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Factory of the Future: Towards an integrated theory for one-of-a-kind production

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Abstract
This paper gives an overview of the Factory Of the Future (FOF) project (ESPRIT 3143). FOF aims at an integration of several fragmented theories about the (re)design of production systems. Such an integration is a prerequisite for a proper understanding of CIM. FOF has undertaken this integration for one-of-a-kind production.

This paper shows that FOF distinguishes between a framework for description (called the theoretical framework) and a framework for redesign (called the design framework).

The theoretical framework consists of three views: the workflow view, the resources view, and the organizational/decisional view. The design framework consists of a connectance network of design choices (DC's), performance indicators (PI's), and relationships between DC's and PI's. These relationships are detailed further in relationship models.

To some extent, these relationship models can be used as particular models to describe a particular company. These models are integrated in a designer's workbench. This workbench seems to be quite useful in roundtable discussions with companies aiming at organizational learning.

1. INTRODUCTION

The title of the ESPRIT 3143 Factory Of the Future (FOF) project is: Towards an integrated theory for design, production, and production management of complex, one-of-a-kind products.

This title covers the aim and scope of the project quite well. First of all, FOF aims at integration of theories. As will be argued in Section 2, the available body of theory on production is quite fragmented. Consequently, an effort for integration is badly needed. The way in which integration is obtained is described in Section 4.

Before discussing integration, however, the nature of one-of-a-kind production has to be elaborated. As mentioned, the FOF project deals with one-of-a-kind production only. The argument for this particular choice is given in Section 3. Section 3 also describes the most important features of one-of-a-kind production (OKP).

The discussion about integration in Section 4 will learn, that there is a need for a framework for description and a need for a framework for (re)design of OKP-systems. The framework of description (also called the theoretical framework) is discussed in Section 5. The framework of (re)design (also called the design framework) is described in Section 6.
The design framework has led to a number of models which support redesign activities of OKP-systems. These models are discussed in Section 7. These models have been implemented in software in an integrated designer's workbench. This workbench is described in Section 8.

Finally, the FOF project covers the areas of product design, production and production management. These areas cannot be separated in production in general, and certainly not in one-of-a-kind production. However, due to fragmentation in education and experience, many actors in OKP act as if these areas were completely independent.

It is the intention to use the FOF results as tools for organizational learning and competence development. This idea is introduced in Section 9. The paper’s conclusions are formulated in Section 10.

FOF was initiated because of the fragmentation in theory. The proposal was accepted as Basic Research Action No. 3143 within ESPRIT II. One reason for acceptance was probably the fact that fragmentation in theory leads to problems in practice. These problems are quite obvious in today’s industries. For example, comprehensive assessment of new technologies in product design, production or production management is limited by fragmented understanding of these areas. Investments in CIM, which seem to be economically sound in advance, may turn out to be a disaster when looking backward. But also the reverse is sometimes true.

Therefore, FOF aims at answering the following questions:

* how should the functioning of a production system be appraised?
* and how should proposed changes to such a system be assessed?

FOF tries to synthesize the theoretical answers to these questions for one-of-a-kind production. Note, that this objective is different from the objective of, for example, the CIM-OSA model. This model aims at a description which is sufficiently detailed to allow for implementation of proposed changes.

2. INTEGRATION OF DIFFERENT VIEWS ON OKP-SYSTEMS

This Section is the result of FOF-Workpackage 1, performed under the responsibility of Guy Doumeingts, GRAI, Bordeaux, F.

2.1. Fragmentation

When a physical artifact is designed, manufactured, repaired, or dismantled, there is no discussion about the necessity of complete documentation. From a philosophical point of view it may be debated whether complete documentation is possible, but the established engineering disciplines have obtained quite some consensus about the meaning of "complete documentation". This is even true for a new discipline such as software engineering.

When an organization is created or changed, the situation is completely opposite. There is no common agreement in organizational theory about its documentation. More specifically, there is no agreement on description languages, neither in terms of semantics, nor in terms of syntax. It can even be doubted whether organizations should be considered as artifacts or as organisms which live, grow, generate progeny, and die. However, although there is no common agreement about documenting organizations, there considerable theory about the functioning of an organization, about its structure, its systems, its economy, its employees and its contribution to society exists. But all this theory is fragmented.

Now consider production systems (including engineering, management, commercial activities, etc.). Production systems are composed of organizational elements and physical elements. The physical elements can be documented completely according to the standards of
their creating disciplines, whereas the organizational elements cannot. However, the combined functioning of both elements is unclear. Therefore, it must be doubted whether the "complete" description of the physical elements is relevant in an organizational context. Probably it is not. Hence there is a good deal of confusion about the analysis or redesign of production systems. The theory is fragmented here, as with organizations in general.

This fragmentation shows up very clearly in practice, when interfaces between automated subsystems have to be designed. For example, consider the situation where a CAD system has to be interfaced with an MRP system. Quite often this means that a product design view of "engineering data management" is confronted with a production control view of "engineering data management", and the result is seldom an elegant, integrated whole.

Now the point to be made here is not that it is sometimes difficult to build a particular interface. The point is that a production system's designer should come up with the idea of distinguishing a process called "engineering data management" and that different opinions about this process should be highlighted. Fragmentation means, in practice, that there is no systematic way to identify such processes and no systematic way to find out how they are affected by proposed changes.

This discussion brings us to another type of fragmentation which should be mentioned, viz. the fragmented description of the workflow through a company. Although many companies have described several flows of work in their procedural handbooks, few have taken the workflow as the basis for their organizational design or for their systems design. This is especially true for the customer-order driven engineering work.

The disadvantage of neglecting the workflow can be observed at many places where computer aided engineering (CAE) has been installed. Usually, CAE systems give considerable support to individual engineers to improve the quality of their work, but they do not contribute to improved cooperation of a team which has to manage a flow of work. In other words, they help in doing the work right, but not in doing the right work.

Both types of fragmentation are illustrated in Figure 1.
2.2. Integration

It is not very realistic to assume that all the problems mentioned above will be solved in a project of limited time and resources. Therefore, the FOF project had to be pragmatic. Integration is considered to occur if agreement could be reached about:
- the elements which should be described in a production system in order to appraise its functioning
- a method of evaluating proposed changes in a production system in terms of effects on performance indicators.

The first issue is called the theoretical framework and the second is referred to as the design framework within FOF.

The FOF project developed these frameworks by considering seven different views. These views are listed in Table 1 below, together with the partner which presented this view description.

<table>
<thead>
<tr>
<th>FOF PARTNER</th>
<th>ACRONYM</th>
<th>VIEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bremen Institute of Industrial Technology</td>
<td>BIBA</td>
<td>Human view</td>
</tr>
<tr>
<td>CIM Research Unit, University College Galway</td>
<td>CIMRU</td>
<td>Communications view</td>
</tr>
<tr>
<td>Technical University of Denmark, Electrical Power Engineering Dept.</td>
<td>DTH</td>
<td>Data-orient view</td>
</tr>
<tr>
<td>GRAI Laboratory, University of Bordeaux I</td>
<td>GRAI</td>
<td>Organizational view</td>
</tr>
<tr>
<td>Institute of Industrial Automation, Helsinki University of Technology</td>
<td>HUT</td>
<td>Economic view</td>
</tr>
<tr>
<td>Production Engineering Laboratory, Technical University of Norway</td>
<td>SINTEF</td>
<td>Functional view</td>
</tr>
<tr>
<td>Dept. of Industrial Engineering and Management Science, Eindhoven University of Technology</td>
<td>TUE</td>
<td>Cybernetic/OR view</td>
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</tbody>
</table>

The above views were considered to cover most of the available theoretical body of knowledge. However, arguments for more views can be found easily. Therefore, FOF does not only aim at integrating these seven particular views. A more ambitious, transcending goal is to develop a method to obtain a synthesis between an infinite number of views. Stated differently: the description framework and the design framework should allow for extension with knowledge which is not yet available.

The project proceeded in the following way. Firstly, these views have been operationalized by developing extensive questionnaires identifying key concepts in each view. These questionnaires were applied by all partners to industrial cases. In this way, the consortium obtained a common understanding of all views (cf. Doumeingts [1]).

These descriptions of several companies by means of different views turned out to be a good vehicle for integration of these views. First, several views were compared and combined which yielded a reduction to three complimentary views, constituting the theoretical framework. In other words: three views are necessary for a description of a production system with the aim of appraising its functioning. These views are (cf. Falster a.o. [2]):

- the workflow view
- the resource view
- the organizational/decisional view.

A more detailed description of the theoretical framework and the above three views is given in Sections 4 and 5 of this paper.

The theoretical framework provides means to describe an OKP system, but does not yet support (re)design of such a system. The common point in theories about redesign (including the usage of IT and the introduction of CIM) is the claim that a particular design choice influences one or more performance indicators. This constitutes the basis for the design framework which adds several elements to theoretical framework, for example:

- the notion of design choices and performance indicators
- the models describing the relationships between design choices and performance indicators.

This will be elaborated in Section 6, 7, and 8.

All this modelling can be criticized for the fact that it does not recognize a basic point made above: the idea that production systems can only be partially object of (re)design and should also be partially the subject of redesign. In other words, OKP-systems should obtain the competence to change themselves rather than be changed by some external change agent. This issue will be discussed in Section 9.

However, we shall first explain in more detail why FOF is restricted to one-of-a-kind production, and what this means in more detail.

### 3. ONE-OF-A-KIND PRODUCTION

Section 3 is the result of many discussions during the first year of the project, although it was not a separate activity or workpackage. However, Section 3 can be attributed to the FOF technical project manager, Rob Kwikkers, TNO-IPL, Eindhoven, NL.

#### 3.1. Reasons for studying one-of-a-kind production

Currently, the FOF project is concentrating on one-of-a-kind production. There are several reasons for this focus.

First of all, the traditional one-of-a-kind production (OKP) firm is the producer of capital goods. The position of European industry in producing these goods is on average not flourishing, in spite of numerous studies about production planning, work organization, and IT-support of these companies. However, there are notable exceptions as well. The question is: why are certain OKP companies performing much better than others?

Secondly, the markets of consumer goods are characterized nowadays by an increase in variety while at the same time showing steadily decreasing product life cycles. In addition, tailoring the product to the customer's needs is increasingly important in quality improvement. These tendencies lead to production in small batches, which are driven by customer orders. Ultimately, this leads to one-of-a-kind production.

Finally, the innovation and redesign of production processes becomes a considerable activity in many plants. It is not uncommon to find a chemical process plant employing some 20% of its direct labour in an OKP machine shop involved in redesigning the main plant. The same is true for plants with repetitive manufacturing of discrete consumer goods.
3.2. A typology of one-of-a-kind production

One of the first questions which the FOF project had to answer was: what is one-of-a-kind production? Is the automotive industry one-of-a-kind if there are no two identical cars ever leaving the production line? Is the daily newspaper a one-of-a-kind product because the editors have to make a new product every day? Is software a one-of-a-kind product?

These questions were dealt with by developing a typology of one-of-a-kind production. The typology does not solve all issues but at least helps in understanding some of them. The typology is based on two dimensions. The first dimension is well known, and it poses the question:

A. up to which point in the workflow are the production activities driven by the customer order?

The second dimension is less well known, and it states the question:

B. up to what extend has the company invested in product development (and/or workflow process development) independent of the customer order?

The resulting typology is shown at a very coarse level in Figure 2. (See Wortmann [3]). For the time being, FOF has concentrated its activities on engineer-to-order production. However, one of the most interesting design choices in the production system is, of course, where a business unit wants to position itself on the map of Figure 2, and what the consequences of movements on this map are.

<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;</td>
<td>Vessel engines;</td>
<td>Trucks;</td>
<td>Furniture;</td>
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<tr>
<td></td>
<td>Packaging</td>
<td>Standard profes-</td>
<td>Computer systems</td>
<td>Consumer</td>
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<td>electronics</td>
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<tr>
<td>B2</td>
<td>Software dev-</td>
<td>Maintenance shop;</td>
<td>Building con-</td>
<td>Supply of car</td>
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<td>Foundry;</td>
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<td></td>
<td>engineering</td>
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Figure 2. Typology of one-of-a-kind production (examples)

3.3. Nature of one-of-a-kind production (engineer-to-order)

What is so peculiar about engineer-to-order? According to our investigations, three issues should be highlighted:

- customer-order driven engineering should be considered as a normal part of the primary process
- human capabilities and accumulated experience of human professionals are the key resource
- customer-order acceptance is the most important decision making activity.

It should be stressed that the above three issues are not independent:
Human capabilities play a major role in the nature of engineering and of decision making in OKP. In turn, engineering and decision making in this case are good examples of the role of human beings in the Factory of the Future.

Engineering is highly involved in customer-order acceptance in OKP. The risk in accepting customer-orders is mainly due to unknown parts of the engineering work. In turn, customer-order acceptance is creating an immediate workload for Engineering.

Perhaps the most intense way of expressing this common part in these three issues is:

* In traditional organizations there is a separation between decision making, information processing, and execution. In customer-order driven engineering these activities are combined. They can be distinguished in theory but should be approached as unified in designing OKP systems. Probably this is typical for the Factory of the Future.

Because of the fact that these three issues constitute the central issues in OKP the models which are developed to support (re)design of OKP systems are focussing on these issues. We will come back to this point in Section 7.

4. TOWARDS INTEGRATION

This Section is the result of the first part of FOF Workpackage 2, performed under the responsibility of Peter Falster, DTH, Lyngby, DK.

4.1. Introduction

Generally speaking, the integration obtained in the FOF-project consists of two parts: a theoretical framework and a design framework. The theoretical framework gives a description of a factory in terms of the three complimentary views mentioned in Section 2:

- the workflow view
- the resources view
- the organizational/decisional view.

The arguments for this choice of "views" and for the predicate "complimentary" will be given below.

The design framework concentrates on design choices and performance indicators which can be related by several models (see Figure 3). To the extent that these models use empirical data, these data rely on the descriptive data of the theoretical framework.

In discussing (re)design of an OKP-system, almost everything can be subject to change, in principle. (Re)design is an interactive pattern of activities where the scope and focus change frequently. This means that OKP design choices should be tackled at different layers. The three levels adopted in our basic model are the following:

- Strategy
- Structure
- Operations
The highest layer (strategy) deals with the strategies to be adopted and the inherent competition factors. It also deals with the economics (particularly long term) of the manufacturing systems. Typical design choices to be made at this layer are listed below (cmp. e.g. Hayes and Wheelwright, 1985 [4]):

- market niche (customer specified / modified vs. standard; brand vs. bulk; cost minimization vs. differentiation)
- product technology (mechanics, electronics, software, ...)
- process technology (scale, flexibility, dedication)
- facilities (location, size, specialization)
- integration (vertical, horizontal, extent, balance)
- suppliers (number, structure, relations, make / buy)
- human resources (selection, training, compensation, security)
- quality (image, responsibilities).

The intermediate layer (structure) deals with the production system as such, i.e. its components (primitive system) and the relationships between them (restrictions). Some typical design choices at the structural layer are:

- products
- resources
- manufacturing layout
- organization

The layer of operations deals with decisions how the inputs of the manufacturing system are applied to the structural manufacturing system. Some typical design choices at the operational layer are:

- operative and medium term decision rules and criteria
- operative and medium term management functions.
The operational input fall into two categories:

- demand pattern
- supply pattern.

The demand pattern is represented as the customer order flow while the supply pattern is resulted from the availability of subcontractors, material suppliers and the resources of the business unit itself.

In any layer of the total conceptual model some of the design choices remain fixed, while free choice can be exercised over the others. There are also situational conditions (such as demand pattern) more or less given at each layer.

Because of the hierarchy of the layers there are most degrees of freedom at the highest layer (strategy), because both structural and operational design choices are at least in principles open. On the contrary, when making operational design choices both the strategic and structural layers are more or less fixed.

In order to be able to discuss and model any design choice in specific terms for a particular OKP-system, it is necessary to have a common description language for the intermediare layer and the layer of operations in a particular case. This language is provided by the theoretical framework. The language should at least describe the "operating core" (Mintzberg [5]) of the OKP-system.

The theoretical framework and the design framework will be explained in more detail in the subsections 4.2 and 4.3.

4.2. The theoretical framework

The concept of a view has changed its meaning slightly during the FOF project. Originally, a view represented an aspect of reality as studied by a particular scientific discipline. In this interpretation, it is quite natural that different views overlap. However, it is also quite frustrating to be tied to one or more views because reality is much more than the sum of several views. Also, the interaction between different views is perhaps more interesting than the behaviour of an OKP system described in one particular view. For this reason, there is a justified aim to abandon the views. Stating the same aim in different terms, there is a need for an infinite number of views. This aim is realized in the design framework.

However, it has been argued that there exists a need to establish a common description framework of the "operating core" (Mintzberg [5]). This is the purpose of the theoretical framework. When such a framework is chosen, the "views" should be complimentary rather than overlapping. We shall now develop the basics for such a framework.

The Walrasian production model

The theoretical framework is based on the so-called Walrasian model. Let us therefore shortly give a presentation of this model. A more comprehensive formulation and discussion of this model is given by Franksen in [6] and [7].

The Walrasian model depicts the transformation process of production factors into finished products. The illustrative example in Figure 4 will be used to describe the model in more general terms, as it applies to production.

The environment, considered as a set of markets or external influence impressed on the system, is divided into an input side and an output side. The input side comprised by the supply of all the production factors, is depicted in the second quadrant, while on the output side we have the demand on the finished products depicted in the fourth quadrant.
The system can be considered from two viewpoints. Horizontally, corresponding to each production factor, it defines:

- a stage or department as the parallel-connection of products involved in the consumption of the single production factor.

Vertically, corresponding to each demanded product, it defines:

- an activity or process as a series-connection of the consumption of all the production factors involved in producing the single product.

The relationship, i.e., production function, or ratio of transformation between the amount of a certain productive service and the amount produced of a given product, is known as a technical coefficient. In Figure 4 a technical coefficient is symbolized by a cross surrounded by a circle.

In summary, therefore, we have seen that to describe uniquely a production system, at least two different kinds of structural properties must be stated: (a) the parallel and series layout, i.e., the topology illustrated by the interconnected set of arcs and nodes, and (b) the technical coefficients depicted by the set of circles.

It is worth noting that the horizontal and vertical viewpoints also correspond to process oriented (functional) and product oriented (group technology) layout.

In the succeeding follows the necessary generalizations of the Walrasian model in order to cope with real life production situations in particular related to OKP. Some of the limitations with this model is that it:

- does not describe product structure and resource structure
- does not describe operation/capabilities
- static or quasi-static model, time-independent
- includes only durable resources (capacity) included, though non-durable resources (stocks) need also to be considered
- does not describe control structures
Those limitations will be treated under the three headings, 1st generalization, 2nd generalization, and 3rd generalization. The 1st and 2nd generalization takes a "horizontal" respectively "vertical" view on the Walrasian model and introduces causality in the model with respect to resources, products and operations/capabilities. The 3rd generalization takes a dynamic view on the Walrasian model and introduces time-dependency, control and decision-making explicitly. The discussion is general and abstract.

**1st Generalization of Walras to a Primary Flow Descriptions**

The Walrasian production model as described above does not consider ordering of products (assemblies and subassemblies, i.e., bill-of-materials) and production operations (routing) as required for real production situations in both repetitive production (RP) and one of a kind production (OKP).

The generalization of Walras to include ordering of products is represented by the so-called Product graph (bill-of-materials), see figure 5.

![Product Graph with Technical Coefficients](image)

**Figure 5. Product Graph with Technical Coefficients.**

The graph is based on the relationships "goes-into" or "where-used" between entities. The graph represents an "and" constraint on the nodes, but could as well represent "or" constraints on the nodes or other types of logical constraints. To the arcs are assigned technical coefficients.

Every node in the graph represents a sequence of operations. We will refer to this as the P-graph. Its relationship to the bill of material graph is depicted in Figure 6. For simplicity the sequence of operations will be referred to as one node in succeeding figures instead of showing the whole sequence of operations.

Alternative production processes can be defined by using or-relationships in the P-graph.

The P-graph will have two dual interpretations:

- A cluster of sequenced nodes will define a component or a subassembly.
- A node will define an operation to be performed.

The word operation is here given a wide interpretation to include production, purchasing, subcontracting, etc. The P-graph as described here, represents the primary flow in the production process. In fact, it defines the work to be done. The purpose of the engineering process is to establish the P-graph as defined here. In fact, the engineering process can be regarded as a production process, however, with a different primary flow. In this case a
similar graph may be used to describe the workflow of the engineering process. Again the same is valid also for the management process.

![Bill of Materials](image)

**Figure 6. P-Graph.**

The P-graph identifies the requirement for resources. This requirement is defined by capability and capacity.

In OKP the P-graph will be developed gradually. Actually production may start before the P-graph is completely defined. The P-graph will also be more or less detailed, dependent on which layer (strategy, structural, operational), or more precisely planning level, we are working at. This corresponds to the fact that different types of bill of materials exist in a company at the same time (f.ex. planning, percentage or generic bill of materials).

The generalization of Walras to include operations and "requirements" for capability and capacity is taken by a vertical view on the model looking along the activities following the products through the operations.

We have called these generalizations of Walras to a workflow description of the primary flow in both engineering and manufacturing the 1st generalization. It goes without saying that the term P-graph is used here metaphorically. An actual data structure is to be developed in relation to a specific modellers requirements.

### 2nd Generalization of Walras to a Resource Description

The Walrasian model describes resources as a set of primitive unordered objects. We need to be able to define how resources are combined and ordered into groups, into departments and into factories. We represent these orderings by so-called R-graphs, see Figure 7. We therefore take a horizontal view on the model looking at the stages. Resources "provide" capabilities and capacities which also should be included in the generalization.
It can for example reflect the organization of a factory's resources in a hierarchical organization, see Figure 7 which reflects an example for machine tools.

![Organizational Structure of Resources](image)

Figure 7. Organizational Structure of Resources (Machine tool example).

The relation or link between the resources and operations are represented by the stage (see definition of stage in fig 4).

As with the P-graph, also the R-graph may be only partly defined at the time of production start. This is especially valid for human resources. Again, the term R-graph is used metaphorically.

This generalization shall consider both group social structure and physical layout of the machines. Generalization to group/departamental physical structure, represented by the layout of machines with transport routes in between, and transportation time assigned as leadtime on the arcs, is well-known. However, the generalization to group social structure, i.e., what kind of relationships are represented, has still to be discussed in details.

We have called these generalizations of Walras to a resource description (social and physical) in both engineering and production the 2nd generalization.

The above two generalizations can according to Rolstadás be summarized in one figure (Fig 8).

3rd Generalization of Walras to a Decisional/Organizational Description

The Walrasian model is a static model of the primary process of resources and products with a fixed production function in terms of technical coefficients. Turning it into a dynamic control model (Figure 9) at the same time putting emphasis on the decision functions and their structure can be depicted in the Grai Grid in figure 10.
Figure 8. From Walras to Ordered Resources and Products.

Figure 9. A System and its Control.
In the left part of figure 10 the Walras model is shown with its resources and products. In addition, a time dimension is included, making the model 3-dimensional. The right part of the figure shows how this is transformed to a GRAI grid. The columns of the grid represent the resources and the products of the Walras model as well as the connection of these (i.e. allocation of resource to products). This connection is referred to as "to coordinate and synchronize". This corresponds with the GRAI method which defines management of production as "to synchronize in time". The time dimension is included in the GRAI grid as several levels. The GRAI method consequently provides a way representing the 3-dimensional model in the left part of figure 10, as a 2-dimensional grid as shown in the right part of figure 10.

The Grai Grid represents the control system. The controlled system, i.e., the primary process is usually not depicted together with the Grid. The concept of synchronization and coordination in the Grid stems from the production function in Walras. If the lowest level, i.e., the primary flow is included in the description, we may end up with a multilevel model which from a nested array point of view is interesting because it opens up for a recursive formulation of models.

The dominant criterion of decision levels should be the period of decision and thereafter the horizon over which decisions have their impact. It seems that the three levels of production control distinguished by Burbidge (programming, ordering, dispatching) are also valid for OKP (aggregate production planning, factory coordination, and production unit control).

We will call this generalization of Walras to the organizational / decisional view of different levels of control of both engineering and production, the 3rd generalization.

It should be clear now, why we have stated that the three views of the theoretical framework are complimentary. Apparently, these views can be fit together into a single description scheme which corresponds to earlier developments in the analysis of production systems.

4.3. The design framework
The idea which is depicted in general in Figure 3 has been implemented in the FOF workbench in several layers.

When the designer takes a large scope, (s)he tends to be more focused on strategic management issues. At strategic level, a designer with a wide scope needs to navigate carefully through theoretical cause-and-effect chains before selecting a particular promising area, suitable for a close up.
In the remainder of this section, it will become clear, that such a means of navigation has been
developed in this work package. It connects design choices (DCs) to performance indicators (PIs), and it will be called therefore the DCPI network. It has the form of a so-called connectance model (Burridge [8], Eloranta [9], Kami [10]). The theoretical background of connectance models is in the soft systems science (e.g. Checkland, 1985, [51]), which has been applied, e.g. on the research of the future, in qualitative economics as well as in qualitative simulation. The type of relationships implemented in the FOF model are the following:

- Affects (is affected by)
- Is element of (has element)
- Increases (is increased by)
- Decreases (is decreased by)

Because of the variety of the permitted relationships, the mathematical properties and thereby the reasonable operations in the connectance model are scarce. Transitivity, e.g., is limited to just a few types of relationships.

At the structural or the operational layer, when the designer takes a more narrow scope, there emerges a need for more qualitative modeling of relationships between design choices and performance indicators, eventually based on situational factors. Such quantitative models for parts of factories are called drawing models, in this report. These drawing models are still relating design choices to performance indicators, but they do not claim to be comprehensive.

However, drawing models can be fed with actual descriptive data about the factory to be redesigned. Therefore, drawing models should be distinguished in:

- Reference models (general theories and knowledge)
- Particular models (company selected knowledge, data and facts)

Finally, there is one advantage of the architecture above which is worthwhile to notify. In principle, the structure of the DCPI network and the various drawing models is such that it can be maintained if our knowledge about the (OKP) manufacturing systems grow. More explicitly, the DCPI network which will be presented below, and the drawing models to be presented in section 7 will probably need further refinement and adoption. However, this will not change anything in the remainder of this report. The integration obtained here is therefore not dependent upon the particular nature of the views and models selected here. It can be expended with future insights from new disciplines without special effort.

In order to clarify these ideas, consider Fig. 11.
In the top part of the figure the DCPI model is shown. In the middle part the DCPI model is sliced into an arbitrary number of views and models (DC, PI), and a relationship model (RM) is shown for each view. In the lower part the views connectance to the basic data structures are shown as well as vertical decomposition analogous to the GRAI grid.

The coordination and decision-making activities are denoted here as D-graph. Of course, this term should be interpreted metaphorically, again.

In order to give a more precise impression of the DCPI network, a part of the network is shown in Fig. 12. (The relationship models will be explained in more detail in Section 7.)
Figure 12. Top of PI-Network.

Note, that the network of design choices and performance indicators may cross the boundaries of disciplines, views, groups, etc. The DCPI network is under continuous improvement and development in the FOF project.
5. THE THEORETICAL FRAMEWORK

This section is, amongst other sections, the result of the second part of the FOF workpackage 2. This workpackage was completed under the responsibility of Asbjorn Rolstadas, NTH, Trondheim, N.

5.1. Introduction

This section describes the theoretical framework in more detail. Recall from section 4.2 that there are three complimentary views used in the description of the structural and operational levels of an OKP company.

Before proceeding with the description of each of the views separately, the following should be noted. A description of whatever system (but especially a production system and a fortiori an OKP system) is always done with a particular purpose in mind. In our case, the level of detail of the description should match the purpose of redesigning an OKP-company. This means, that the theoretical framework cannot be considered independently of the models used in the design framework. This notion is depicted in Figure 13, which shows once again the design framework.

![Design Framework Diagram](image)

Figure 13 Models and views in the design framework

This split in reference and particular models are in line with the ESPRIT CIM-OSA model [11]. Reference models represent available theory. These models link general design choices via intermediate variables to general performance indicators. They may give due recognition to...
the existence of situational factors, but these models claim to be generalizations over such situational factors. Particular models represent an abstract example of a particular case or an existing or conceived real-life situation. These models show particular design choices which have been made in a particular case. They enable the designer to specify alternatives for these design choices, and to compute the consequences of these alternatives within a limited domain of knowledge.

The reference models can be split on two sub-levels, A1 and A2. In the theoretical framework these levels represent:

A1 - The primitive system, i.e., the various components of the system.
A2 - The constraints, i.e., how the system components are connected together (topology of the system).

In the design framework the counterpart to the primitive system is denoted an entity model. An entity model thus represents a description scheme for a particular real-life situation by design choices and performance indicators. The counterpart to the constraints is called a relationship model. The relationship model represents a heuristic to interconnect design choices, performance indicators and intermediate/independent variables of the entity model.

Based on these considerations, we will identify the key concepts for each of the views in subsequent subsections. The details can be found in Falster a.o. [2]. These details would require too much space here. However, there is an interesting common scheme, according to which each of the views describes the required data. This scheme is depicted in Table 2 below. Note, that the term "synthesis" should be interpreted in its literal meaning from Greek, viz. "putting the elements together in the description".

The notion of optimization indicates the fact that the description is derived from the (re)design purposes of the design framework.

<table>
<thead>
<tr>
<th>Design Step</th>
<th>System Concept</th>
<th>Parameter/Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primitive systems</td>
<td>specified parameter from outside (PO)</td>
<td></td>
</tr>
<tr>
<td>Synthesis</td>
<td>specified parameter from inside (DC)</td>
<td></td>
</tr>
<tr>
<td>System constraints</td>
<td>bilateral/unilateral/etc. (DC)</td>
<td></td>
</tr>
<tr>
<td>Analysis</td>
<td>independent variables (IV)</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>dependent/output variables (OV)</td>
<td></td>
</tr>
<tr>
<td>Optimization</td>
<td>performance indicators (PI)</td>
<td></td>
</tr>
<tr>
<td>Tools</td>
<td>tools for analysis/synthesis</td>
<td></td>
</tr>
</tbody>
</table>

PO = parameter from outside, DC = design choice, IV = intermediate variable
OV = output variable, PI = performance indicator
5.2. **Workflow view**

The objective of the workflow view is to specify the work to be done, and the capabilities that are needed. I.e., the view wants to describe the activities of the primary process. A function needs a capability provided by a resource to do work. When the resource is used, it performs an activity.

The workflow view focuses on the functions that are applied on the products, from design to delivery. It does not focus on the control-, decisions- or information-flow, as these are to be coordinated after the functional sequence and/or distribution of the functions has been decided. A clever distribution will in general make the coordination task simple, and thereby reduce the overall needs for control, decisions, and communication.

The workflow view both describes functions primarily for the primary process (engineering and manufacturing) but also for the management process (Rolstadas [12]). The decisional view is responsible for the decision logic within the functions.

There is a duality between the workflow and the resource view. One describes the work, and the capabilities that are needed. The other describes the means (both humans and tools) and the capabilities provided.

The definition of a function is: “The capability of performing a transformation from a certain set of input to certain set of output. The input and output may be physical or non-physical or both.” Strictly speaking, if we relate this definition to the Walrasian model, it is a description of the Production function, i.e., the transformation from resources (input) to products (output). Thus, the functional view studies simultaneously both the vertical side of Walras (workflow or primary process) on which it puts its main emphasis and the intersection points of Walras (capacities). Product modelling is an important issue in the workflow view.

The workflow description should create a structure of transformation functions and capabilities. Simultaneously, combining types of work to be allocated to these functions is required. Group Technology as discussed by Burbidge is clearly intended for physical transformation, in particular component manufacturing. Whether this technique and Production Flow Analysis can be applied for engineering work has to be investigated, but is not included in the FOF project. Further details can be found in Burbidge [13]).

5.3. **Resources view**

Subject of the Resource View are the human and physical resources in an OKP-system. Different to current production theory the Resource View emphasizes the human resources as resources like creativity, experience and awareness are seen as the most important driving forces especially in OKP. So the resource view analyses and describes, what the conditions are that these resources grow. This is done on the basis of existing theories especially from social science.

We consider the factory of the future from the Resource View as a network of autonomous and qualified working-groups, able to produce complex one of a kind products in an active and cooperative way. In this view the adequate resource structure for OKP is not a primary process, pushed by a separated management process, but a process of mutual interaction, pulled by active, powerful and competent working-groups as basic building blocks. This is the fundamental difference to current production theory.
So the Resource View proposes working-groups, designed as work-systems, as organizational building blocks for OKP. Work-systems are complementary organized human and physical resources to perform autonomous a specific range of functions.

Work-systems offer a range capabilities described as capacities. Capabilities/capacities are the interface to the requirements from the workflow view.

The design of work-systems is not a simple derivation process from workflow-requirements, but a system design process establishing the conditions for production and reproduction of work-systems. Central questions are:

- What are the conditions, that the capabilities of work-systems grow over time?
- What are the conditions, that work-systems will be viable?

The general answers to this questions are the coherent reintegration of engineering, planning, executing and feedback on results and the understanding of work-systems as social systems as general design principles. This includes objectives like to integrate human resources as subject of the process, personality support and tolerance regarding individual differences.

Further details can be found in Hamacher [14].

5.4. Organizational/Decisional view

The goal of the OD view is to develop a conceptual model for the description and the design of organizations and decision making processes in FOF-OKP. This conceptual model should support a designer in performing his task. The objective of a system designer from the OD point of view is to develop a production management system. This production management system translates the missions, goals and objectives of a production system (long term) into operational goals for the primary process (very short term). An OD designer will use the conceptual model which supports him in his design activities. The developed conceptual model consists of two parts: (1) three major decomposition dimensions (organization structures), and (2) a reference model of decision making processes. The result of the designer's work will eventually consist of decision structures and organization structures. Concerning the latter, a distinction can be made between authority structures and responsibility structures. This distinction has not been developed until now.

Decision structures consist of individual decision functions which are in some way related to each other. These relations are the fundamentals of the choices which have to be made by the designer. Through it, the designer describes the way the enterprise objectives are decomposed. Depending on the type of design situation, the designer will start from scratch, or he will both make an as-is analysis and a to-be analysis, using reference architectures or existing systems. Subsequently, the second step of the designer will be to structure the perceived decision functions and to impose an authority and responsibility structure on this decision structure.

For the OD view, the acknowledgment of the three decomposition dimensions (horizontal, vertical and layout) is essential. Based on the GRAI conceptual mode, the vertical and the horizontal decomposition dimensions together define the criteria to structure decision systems. The vertical decomposition criterion is the horizon and the period (frequency) of the decision. This criterion allows to classify the decisions according to their scope; it defines decisional levels. The horizontal decomposition is the type of the decision. The decisions are grouped according to their finality (synchronization, resource management, ...). These two decomposition dimensions allow to build a grid which is a representation of the decisional structure. The third decomposition dimension, the logistic layout, enables the coupling
between the "decisional system" and the "executational system". It allows to take into account the executational system structure which influences the structure of the management system.

The framework of decomposition dimensions can be used for describing and designing organizational and decisional structures. However, it is not sufficient for the OD view to develop only a theory of the structure of decisional systems. In order to have a necessary and sufficient theory of decisional systems, the OD view has also to present a theory for describing decisional tasks. A decisional task is composed of the decision making itself and the activities which surround it. A first result is a reference model for decision making. The reference model depicts which steps are involved in making a decision and indicates where the information flows between those steps reside. Defining decisions and decisional structure in the total organization of the manufacturing system.

The task of the OD designer is as follows: For a specific FOF-OKP system an OD designer will design one decision structure and a lot of decision procedures, one decision procedure for each of the decision functions specified in the decision structure. The decision structure (global) is the overall operational logistics decision process of a firm. This is done by describing the most important operational production management functions, where the emphasis is on the inter-relationships and not on the description of the decision function themselves. Furthermore a decision making procedure (local) is designed for each of the decision functions in the decision structure. These decision procedures specify how the decision making processes should be performed.

In OKP, the synchronization of engineering activities with other activities is aiming at the timing of having operational information available. The medium decision making level tries to have drawings, bill-of-material, routing available by the time these documents are needed for purchasing or manufacturing. The organization of the availability of sufficient information for executing the required operation is important.

The decisional view is basically short, middle and long term oriented.

A final element of decision making, 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 and manufacturing. Such a "workflow" analysis of decision making is important.

For further reading about the OD-view, see Doumeingts [15], and Timmermans a.o. [16].
6. THE DESIGN FRAMEWORK

This section has been influenced by nearly all the FOF workpackages, but the ideas about an open architecture and different simulation models stem mainly from Workpackage 3. This Workpackage was performed under the responsibility of Eero Eloranta, HUT, Helsinki, SF.

Let us shortly summarize the discussion of the design framework as it has been discussed up to this point (see Figures 11 and 13). There are several layers in the framework. The lowest level consists of several particular models, which employ the data from the theoretical framework (P-, R- and D-graphs, for short). The highest level consists of design choices and performance indicators (DC's and PI's).

The list of DC's and PI's was called entity model in Figure 13. We showed in Figure 12 that there exists a connectance model which depicts qualitative or quantitative relationships between these entities.

Before discussing in more detail, what layers and which kind of models exactly may exist between the two extreme layers, it is worthwhile to consider the top layer and the bottom layer first in more detail.

The purpose of the connectance model is simply, to allow for navigating through the available body of theoretical knowledge. It is possible to ask such questions as:

- Which design choices affect immediately a particular performance indicator?
- Is there a guaranteed increase in performance indicator P if there is a decrease in design choice D?

Note, that the answers to these questions are not at all influenced by situational factors of a particular case. Consequently, the answers should be true for any OKP-company. This means, that the connectance model contains knowledge at a fairly high level of generality. It means also, that many questions should remain unanswered at this layer in the workbench.

We are now in a position to explain the type of models which may exist between the two extreme levels.

First of all, there may exist models which explain certain relationships in more detail, but which still claim generalizability over all OKP-systems. Such models have not been developed within FOF, but some (Stella) models come pretty close (e.g. the INTERDEPARTMENTAL CO-ORDINATION MODEL). We will call these models relationship models.

At the other extreme, there may be models which are developed for a particular situation and which do not claim to have generalizability whatsoever. Again, such extreme particular models have not been built within FOF, but e.g. the ENGINEERING ALLOCATION MODEL tends towards this extreme.

We may conclude therefore, that there is a kind of continuous area between generalizability and particularity between the top layer and the bottom layer.

The general approach strived at within FOF has been the following. We have tried to develop models, which can be fed easily with available data of OKP-companies. These models act as "templates" for the description of a particular part of the real world. The current effort of the FOF-consortium is directed at testing, whether this strategy has been succesfull for most of the models.

These models are called drawing models, which refers to their "template" nature. If drawing models are fed with actual data, they are called particular drawing models, otherwise reference drawing models. These concepts are shown in Figure 14 below.
One final remark should be made, before closing this discussion about the design framework. Most drawing models can be run as simulation models on a computer, as soon as they are fed with actual data. However, the models using XBE serve a different purpose. These models collect data on actual cases in order to be able to compare cases to each other and in order to trace the behaviour of OKP-systems over time. This is a more empirical approach to obtain knowledge of interesting DC's and PI's, which can be quite promising if intelligent reasoning and navigating through case material will be provided.
7. MODELS SUPPORTING REDESIGN

This section describes in some detail the various drawing models which have been realized in the first prototype of the FOF workbench. These models were demonstrated at the IFIP WG 5.7 conference, the proceedings of which are contained in this volume. The models were developed in the FOF Workpackage 4 under the responsibility of Jimmie Browne, CIMRU, Galway, l.

7.1. Introduction
In section 3 it was stated, that there are three important areas where OKP-companies should focus on:
- engineering (especially related to the workflow view)
- human resources management
- customer order acceptance (especially related to the organizational/decisional view)

Consequently, the majority of the FOF drawing models can be clustered in one of these areas. However, as just mentioned the models based on XBE are slightly different. The same holds for the model CRIMP. Therefore, in subsections 7.2, 7.3, and 7.4, the drawing models for engineering, human resources management, and organizational/decisional design choices will be discussed. Subsection 7.5 closes the discussion with a reference to XBE and CRIMP.

7.2. Engineering models

Engineering Allocation model
The Engineering Allocation Model (EAM) aims at supporting (re)designers of one-of-a-kind production companies in deciding how much engineering effort to use for different objectives. The model also evaluates the distribution of tasks for work preparation, detail planning, quality control, maintenance and repairs in an organization.

Since each order is unique the engineering work is very important in the one of a kind (OKP) situation. Three other reasons why the engineering work is important in an engineer to order situation are the following. Firstly, the engineering costs are relatively high compared to the production costs. The product development costs must be earned from the profits of one specific product.

Secondly, the quality, leadtime and the costs of the product are largely dependent on the engineering work. The opportunity to save costs is maximal and the costs of changes are minimal when the order is still at a conceptual level.

Thirdly, the uncertainties in an engineer-to-order situation are very high compared to other production situations. These uncertainties are for the greater part caused by the development of the product. The quality, leadtime and costs are not known for new parts which have to be developed for customized products.

Order Release model
A company based on one-of-a-kind engineering, production and production management faces more uncertainty and risk than a company making standard products. this risk rises from the fact that up to a point close to the due date of an order, there may still be uncertainty about parts of the engineering and manufacturing of the product. And up to the shipping date there is uncertainty about the costs, about weather it will be finished in time, weather it will meet the quality requirements etc.

Although producing OKP-products many companies faces the demand for the short delivery times of those of non OKP-companies. This, combined with the economical risk involved, makes the order release strategies very important.

Another important issue is the expected workload in the engineering and manufacturing departments. A heavy workload reduces the flexibility of the company. The question is
weather the order release strategy influence on this flexibility, and thus influence on the ability
to satisfy changing demands from the customer.
This model investigates different strategies for order release, both engineering and
manufacturing orders. The strategies are investigated under different Frame Conditions like
workload, percentage of OKP-components, penalty costs etc.
The model will show that there is no strategy for order release that is superior in all situations.
But it will show that it is normally better to have an early order release (before
specifications/engineering is complete). This is more true when labour costs are a large
percentage of standard components/parts is high. This is even strengthened if the due date is
close and the penalty costs are high.

7.3. Human Resource Management models

Group Design model
The Group Design model is one of the models of the Resources View of the FOF project. The
Resources View considers the factory of the future as a network of autonomous and qualified
working-groups, able to produce complex one-of-a-kind products in an active and cooperative
way. This means that working groups are used as the basic building blocks to meet all required
work.
As the name of the model already indicates, the Group Design model is concerned with the
grouping of employees in the most effective and efficient way (the basic building blocks). The
model tries to give an answer to the question: "What can managers of small working groups do
to keep the capacities and capabilities of these groups on the appropriate level". This means that
the Group Design model tries to give some solutions or at least ideas to, for example, the
operations manager or the personnel manager, to keep their groups organised in the right way.
The Group Design model is therefore not intended for (social) scientists trying to find the exact
relationships between human factors.
This choice and other opportunities to influence the capabilities and capacities of the groups
are the design choices of the Group Design model. The effects of the shift towards OKP or the
setting of design choices on the production system are measured through so-called
performance indicators. The next sections will list the design choices and performance
indicators of the Group Design model and give some examples from the Eurowinch point of
view.

Human Resource Management model
The availability of adequate human resources is a key factor for successful OKP. Caused by
the uncertainty typically for OKP, human work cannot rely here on exact predefined proce­
dures, but has to rely on factors like skills, experience, motivation and coherence represented
by the employees. These factors are living factors, which cannot simply be bought or stored
like other resources. They must be produced and reproduced in a permanent process.
In case of skills and motivation these are relatively simple management problems. External
skills can either be hired from the labour market or internally produced by appropriate training
activities. In order to keep up motivation as well known management policies are available to
tackle this problem.
The more difficult problem is the maintenance of experience and coherence within the staff.
As we know from literature and case studies the acquisition of the necessary (and in the company
available) experience in OKP lasts up to 12 years. This long lead-time of company
internal experience-transfer requires long-term strategies of HRM. This long-term management
view is as well necessary for coherence mutual understanding within the staff. As in OKP
sequences and procedures are not fixed, but different for each order, well developed informal
structures are a backbone of OKP. The development of coherence and mutual understanding
can as well be supported by various HRM-strategies. But the nature of this development is a
growing process - and growing-processes need long-term considerations.
7.4. Organisational/Decisional models

Customer Order Acceptance model
The Customer Order Acceptance model is one of the models of the Organizational/Decisional view of the FOF project. The OD view is to develop a conceptual model for the description and design of an organization and the decision making process within an organization. The Customer Order Acceptance Model aims at aiding a designer in setting appropriate strategies of the Level of OKP for the Factory of the Future by considering the function of customer order acceptance.

The COA model analyses the effects of customer orders on a factory's situational factors given that a strategy for a so called Level of OKP has been set by management. The Level of OKP is defined as the number of standard options for any part of level 1 of a Winch's BOM that are offered to the customer during customer order acceptance. Levels of OKP refers to the setting of Levels of OKP for each part of the winch's BOM. The model considers customer order acceptance for a Make-to-Order company.

The COA model tries to lead the management team through the shift from producing according to forecasts to producing according to customer orders. It aids the management in analyzing the effects of the number of make alternatives (Levels of OKP) on the COA function and consequently on performance indicators like product cost and throughput time. The model tries to learn the management in setting the strategy for the Level of OKP by analyzing (through performance indicators) the effects of orders on the company's situational factors.

Aggregate Production Control model
This model is concerned with two main strategies, namely, a hybrid production management system and aggregated capacity control, both of which strongly influence the productivity of the OKP factory. The model tests these strategies, for different design choices, to see if they result in an effective production control system which allows a factory to move towards OKP. A company capable of OKP production would have a competitive edge in an increasingly competitive market.

In manufacturing, price competition has developed towards competition on performance in delivery and quality, partly due to the increase in product variety. The Factory Of the Future will have to deal with these problems. The timely and correct management of resources is a key area strongly influencing the the productivity of the OKP factory. This is, in turn, strongly influenced by the type of production control system. Production control systems, as they currently exist, are relatively limited in their areas of application. The Aggregate Production Control (APC) model strategy is to use MRP for standard part and standard option part scheduling and JIT for final assembly.

Departmental Coordination model
The departmental coordination drawing model is basically aiming at illustrating the influence of the organization of the primary process on a control point of view. The organization of the primary process can move from an organization by technics (functional organization) to an organization by product (Group Technology organization). This corresponds to our main Design Choice. We have called it the "Type of process". The model has been developed at the level of a production department.

In One of a Kind Production, there is an important need of product type flexibility and in the capability of envolving in an uncertain environment. Through this model, we will try to illustrate various properties of the production process and of the control structure, according to the organization of the primary process.

This model is aiming at illustrating the consequences of different type of organization for these processes. Further more, changes in the organization of the process in a department, lead to adaptation required for the control structure of the department. The model is more to
make the managers aware of the consequences of choosing an organization in a certain context, than finding the optimum solution.

**Inter-Departmental Coordination model**

The Inter-Departmental Coordination Model (IDC) aims at supporting a designer in developing a global inter-departmental control structure. After this global structure is established, the departmental control and each of the decision functions can be described in more detail. For instance, the customer order acceptance (COA) and the aggregate production control (APC) models aim at demonstrating these decision functions in a particular situation, viz. the assemble to order situation (which corresponds with a certain control architecture).

Not all design choices regarding the Inter-Departmental Coordination (IDC) are taken into consideration in the model. The major issues in IDC are: the level at which COA takes place, the role of the engineering department in relation to the manufacturing and assembly, the approach to capacity adjustment on both long term and short term, and the frequency of decision making for each of the levels. Of all these design choices and perhaps more, the IDC DM considers the level of COA, and the frequency of APP decision making.

**7.5. XBE and CRIMP models**

**Expert By Example (XBE)**

XBE - eXpert system By Example - is a tool for supporting analysis and redesign of one-of-a-kind production systems. XBE is an expert system based on case-based reasoning and common theories about production systems.

Improving production system is a continuous process in a company. This redesign usually begins with the analysis of the company’s current performance to find out the areas that have biggest problems or biggest potential for improvement. XBE includes possibilities for both rough analysis and more thorough analysis of company’s situational conditions.

After thorough analysis situational factors describing the company’s situation are grouped into profiles. Based on these profiles the current case company is compared with previous cases in XBE’s casebank to find relevant similarities and feasible design choices. All major business processes like engineering, purchasing, parts manufacturing and assembly are depicted in profiles.

Matching can also occur for instance between design choices or performance indicators if the company wants to know how a particular change may affect the production system or what has been done in other companies to achieve improvement in a particular performance indicator. XBE has been developed to be as flexible a tool as possible with few restrictions in analyzing methods or in scanning the casebank for development alternatives.

**Cross-Impact (CRIMP) Analysis model**

Cross-Impact Analysis is especially designed for strategy search; i.e. the manoeuvring space of a company can be determined, and within this manoeuvring space different action combinations can be compared w.r.t. goal achievement and other criteria. The manoeuvring space of an enterprise is unevenly distributed over the three spheres market, manufacturing, and finance: a company can do a lot to improve its manufacturing performance, while its market and financial situation are more in the nature of opportunities and constraints which the company must observe.

A reliable factory redesign solution requires not only a detailed assessment of changes of performance in production scheduling, manufacturing efficiencies, and specific costs of (component) manufacturing in each function area. Strategically, a company also needs a bird’s-eye view of the interactions between the market, manufacturing management, human conditions, and the financial situation. Such a view sacrifices logistic details and high time resolution for a rough assessment of long-term costs, risks, and benefits of alternative factory redesign options and implementation strategies.
A CRIMP model is a tool with which a bird’s-eye view can be created and manipulated in response to assumed events in the market, in response to technological breakthroughs, etc. It is complementary to the other FOF Drawing Models and requires inputs from them in the form of technical and bottom-line financial scenarios; in addition, it requires a priori assumptions about market developments. Thus it is not a market model, but rather provides an interface to market assessment tools (such as product portfolio analysis or opportunity cost assessment).

8. THE FOF-WORKBENCH

This section describes the architecture and implementation of the first prototype of the FOF workbench. The platform for realization of the workbench was established in the FOF Workpackage 3. The architecture of the workbench was a deliverable of the FOF Workpackage 4. The realization was performed in Workpackage 6, under the responsibility of Bernd Hirsch, BIBA, Bremen, FRG.

8.1. Introduction

The idea of a first prototype of a workbench requires a highly user-friendly platform which can be made available for all partners at reasonable costs. For this reason the FOF Workpackage 3 report [16] recommended the usage of a Macintosh platform. In the FOF project, software engineering is more an experiment, where the functionality of the software is not predefined, but result of a process of permanent refinement. Modelling and systems development has here more the function to express ideas, rather to solidify a piece of reality.

This requires expressive and high-level interactive programming languages like STELLA and HYPERTALK instead of formal methods. When using formal methods, semantic domains, semantic operations and syntactical operations are specified in each step of the approach. The transition from step to step implies the transformation of these domains and operations for representations closer to the final code. Using rapid prototyping no refinement of representations occur, but for each step the domains and operations are changed.

8.2. The software architecture of the FOF-workbench

The purpose of a software architecture for a FOF-workbench is to provide a set of elements and rules as a common environment for all intended Drawing Models. As the Drawing Models stemming from different academic domains, the architecture must be flexible enough to support autonomous developments to express specific views. On the other hand an adequate architecture for FOF must support the integration of different models at different levels of specification.

The software architecture in the FOF workbench is illustrated in Figure 15 below. This architecture considers the workbench of Drawing Models in analogy to a number of cooperating decision support systems as defined by Sprague and Carlson [20]. Each of these Drawing Models is considered as a piece of software, comprising three interacting parts: a database (semantic domains), a model base (semantic operations) and a user-interface (syntactic operations). The database contains all the data required to perform a simulation run of the single Drawing Model. The model base contains one model, viz. the Drawing Model at a generic level while the user-interface defines in what way the user can control the simulation system.

The interaction between each of these parts can be arranged by means of interface languages. This language to interface different Drawing Models was provided by the used language HYPERTALK.

The software architecture in the FOF workbench is illustrated in Figure 15 below.
Although in this architecture each Drawing Model is considered as a separate system, all systems can be accessed by the user via a common access medium on a common hardware platform.

Furthermore each of the Drawing Models does not stand on its own as different models can interact via common data. From a conceptual (data) point of view this means, that each of the models uses its own local conceptual scheme. Together these local conceptual schemes establish a global conceptual scheme for the workbench. The parts of the global conceptual scheme is called the view domain of that model on the global conceptual scheme. This view domain can be split up into an own domain and a foreign domain. The own domain contains the data which are created by the model itself, while the foreign domain contains the data which are obtained from another simulator. This means that the interaction between the models takes place on the overlaps in their own and foreign domain. In the implementation of the workbench this can be seen as the parts of each of the databases, which should be accessible.

Figure 15. Software architecture for the FOF-workbench
8.3. The Model Integration Approach

The above described software engineering approach establishes technical prerequisites for the integration of the Drawing Models into a common workbench. This can be designated as the syntactic prerequisite for integration. But additional to that some semantic prerequisites must be given to enable a real integration process.

A conceptual integration based on a common conceptual model is probably the most sophisticated means to achieve integration. However, the various attempts in this project to achieve a conceptual integration were only partly successful (see [18]). But as outlined there as well, the degree of understanding that has been built up between the members of the FOF consortium provides a good basis to overcome these problems in the future. So this project was to build up this mutual understanding.

In order to align the different intrinsic meanings behind the models into a common direction some specific means were developed and applied: a set of scenarios, entity-relationship diagrams, common user-interfaces and integration workshops between the members of the consortium. These means can be described as vehicles to facilitate mutual understanding and alignment from different intrinsic conceptual meanings.

So in summary the integration approach in this project was initiated and guided by a social process to achieve mutual understanding by appropriate communication vehicles which evolved during the project. The content and function of these vehicles will be subsequently described.

8.4. Common user-interfaces and access mechanism

As the FOF demonstrator consists of several models developed by different authors the danger arose, that a user is faced with very different user-interfaces and access-structures.

To avoid this problem some effort was spent, to define a common user-interface and a unified access structure, both supporting the redesign-scenario described above. This section describes the work done in this area.

Access Mechanism

The access mechanism of the workbench is realized using HYPERTALK. As the Macintosh is currently the common hardware platform for the workbench prototype, it was close at hand to employ the excellent prototyping-features of HYPERCARD for this purpose. So a common access mechanism was developed, which offers a user three ways to access a certain Drawing Model:

1. The default access to the workbench is offered by a window, displaying the round-table picture as shown in figure 2. By clicking to the symbol of one of the managers, a user will access the models related to the view of this management function. A user then can select one of the listed models to call the wanted model. This access is appropriate for a problem oriented entry to the workbench.

2. Alternatively the models in the workbench can be called through REMBRANDT (see WP 3 report), the tool which represents the DCPI network. This can be done by selecting the part of the DCPI network which is of interest to a user. Then a user can depict a node which is related to the problems or questions of interest. By selecting this node, REMBRANDT will show all models which are related to this variable. Clicking to one of the listed models will call the wanted simulation model. This access is appropriate for a conceptual oriented entry.
3. The third possibility to access a model is simply by choosing one of the models from a FOF Drawing Model list. The model will then be called from the general access tool.

This access is appropriate for user, familiar with the structure of the workbench for a quick access to specific Drawing Models.

**User Interface**

In order to offer a user an uniform user-interface a common template was developed using HYPERTALK. As the functionality between the models slightly differs a totally unified user-interface was not feasible. The general structure, however, remains the same for all models. This is presented in Figure 16 below.

![Main control screen](image)

**Figure 16. Main Workbench Model Control Screen**

This entry-screen contains apart from a Information and Quit/Return-button five fields to structure the further access to the model. The standard functions offered at this level are: data input for the model, set the Design Choices for a run, start the a model run, display the Performance Indicators and the store the generated data in a database.
The horizontal aspect of the screen represents the data flow using the model (input -> run -> output), whereas the vertical aspect of the screen represents the control of the model (Design Choices and Performance Indicators).

The function executed by the five fields can be briefly described as follows:

1. **Input for the model**
   This button gives the user the opportunity to load the data from the current case into the model. In some cases this means loading data from a shared database or when there is only a local database, it means loading data from the local database. In some models this field allows as well to load sample data or to edit data by hand.

2. **Design Choices**
   Clicking this button a user can preset the available Design Choices of a model for a simulation run. The design of this function is highly dependant from the specific model selected.

3. **Run the model**
   This object gives the user the opportunity to start, pause and stop a model-run. This means that the loaded data and Design Choices are transferred to the selected model, a model run is started and the results of the run are transferred back to the user-interface for displaying or storage.

4. **Performance Indicators**
   After performing a model-run a user can view the resulting readings on Performance Indicators so that he is able to decide to change his Design Choices on a next run. An example of a Performance Indicator screen is shown in figure 7.

5. **Output to common database**
   If the results of a run are significant, the user can, by clicking this button, storing data in a shared database so they become available to the other models.

9. **CONCURRENT COMPETENCE DEVELOPMENT**

   This section describes the scenario used in employing the FOF workbench in a simulated real-world environment, as demonstrated at the Bremen conference. The ideas and realization of this work was part of the FOF workpackage 6 and were mainly guided by Bernd Hamacher, BIBA, Bremen, FRG.

   The purpose of the FOF workbench is not primarily to stimulate outside redesigners of an organisation in redesign without interaction. On the contrary, the purpose of the workbench is to stimulate mutual understanding of participants in the organisation, and to enhance organisational learning through round-table discussions about alternatives while using the workbench. To illustrate this view on the use of the workbench, consider Figure xx. This figure serves as an illustration of a scenario, whereby a company discusses the strategy of becoming more one-of-a-kind-like. This imaginary company, producing winches, is called EUROWINCH.

   The redesign scenario story around EUROWINCH had the function to illustrate the idea of the FOF-redesign team in a round-table situation as shown in Figure 17 below.
A shortened version of the redesign scenario story is as follows:

"The picture shows managers, responsible for different departments/functions, sitting together as a multidisciplinary team. Members of this team are the financial manager, the marketing manager, the resources manager, the product manager, the operations manager and organisation manager and the Chief Executive Officer (CEO).

This picture shows the top-management of EUROWINCH company. The CEO now has the position, that the future of EUROWINCH lies in OKP. He has the strong feeling and belief that the whole organisation should focus on OKP. But he knows as well, that viable OKP requires an integrated production system based on an integrated strategy.

The CEO is aware, that he by himself does not has the knowledge to sort out the actions to be taken for such a strategy. So he challenges his managers at the round table to make proposals how to arrive best at OKP.

The product manager starts talking about Concurrent Engineering, the concept of Reusability and the urgent necessity to join the world-wide PDES/STEP activities. The round is impressed by this speech, but everyone has the feeling, that he didn't got the point. Then the operations manager continues talking about pro and cons of MRP and JIT and he insists that a combination of these two concepts is the key for successful OKP. But on the question of the CEO how this is related to the proposals of the product manager he has no answer. Even the dispute between the marketing manager and the organisation manager on causes for insufficient customer order acceptance is for most of the other managers not really perceivable."
After finalizing the round of proposals all attended people come to the conclusion, that each proposal is sensitive in itself, but the problem to bridge the knowledge gaps in between is the unsolved and major problem.

The proposal to order a scientific consultant for this knowledge-integration task was soon rejected, referring to bad experiences with such exercises. Especially the CEO points out, that he prefers examples of successful implementations rather sophisticated academic concepts.

Then suddenly someone reports about the FOF-workbench, the different Drawing Models for different views and the uniform structure of Design Choices and Performance Indicators. He points out, that this structure is very well suitable to deepen the knowledge on specific theories and to experience the main characteristics and intentions basically of other views. This would be a very good means to improve the level of mutual understanding. Furthermore this workbench would support a holistic learning by examples as well as the application of scenarios.

So they decided to use this workbench for the intended strategy towards OKP. And indeed they learned, that the different models are useful to translate the vision of the CEO into appropriate strategies within the own view and on the other hand, to express the own intentions to the colleagues. Although the group in the beginning was a bit surprised, that the workbench does not remove the burden of decision making, they soon realized, that they feel now more involved to understand the consequences of decisions. Furthermore they grasped the value, that this workbench does not inhibit to bring in the own knowledge and experience to develop a strategy for EUROWINCH.

This scenario has been used throughout the Bremen workshop as an illustration in demonstrating the FOF workbench. The idea conveyed is that the purpose of the workbench should ultimately be to help the development of cooperating teams to redesign their own part of the organization, by providing insight in the OKP-system as a whole.

10. CONCLUSIONS

In this paper, the most important results of the FOF project have been described. The project claims to have made quite some progress towards integration. The most important results are:

- insight in the nature and the variety of OKP-systems
- establishment of a common description scheme in describing OKP-systems for the purpose of redesign
- establishment of an open modelling framework for redesign in terms of design choices and performance indicators
- implementation of this framework with 10 different models in a prototype workbench.
11. REFERENCES


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