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Wortmann, J.C.

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1. Introduction

The FOF-project is an ESPRIT Basic Research Action which started on February 1st, 1989. The Action will take 2.5 years, and it is at the time of writing of this report half-way. The FOF-consortium consists of seven European research institutes and universities.

The ultimate goal of the Action is to obtain a designer's workbench for the (re)design of one-of-a-kind production systems (OKP-systems). The restriction to the production of "complex, one-of-a-kind products" has been chosen for two reasons. On the one hand, restriction in scope is required in order to avoid a too ambitious project. On the other hand the importance of OKP-systems in European industry is expected to increase.

A designer's workbench requires a method to describe operations in a production system. These operations include product design, tendering, logistics, quality control, etc.

There are many methods for describing the operations in production systems, but these methods are all fragmented in nature. In fact, they are based on a set of fragmented theoretical notions. The major part of available theory is based on questionable assumptions such as:

- complete and reliable information is available before design or production operations take place
- CIM-components are installed once and for always
- boundaries between such operations as product design, process planning, manufacturing and logistics are fixed and for all companies identical.

The present approaches to CIM may deserve respect from a pragmatical point of view, but these approaches are not based on a thorough theoretical foundation. Presently, such a thorough foundation for CIM does not exist, because current theory is highly fragmented.

The fragmentation of theory is twofold in nature. Firstly, there is a fragmentation of production phases. Design, process planning, logistics and manufacturing have all become "computer-aided". CIM denotes the effort to cross the boundaries between these phases. The question, whether the boundaries are always appropriate, remains to be investigated.

Secondly, there is a fragmentation in views on CIM. A communication-oriented view differs from an organizational view. These views are rooted in different theoretical frameworks. It is currently not clear whether these views overlap or contradict, nor whether all important aspects of reality are covered.
The research contracted here tries to unify these fragmented theoretical parts.

This effort to unify and expand the existing body of theory is carried out in the first two Work Packages of the project. The first Work Package describes seven relevant views for operations management. Each view is applied to all operations of at least two different CIM-systems. Five CIM-systems are described in this way. This results in a coherent description of current theory. The second package synthesizes the different views to a unified approach. This leads to a systematic way to describe existing or future production systems. This systematic way of describing is called "the conceptual model." It is to be expected, that the conceptual model, although unified, will be multidisciplinary in nature.

The third Work Package of the project focuses on formalisation of the conceptual model. In this Work Package, languages and specification methods for the conceptual model are investigated. If suitable, existing specification methods, languages and tools will be adapted, and brought together into a workbench. Unfortunately, the budget does not allow for the development of new languages or tools in the workbench. Consequently, it is foreseen that we are forced to restrict ourselves to a subset of operations at this point. Work Package 4 should provide guidelines and examples of the way in which to employ the utilities in the workbench for the design and description of production systems.

The last Work Package of the project comprises a demonstration of the capabilities of the workbench for simulated practical applications. For example, it should be possible to investigate a gradually changing implementation of CIM in a simulated production system, with consequences for such different aspects as cash flow, required personnel, stock levels, flexibility, production capabilities etc.

2. The nature of one-of-a-kind production (OKP)

A common distinction of different types of supply systems to the market is the distinction between standard-products supply and customer-order driven supply. However, customer-order driven supply encloses a number of different situations. For example, shipbuilders, maintenance shops, construction companies, and automotive component subcontractors may all be considered as customer-order driven suppliers. These production systems are so different, that a typology is needed.

Wortmann [2] distinguishes the following two questions in order to create a typology (the typology is shown with examples in Fig.1.):
A. Which activities in the primary process are customer-order driven?
B. Which investments (in e.g. product-design, resources, procedures, or supporting activities) are customer order independent?

Based on question A, a well-known dimension emerges, viz.:
A1. Make to stock : only distribution is customer-order driven
A2. Assemble to order: assembly and distribution are customer-order driven.

A3. Make to order: purchasing, component manufacturing, assembly and distribution are customer-order driven.

A4. Engineer to order: even (part of the) product design is customer-order driven.

Based on question B, a much less known dimension emerges, viz.

B1. Product-oriented systems: these systems supply the market with products which have been designed (to some extend) independently of existing customer orders.

B2. Capability-oriented systems: these systems offer particular skills or resources, but not predefined products, to the market.

<table>
<thead>
<tr>
<th></th>
<th>A4</th>
<th>A3</th>
<th>A2</th>
<th>A1</th>
</tr>
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<tbody>
<tr>
<td>B1</td>
<td>airplanes; packaging machines</td>
<td>vessel engines; standard professional equipment</td>
<td>trucks; computer systems</td>
<td>furniture; consumer electronics</td>
</tr>
<tr>
<td>B2</td>
<td>software development; civil engineering</td>
<td>maintenance shop; foundry; forge shop</td>
<td>building construction work</td>
<td>supply of car outlets</td>
</tr>
</tbody>
</table>

FIGURE 1. Typology of one-of-a-kind production (examples)

As always with typologies of companies, many companies do not fit neatly into this scheme. Usually, this is because a company may produce different product families or operate on different markets. This leads to different positions in Fig. 1. However, Fig. 1 illustrates the variety of situations which might be covered by the term "one-of-a-kind".

3. Currently available knowledge on OKP-systems

In the remainder of this paper, we will concentrate on column A4 and row B1 of Fig.1, unless explicitly stated otherwise. Note that in this case, there are two separate product-design activities, viz. customer-order driven design and customer-order independent design.

The last decade has shown an affluent wave of literature on product design, production and production management. Unfortunately, nearly all material is rooted in the production of standard products (row B1, columns A1 and A2 of Fig.1). As argued in Bertrand et al. [3], a production control system such as MRP II is based on standard products, produced in (large) batches. The OPT system is even more based on column A1 of Fig.1.
A production systems' design philosophy as Just-in-Time (JIT) production originates from automotive industry, and it carries many elements which are relevant for line-assembly only. The same holds for Total Quality Control (TQC); anyone who tries to apply these concepts to engineering design work is struck by the implicit assumption of standard products. This is true even for a book which takes distance from technicalities and details (such as Garvin [4]).

Computer Integrated Manufacturing (CIM) is another field where claims of applicability to OKP are suspect. Gunn [5], for example, stresses the fact that CIM has to go together with TQC and JIT. We will argue in Section 7 that information technology can contribute considerably to OKP-systems' performance, but not in the same way as elsewhere.

The COSIMA-approach to shop floor management is also embedded in a frame of reference, where customer-order driven engineering is not included in the frame of reference. This follows from the well-known picture of functional building blocks of integrated manufacturing (FIGURE 2). In this figure, the product design flow is customer-order independent.

Theories on product design (such as Wheelwright and Sasser [6]) are typically focussing on customer-order independent design (for an overview, see Sederholm [7]; the general nature of design is discussed in Takala [8]). Although this is certainly valuable, it is not dealing with one-of-a-kind production. Here, again, there seems to be a lack of interest in current literature.

A notable exception is the literature on Group Technology. Burbidge [1] is focussing explicitly on engineering companies. However, the ideas of Group Technology are mainly described for component manufacturing. In fact, the close connection of Group Technology to Period Batch Control, advocated by Burbidge, suggests that the majority of the parts produced are standard parts. However, many ideas from Group Technology are formulated in quite a general way. Therefore, the attempt to specify Group Technology for OKP seems worthwhile.

When considering theories of production organization, such as JIT, GT, or sociotechnical design, there seem to be at least three frameworks (paradigms) which have to be synthesized (see Falster [9] for a methodological justification). Each of these frameworks provides ways to describe an existing or hypothesized production system. Each framework relates design alternatives to performance indicators. Therefore, each framework presents an evaluation of an existing production system with respect to particular performance indicators. These frameworks are:

- A framework with theories about the appropriate way to structure the workflow through a factory. This workflow is not restricted to "physical" transformation of material. These theories lead to a structure of the workflow which is closely connected to an organizational structure in terms of departments, groups, task forces, teams, etc.

- A framework with theories about the internal structure of the resources. In component manufacturing, this structure consists of the physical layout, the equipment, the task structure of individuals and groups. In OKP, and especially in customer-order driven engineering, the human aspect seems to be most important.
A framework with theories about decision making. In OKP it seems that the boundaries between decision making and other activities (such as design) are less strict than elsewhere.

- Figure 2. COSIMA Functional Building Blocks

4. Integrating different views

Our current idea of the conceptual model is illustrated in Fig. 3. In this Figure, a number of design choices are shown. These are the instances ("variables") of an OKP-system, which are considered to be subject to design alternatives. Surprisingly enough, it was by no means easy to collect these design choices.

The design choices are related to performance indicators, by means of models. The performance indicators are not only of an economical nature, but could include many kinds of variables. The performance indicators are expected to change when alternative design choices are made.

The models can be of different nature also. At the most global level of description of our knowledge, these models take the form of connectance networks, which indicate a qualitative relationship between variables. If our knowledge becomes more precise, we can use more detailed and quantitative models for certain parts of the OKP-system. Our aim is to build models at different levels of detail and different levels of quantification.

However, these models should fit together: for example, a relationship at one level can be replaced by a detailed simulation model at another level.
First of all, note that the design choices will usually influence several performance indicators. This means, that trade-offs in the design of OKP-systems will become clear. This point will be discussed in more detail below.

An interesting point in Fig. 4 is the fact, that the distinction between different views vanishes. More specifically, it turns out that design choices do not belong to one view only. For example, a design choice could be, how the company selects and obtains personnel of a particular qualification. Such a design choice is interesting from the resources point of view, but also from the decisional/organizational point of view. Another design choice could be, whether product engineering and process engineering are disjunct activities or integrated activities. Such a design choice, which is closely connected to the choice of CAD-systems, is interesting from the functional point of view, but also from the resources point of view.

Still another design choice has to do with the application of Group Technology or Automatic Guided Vehicles in component manufacturing. Such a design choice is studied both in the functional view, and in the decisional/organizational view.

The same situation occurs with respect to performance criteria. For example, lead times are important in the functional view but also in the decisional/organizational view; labour turnover is important in the resources view and in the decisional/organizational view; and "innovativeness" is studied both from the resources viewpoint and from the functional viewpoint.

Because of the fact that these viewpoints tend to vanish in design choices and performance criteria, the models used to relate those two types of variables are losing their single-discipline nature also. It seems most logical now, that models which relate the same design choices and the same performance criteria from different views, become integrated.
Figure 1 supports furthermore our hope, that additional knowledge from other design-disciplines can be integrated into the available knowledge. For example, the role of information technology in future OKP-systems can be added by investigating the change which will be occur in the design-tradeoffs.

5. Nature of the conceptual model

At the time of writing of this paper, we have at disposal:
- an initial network of performance-indicators
- an initial set of design choices from the three different views
- the first prototype-models depicted in the middle of Fig. 3.

Up to this point in the present paper, we have left unmentioned one important distinction, viz. the distinction between reference models and particular models (cf. CIM-OSA[1988]). A reference model gives a general description of available knowledge, without having any data about a particular system in practice. A particular model describes a particular OKP-system in practice, which exists, or is being (re)designed. Of course, particular models include many details which are left unspecified in reference models.

The transition of reference models to particular models is not trivial. In physics, such a transition is usually performed by measuring. The term "measuring" could be applied here also, but should be interpreted metaphorically. We are currently investigating, how this transition can be done in practice.

The resulting structure of the conceptual model is depicted in Fig. 4. It is our current main objective to develop the models depicted here and to specify the "measuring instruments".
6. The role of IT in one-of-a-kind production

The discussion in the previous Sections sheds some new light on the role of information technology in OKP. It is well known, that IT provides the possibility to support individual tasks such as product design, process planning, or component manufacturing. It is also widely accepted, that IT can be helpful communicating engineering documents within a group, or to subsequent stages in the customer order processing cycle (this is sometimes called: CIM). Finally, IT may contribute to decision support, with respect to the various decision functions discussed earlier (sometimes called MIS). However, it is not widely recognised, that information technology can be helpful to support the timing of operational information, much in the same way as it may be helpful in supporting the timing of the material flow. In our opinion, this is a good opportunity to increase the benefits of IT in OKP.

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