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Abstract The concept of mobile manufacturing systems is presented in the literature as an enabler for improving company competitiveness by cost reduction, delay respect and quality control. In comparison with classical sedentary systems, added characteristics should be taken into consideration, such as the system life phases, the dependency to the production location, human qualification as well as means supply constraints. Such considerations might be addressed as soon as possible in the design process. This paper aims at presenting a contribution for the design of mobile manufacturing systems based on three analysis: (1) an analysis of the mobile manufacturing system features (2) an identification of the attributes enabling the system mobility assessment, and (3) the proposal of a framework for mobile production system design considering new context-specific decision criteria.

Keywords: production system, mobile manufacturing system, design of manufacturing plant.

1 Introduction

Ensuring shipment of bulky and fragile product can be economically and technically challenging. The solution that can be adopted is to conduct production activities close to the end client. In case of a one-time demand, implanting a permanent production plant may seem unrealistic and then the concept of Mobile Manufacturing System (MMS) that consists in using the same production system to satisfy successively several geographically dispersed customer orders, directly on the end client location can be a good alternative.

The use of mobility of production systems has been encountered in many industries: construction industry [1], shipyard industry, etc. As interesting as it seems, the concept has been rarely discussed in the literature. The few existing definitions of mobility depend on authors and contexts [2]. Mobility is also defined at different levels for manufacturing system. There is an internal mobility concerning manufacturing system modules (machinery, material handling modules, etc.) and a global or external mobility concerning the movement of the whole manufacturing system. This last level is analyzed across geographic areas and underpins strategic considerations with medium to long-term implications.

In order to facilitate the movement of the manufacturing system to a new geographical location, Rösiö [3] evokes three required characteristics that are: the mobility of module, the modularity [4] and the integrability of modules.

In this paper, a holistic view of the manufacturing system is adopted. The mobility of the manufacturing system is defined as the ability of a manufacturing system, defined by its technical, human and information components, to move and produce on a number of successive geographical locations. The definition includes two aspects:

- Transportability: the manufacturing system must be transportable and must be able to adapt to the requirements of the different transportation modes (road, sea, etc.)
- Operationality: the system must be able to be quickly operational on different locations for which it is designed.

The following section proposes to discuss how a Mobile Manufacturing System (MMS) may differ from a sedentary manufacturing system.

2 Requirements for manufacturing system mobility

The concept of mobility implies to consider some additional system life-phases regarding traditional manufacturing systems: mobility of modules, on-site maintenance management, organizational aspects and training needs, energy supply.

2.1 Manufacturing system design

The production system design process is based on four macro phases [7]: (1) initialization, (2) preliminary design, (3) embodiment design and, (4) detailed design. Each of these phases consists in selection, evaluation and decision activities. Taking into account the characteristics of mobility is built through each phase of the MMS design process. Obviously, in a context of mobility, the production system environment changes from one implementation location to another and the analysis of the system' environment is of huge importance.

A production system is currently seen as a system composed of several subsystems generally analyzed through an external and internal views coupled with other physical system, decisions and informational views. Then the production system design depends on the design (or selection of items when solutions may exist in the market) of each system component, but also depends on the connection between these subsystems for their integration into the overall system.

A production system can be defined as a system of systems to the extent that on the one hand, it is composed of a set of subsystems. Each one has its own life cycle and each one may be defined independently from the others. On the other hand, interactions between these subsystems define constraints for the system of systems, affecting the performance of the overall system [8].

The Systems engineering adopts two complementary points of view for systems analysis [9]:

- An external view or “black box” approach defining the system boundaries used to identify the external environment elements that force the system and that the system must respond to by providing the expected services. The environment is defined by all factors that might influence or be influenced by the system [9].
- An internal view or “white box” approaches that considers the internal system interacting elements, which define its organization (architecture) and its operation.

2.2 Additional system life-phases

During its operation, the *MMS* is first put into service on its implantation site before being used for production. Throughout this phase, maintenance and configuration operations carried out in order to adapt its behavior to meet at best the expected performance. However, unlike to sedentary manufacturing systems, Mobility requires additional operational phases:

- Transportation phase (a): the MMS is packaged and transported to its implantation location.
- On-site installation phase (b): the MMS arriving on site is composed of independent modules and components that are integrated and lead to the plant installation. Upstream, operations to prepare the site are performed. Downstream, the factory is installed and operations of verification and commissioning are carried out.
- On-site production phase (c): the plant is used to produce locally. In parallel, maintenance operations are necessary to maintain high system performance.
- Diagnosis and control phase (d): at the end of the production phase, a diagnosis of all modules is carried out to ensure that the mobile plant will be operational for the next production run. The modules requiring heavy maintenance or replacement are identified. Replacement and procurement orders are launched during this phase.
- Dismantling phase (e): the plant is dismantled. Various modules and components are conditioned and prepared for the transportation phase.
- Transportation phase (f): the modules are placed in the transportation configuration, two scenarios are then possible depending on the business strategy of the company:
    - A new order arrives and a new site is identified. The MMS is routed to the new location and the operational cycle resumes at the phase (b);

- o No new order is identified and thus no new implantation location is identified. The MMS is then routed to its storage location that corresponds to the phase (g). Depending on negotiations with the manager (client, institution, etc.) of the site where the system has been used, the MMS storage phase could take place in the former location in the expectation of a new order.

- Storage phase (g): During the MMS inoperability period, the modules have to be stored until a new order. The storage can take place on the stationary basis, or on the latest operating location in order to stay closer to a potential market. During this phase, heavy maintenance operations can be conducted such as: maintenance or replacement of machines, modules reconfiguration, etc.

The identification of the life-phases is important as evaluating the overall performance (cost, delay, etc.) of the system depends on it.

2.3 Organizational aspects and training needs

Geographic mobility of the manufacturing system requires adapting the automation level required to the qualification level of the personnel available on-site. To ensure the production system independence regarding the on-site operator qualification, the level of the manufacturing system automation must be adapted. An independent production system to operator's qualification can be imagined as a highly automated system. However, too many automation leads to a complexity requiring some expertise to ensure MMS maintenance operations. A trade-off must be achieved between the required automation level and the on-site available qualification. An on-site operator' training offer facilitate this trade-off.

System mobility means that each time a new team is involved in the system for a new implantation location [5]. Hence, the need to provide operator training for running the manufacturing system is crucial. Moreover, Fox recalls the need for a qualified local middle management which makes the link between foreign personnel and the local population, and who could be also responsible for applying best practices [6].

2.4 Mobility of modules

Mobility of the manufacturing system modules implies that each module is being transportable and operational on site. Modularity is an enabler of component mobility. The weight and volume of each module must be compliant to transportation modes. In addition, the modules must withstand different transportation constraints (mechanical shock, tightness constraints, etc.). Finally, the equipment on-site operationality (equipment) must adapt to on-site available energy sources. The equipment must be easily integrated and commissioned.

2.5 On-site maintenance management

On the one hand, maintaining system performance during the operation phase implies to adopt a comprehensive strategy that takes into account the duration of the manufacturing system presence on a specific implantation location in order to minimize the need for shutdown. On the other hand, in order to carry out on-site interventions, spare parts supply chain management must be adapted according to the manufacturing system mobility.

2.6 Energy supply

Depending of each implantation location characteristics, the energy supply issue arises each time. The MMS autonomy depends on its ability to be independent in supplying the necessary energy required for the operations of its resources [1]. The energy supply system can be based on diesel generators or by using solar panels to provide the necessary power [6]. The issue of energy consumption (nature and quantity) can be a determining factor for choosing the MMS constituent resources.

After reviewing the requirements to be taken into account into a mobile manufacturing system analysis, we propose to discuss in the next section the system design issue

3. A design framework adapted for a single implantation location

The sequence of the key steps in the MMS design process [10] (figure1) starts with 1) a refinement of the requirement specification 2) the determination of what is to be carried out in-house or is to be outsourced and 3) some technical solutions proposal (MMS configuration design). These three steps are discussed hereafter.

3.1 Requirements specification refinement

The design activity starts from the requirements specification that contains a description of the product to be manufactured (BOM) and details the client's request (production volume, delays, requirements, etc.). The initial requirements specification will be supplemented with information and details obtained after MMS and implantation location environment analysis. This first enhanced specifications version (noted CdC_1 in figure 1) allows imagining a first configuration of MMS. This MMS configuration, not economically efficient, represents a generic definition able to satisfy the demand on the proposed location.

3.2 Manufacturing strategy analysis

The MMS generic configuration will be then refined through an analysis of what is relevant to produce on site or what needs to be outsourced. This analysis involves several criteria and requires the establishment of evaluation process and decision support [11]. The analysis of the make or buy strategy enables to decide the MMS functionalities, i.e. operations that the MMS should be able to carry on the implantation location. The description of the necessary MMS functionalities supplements the previous requirements specification (noted CdC in figure 1). The MMS design activity can be now conducted.

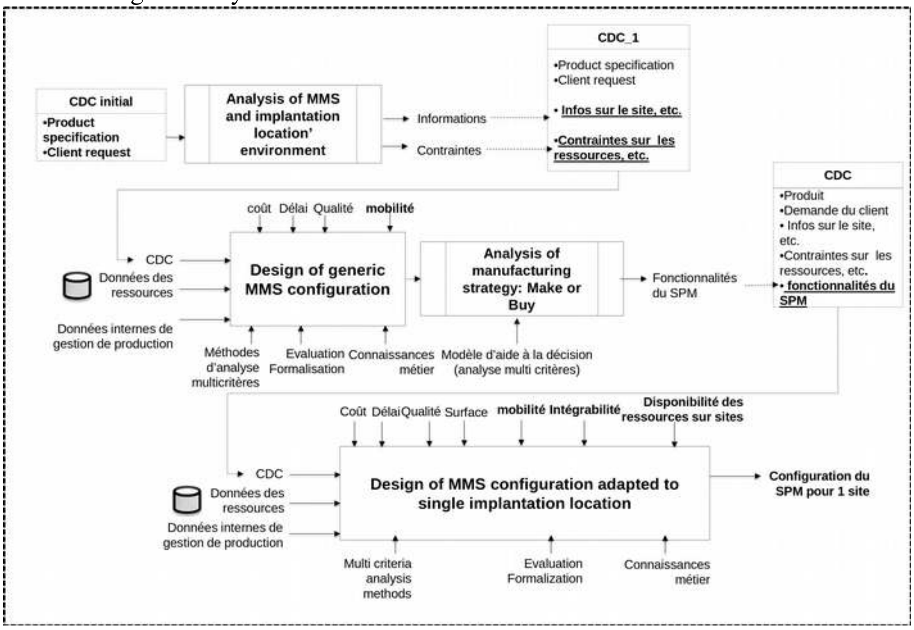

Fig. 1 Mobile Manufacturing system design framework adapted for single implantation location

3.3 Design of MMS configuration

This activity considers as input the latest requirements specification version and technical data about all the resources that will be integrated into the MMS configuration as well as the production management information. The choice of MMS configuration is based on classical criteria such as cost, quality and delay; in addition to other criteria specific to the mobility concept, namely: the mobility indicator

3.4 Design of MMS configuration

This activity considers as input the latest version of the specification and the technical data about all resources that will be integrated into the MMS configuration as well as production management information and assumptions. The choice of the MMS configuration is based on several decision criteria.

In addition to the typical cost, quality and delay requirements, the proposed approach incorporates new criteria that are specific to the context of mobility [10]: the mobility index, the integrability index and the criterion of on-site resources availability

3.4.1 Mobility index

Analyzing mobility during the embodiment design phase concerns the whole production system defined by all its components. These components can be classified into two categories: technical equipment and human modules. The assessment of technical equipment and human modules mobility is based on different approaches involving several criteria. It is therefore necessary to evaluate each category and then aggregate the results to give a unique appreciation of the whole manufacturing system mobility [10]. This appreciation can be expressed by a quantitative value between 0 and 1 that indicates a satisfaction index. The index construction approach is based on a multi-criteria analysis. Two important concepts are used: the expression of preference and the criteria aggregation.

On the one hand, the mobility of MMS technical module has to be satisfied through all its life phases. To be mobile, a technical module must be: transportable, mountable on site, operating on site and dismantled. On the other hand, the human system operates by providing flexible working ability to carry out simple or complex operations contributing to the functioning of MMS. This requires skills acquired or developed on-site during the on-site production phase. The human system mobility can be understood as the mobility of one or more skills necessary for the manufacturing system operation.

3.4.2 Integrability index

Generating a MMS configuration consists in the integration of various independent modules (machines, operators, conveyors, etc.). In order to have feasible configurations, it is necessary to ensure that the selected modules can be integrated with each other. Each module has one or more interfaces to bind to other modules. The Integrability evaluation process of a MMS configuration combines two approaches [10]:

- A decomposition analysis approach (top-down): The MMS configuration is broken down into individual modules. Each module integrates common interfaces with one or more other MMS modules. The analysis of Integrability is carried out at the level of each MMS configuration' elementary module.
- An assessment approach based on integration (bottom-up): it is based on the definition and evaluation of all nodes in the system configuration. Individual measurements will be aggregated to give a single measure of the MMS configuration' Integrability.

3.4.3 Criterion of on-site resource availability

For a given MMS configuration, the evaluation phase of the availability of the competences starts with the assessment of required skills in this configuration. Thus, for each configuration' entity, required skills are identified based on the attribute "needed sills" contained in the description of each resource. This attribute is faced to available competences on the implantation location. An evaluation method is proposed to ensure that the required resources by the MMS configuration that had been suggested are available on the implantation location

[10]. The assessment of skills availability is split into three stages: identification of the required skills, identification of relevant actor profiles and assessment of the profiles availability on the implantation location.

4 Conclusions

In this communication, we discussed the concept of mobile manufacturing system. The mobility requirements were addressed and a mobile manufacturing system design framework is presented. The design process is based on some decision criteria. In addition to the typical cost, quality and delay criteria, three other decision criteria are proposed: the mobility index, the integrability index and a criterion of on-site resources availability. The proposed design approach is limited to the consideration of a single implantation location. However, the concept of successive mobility requires that the same production system is operated successively on several implantation locations. The design approach must be adapted to the multi-sites context by integrating the concept of reconfigurability. A first analysis of this issue is presented in [10]. This issue of successive multi-sites mobility will be addressed in future communications.

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