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A Decision Support Framework

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Abstract

In this paper we discuss a decision support framework for concurrent engineering with emphasis on the impact of engineering decisions on the performance of the logistics discipline. It is shown that already existent OR models and methods enable engineers to evaluate their decisions based on quantitative trade-offs. Through this approach the number of iterations in the engineering process needed to correct mistakes discovered during test runs can be reduced and the cost- and performance-effectiveness of product and process design can be increased. The approach is illustrated by a case study compiled of a number of consultancy projects executed by the author over a period of seven years at an electronics multinational.

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1. Introduction

During the last two decades logistics as a business discipline has acquired a lot of attention judging from the amount of literature on the subject. Parallel to the attention for logistics people got aware of the importance of an efficient and effective creation/design process. It turned out that the need for coordination of activities in the supply chain advocated by logistics professionals had its equivalent in the need for coordination of activities during the creation process and, more importantly, a need for input from other business disciplines like production, distributions, sales and service, to be taken into account when engineers take decisions on product and process design. The inherent overall view of logistics professionals turns out be of high interest when thinking about problems such as reduction of time to market, reducing the technical diversity of a product family and product portfolio.

When looking at the literature on logistics one may identify a school of thought commonly defined as the Operations Management (OM) area. Most contributions have a conceptual and case-oriented nature from which practitioners can derive directions for improvement in their own situations. Important contributions in this field are a.o. Prahalad and Hamel[1990], Hamel and Prahalad[1989], Crosby[1979], Imai[1986], Hayes and Wheelwright[1984], Volmann, Berry and Whybark[1992] and Schonberger[1982]. An important issue in the OM area is the effective use of information systems for operations control. These issues are particularly important in discussions of concepts like MRP II (Orlicky[1975], Wight and Landvater[1983]), JIT(Hall[1983]) and OPT(Fox[1984]).

Another school of thought of interest can be found in the Operations Research (OR) area. Logistics control problems have inspired many OR researchers to develop models and methods to support decision making in Logistics and Production control. An excellent overview of the progress made until 1991 can be found in Graves et al[1993].

When studying both sources of literature one tends to conclude that there is a need to combine results and insights from both the OM area and the OR area. In this paper we propose a framework for decision support during the creation process based on insights and results form research on logistics and production control problems. The framework as such is based on well-known results from OM literature, while the decisions support tools are based on results from the OR literature.

The paper is organized as follows. In section 2 we give a generic description of the so-called business chain(Sharman[1984]) and in particular of the relation between the creation/design process and the other parts of business chain. Furthermore we discuss the concept of concurrent engineering. In section 3 we present the overall framework for decision support in concurrent engineering. We emphasize the logistics aspects related to control, performance and costs. In section 4 we discuss the key role played by the Bill Of Material and introduce the Product Family Structures concept. In sections 5 to 8 we apply the framework to a case. The case itself should be seen as a compilation of cases. These cases are based on a number of projects executed by the author over a period of seven years at an Electronics multinational. The cases cover most of the supply chain. The idea is that the problems discussed in each case are problems that a multidisciplinary design team is confronted with. Finally in section 9 we draw some conclusions and indicate directions for further research.

2.   The creation process

In Sharman[1984] a conceptual model of the so-called business chain is given to categorize manufacturing activities. In figure 1 we picture this conceptual model. We adapted the model in Sharman[1984] to emphasize the fact that the activities are executed continually. In this paper we concentrate on the creation process, which has as primary outputs

- products to be sold to customers to generate turnover
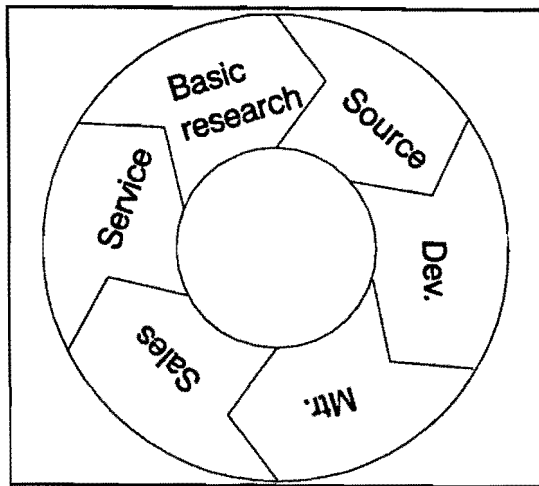- processes that generate these products efficiently and effectively.

Figure 1.   The business chain

From practical experience we know that these two outputs, products and processes, are mostly the outcome of two more or less independent organizations: Product Engineering and Process Engineering. To understand this we study figure 2, which pictures a typical creation process with its subsequent phases. Product Engineering builds prototype products based on the knowhow available, and the concepts agreed on the prototype products are tested for their manufacturability during the product realization phase by Process Engineering and Production. In many cases the production process is less subject to changes then the products, so that new products are manufactured in test-runs on existing production processes. In many cases the test runs reveal problems that are fed back to the product engineers. This process of prototyping, testing and feed-back may repeat itself several times and may be time consuming.

To circumvent these problems it has been proposed by several authors (Hammer and Champy[1993],Boorsma[1993]) to use a multi-disciplinary approach. Furthermore conceptual approaches which provide clear procedures for these teams to ensure coherent decision making have been proposed, e.g. Design For Assembly (Boothroyd[1982]), Quality Function Deployment(Dale et al[1990] and Value Engineering(Mudge[1968]). Most of these multi-disciplinary approaches and applications of the related procedures have been successful in achieving objectives like reduction of time to market, reduction of engineering costs and reduction of manufacturing costs.
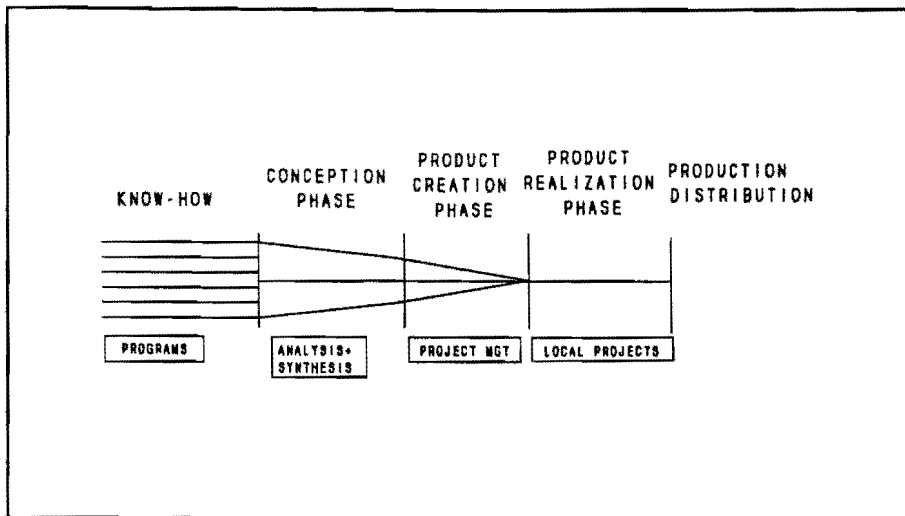
Figure 2.   The creation process.

Another important new main stream in the OM area is Concurrent Engineering. In figure 2 we pictured a creation process with subsequent steps. It has been noted by several authors, e.g. McCord and Eppinger[1993], that it is possible to organize the creation process in such a way, that activities are executed in parallel. When a new product is developed, mostly only in small part of the product is really new. Only for this part we must define new concepts, create new functionality and test extensively. Other parts, e.g. functions, can be re-used such that the creation process for these functions starts in the Product Realization Phase. By concentrating skills on the new part it is possible to reduce the throughputtime of the creation of this new part, thereby reducing overall throughputtime.

From recent experience we have identified a major problem with multi-disciplinary approaches. One of the key factors of success is the ability to build consensus in the team. In many cases this consensus is built by outside experts with a lot of experience in multi-disciplinary teamwork. These experts are used in pilot projects, which are successful, showing the effectiveness of a multi-disciplinary team. However, the expert has played a key role in achieving this success. When new projects are started without the expert supporting the team there is a high risk that consensus is not achieved and the multi-disciplinary team is no longer effective implying higher engineering costs than expected from the results of the pilot project. The conclusion is that consensus can only be achieved if everyone in the team understands why he/she has to compromise on his/her objectives. In the pilot project the outside expert usually has the skills and tools to convince the team of the need for compromise.

Another way to help people in the team to understand the trade-offs to be made is the use of quantitative models. These models can provide information about performance and costs of the future manufacturing process resulting from decisions to be taken by the team. Key factor for success of the use of Decision Support Systems is the validity of the information provided by the system, c.q. models. If the team has verified the validity of the information, e.g. based on comparison of actual performance and costs with expected performance and costs for an existing product family, the team is likely to accept the DSS as a support in decision making.

In the next sections we discuss various aspects of the problem of creating a new product family and show the ability of quantitative models to make trade-offs for complex problems. We claim that the progress made in the OR area on modelling and analysis enables the use of DSS in the creation process.

The aspects discussed have in common that they determine for a large part the ability to control the manufacturing process from supplier to customer. Consequently, the performance of the logistics function is influenced by the decisions made on these aspects, such as commercial and technical diversity.

3. A decision support framework for concurrent engineering

In this section we present a decision support framework for concurrent engineering. The framework enables to identify the decisions to be taken during the creation process and more importantly,

- their relations with the primary process, i.e. the process that satisfies needs in the market from materials that are bought from suppliers, consisting of purchasing, production, distribution, sales and service.
- the way these decision are interrelated.

The emphasis in the framework is on these relations. To be able to identify these relations we use mathematical models from the OR area. Based on the bulk of knowledge from the OM area, e.g. Design For X, modular design, Bill Of Material (BOM), Bill Of Operations (BOO), Activity Based Costing (ABC), Quality Function Deployment, we can develop mathematical models that incorporate these ideas and enable to quantify effects of different decisions.

The underlying idea of the approach is that subsequent decisions determine characteristics of the primary process. These characteristics can be categorized as follows:

1. product structure (BOM)
2. market process structure (customer population, quantities in time)
3. distribution process structure (transport modes, warehouses)
4. manufacturing process structure (BOO, set-up characteristics
5. supplier process structure (geographies, lead times, set-up characteristics)
6. planning and control process (hierarchy, time fences, performance indicators)

In each product creation process one can identify, which decisions affect each of the six categories. The above mentioned multi-disciplinary approaches recognize this by having these multi-disciplinary teams consisting of the following functions:

1. Marketing
2. Sales
3. Production
4. Purchasing
5. Engineering
6. Logistics

In practice one finds a project approach, with a multi-disciplinary steering group, a project manager and a number of smaller teams, mainly consisting of engineers with in addition support from members of the other functions.

As said before experiences of the last five years have shown substantial improvements in quality of the creation process in terms of effectiveness and efficiency due to the application of multi-disciplinary approaches. In spite of the success, it is often unclear what brings about the success. Different functions have conflicting interests. Marketing prefers a great variety of products, production and logistics prefer only one. One might argue that the multi-disciplinary team compromises between the different points of view, where the bias is towards the strongest function. Hardly ever the compromise is based on more or less objective insights into the consequences of decisions taken.

Using the decision support framework the quantitative models applied enable such a more or less objective trade-off. Comparison of alternative decisions should be based on targets set for costs, turnover, profits, ROI, customer service and other performance indicators of interest. One might question the feasibility of such a trade-off during the creation process, since a lot of information may not be available and otherwise the interrelationships are far too complex for a mathematical model to capture adequately. We claim that the progress made in the areas of Operations Research, Information Technology and Artificial Intelligence are such that nowadays a multi-disciplinary team can be supported in decision-making by quantitative analysis of the primary process to be designed. We formulate the following hypothesis:

To quantify the effect of a decision during the creation phase on the performance of the future primary process, one requires a quantitative model of the future primary process.

Here the primary process encompasses the six categories mentioned above. Supposing that the quantitative model has been developed and validated, each function can test the impact of their views through the model analyses. By combining views one can design a number of scenarios, which are analyzed. Based on the analysis one may develop alternative scenarios, until the results in terms of profits, costs, capital investment and customer service are satisfactory. Before going into more detail into the problems faced with this approach we first show that it is nowadays possible to design quantitative models of future and existing primary process.

Modelling the primary process

The keys to the feasibility of modelling the primary process is hierarchy and iteration. The hierarchical decomposition we propose is in line with Bertrand et al[1990]. In figure 3 we show the modelling hierarchy.

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┌─────────────────────────────────────────────────────┐
│   ┌───────────────────────────────────────────┐     │
│   │          goodsflow control model          │     │
│   └───────────────────────────────────────────┘     │
│      ↕↑              ↕↑              ↕↑              │
│   capacity       lead times                          │
│   requirements   characteristics                     │
│                                                      │
│   ┌──────────┐  ┌──────────┐  ┌──────────┐          │
│   │production │  │production │  │production │         │
│   │unit model │  │unit model │  │unit model │         │
│   └──────────┘  └──────────┘  └──────────┘          │
└─────────────────────────────────────────────────────┘
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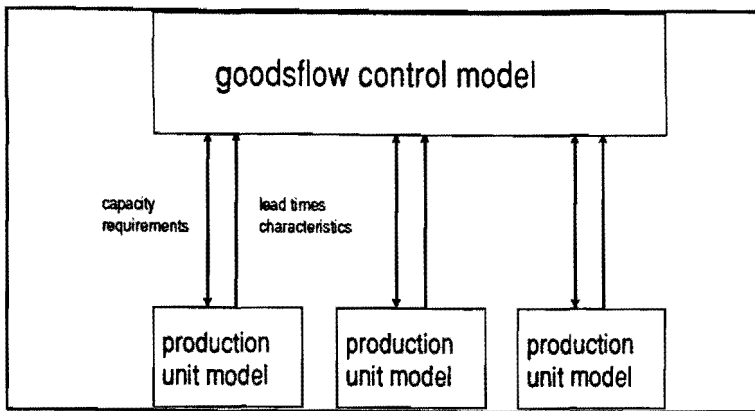
Figure 3   The primary process modelling framework

The upper level model is a so-called multi-echelon model consisting of stockpoints. Each stockpoint uses a replenishment policy. The time between the issue of a replenishment order and its receipt is called the replenishment lead time. Based on lead time characteristics and replenishment policies the multi-echelon network is analyzed to obtain information about performance and costs.The replenishment lead times comprise transport, production and planning lead times. These lead times are determined from the lower level models for so-called production units. In fact at the upper level these production units are black boxes characterized by their lead time characteristics. The goods flow control model is used to support decisions concerning:

- production and warehouse location
- customer service
- stock investments
- stock deployment
- capacity requirements in production and distribution

The analysis applied is based on models from multi-echelon inventory theory, taking into account uncertainty, and combinatorial optimization and mathematical programming in general, taking into account specific constraints w.r.t. capacity and location. For an overview of these models we refer to Graves et al[1993].

A production unit comprises a number of interlinked manufacturing phases for which a due date policy is given, based on throughputtime characteristics. It is clear that the definition of a production unit is a problem in itself. A production unit should be defined in such a way that the production unit manager is able to control the part of the primary process that is executed within the production unit, such that the due date targets can be met, assuming availability of material. In Bertrand et al[1990] it is assumed that the goodsflow control level deals with capacity issues, as well. In this modelling framework capacity is modelled at the production unit level, since capacity requirements are dependent on the capacity structure of the primary process. From the point of view of control indeed the goodsflow control level should ensure sufficient capacity for the production unit the execute the primary process according to targets set.

The models used for production unit modelling are typically taken from queueing theory, in particular the theory for networks of queues (cf. Suri and Sanders[1993]). Furthermore we can apply mathematical programming and combinatorial optimization to more detailed problems w.r.t. capacity requirements, such as short-term or even real-time scheduling. Again we refer to Graves et al [1993] for an excellent survey.

The Decision Support framework consists of the modelling framework together with the information technology that enables to record all information gathered and decided upon during the creation process. To be able to record this information we need the BOM and BOO to be discussed in the next section.

4. The product family structure

During the creation process a key role is played by the Bill Of Material (BOM). The BOM records the decisions taken by product and process engineers. At the beginning of the creation process the BOM is empty, since nothing is known. On the other hand in many situations the creation process builds on existent knowledge about products already on the market. Thus existent BOM's can be used as a starting point. The same holds for the Bill Of Operations, which describes the route of a product along the various capacity units, like machines and operators. In most cases a large part of the production process is known at the start of the creation process.

Many authors (e.g. Orlicky[1975], Van Veen en Wortmann[1987], have suggested ways to use the BOM and BOO as a means of information during the creation process instead of only using these bills as means for registration. A major problem is the magnitude of data involved when creating bills. The point is that in almost any situation not a single product is developed but a family of products. We discuss one particular way of using the BOM and BOO as means of information to be used by all people involved in the creation process. We find that this approach can be tightly linked to our decision support framework.

We start the creation process by determining the commercial requirements in terms of features and functionality for the markets on which we want to sell products. This should be done for each (set of) product(s). E.g. for colour televisions we find that although functionality and features required are the same in two markets, they still may have different commercial requirements for technical reasons. This first step should yield a set of matrices of commercial requirements vs. markets.

The second step is to determine which technical functions are required to fulfil the commercial requirements. For the situation in which the author was present in fact a detailed survey of technical functions was available. This second step yields a matrix of commercial requirements vs. technical functions.

The third step is to generate for each product from these two sets of matrices for each technical function a matrix of commercial requirements associated with this function and the markets on which the technical function is needed. This matrix usually shows that the same technical function is different for different markets. In this step the major choice to be made is how many versions should be developed of each technical function, from which the products are built. Here we have to make a trade-off between many different material-wise

cheap versions or a few material-wise more expensive versions, which yield a lower technical diversity, which in turn is easier to manage at lower cost.

After the decision on the number of technical versions has been taken the fourth step is to create a BOM by building a product from these technical function versions. Typically this approach enables to show the basic product structure in terms of generic technical functions and assemblies, whereas the BOM of a specific product follows from the selection of the appropriate versions. Especially the basic structure for the product family is a powerful communication tool for engineering. Indeed the BOM derived along the lines sketched above is typically an Engineering BOM.

From this Engineering BOM a BOO, the production BOM and the logistics BOM have to be derived. Here we may find that the basic structure has to be fundamentally changed, e.g. for process reasons, which is the case for Printed Circuit Board assembly, where the processes are able to mount specific components, where these components are part of totally different technical function versions. Here we find that the idea of one BOM structure for all business disciplines is a mirage. We belief that we must think in terms of Product Data Management systems, which are based on relational databases and from which the tree-type BOM structures can be derived as needed by different business disciplines.

In the logistics discipline the use of so-called Planning Bills or modular bills has been advocated, especially for Assemble-To-Order and Engineer-To-Order environments (Orlicky[1975], Van Veen en Wortmann[1987]). We have found that these structures can also be very effective during the creation process when developing a large set of consumer products. The planning bill consists of a so-called common block, which in turn consists of all components common to all products, and a number of feature-oriented blocks, consisting of the feature-specific components. It may well be that for the same feature different blocks are needed for technical or commercial reasons. Again these different blocks may be seen as versions. The resulting BOM can be effectively used both in production and logistics. However, effective use of such a BOM requires that especially the common block is frozen early in development, otherwise the maintenance of this BOM is prohibitively time-consuming. Therefore this BOM can only be used when developing new products for which a lot of knowledge about its structure is available at the start of the creation process. This typically holds for low- and mid-end products, but not for high-end products with a lot of new features.

Both approaches, when used appropriately, have the powerful feature that on more or less one A4 the generic family product structure can be shown, which makes it easy to communicate between different disciplines. However, the above mentioned Product Data Management system should truly enable to provide more detailed information on BOM and BOO as required by each discipline. Below we give an indication what kind of data are needed to quantify trade-offs during the creation process. We find that the data needed includes, besides CAD/CAM information, information about past and future sales, logistics costs and production characteristics like setup times and breakdown times.

The information stored in the BOM and BOO is used in the quantitative models to make the quantitative trade-offs needed to ensure effective and efficient decision-making. In the next sections we present a number of such trade-offs.

In this section we only gave a flavour of the power of appropriate BOM- and BOO-structures. We give no further details, although we recognize that creating the appropriate databases for decision support systems for engineering is one of the major problems to be solved in the near future.

5. The market process structure

The first step in the framework is to determine the Market Process Structure. In most cases there is no need for detailed knowledge about the characteristics of the other five categories other then being sure that a product designed for a market can be manufactured such that a profit can be made and the market can be serviced according to customer requirements. The purpose of the analysis of the market process structure is the identification of Product Customer Combinations (PCC). For each PCC a salesplan must be determined from which turnover can be derived, both in quantity and value. For each PCC customer service targets must be set, i.e. required customer lead time, required service level, required flexibility. The salesplan and the service targets are needed to make sure that different scenarios resulting from different decisions proposed during the creation process can be compared on a sound basis. It should be noted that different decisions may result in different PCC's, salesplans and service targets. Scenarios that differ in this respect must be compared with respect to costs and profits. Yet the intention is to get agreement on the PCC's. In fact one should be able to define the PCC's in such a way that in most cases two scenarios differ w.r.t. PCC's because one of the scenarios contains all PCC's of the other scenario and some more. Another comment is that PCC's can be identical to Product Market Combination (PMC), yet more and more it is recognized that targets should be set per customer class (Christopher[1985]).

The identification of PCC's is primarily based on market intelligence and experience. The analysis required to come up with reliable salesplans can be supported by Pareto analysis. An example of such an analysis is given in figure 3. It shows the comparison of the Pareto analysis of a product range in 1989-1990 and the Pareto analysis of the proposed salesplan for 1991.
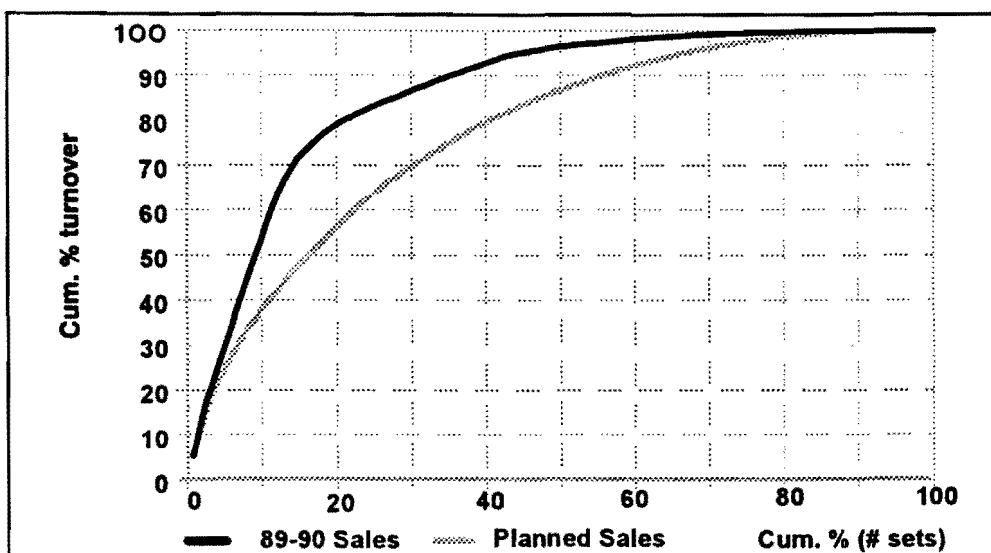

Figure 3.   Pareto analysis of actual sales and salesplan

From this comparison one can conclude that the salesplan is overly optimistic about the sales of slow-movers in comparison with the sales of fast-movers. Clearly a revision of the salesplans is required until the salesplans are in line with the so-called 80-20-rule, i.e. 80% of the sales are realized by 20% of the products.

The Pareto analysis can also be used to test application of a consistent commercial policy in a number of regions, e.g. different countries in Europe. Towards this end we apply a Pareto analysis for the whole market and a Pareto analysis for each region. Next we plot the Pareto index, i.e. the index of a product when sorted according to decreasing turnover, of the whole market against the Pareto index of each region. The result of this is shown in figures 4a and 4b. A consistent commercial policy should yield a strictly increasing function. Figure 4a shows a country which seems to follow its own commercial policy, probably selling countryspecifically styled products for whatever reason. It is important to question these reasons, since such countryspecific products usually require relatively high engineering and production costs, while generating a low turnover. Figure 4b shows a country which follows the overall market policy. In general the function is increasing, yet some downward peeks imply a need for further investigation. In this case these peeks are caused by the fact that some fast-moving products cannot be sold in this country for technical reasons. Note that this analysis can be applied to both actual sales and planned sales.
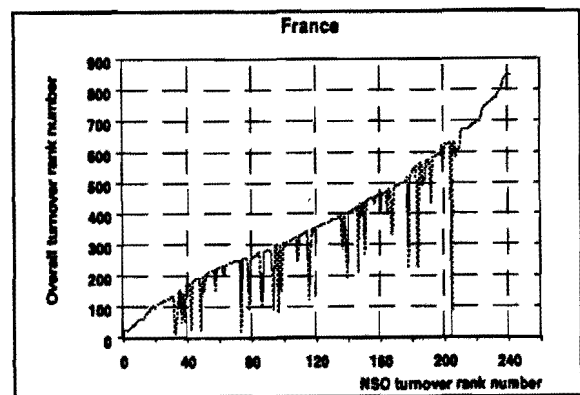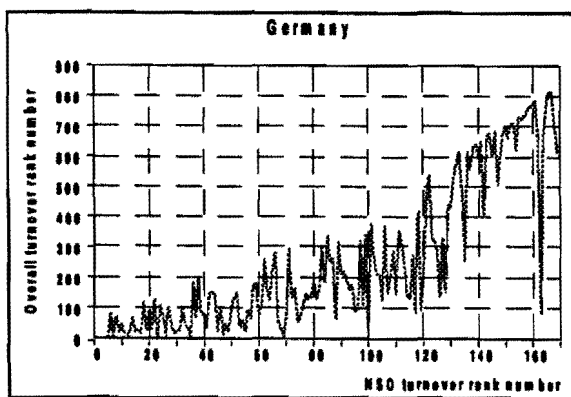

Figure 4a. Non-consistent commercial policy   Figure 4b. Consistent commercial policy.

The outcome of the market process structure analysis should be an agreed salesplan, agreed market prices and guesstimates for the costs. The salesplan and the product mix that results from these salesplans are used for analysis of costs and performance in distribution, production and purchasing. Boorsma[1993] also uses the salesplans for the analysis of engineering costs to be expected together with estimated costs for production in order to assess the profitability of the product mix. Such an analysis further reduces the need for iterations during the creation process because of an ill-defined product portfolio. Note that the product family structures approach discussed in section 4 provides the means to record the information obtained from the market process structure analysis.

6.   The distribution process structure

Once the market process structure and the product portfolio has been identified it is necessary to investigate the appropriateness of the distribution structure when taking into account salesplans and customer service targets. The salesplan can be translated into capacity needs concerning

- transport
- storage
- handling
- administration, including information systems,

so that it is ensured that the right capacity is available. Over the last five years many multinational companies have conducted a study on their distribution process structure. Main input for such an analysis are the sales per product per region. Together with lead time requirements a number of physical distribution scenarios are developed. Typically one varies

- warehouse locations
- modes of transport
- transport frequencies (or equivalently transport lot sizes).
- do-or-buy transport

The optimal scenario minimizes physical distribution costs and satisfies the capacity constraints. A discussion of such an analysis is given in Fleuren and Van Doremalen[1991].

Usually customer service targets with respect to flexibility, reliability and availability are hardly incorporated in such studies. Yet these targets have an immediate impact on the distribution process structure. High availability requirements together with short customer lead times imply a large number of local warehouse, whereas high availability requirements together with relatively long customer lead times may enable to hold stock at only one location. The former situation typically occurs in the food sector, the latter situation occurs in the PC market.

A control problem occurs when a central warehouse (e.g. European Distribution Centre (EDC)) supplies both customers and local warehouses. The question to be answered is in that case: How much stock should be held locally and how much stock should be held centrally. In figure 5 we show the dependence of overall stock investment, expressed in weeks turnover, on the service level of the central warehouse towards the local warehouses. The customer service constraint is that 90% of customer demand should be satisfied from the shelf.

It can be concluded that a central warehouse service level of 50% suffices. A similar scenario analysis can give quantitative estimates of

- required stock levels at all stock locations
- capital investments
- distribution costs (see above)
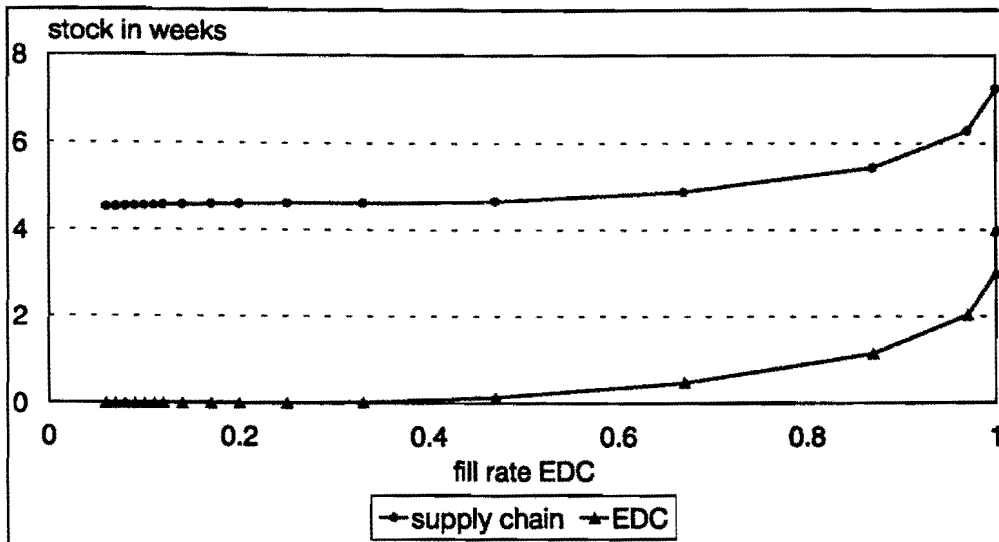- control parameters, such as safety stocks and lot sizes.

Figure 5.   Overall stock investment as a function of central warehouse service level.

Comparing different feasible distribution process structures one can select the best, based on cost, robustness against deviations from salesplans, tariff structures, etc. For more details about this type of analysis we refer to Graves et al[1992] and De Kok et al[1994].

7.   The production process structure

The analysis of the production process structure can be done in parallel to the analysis of the distribution process structure based on the market process structure. In most cases aggregation of PCC's into production process oriented product groups is needed to determine capacity requirements. To do this we follow standard MRP II reasoning (cf. Volmann, Berry and Whybark[1992]). We define a Bill Of Operations (BOO) for each product, i.e. we define for each product its routing along a number of operations. Each operation is executed by some capacity unit, like a machine, robot, operator or production line. The definition of the capacity unit depends on the level of detail used when describing the BOO. For each PCC (or product if there are no specific customer requirements w.r.t. processing) we define the processing characteristics for each operation in the BOO. These processing characteristics include e.g.

-    processing times
-    setup times
-    production batch
-    transport batch
-    reject rates

For each (type of) capacity unit we define its operation-specific characteristics such as

-    break-down times
-    number of shifts, c.q. uptime

Finally we can estimate costs and capital investments involved w.r.t. products, capacity units and operators.

Based on the above mapping of products on operations, c.q. capacity units, we are able to calculate a number of important production process structure characteristics such as

- number of capacity units required
- utilization degree
- fraction of time spent on processing, setup and breakdown
- throughput times
- rejects
- costs and investments

The calculation of these characteristics is based on a queueing network model as discussed in Suri and Sanders[1993] and Whitt[1983]. Queueing networks have been shown to be applicable in many practical situations, where networks consisting of capacity nodes with intermediate flows of jobs to be processed can be identified as in the case in computer networks, data communication networks and production process networks, such as job shops. Based on these powerful models computer packages for analysis of these networks have been developed, such as QNA (Whitt[1983]), MPX (Suri and De Treville [1991] and IDEAL (De Kok[1993]).

To give an idea of the use of such a computer package we discuss the application of the computer package IDEAL. We consider the production process for making colour televisions. In figure 6 we show the parameters that describe the capacity unit, a so-called sub process, ENCASING, which is in fact the last stage in the production process. In IDEAL it is assumed that all products follow one route, i.e. a flow shop is assumed. Furthermore it is assumed that the mapping of PCC's on the BOO can be translated into processing characteristics of an aggregate product. Hence all processing characteristics can be associated with a capacity unit.

SUB PROCESS PARAMETERS			
Name subprocess	ENCASING		
Number of units	4		
Positions	80	Multiplicity	1
Mean processing time	2800.00	C.V. Processing time	0.10
Mean set-up time	420.00	C.V. set-up time	0.00
Empty	0		
Mean org. down time	300.00	C.V. org. down time	0.25
Org. efficiency	85.00		
Mean tech. down time	60.00	C.V. tech. down time	0.50
Technical efficiency	95.00	Rejects	1.00
Production batch	200	Transportation batch	1
Working hours	14.66	# Shifts / day	2
Replacement val. (K)	200.00	Depreciation period	5.00
Interest rate	7.00		
m2 / unit	2.00	Cost / m2	300.00
R&M percentage	8.00	Energy percentage	2.00
Misc. percentage	3.00		
Operators / unit	1.05	Operator costs (K)	40.50

Figure 6.   Capacity unit process description

The capacity unit description is such that almost any kind of production process can be described. E.g. oven processes where multiple products are processes while flowing through an oven can be described by defining setting the variable *positions* equal to the number of products that is processed simultaneously in the oven at any point in time. Another type of simultaneous processing occurs when a capacity unit performs the same operations at multiple

products at the same time, e.g. mounting components on 4 PCB's. Note that in the oven process the products do not have identical operations at the same time, since different products are in the oven for a different time period. One product is about to leave the oven, another just entered it. Of course combination of these two types of simultaneous processing is allowed as well. The capacity unit ENCASING has 80 positions since the ENCASING line is a flow line with 80 work stations and small intermediate buffers.

Based on the queueing network analysis we derive results about performance of the production process. In figure 7 we give an overview of the performance of the production process for the assembly of colour televisions. The number of capacity units per operation is given, the utilization, throughput time and Work In Process of each operation and the overall performance in terms of output and rejects. Note that in the left-lower corner setups, break-downs and rejects are either on or off. IDEAL provides the possibility to put in all the characteristics of the process and then to compare the performance with a (partially) ideal situation with no breakdowns and/or no setup times and/or no rejects. This gives insight in where to improve on the process first. Furthermore we see in figure 7 that a cur(rent) situation is compared with a ref(erence) situation. The latter may be the best alternative until now.

TV-ASSEMBLY	UNITS		PERFORMANCE UTILIZATION(%)		PROD TPT (DAYS		WIP (X 100)	
	cur	ref	cur	ref	cur	ref	cur	ref
AXIAL	6	6	87.6	85.6	0.00	0.00	0.1	0.1
RADIAL INCL.	4	4	99.9	97.6	0.12	0.01	5.2	0.4
SMD	6	6	96.1	93.9	0.00	0.00	0.1	0.1
HAND	3	3	89.6	87.5	0.16	0.13	6.7	5.3
SOLDER	4	4	79.2	77.4	0.08	0.08	3.4	3.4
TESTING	4	4	86.3	84.3	0.03	0.03	1.5	1.2
ENCASING	4	4	79.3	77.5	0.06	0.06	2.5	2.4
TOTAL					0.45	0.31	19.5	12.9

ORG. DOWNS	off	off	OUTPUT / DAY	4300.0	4200.0
TECH. DOWNS	on	on	REJECTS / DAY	0.0	0.0
REJECTS	off	off	OVERALL TPT (DAYS)	7.5	1.9
SET-UPS	on	on			

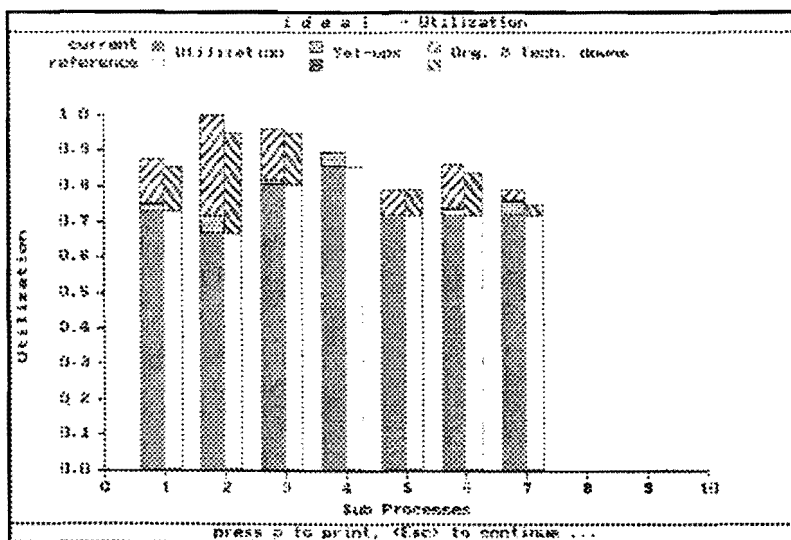Figure 7.   Performance overview

Figure 8.   Utilization characteristics of the production process

In figure 8 we plot the utilization of the capacity units that constitute the production process. We distinguish between processing, setup and breakdown. From this graph we can identify whether there is a need for setup time reduction and/or improvement of the reliability of the capacity unit. Figure 9 shows the dependence of the throughput time on the production batch size. It shows the well-known phenomenon (cf. Karmarkar[1987]) that throughput time increases with the production batch size when the batch is large, but also increases when the production batch is small. The latter is caused by the amount of capacity wasted on setups leading to high utilization and thereby high throughput times.
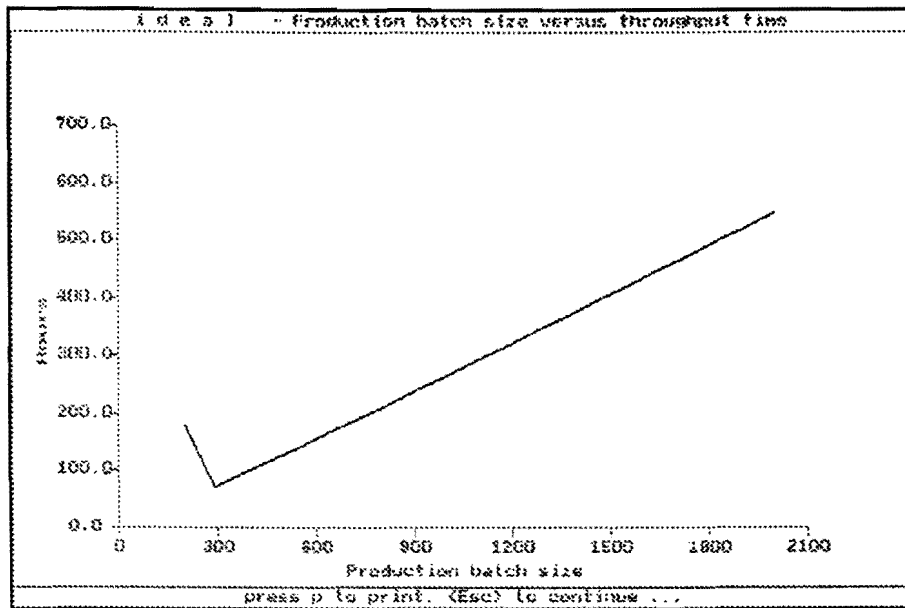

Figure 9.   Throughput time dependence on the production batch size

In figure 10 we give a summary of the total costs and investments involved with the present production process.

```
                      ————— Cost Summary —————
                INVESTMENT  <———————— ANNUAL COST x 1000 ————————>
SUB-PROCESSES    x 1000     INVESTMENT     SQM      OPERATOR      TOTAL
                cur   ref    cur   ref   cur  ref   cur   ref    cur   ref

         AXIAL  2280  2280   460   460    45   45   483   483   1285  1285
RADIAL  INCL.   1804  1804   364   364     4    4   594   594   1196  1196
           SMD  4872  4872   983   983    18   18   846   846   2480  2480
          HAND    96    96    13    13     2    2   243   243    270   270
        SOLDER   742   742   132   132     2    2   170   170    401   401
       TESTING  1200  1200   342   342     2    2    37    37    537   537
       ENCASING  800   800   188   188     2    2   340   340    635   635

        TOTAL 11794 11794   2481  2481    76   76  2714  2714   6804  6804
```

Figure 10.   Cost and investment summary

Figure 11 gives an overview of the capacity requirements, i.e. number of machines and operators required.

SUB-PROCESSES	UNITS				OPERATORS			
	PRESENT		MINIMUM		PRESENT		MINIMUM	
	cur	ref	cur	ref	cur	ref	cur	ref
AXIAL	6.0	6.0	5.3	5.1	11.5	11.5	10.1	9.9
RADIAL INCL.	4.0	4.0	4.0	3.9	14.2	14.2	14.1	13.8
SMD	6.0	6.0	5.8	5.6	20.2	20.2	19.4	18.9
HAND	3.0	3.0	2.7	2.6	6.2	6.2	5.5	5.4
SOLDER	4.0	4.0	3.2	3.1	4.2	4.2	3.4	3.3
TESTING	4.0	4.0	3.5	3.4	0.8	0.8	0.7	0.7
ENCASING	4.0	4.0	3.2	3.1	8.4	8.4	6.7	6.5
TOTAL					65.5	65.5	59.9	58.5

Figure 11. Requirements for capacity units and operators

Using computer packages like IDEAL and MPX rapid modelling becomes available to people who have to take decisions on both process and product design. Introducing new components and new features both may lead to considerably higher costs in production because of additional setup requirements and higher probability of machine failures. The tools enable to analyze a lot of alternatives without the consequences of real-world experimentation. This is one of the keys to truly concurrent engineering and the reduction of the number of iterations during the creation process.

8. The supplier process structure

As discussed in section 4 during the creation process the BOM is determined. Consequently specifications of components to be manufactured by suppliers are defined. More and more it is acknowledged that during the creation process suppliers must be involved for the same reasons why production and distribution must be involved: The components to be supplied must be specified in such a way that the function they must fulfil is provided by the supplier in a cost-optimal way. Cost-optimal implies that from the manufacturer's point of view the business chain costs associated with the component are lowest. Hence these costs should include production costs, like rejects and rework, and service costs because of malfunctioning of the component.

The specification of the BOM and the selection of suppliers have an immediate impact on the performance and costs of the logistics function. Unreliable suppliers cause high component stocks and frequent replanning because of quality and availability problems. If a component causes malfunctioning of a final product then special actions have to be organized by logistics and service to ensure that the customer's problems are solved adequately.

ITEM 12NC	DESCRIP TION	PRICE	CUR REN CY	LEADTIMES			ENDPRODUCT: 12NC/CTV						
				SLT	TT	ST	1	2	3	4	5	...	N
12345	ABC	12	NLG				1						
23456	DEF	34	BEF				1		1	1	1		
34567	REF	234	FF					1					
45678	TRE	4568	PES				1	1		1	1		
56789	GRT	72	LT				1						
67890	TYH	54	NKR					1			1		
78901	WEB	129	SKR					1		1			
89012	TRF	456	DEM				1			1	1		

Figure 12.   BOM and planning data

In this section we restrict ourselves to the analysis of the impact of a particular choice of the set of components from which a product family of colour televisions is built on the costs and performance of manufacturing. In figure 12 we give the basic data we start from, i.e. the BOM and the lead times of the suppliers, the safety lead times and prices of the components.

From these data we can derive the so-called commonality of the component. In figure 13 we give two different types of commonality definitions, which are both valuable. For both definitions we conjecture that a higher commonality implies lower logistics costs, caused by lower costs for supplier management and stock capital investment.

In figure 14 we show how components can be characterized by a combination of the two defined commonality levels. For each combination we highlight which business discipline should work at solving the problem of a possibly too low commonality.

Figure 13.   Two definitions of commonality

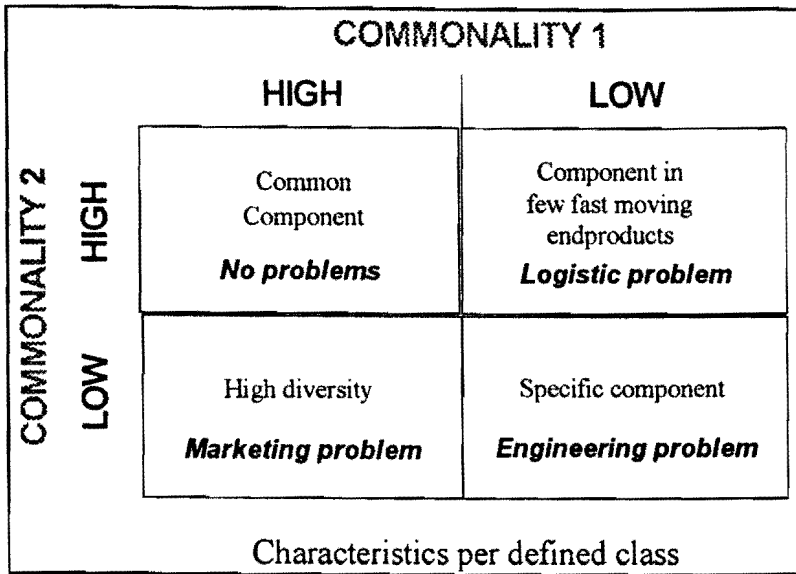|	COMMONALITY 1	
	HIGH	**LOW**
COMMONALITY 2 — HIGH	Common Component *No problems*	Component in few fast moving endproducts *Logistic problem*
COMMONALITY 2 — LOW	High diversity *Marketing problem*	Specific component *Engineering problem*

Characteristics per defined class

Figure 14.   Component characterization and associated management problem

On the other hand we found from a more detailed analysis that a low commonality does not imply high stock capital investments. This follows from figure 15 where we plotted the commonality against the number of days of stocks needed to guarantee a pre-specified fill rate. We find that the same stock investment can follow from almost any commonality level. Note that there two components with commonality 1 and high stock investment. These components turn out be common, indeed, but these components are used in different numbers by different products. This causes high fluctuations in component demand when the product mix changes. We found that for our case of colour televisions there are a number of very expensive components with a commonality of about 10%. These components are CRT's. Yet the capital investment required was low. This implies that the demand for a particular CRT is quite stable and probably very easy to forecast. From figure 15 we can in fact try to group end products by their components with both a low commonality and low stock investment. The sales volumes for the resulting product groups should be easy to forecast. It may be expected that these product groups can be linked to one or more features. If so, one can forecast mid-term component requirements from mid-term feature forecasts in stead of mid-term detailed end product forecasts.
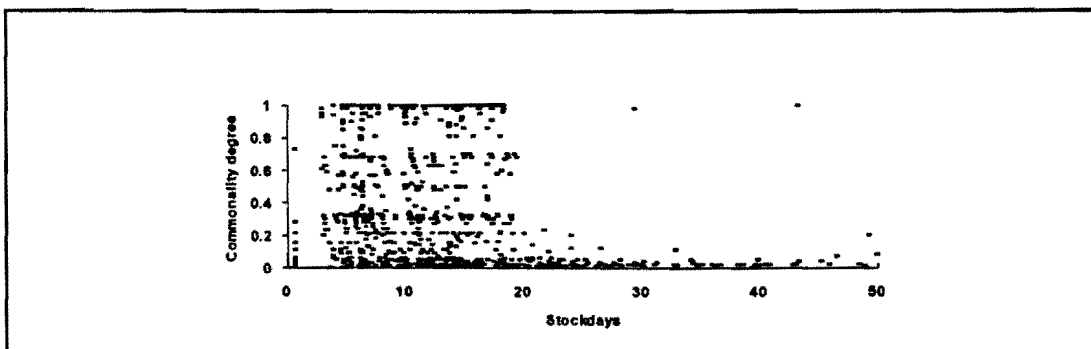

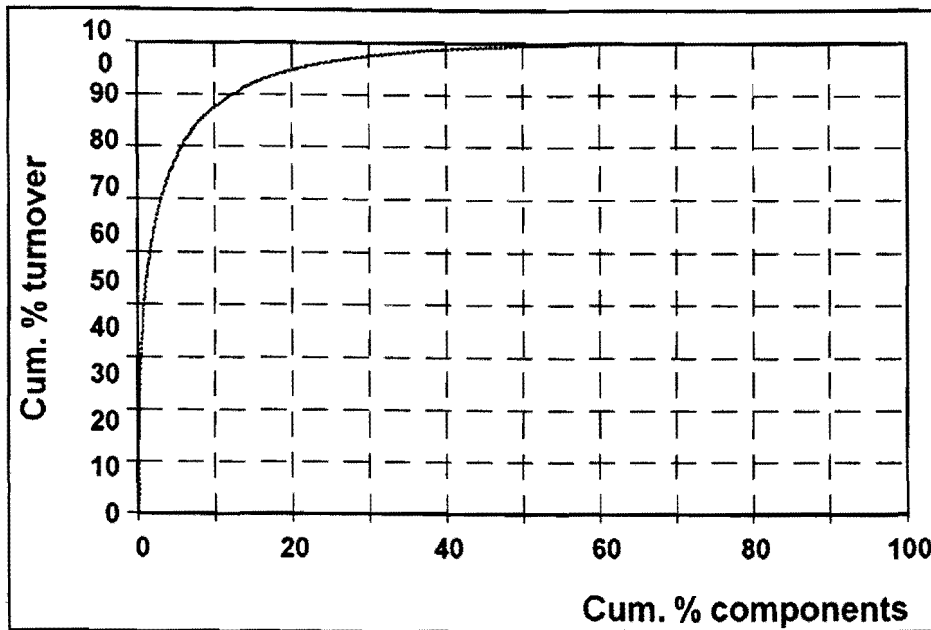Figure 15.   Commonality versus required number of stockdays

Figure 16.   Pareto curve for the components

In figure 16 we plot the pareto curve. Note that the 80-20-rule does not apply. This is caused by the relatively expensive CRT's that constitute most of the cost. We use this Pareto sort of components to order there relative importance. The next step in the analysis is to estimate the fill rate for each component based on current parameters for supplier lead times, safety lead times, lot sizes and demand patterns. Typically we want to ensure that the fill rate is sufficiently high for each component, otherwise we will be confronted with the combined lack of availability when assembling the colour televisions, leading to a lot of planning instability and overhead costs. From figure 17 we find that there is a considerable difference in fill rate for different components. We do not see any clear pattern, while we might expect high fill rates for the cheap components in the tail of the Pareto curve. We note here that we used standard inventory theory (cf. De Kok [1991], Silver and Peterson[1985]) to determine the fill rates for each component.
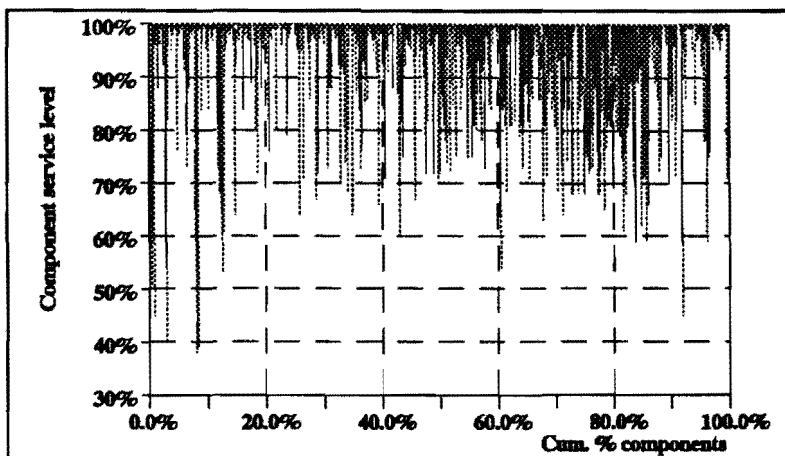

Figure 17.   Actual fill rate for the components sorted according to the Pareto-order.

However, we are not interested in the fill rate of components as such, but in the impact they have on the planning of set assembly. In figure 18 we plot the probability that we can assemble a set according to planning. It should be noted that the analysis yielding this so-called set completeness probability is a heuristic analysis. Until now no straightforward exact method exists to determine the set completeness probability for arbitrary mixed product structures, where a component is used in a number of products and a product consists of different components. Yet the results obtained heuristically are quite useful, firstly qualitatively, but secondly, quantitatively as well, since the set completeness probabilities seem reasonable. Interestingly, we do not find the commonly stated result that if the fill rate is 99% for 100 components, say, then the fill rate for the product is $(99\%)^{100}$, which is about 0. In this case each television consists of about 700 different components and yet the factory is able to execute according to plan most of the times.

The results in figure 18 indicate that there are some problematic sets. For these sets we must investigate which components with low fill rates cause the low set completeness probability. Increasing only the stocks for these components may have a considerable positive effect at low cost.
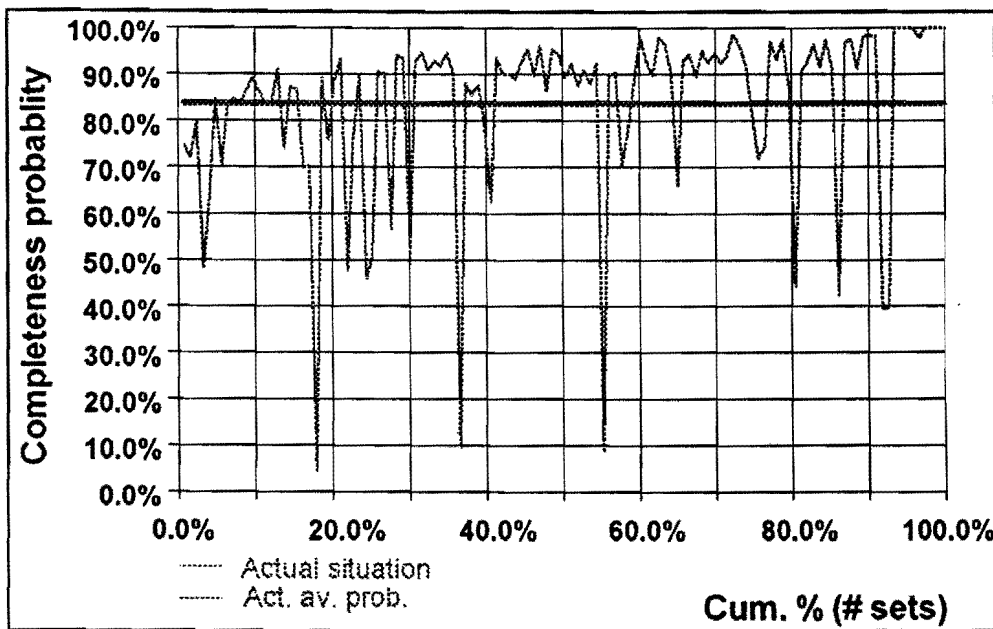

Figure 18.   Set completeness probability

The analysis sketched above provides a means to systematically evaluate the current component selection w.r.t. costs and performance, while specifying the BOM in more and more detail. Klinker[1991] developed a similar hands-on method to show the quality of purchasing management. From existing BOM information the geographical spread of suppliers is analyzed, the number of suppliers, the correspondence between actual stock levels and the expected stock levels according to the parameters set in the MRP Purchasing system. This latter method has proven to be effective and has been applied in factories in Europe and the Far-East.

9.   Conclusions and further research

In this paper we have discussed a decision support framework for (concurrent) product and process engineering with an emphasis on logistics aspects. The framework shows what information is required to be able to make quantitative trade-offs using mathematical models. The fact that models are used enable to make these trade-offs in the absence of physical products and processes and while information is only partially available. The use of models prevents extensive and expensive testing on existing production systems and also prevents iterations because of problems that surface during testing.

We furthermore showed that already available models and methods can be used, so that the attention can be focused on the application of the models and methods to the situation under consideration.   In section 7 we discussed the production process structure and showed a generic definition of a capacity unit in industrial engineering terms. Similar generic definitions are required for the market process structure, distribution process structure and the supplier process structure. Such generic definitions bridge the gap between quantitative modelling and standard engineering terminology and standard engineering modelling concepts. This area is a fruitful research area for both OM and OR scientists as well as for IT scientists, that provide the enabling technology.

A final remark is in order here. The reader must have become aware of the fact that no discrete simulation modelling and analysis has been used. Although such modelling provides great flexibility, numerous projects have shown that in situations where a lot of decision variables have to be set, discrete simulation is too time consuming. A simple example can illustrate this. We discussed in section 6 the distribution process structure. The EDC scenario comparison is based on equal customer service levels for all scenarios. If one would use discrete simulation modelling only, even finding the appropriate control policy for one scenario ensuring the target customer service levels may be too time consuming. Progress made in the OR field enables a hybrid approach, using mathematical models for scenario selection and discrete simulation modelling for further details of the selected scenario(s).

Further research of the author is focussed on extending the Decision Support Framework into a DSS, that can be considered to be generic for specific types of production environments, following the typology in Bertrand et al[1990]. This research should clarify issues concerning BOM- and BOO structures to be used in engineering, production and logistics.

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