TOWARDS ONE-OF-A-KIND PRODUCTION: THE FUTURE OF EUROPEAN INDUSTRY

John C. WORTMANN

Department of Industrial Engineering
Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven, The Netherlands

This paper conjectures that European industry will move more and more towards one-of-a-kind production in the future. The nature of future one-of-a-kind production is indicated: it is characterized by customer-order driven engineering and manufacturing, while reusing past experience and existing products and processes.

The design of production systems in general is based on a highly fragmented body of knowledge. Popular approaches such as JIT, CIM, TQC, or MRP/DRP focus on a limited number of aspects, and are not based on a coherent theoretical framework. Furthermore, these approaches are rooted in design of repetitive production systems and their application to one-of-a-kind production is questionable.

The paper describes an action to improve this situation, by synthesizing three theoretical frameworks (paradigms) for the design of production systems.

These frameworks are, roughly, the "organization and decision-making" paradigm, the "human resources" paradigm, and the "workflow structuring" paradigm. The synthesis yields interesting new perspectives. For example, it is quite unconventional to consider engineering activities as a normal part of production, and to try to design an appropriate production system, for both manufacturing and engineering.

Finally, the paper addresses the role of information technology in designing future one-of-a-kind production systems.

1. INTRODUCTION

There seems to be a wide-spread agreement that European industry moves away from producing large anonymous batches. Large batches of identical products used to be the basis of the competitive edge when price competition was the dominant way of competing, early after the second world war. However, it is commonly known that price-competition has developed towards competition on performance in delivery and quality, in the last two decades.

* This research is part of the ESPRIT project 3143 (Factory of the Future)
The markets for consumer goods are characterized nowadays by an increase of variety, while at the same time showing steadily decreasing product life-cycles. Improved delivery performance for short and unpredictable life-cycles is only possible with small batches. In addition, tailoring the product to the individual customer’s needs is increasingly important in quality improvement. This tendency also results in production in small batches, which are often driven by customer orders. Ultimately, this leads to one-of-a-kind production. Traditionally, one-of-a-kind production (OKP) has been associated with capital goods. However, European producers have shown a poor delivery performance, which resulted in a loss of market share in branches of industry such as shipbuilding (see Burbidge [1]). Consequently, the general public does not associate OKP with the future of European industry, but with its history. Hopefully, this is a misunderstanding of the general public.

The fact that consumer goods production itself moves towards OKP is only half of the story. In addition, the innovation and redesign of the production process is in many plants a considerable activity. It is not uncommon nowadays, to find in a repetitive manufacturing production site 10%-50% of the direct labour employed in a OKP machine shop involved in redesigning the repetitive factory. No doubt, the real issue in such plants is the performance of such an OKP-system.

The conviction that European industry moves towards OKP was the reason for a consortium of seven European research institutes to start a joint research effort. This effort is sponsored by the ESPRIT Basic Research Actions Program, as project 3143 (Acronym: FOF). This paper is an intermediate result of the research effort, in which all partners have participated.

The remainder of this paper is organized as follows. First of all, a short discussion on the nature of OKP is required. This issue is dealt with in Section 2. Not surprising, there are several types of OKP-systems. Therefore, Section 2 presents a typology. Section 3 investigates current knowledge on OKP-systems, where customer-order driven product design plays a role. We will argue, that the vast majority of literature on design, production, and production management stems from the production of standard products, often in large batches. This is also true for the more applied literature on Just-in-Time (JIT), Total Quality Control (TQC) and other famous three-letter acronyms (CIM, MRP, FMS, ...). Thus, there is a need for more research. Section 3 argues that the knowledge to be developed and integrated can be approached from three theoretical frameworks (paradigms) for the design of production systems. These frameworks are dealing with:
- the workflow through the production system (to be discussed in Section 4)
- the structure of the primary resources (to be discussed in Section 5)
- the organization of decision making (to be discussed in Section 6).
Section 6 considers engineering functions such as product design and process design, as normal operational functions. In other words, engineering work produces output which is planned and delivered in the same way as materials are.
The output of these engineering functions ("paperwork", or better: information) can be managed according to known principles in manufacturing. The information-producing nature of engineering output, will enable the use of IT in managing the timing of the output. This sheds a new light on CIM in OKP, to be discussed in Section 7, which concludes the paper.

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.):

E. 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>
</thead>
<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.

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. This attempt will be sketched in the remainder of this paper.
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. For further discussion, see Section 4.
- 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. For further discussion, see Section 5.
- 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. For further discussion, see Section 6.

4. STRUCTURING THE FLOW OF WORK

According to Burbidge [1], "Group Technology is an approach to the organisation of work in which organisational units are relatively independent groups, each responsible for the production of a given family of products. The smallest organisational unit is the group, but the same principle of organisation is used when forming larger organisational units, such as departments."

Furthermore, "A group is a combination of a set of workers and a set of machines, and/or other facilities laid out in one reserved area, which is designated to complete a specified set of products. The workers in a group share a series of common output targets in terms of lists of products to be completed by a series of common due-dates. The number of workers in a group is limited by the need to obtain social cohesion."

This description of Group Technology is clearly intended for physical transformation, in particular for component manufacturing. The question is, whether the same principles and the same line of thought can be followed for engineering work. For physical products, it is relatively easy to form a family of products. Techniques such as Production Flow Analysis (see [10]), are available. These techniques relate the formation of groups to the physical transformation performed. Thus, a group is formed for a family of parts requiring, say, turning, grinding and welding. It is not immediately clear, how the analogon of physical transformation should be defined in engineering work.
More generally, in all kinds of knowledge work, the transformation to be performed from a specification of a problem to a solution for that problem is less easily classified than for physical transformations. A solution for this problem could be, to use the human skills required for this knowledge work as the basis for classification. However, this suggestion does not solve all problems. It is not immediately clear what should be understood by the term "skill". Furthermore the approach presupposes, for example, that engineering work can be classified uniquely according to skills required, and that groups of a required size can always be formed. There is as yet no empirical evidence in the FOF-project, that this kind of approach leads to the required result.

Within the FOF-project, the research focusses on the definition of elementary "functions" which describe the capability to transform a particular input into a particular output (see SINTEF [11]).

5. THE STRUCTURE OF THE PRIMARY RESOURCES

The second framework of theories, required to design OKP-systems, is concerned with the internal organization of the groups. In general, there exist three types of resources:
- materials
- capacities
- information for executing the required operations (cf. Marcotte [12]).

Capacities can be subdivided further into:
- humans
- machines/tools
- storage/positioning equipment.

Assuming that workflow analysis has created a structure of departments (major groups) and parallel autonomous working groups within these departments, the design of the internal group organization itself enters the scene. In OKP (especially in engineering), the humans play the most important role; issues such as group structure, inter-group coordination, and human resources management strategies are discussed in [13].

The human resources management strategies are closely related to aggregate production planning, to be discussed in the next Section. Group structures are classified according to two dimensions:
- the number of workers assigned to a group (n)
- the number of tasks assigned to a group (m).

In traditional jobs, both n and m equal 1. In traditional work groups, n is larger than 1, but m remains equal to one. In traditional job enrichment programs, the reverse situation occurs. Autonomous working groups are characterized by both m and n being larger than 1. For more details, hypotheses, and design guidelines see Hamacher [13]. It is interesting to see that group structure design is also related to issues such as group stability, order horizon, and level of automation. Group stability and order horizon are also mentioned in the work of Burbidge [1], [10].
Second to the organization of the human capabilities, it is also important to organize the availability of sufficient information for executing the required operations. This type of information, to be called operational information (in contrast to management information) is generated by the engineering activities in the first stages of customer order processing. It should be borne in mind, that in customer-order driven engineering, the coordination of this operational information flow is most crucial. This information flows from the customer to the product design activities, then towards manufacturing engineering (process planning) and purchasing, and finally towards the factory floor and back to the customer. The term "flows" should be interpreted metaphorically: in fact, the information itself does not flow, but is transformed by engineering activities of a more or less creative nature. The coordination of this flow resembles in many respects the coordination of the material flow, to be discussed in the next Section.

6. THE ORGANIZATION OF DECISION MAKING

Although OKP-systems tend to be less formalized than other production systems, it is argued in Marcotte [12] that some form of hierarchical decision making is necessary and useful. The dominant criterion in choosing decision levels should be the horizon over which decision have their impact. It seems that the three levels of production control distinguished by Burbidge [1] ("programming", "ordering", and "dispatching") are also valid for OKP (cf. Bertrand et al. [3] who use the terms "aggregate production planning", "factory coordination", and "production unit control").

It is interesting to note, that the human resources management strategies mentioned in Section 5 fit neatly into the top-level decision making. It is also interesting, that the choice of departments and groups mentioned in Section 4, corresponds to the number of production units for which a production unit decision making activity has to be designed.

The medium level of decision making differs most sharply in OKP from similar decision functions elsewhere. As noted in Marcotte [12], each level of decision making has the general function of synchronizing future activities. However, this particular level focusses on synchronizing the time-phased availability of capacity, materials, and operational information.

In the production of standard products, this synchronization is based on existing bills-of-material and routings. In other words, operational information is considered to be available. In addition, safety stocks and lot sizes provide some slack to cope with future disturbances. Therefore, an important aspect of this medium level decision making is to create and use this type of slack.

In OKP, the synchronization of engineering activities with other activities is aiming at the timing of having operational information available. In other words, the medium level decision making tries to
have drawings, bills-of-material, and routings available by the time these documents are needed for purchasing or manufacturing. This requires considerable knowledge of the products being designed, because the need dates of operational information depends upon the content of this information! For example, a planner has to know the routing of a component in order to estimate the lead time; and he has to know the lead time in order to set a due date for manufacturing engineering to produce the routing.

A final element of decision making in general, but especially in OKP is the fact that decision making is a process in itself. In other words, decision making activities can be considered normal organizational activities, such as design or manufacturing. Such a "workflow" analysis of decision making is described in Schalla [14]. Decision making in OKP is described in more detail in Timmermans et al. [15]. See also Hynynen [13].

7. 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 recognized, 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.

ACKNOWLEDGEMENTS
This work has been performed in close discussion with the FOF consortium:

Prof. dr. ing. B.E. Hirsch (BIBA)
Dr. P. Falster (DTH)
Dr. J. Browne (CIMRU)
Prof. G. Doumeingts (GRAI)
Dr. E. Eloranta (HUT)
Prof. dr. A. Rolstadas (SINTEF)
Dr. ir. R. Kwikkers (TUE/ITP)

NOTES
** For this reason, the "workflow structuring" framework within the FOF-project is called the functional view, which should not be confused with a bias towards the functional organization!
REFERENCES