up gradation or down gradation of the manufacturing system capacity.

Solar fields are installed in desert environment, with high temperatures and rough climatic conditions, the functionality of the manufacturing system must be adapted to the specifications of each site. Finally, the manufacturing system is operated by technical and human resources. The need to employ local labor requires to adapt the mobile manufacturing system. Available qualification and socio-cultural background should be taken into account when reconfiguring the manufacturing system.

3.2 RMS in the solar energy field

For economic and feasibility reasons, the production system must be moveable to various end-user sites. The main idea is to easily reuse manufacturing capacity between different orders or projects. Manufacturing system must be prepared for reconfiguration according to market and order situation. System reconfigurability is driven by external change triggers, The main change drivers are:

- Variable volume demand: the demand profile is characterized by mass production, and high volume variability due to market uncertainties. Scalable capacity is needed to handle volume demand variability.
- Geographical location change: To be able to move to each final location, manufacturing system and all its components should be mobile.
- Location specifications: Production system must be operational in various final locations with specific specifications (e.g. temperature, climate conditions).

To cope with these changes, scalability, mobility and convertibility are considered as necessary characteristics and must be embedded into the manufacturing system.

3.3 Design framework for RMS

Manufacturing systems engineering frameworks can be classified into 3 families:

- frameworks that address the manufacturing system selection process [1]
- manufacturing system design [9]
- manufacturing system control [10].

[11] proposed a systematic design approach for reconfigurable manufacturing system. The architecture is composed of two modules, the first module describes the design process of the reconfigurable manufacturing systems and the second module describes the control of the design process at each level. The control module is based on performance measurements that reflect the strategic objectives of RMS. The architecture of design process is made of 3 layers: (1) market-capture layer, (2) system-level reconfiguration layer and (3) component-level reconfiguration layer.

Determination of decisions that drive the design of the manufacturing system is necessary. These decisions impact both the nature and the number of resources needed to satisfy the demand. The design framework that we propose allow to take into account and structure major decisions driving generation of manufacturing system configurations. This framework, which is adapted from the framework proposed by[11], is based on 3 layers :

Strategic Level: The main objective of this level is to capture the market demand to generate the required capacity and functionality that will be used as inputs to the tactical level. Control module is based on performance measurements: cost, quality and responsiveness time.

Tactical level: The objective of this level is to select the best configuration that will enable the satisfaction of the market demand. Figure 4 shows some examples of decisions that will impact the design of the manufacturing system. Generation of multiple configurations is enabled by the modular design of the manufacturing system components and consists on a genetic algorithm. The selection of the best solution is based on an evaluation module, using simulation tool.

The generation of reconfigurable manufacturing system configurations is controlled by constraints (cost, space, demand satisfaction...). Best feasible configuration among the generated ones is then selected using predetermined performance measurements: Time, Quality, Reconfiguration smoothness index

Operational level: Operational level deals with the physical implementation of a selected configuration. The implementation affects physical, logical and human components. Integrability and machine open control architecture are the major enabling technologies for the successful of the real physical implementation of the reconfigurable manufacturing system[11]. This level is controlled by performance measurements like cost, quality, time and reconfigurability.

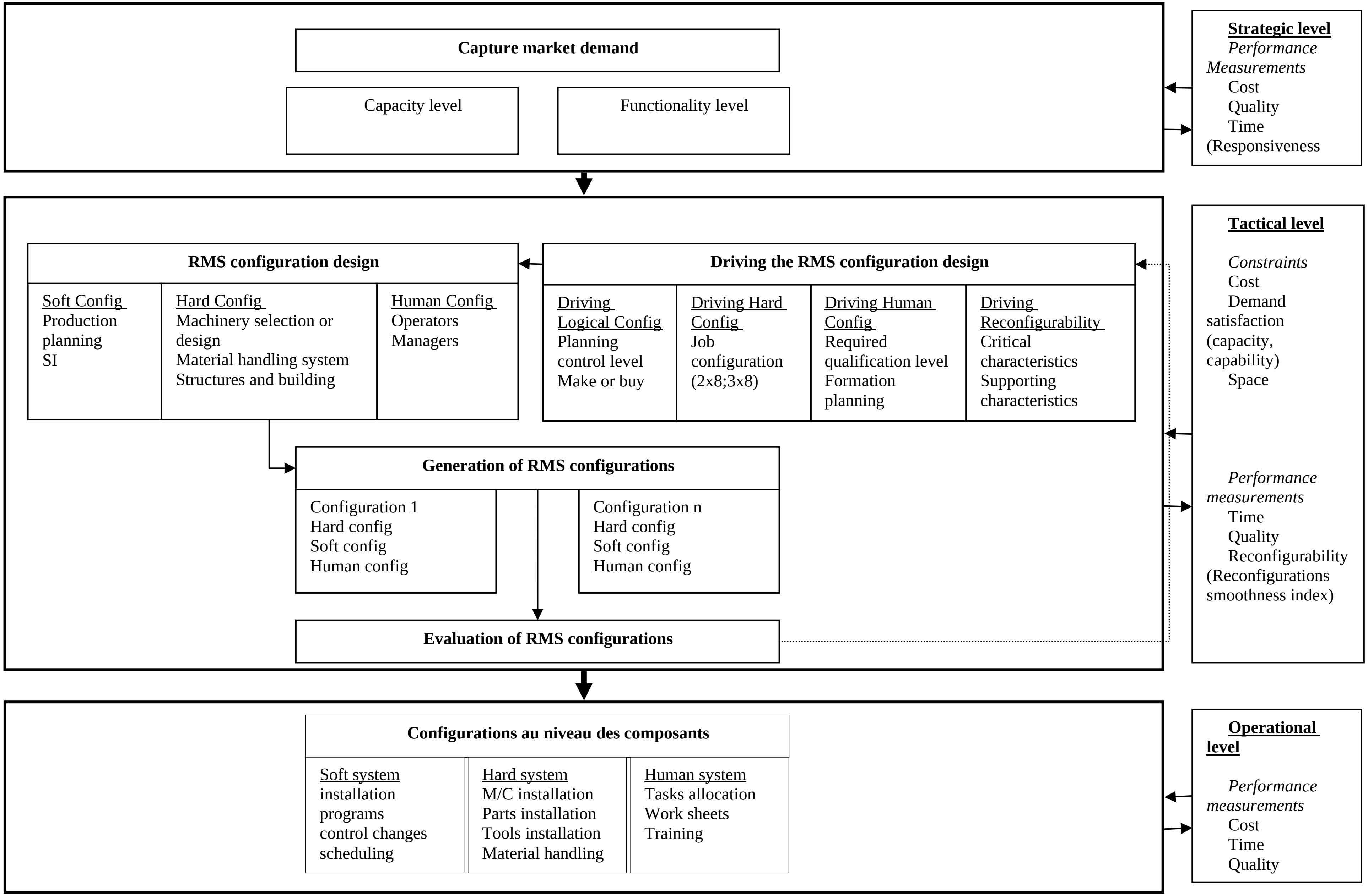

Fig. 5. : Reconfigurable manufacturing system design framework

4. Conclusion

A number of situation where the concept of mobile manufacturing system could be needed, were identified. Factors impacting mobility have been described. Special issues about the management of the mobility between the stationary and temporary location have been addressed. Furthermore, questions related to the interaction of the manufacturing system with its environment have been addressed as well as reflections induced by mobility constraints.

In addition to the need for mobility, the manufacturing system must cope with variability in demand volume and product mix. Reconfigurable manufacturing system paradigm has been analyzed. In this connection a design framework for RMS has been presented. Finally, the make or buy problem for RMS operation in multi-site context has been addressed, the reader is encouraged to consult (BENAMA, ALIX, and PERRY 2014) for in-depth analysis of this question.

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