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A problem driven approach to interface manufacturing strategy analysis and manufacturing system design

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ABSTRACT

This paper introduces an interface between manufacturing strategy analysis (MSA) and manufacturing system design (MSD). MSA methods are not accurate enough to assess the manufacturing design choices. MSD requires functional-oriented scopes, and not only strategic initiatives resulting from MSA. That is why MSA and MSD must be interfaced. The proposed interface consists in the Model of Operational Manufacturing System, the evolution class framework, the model of problem and the problem handling procedure using these models. They point out the proposed detailed evolution classes (domains which have to be improved) adapted to a specific manufacturing system. Finally, the proposal is illustrated within an industrial case study, which underlines its efficiency.

1. Introduction

This paper tackles the domain of the design process management of manufacturing systems (MS). According to Austin, Newton, Steele, and Waskett (2002), the early phases of MS design projects seem to be less studied. Even though the decisions made during this period have the most far-reaching effects on the remainder of the project. Indeed, before the design begins, user requirements must be consolidated as proved by Chen, Vallespir, and Dougmeints (1997). Moreover, as stated by Barad and Gien (2001), enterprises need support to define their specific technological and organisational needs and then to find the right way to fulfil these needs. The objective of this paper is to develop models and their exploitation procedure. They aim at enabling the identification of the main scopes of the project, i.e. the definition of domains where evolutions will be efficient to contribute to manufacturing process improvement. Several fields of research are concerned with this topic.

The first field is manufacturing strategy analysis (MSA). Carrie, Durrani, Forbes, and Martowidjo (2000) define the results of MSA, as follows:

- A technology portfolio (choices of alternative processes), completed by relative parameters (capacity, size, timing, location, investments).
- The manufacturing infrastructure required to support production: function support, manufacturing planning and control systems, manufacturing system engineering, quality assurance and control, clerical procedures, work structuring, organisational structure,...

The state of the art in MSA provides classes of methods to help a company analysing its products, market and operations. They allow to set objectives for relevant areas of concern (Wu and Ellis (2000)). In this domain, Chan and Spedding (2003) and Zantek, Wright, and Plante (2002) propose some analyses based on Statistical Process Control. From data retrieved from manufacturing system monitoring, lacks of quality are identified and located in the system. These metrics oriented methods are completed by user-oriented methods. Thus, Barad and Gien (2001) or Chen et al. (1997) interpret interviews with the stakeholders of the manufacturing system, in order to define the areas of concerns. No process monitoring is required for these approaches. Both methods result in a pattern of actions or in a set of areas of concern.

The second field of research concerned by our topic is manufacturing system design (MSD). It aims at determining the best structure of a manufacturing system, in order to provide the skills required to support strategic objectives. This must be achieved within the allocated resources, and satisfy other constraints (Wu and Ellis (2000)). Some generic design methods exist, like the production system design of Cochran, Eversheim, Kubin, and Sesterhenn (2000) for implementing lean manufacturing, or GRAI–GIM methodology (GRAI Integrated Methodology) proposed by Doumeingts (1984). There are numerous applications of these methods in the literature. Among these, Kulak, Durmusoglu, and

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Tufekci (2005) propose a complete Cellular manufacturing system design.

Such a choice of shop floor evolution should be based on a MSA, according to Carrie et al. (2000). Otherwise, as proved by Zantek et al. (2002), ignoring quality linkages can lead manufacturers to make suboptimal investments in quality improvement. However, MSA methods are not accurate enough to assess this manufacturing design choice. MSD requires functional-oriented scopes, and not only strategic initiatives resulting from MSA. That is why MSA and MSD must be interfaced. Existing design methods propose this interface through requirements consolidation. None of them provides formal models. Formal models are required to satisfy the consistency between strategic, organisational and operational viewpoints.

This paper introduces an interface between MSA and MSD by suggesting a detailed manufacturing system evolution class framework, including the formal models and the exploitation procedure. They provide an accurate and consistent framework for setting MSD scopes. The next section introduces the generic model of manufacturing system (MOMS), the related taxonomy of evolution classes and the model of problem. They allow to classify the potential evolutions of a given manufacturing system. The third section details the computer based exploitation procedure of these models. The treatment of the problems through this procedure is the core of the proposed interface. This interface leads to the consolidated design requirements and their association to the particular evolution classes. So, our approach is based on a user-oriented problem analysis. At last, an industrial case study illustrates how problems encountered in a shop floor (manufacture of electrical gear-motors) have been processed to specify the objectives of the 'High Speed Machining Implementation' project. The case study outlines the use of the computer in the problem driven approach.

2. Manufacturing system modelling

In order to interface MSA and MSD, we are interested in identifying the evolution classes for a given project. These enable to ensure the project scope definition. First, the concepts expected to model efficiently MS are exposed. Then, the MOMS is introduced and the evolution classes are identified. At last, to support the interfacing process, the model of problem is introduced, aiming at specifying the right classes for a given project.

2.1. Generic activities and structure

Actual models of manufacturing systems are part of generic enterprise models proposed in the enterprise modelling field. Enterprise modelling is concerned with representation and analysis methods for design engineering and automation of enterprise operations at various levels of details Vernadat (1996). The purpose of these models is to provide common understanding among users about enterprise operations and structure, to support analysis or decision-making or to control operations of the enterprise, according to Berio and Vernadat (1999). Among the relevant proposals, the reference architectures like CIMOSA, GIM, ARIS, ENV 40 003, PERA et GERAM can be cited. They all deal with three fundamental types of flows, within or across the system (material flows, information flows and decision/control flows) and four modelling views (function view, information view, resource view, organisation view). Only GRAI (Doumeingts, 1984; ISO TR 10414, 1991) models deal with shop floor production modelling. Fig. 1 shows a common structure for both generic models.

The factory structure is shared in four levels, from the production means up to the manufacturing plant. The technical level corresponds to the production cells, including several coordinated posts. Inside each post, resources are used: robot, coordinate measuring machine, milling center for example. Four generic functions are associated to this structure: move, transform, support and control.

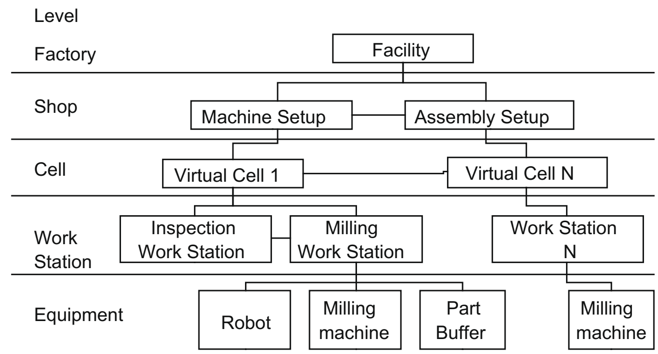

Fig. 1. Structure of manufacturing systems (NIST) ISO TC 184 (1991).

GERAM results show that no reference architecture provides any manufacturing system model at the operational level. This evidence is true for all four views of the system: functions, information, resource and organisation. Operational models are limited to particular systems. For example, a manufacturing process is restricted to the "equipment" level. No element concerning specific components, like tools or fixtures, are taken into account. However these technical components could influence manufacturing strategies, particularly in the current industrial context (Dagiloke, Kaldos, Douglas, and Mills (1995)). Moreover, such a model could be useful to link MSA and MSD. During the requirement consolidation, the strategic objectives have to be translated into operational objectives to specify the target system. Therefore, a model of the manufacturing system at the operational level would be useful.

That is why it is proposed to complete these reference architectures to model all components usually considered as technical ones, and obtain a relevant model of the manufacturing system. The introduced model is based on the classical reference models of manufacturing systems (previously cited), and on the model of technical systems, proposed by Salamatov (1999). This model is the only generic model of technical systems at the operational level, according to our state of the art. Fig. 2 shows it.

Each component shown in Fig. 2 (power source, engine, transmission, working unit, control unit) can be modelled with the same pattern (component and structure). Indeed, this model appears to be fractal. Whatever the level of decomposition is, the modelling pattern of the components is repeated. On this basis, the proposed model, named MOMS (acronym for Model of Operational Manufacturing System), consists in the following concepts:

- The levels of operational manufacturing systems;
- The technical components related to each level;
- The relationships between the levels;
- The activities in which these technical components are implied.

The levels have been obtained applying the systemic principles, underlying the reference architectures. These principles enable to identify the generic subprocesses of the operational level, through the set [process, resource, product]. The four identified subprocess-

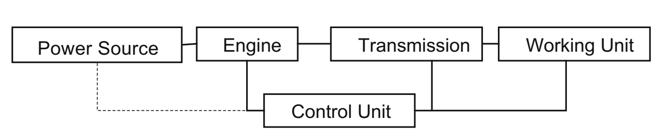

Fig. 2. Modelling pattern of technical systems, from Salamatov (1999).