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Dynamics of the customer order decoupling point: impact on information systems for production control

PAUL M. J. GIESBERTS and LAURENS VAN DER TANG

Abstract. The difficulty of information support for production control in hybrid production situations is discussed This means in production situations in which make-to-stock, assemble-to-order and engineer-to-order are combined and where the combination may also be dynamic The first part describes the main information requirements in different production situations Different types of hybrid situations and the specific information support required in such situations are described In the second part a commercial system is described that offers functions for different production situations and which at least partly supports production hybridity

1. Introduction

The structure of production control systems is significantly influenced by the extent to which a customer determines product specifications Furthermore, this structure is influenced by the point in the goods flow where forecast-driven production and customer order-driven production are separated. This point is called the customer order decoupling point (CODP). With respect to these two characteristics, three different production situations are distinguished in this article (Figure 1) Each of these situations calls for specific requirements on the production control system

These production situations each have their own production control characteristics In the make-to-stock situation, standard end products are made forecast-driven and delivered to customers from stock The major production control issues in this situation are the determination of the forecast by end product and the preparation

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Authors. Paul M J Giesberts, Faculty of Industrial Engineering and Management Science, Eindhoven University of Technology, PO Box 513, NL-5600 MB, Eindhoven, The Netherlands; Laurens van der Tang, Software Development Group, Baan International B V , P O Box 250, NL-6710 BG Ede, The Netherlands, (*corresponding author*)

PAUL M J GIESBERTS received his MSc degree at the Eindhoven University of Technology, Faculty of Industrial Engineering and Management Science, in Eindhoven, the Netherlands He currently is a graduate student at the same University His research is directed at operations management, especially the improvement of the master production scheduling function

LAURENS VAN DER TANG started his career in Baan Info Systems as a project manager He was responsible for several projects in Europe where standard packages for production control have been implemented At this moment he is still working for Baan, and, in his position as Product Development Manager, he is responsible for the development of Baan International's standard software products

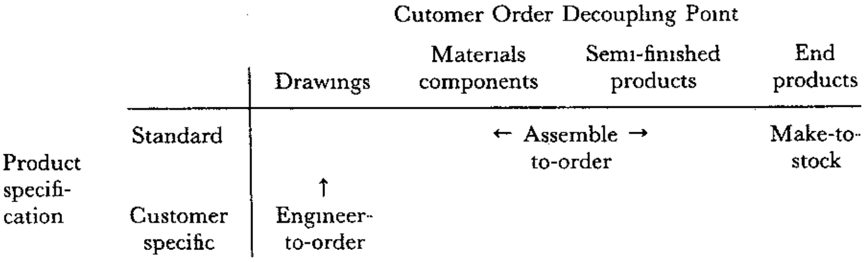

Figure 1 Production situations

of a production plan for these products, considering restricted capacity availability (Berry *et al* 1988). Work orders for items on a lower level in the product structure can be derived directly from the production plan for the end products.

In the assemble-to-order situation a wide variety of standard end products exist. Building all end products to stock would result in high stocks and a poor customer service. Hence the end products are assembled to customer order from standard assemblies and components available in a range of end products. These assemblies and components, the CODP items, are produced on forecast. Production control decisions in this situation can be distinguished as decisions concerning forecast-driven production of CODP items and decisions concerning customer order-driven production of end products (Berry *et al*, 1988, Wammerlov 1984). Production control of the forecast-driven part of the production is comparable with the make-to-stock situation. For the CODP items a forecast and a production plan are made. Work orders for lower level items are derived from the production plan. In an assemble-to-order situation, however, there is a need to coordinate the forecasts of the CODP items in order to obtain matching sets of parts for the assembly of end products. A well-known method to obtain these matching sets of parts is the two-level MPS technique. For a family of end product variants a forecast and a production plan are made. The production plan (corrected for promised customer orders) is exploded to the forecast of the CODP items with a planning bill of material. This planning bill of material represents the usage of the CODP item in the family. The customer order acceptance decision initiates the production of the end product in the assemble-to-order situation. For a customer order the availability of CODP items and capacity must be checked to confirm or to set a certain due date. The customer order is then translated to work orders for (customer order-driven) assemblies and for the end product. Monitoring of the progress of each customer order is necessary to meet the agreed due dates.

In the engineer-to-order situation the product is not fully technically specified the moment a customer order is to be accepted. In this situation a network of aggregate tasks is made based on a rough specification of the customer order (Bertrand *et al* 1991). In this network, engineering is also considered as an aggregate task. For each of the aggregate tasks the lead time and the use of critical capacities is estimated. Based on the actual workload in production, the already accepted projects and the availability of capacities, the aggregate network is scheduled and a due date for the customer order is promised.

In the first phase of the project, engineering work is done and some long lead time materials are purchased. As a result of the engineering activities, specifications of parts of the product (aggregate tasks) become gradually known. Based on these specifications each aggregate task is gradually translated into a detailed activity network which accurately describes the production activities which should be performed. The detailed network is scheduled between the start date and due date of the aggregate task from which it is derived. After detailed scheduling the activities (work orders) can be released to the shop floor.

Each of the production situations in question requires specific production control decisions. For companies, this implies the following problem. Most of them discern more than one of these three production situations. There are, for instance, a lot of companies which make special products to customer order in addition to their standard assortment. Even more complicating is the fact that, in practice, the CODP is not fixed at a certain level in the product structure. Assemble-to-order companies, for instance, sometimes produce fast-moving variants of the end product to stock if a situation of idle capacity occurs. Hence, companies often have a hybrid production situation and therefore must combine production control decisions for different production situations. These companies need information systems which are capable of supporting combinations of these different production control decision types.

In this article we focus on the impact of hybrid production situations on requirements for standard software packages for production control. First a description is given of different types of hybrid production situations

(Section 2) Then the consequences of each of the three distinguished types of production situations (make-to-stock, assemble-to-order and engineer-to-order) on the structure of information systems is given (Section 3) Next the impact of hybrid production situations on the structure of information systems is described (Section 4). Finally, specific solutions are presented as currently applied in a standard software package for these kinds of situations (Section 5).

2. Different production situations within one company

Most companies face hybrid production situations. In this section three types of hybrid production situations are distinguished. These types can occur in combination within one company

The first type of hybridity, called *assortment hybridity*, concerns situations where the items of the total product range of the company cannot all be characterized as either make-to-stock, assemble-to-order or engineer-to-order This type of hybridity can occur in two forms In the first place, end products in the assortment of a company may be of a different CODP-type. There are many examples of companies which produce standard products to stock but also make products to customer specification (e.g. producers of heating systems) In the second place, *within* the product structure of a certain product, items can be produced according to different CODP-types For instance, some engineer-to-order companies purchase and produce long lead time components with a high commonality on forecast to reduce delivery times.

The second type, called *long-term hybridity*, is caused by the evolution of a product during its life cycle During the subsequent phases of the product's life cycle it may have different CODP-types Examples of long-term hybridity are found among manufacturers of machinery The design of a new product is made as commissioned by and in close consultation with the customer (engineer- to-order) After the first machine is delivered, the customer sometimes orders the same configuration again (assemble-to-order). It frequently occurs that a manufacturer of machinery develops a standard machine based on a configuration which is initially built to customer specifications (assemble-to-order or make-to-stock). If the product has reached the end of its life cycle, production is again solely to customer order (assemble-to-order).

The last type, called *operational hybridity*, is the short-term dynamics of the CODP caused by customer order characteristics and incidental factors. Four different causes for operational hybridity are distinguished:

(1) *Customer order flow*
The position of the CODP depends on the size of the order flow. Companies confronted with a decreasing order portfolio may decide to switch to manufacturing sub-assemblies or finished goods to stock, whereas normally they would produce them to order. We find this type of situation in, for instance, the aircraft industry, which in periods of low market demand will resort to 'white airplane' production. In companies subject to season-dependent demand the position of the decoupling point may vary as well, depending on the stage in the seasonal pattern

(2) *Size of the customer order*
The position of the CODP depends on the size of the individual customer order The arrival of a customer order for standard products of uncommon size, for instance, may lead the company to decide to make the product to order Purchasing is sometimes done to order as well, in order to profit from price advantages involved in purchasing large quantities.

(3) *(Unexpected) shortage of stock*
The position of the CODP depends on the availability of CODP items in stock For instance, if a customer orders a make-to-stock end product which is not available, a quantity of the replenishment order in production (which equals the order quantity) will be reserved for the customer Obviously the CODP then moves upstream Another example is the 'reconfiguration' of end products already produced to stock, to fulfil a certain customer order It may even be necessary to use products made or being made for other customers!

(4) *Incidental factors*
Finally, all kinds of more or less coincidental factors influence the position of the CODP For instance, customer orders in an assemble-to-order situation which are cancelled when the (customer-specific) product is already in production A second example is the use of alternative components in a product, because the shipment of the original component has not passed the quality check

The different types of hybrid production situations have an impact on the requirements for the production control information system This will be explained in Section 4 To fully understand this impact, however, it is important to first explain the impact of the three different 'pure' production situations (make-to-stock, assemble-to-order and engineer-to-order) on the requirements for the information system This is described in the next section

3. Impact of production situation on requirements for information systems

In describing information systems for production control, a *registration* and a *decision support system (DSS)* function of the information system are distinguished. The registration function consists of a *state-independent* and a *state-dependent* part.

The state-independent part of the information system records all data which does not depend on the order and material flow. In a make-to-stock situation for instance, the product, product structure, machines, personnel, suppliers, etc., are state-independent data. Moving from a make-to-stock situation to an engineer-to-order situation, the product and routeing data becomes more dependent on the customer order. This *order-dependent product data* can be seen as a transition from state-independent to state-dependent data.

The state-dependent or *transaction processing* part of the information system records all data that represents the state of the materials and orders in the production system, e.g. customer orders, work orders, stock positions, work-in-progress, etc.

The decision support system part of the information system supports the user in making production control decisions. Examples of such support are the advising of production plans, determination of work order priorities, progress monitoring and exception reporting, etc.

Dependent on the production situation considered, requirements on these different functions of the information system differ (Bertrand *et al.* 1991). These differences are shown in Figure 2.

3.1. *State-independent data*

For all three production situations the required state-independent data are, to a large extent, the same. Information on machines, personnel, customers, suppliers, etc., can be represented by the same data structure. However, the data concerning products, product structures and routeing differs significantly between the production situations.

In the make-to-stock situation the assortment consists of a 'limited' number of end products. All these products and all lower level items in the product structure of these end products are specified in item records. Relations between the items are specified in single level bills of material (BOM). For all items a routeing can be specified, which determines the sequence of operations to be performed in order to produce the product. The operations are related to the capacities necessary to perform the operation.

In the assemble-to-order situation a large assortment of end products exists. Hence recording of all possible end product variants per family, with their product structure and routeing would result in excessive computer storage use and considerable efforts to maintain all data. In this situation the use of generic items, bills of material and routeings is proposed (Guerrero and Kern 1990, Van Veen 1991). A family of products with a similar product structure is described as a generic structure. All possible variants of the end product within a family are considered as one generic item, which can be characterized by a set of features (e.g. colour, length, power, material, etc.). By choosing an option for each feature, a variant of the family can be specified. The chosen feature option combinations determine which (single level) generic BOM relations are valid for the variant of the generic end product, but also specify lower level generic items with their generic BOM. The corresponding routeings are also generated from the generic routeings based on the chosen feature option combinations. This generation process stops at the level in the BOM

	Main difference	Make to stock	Assemble-to-order	Engineer-to-order
State independent	Items BOM routeing	Standard item Standard BOM Standard routeing	Generic item Generic BOM Generic routeing	Reference item Reference BOM Reference routeing Reference network
Order dependent production data			Configured item Configured BOM Configured routeing	Customer specific item/BOM/routeing/network
State dependent	Stock + orders	Anonymous by item	Anonymous by item + customer	By customer
DSS	Control concept	MPS + MRP	Two-level MPS + MRP and FAS	Multi project planning + detailed schedule

Figure 2 Requirements on information systems

where standard items are used. In most cases this is the level at which the CODP is defined. Note that, as soon as the BOM is specified by the feature option combinations required by the customer, the specific BOM is identified by the customer order and therefore becomes state-dependent information.

In the assemble-to-order situation a planning BOM is used to generate forecasts for CODP items A planning BOM relates the family of end product variants to the assemblies and components which are produced by forecast, using quantity-per numbers and percentages

In the engineer-to-order situation, state-independent items, BOM and routeing data are no longer used as a basis for production control. Instead, these data are used as a tool to support engineering activities and are called reference data (Bertrand *et al* 1991). The main requirement for the reference data is that they can easily be identified in terms of product functions This enables a company to reuse former engineering and job assembly results New projects should be related to reference aggregate networks and reference aggregate tasks This enables engineer-to-order companies to quickly define aggregate networks for new projects

As soon as reference data are related to a customer order they become a part of the state-dependent part of the information system

3 2 *State-dependent data*

The registration of state-dependent information (orders and materials) for the three production situations differs merely in the identification of products, stock and orders In the make-to-stock situation all end products are made by forecast. Hence all material and order state information is identified by item

In the assemble-to-order situation the materials and orders upstream of the CODP are also identified by items The orders for the production of the customer-specified variant and the resulting customer-specific work in progress and stock are identified by the customer order This is necessary because in this part of the goods flow standard items do not exist. The specified items and BOMs are generated from generic structures Another reason for identifying materials and work orders by customer order is that the progress of the customer order can be monitored. The last reason for identification by customer order is that the product's configuration determines the cost of the product. Identification of production activities by customer orders makes it possible to compare the estimated with the actual cost.

In the engineer-to-order situation the detailed network and activities (work orders and purchase orders) and materials are identified by the customer order, for the same reasons as mentioned for the assemble-to-order situation An extra requirement for the engineer-to-order situation is that aggregate tasks and aggregate networks entities are defined. The information system must be able to relate the detailed activities to the task from which the activities are derived, to monitor the progress of the total project on aggregate level

3 3 *Decision support system*

In describing the requirements for the DSS part of the information system for different production situations, we distinguish levels of decision making (Bertrand *et al* 1991) At shopfloor control (SFC) level, work order recommendations are released and assigned to capacities, and progress of the order is monitored On a higher level, the work order recommendations for production departments and purchase order recommendations are determined by the material planning function. On the highest level, production and sales are co-ordinated Differences between the make-to-stock, assemble-to-order and engineer-to-order situations on the DSS information system requirements mainly present themselves at material planning level and at the level where sales and production are co-ordinated. Therefore we only discuss these two levels

In the make-to-stock situation, co-ordination between production and sales is concentrated on forecasting of end product demand and determining the production plan for these items, considering capacity availability Customer orders are accepted based on current and projected available stock. The information system should support the determination of forecasts, the preparation of a production plan, the capacity check of the production plan and the acceptance of customer orders using an available-to-promise kind of logic (Everdell 1984) If the production plan is feasible, material planning can determine order recommendations for lower level items directly from the production plan This is possible since lead times can on the average be considered as constant in a situation of standard products and a constant capacity utilization

In the assemble-to-order situation, the forecast-driven part and the customer order-driven part of production should be distinguished For the forecast-driven part, requirements on the DSS part of the information system are comparable with the make-to-stock situation. An extra requirement in the assemble-to-order situation concerns the co-ordination of the forecasts of the CODP items The solution in standard MRP packages is the determination of a forecast and a production plan at family level, and the explosion of this production plan (corrected for promised customer orders) to the CODP items using a planning BOM (Berry *et al.* 1988).

For the customer order-driven part of the production, order acceptance results in co-ordination between production and sales. If a customer order request is received and a specific BOM is generated, availability of the CODP items and assembly capacity are checked and a due date is promised. The information system should be able to check the time-phased availability of each of the CODP items which will be used in the ordered product configuration. Furthermore, the information system must be able to check the availability of the capacity in the customer order-driven part of the production system (Everdell 1984). If the customer order is accepted material planning determines the work order recommendations for the production department(s) (final assembly scheduling!) and possibly the purchase order recommendations. The information system should be capable of supporting such a multi-phase final assembly scheduling. And it must be capable of supporting progress monitoring of the customer order.

In the engineer-to-order situation the co-ordination between production and sales is focused on the acceptance of customer projects (Bertrand *et al.* 1991). After an aggregate task network of the quoted product is made (with specified lead times and critical capacity use per task), the aggregate network is scheduled forward by task, considering permitted floats within and between tasks, capacity availability and already accepted projects. Rescheduling of tasks of other projects can be considered as long as the due date of that project is not altered. The latest permissible end date of the last task in the network determines the due date of the project. If the order for the project is accepted, capacity is allocated for the tasks. The DSS part of the information system should be able to support this kind of multi-project planning considering floats and available capacity. Material planning in the engineer-to-order situation is concerned with (single-project) scheduling of the detailed activity network within a certain aggregate task. Material planning considers the earliest start date and the latest due date of the task. The activities (work orders) should be planned in such a way that a balanced capacity load is laid on the shop floor. An information system should support network planning at both levels (aggregate and detailed), in such a way that these two network plans can be related. Detailed network planning should be able to balance capacity load for the shop floor.

4. Impact of hybrid production situations on information systems

In the previous section information system requirements are derived for the three distinguished production situations. In Section 2 however, it was argued that companies often have more than one production situation which, in addition, is dynamic in the long and short term. Information systems for production control must cover the requirements which result from these hybrid production situations. In this section some of these requirements for the different types of hybridity are described.

Assortment hybridity implies interaction of capacity and material use of different production situations. Capacity interaction often occurs in situations where end products are made according to different production situations (Figure 3).

In this situation the determination of the production plan of E1 and the aggregate network planning of E2 must be co-ordinated. A minimum requirement on the information system is that the capacity use of both end products is visible while production is being planned. The real difficulty in this situation, however, is the decision as to which products the capacity is assigned. The market requirements for standard products are relatively well known over time. But future customer orders for specials are rather uncertain. Hence a certain part of the capacity must be reserved for possible customer orders in the future. The decision how much capacity must be reserved and when this reservation can be cancelled in order to produce other products is highly company dependent. Requirements for decision support of information systems therefore cannot be determined unambiguously.

Material interaction occurs in situations where end products are made according to different production situations, but have common lower level items (Figure 4).

Component C1 is used in product (family) E2 which is designed to customer specifications and in the product

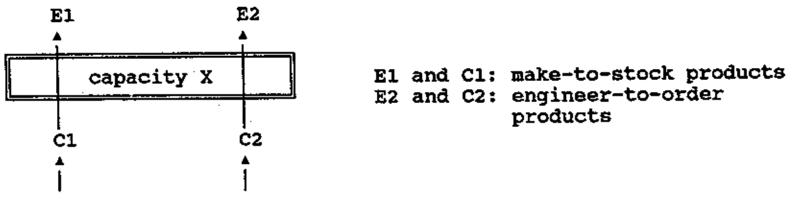

Figure 3 Joint capacity use of different production situations.

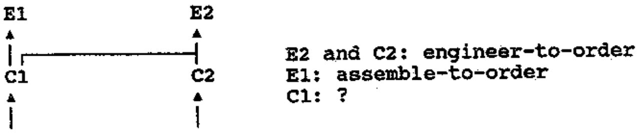

Figure 4. Two production situations with a common component

variant E1 which is assembled-to-order. For the production of C1 two demand sources exist: production of E1 and production of E2. For the production of E1, C1 is produced to forecast (assemble-to-order situation). A production plan is made for this item. For the production of E2, C1 is produced if the project is accepted, i.e. to customer order. The information system must be able to separate both types of planning for the same item. Available components C1 for the project E1 may not be used to produce E2!

Long-term hybridity does not directly influence the operational performance of the information system, but it has a significant impact on the maintenance of data. For an engineer-to-order end product which is added to the standard assortment of a company for instance, item numbers, stock locations, lot sizes, safety stock levels, etc., must be recorded. Information systems can only support this change to a limited extent. An example of a support tool is the facility to copy customer-specific product structures to standard product structures.

In Section 2 four different causes for operational hybridity are given. For these four causes we give requirements for the information system. A first cause for operational hybridity is the flow of customer orders imposed on the production system. Consider a company which assembles products to order, having rather expensive capacities in the assembly phase. If demand temporarily decreases in a certain period, the company probably decides to produce a few fast-moving end products to stock. The information system therefore should be able to determine fast movers, and to advise work orders for end products based on the *availability* of assembly capacity. If the situation changes and demand increases again, the end product stock of fast movers should be consumed. The information system therefore must be able to recognize configured assembly variants and end product variants, and promise delivery dates depending on delivery from end product stock or from the CODP item level.

The size of the customer order also has an operational impact on the CODP level. Many make-to-stock companies, for instance, have a policy to deliver large orders with a longer delivery time. For these orders the CODP is situated on a lower level in the product structure, e.g. at the level of long lead time components. In such a situation the customer order is produced from this lower level CODP. The delivery time is equal to the production lead time of the phases from the lower level CODP to the end product.

The information system must have several special properties in this case. In the first place stock must be maintained of the low level CODP items. It is not allowed to use this stock for the production of end products to be delivered from stock. In making a production plan for the end products, some capacity must be reserved for the possible acceptance of a large customer order. If a large customer order is received, the system is not allowed to consume the end products stock. Instead, the order must be exploded to the low-level CODP, where the CODP item stock is then consumed. Furthermore, the information system must be able to separate work orders for a specific customer order from work orders for end product replenishment which are issued for the same item. This is necessary to control customer order progress and to perform separate actual cost price calculations.

The third reason for operational hybridity is (unexpected) stock shortage. Assume, for instance, that the CODP end product as ordered by the customer is out of stock. In this case it is sometimes possible to disassemble other end products and rebuild them to the requested product. The information system should be able to support the creation, planning, release and closing of the rebuild order. This implies that the system must be able to support registration of orders which:

- result in more than one product,
- do not coincide with a parent–component BOM relation.

This is illustrated by the example in Figure 5 where end product E1 is rebuilt to end product E2.

If it concerns an order from an important customer, an alternative to rebuilding may be to cancel the reservation for an existing customer order and assign the end

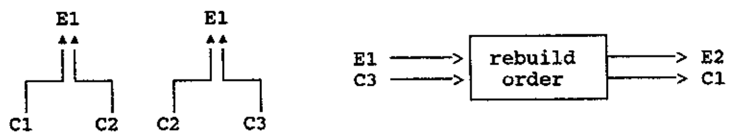

Figure 5. Example of the structure of a rebuild order

product to the more important customer order. The customer order with the cancelled reservation is then postponed. This possibility should also be suggested by the information system.

Finally there are incidental factors which cause operational hybridity. If, in an assemble-to-order company, a product configured by a customer is taken into production and the customer cancels the order, this results in stock of a configured generic item. Because the item is not a standard item, it is only registered by the generic item code and the customer order. The company then has two alternatives: disassemble the configuration and restock the CODP items, or stock the configuration until an exactly matching configuration is ordered. The information system should support this decision by registering the frequency with which configurations are ordered (this determines the expected time the configuration must be stocked). If the configured item is stocked, the system must recognize it as being an appropriate item, when a customer orders a configuration in which the item can be used. (It might even be desirable to influence the customer to take a configuration for which the configured item is already in stock.) If the configuration is disassembled, a 'negative order' should be advised by the system, considering the capacity of the assembly department and taking care of the appropriate stock transactions.

5. A new concept in standard software

5.1 *General*

After the preceding discussion of the significance of the decoupling point concept and the impact of hybridity in production situations on information systems for production control, a standard software package will be described, which centres around flexible dealing with customer order decoupling points. It is the TRITON package, a Dutch product, released in early 1990 and developed by Baan International BV. The functional concept of the product is presented in Figure 6.

First of all, at *level 1* this figure shows the MPS function. A main difference of this function compared with traditional production control software, is that it is able to integrate the master planning for the different production situations. An example is the integration with the engineer-to-order part of the system. For this purpose, customer-specific items, used in different projects and defined for these specific projects, can be linked to a single (standard) MPS item in the system. This MPS item represents then a group of similar customer-specific items. With the aid of this link the system is able to consume the forecasts at MPS level of the MPS item after requiring the order and definition of the product struc-

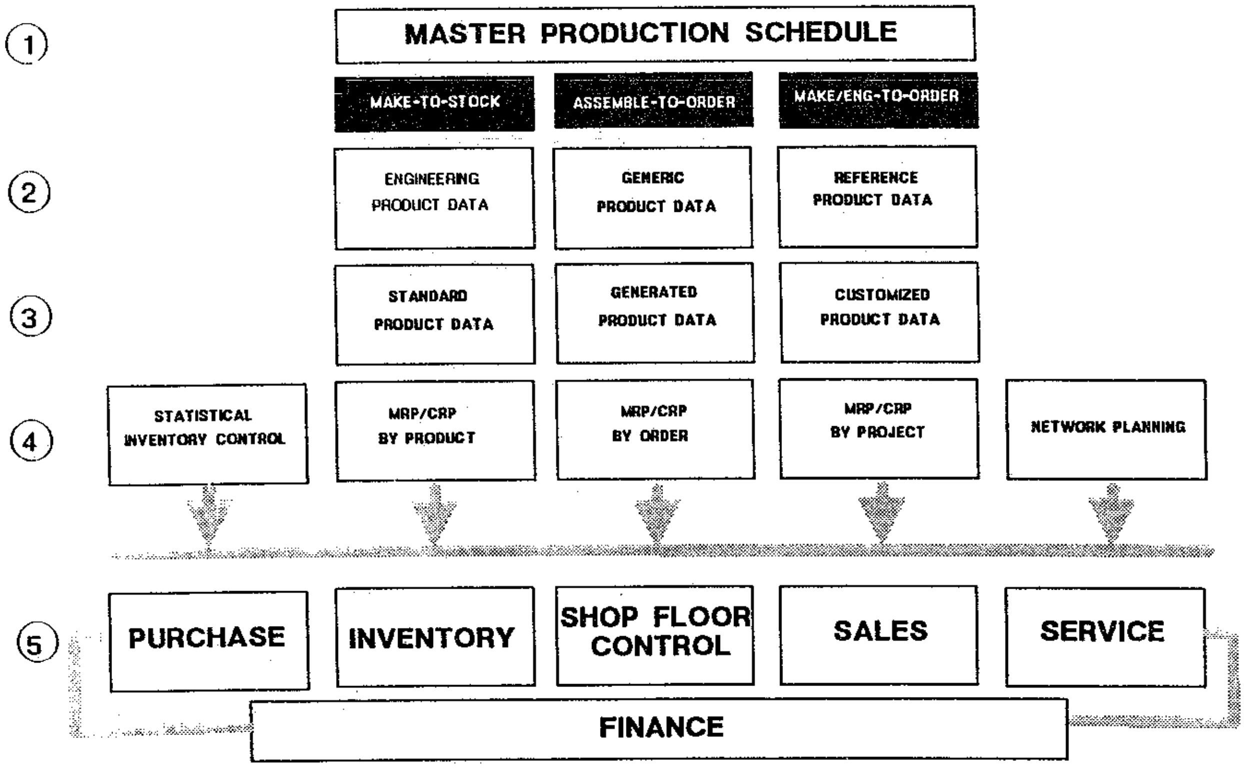

Figure 6. General concept

tures for the projects. This functionality makes it possible, for example, to estimate and allocate the rough required capacity for multiple projects over the long term, or to obtain information about rough material requirements. This integrated MPS concept is especially of importance in cases where assortment hybridity exists

Next, at *levels 2 and 3* the figure shows the different types of product data in the different production situations. As mentioned in Section 3, these data can be state-independent or order-dependent The figure illustrates that in an assemble-to-order situation a distinction is made between state-independent generic product data and state-dependent generated or configured product data. In the engineer-to-order situation the distinction is between state-independent reference product data and state-dependent customer-specific product data.

At *level 4*, the figure shows some decision support functions, which are different for each production situation The functionality of the decision support functions is based on the requirements for the production situations as described in Section 3.

Finally, at *level 5* the state-dependent transaction processing functions of the system are shown. Figure 5 illustrates that the same transaction processing functions are used in the different production situations; which again is important in hybrid situations. This does not mean, however, that no functionality had to be added or modified in order to be able to cover the requirements for the different production situations An example of this is the fact that in most engineer-to-order situations it is important to base calculations on actual prices. This even means, for instance, that it has to be possible to post incoming invoices directly to project costing, in order to compare budgeted, estimated and actual costs of a project. Another example is the fact that for the order-driven part of a company, in many cases traditional warehouse stock does not exist. It is not practical if a project first has to be booked to warehouse stock, before delivery can be processed in the system There are many more of these examples which could be mentioned.

It is nearly impossible to address all elements of the concept in this article Therefore we will focus on a few of the main elements of the system, compared with most of the traditional standard software packages for production control.

First, the functionality of the system in the assemble-to-order situation will be explained. Most attention will be given to a description of the product configurator.

Second, some aspects of the functionality for engineer-to-order situations will be described. Especially the handling of product data and the possibilities for activity-based material and capacity requirements planning will be discussed in detail.

Finally, it will be explained how the three basic types of hybridity are handled, and a review will be given of the experience gathered thus far with the implementation of the package.

5 2 *Assemble to order*

Generic product data For the purpose of supporting the assemble-to-order situation, state-independent product data can be defined in a generic format The system uses this generic data to generate the specific product data for a customer order, with the aid of a product configurator and generator The architecture of this product configurator and generator is depicted in Figure 7

For each generic item it can be defined which 'features' and 'options' it has A *generic item* refers to a product family, e g 'car' *Features* can be defined as product characteristics by which the layout of the product may differ from one customer order to another, e g 'cylinder capacity', 'transmission' or 'fuel' *Options* are the permitted choices per feature Options for the 'transmission' feature could be '4-speed', '5-speed' and 'automatic' Furthermore, *configuration constraints* can be defined They specify that certain option combinations are not allowed or, the opposite, mandatory. An example of a configuration constraint could be: 'if cylinder capacity (feature) is 1 3 litre (option) and fuel (feature) is diesel (option), a 5-speed (option) gear-box (feature) is mandatory To be able to record these constraints in a flexible and user-friendly way, a special 'meta-language' has been designed.

For each generic item, a *generic BOM* can be specified Figure 8 illustrates that the generic BOM contains all components which may occur, depending on which choices can be made by the customer In other words. depending on the combination of features and options chosen by the customer

A generic BOM may have multiple levels This means that a generic BOM may contain items which are generic ones themselves Important is that features and options can be defined for generic items at each level in a generic BOM structure With the aid of this a multi-level choice structure can be defined. The lowest level of the generic BOM lies at the decoupling point Incidentally, this may be the purchased parts level. The purchased parts may even be generic items themselves! However, in most assemble-to-order situations the lowest level of the generic BOMs consists of standard sub-assemblies, with standard BOMs and routeings, which are produced to stock

For each component in a generic BOM structure *decision rules* and *formulae* can be defined Decision rules specify whether the BOM line is to be included or excluded when generating the customer order-specific

BOM This may directly or indirectly depend on choices or specific combinations of choices made by the customer In the same way, formulae can be used in case the required material quantities are variable and depend on selected options and features. The definition of decision rules and formulae can be done with the help of the same meta language as was described for the definition of configuration constraints.

In an analogous manner, *generic item codes, generic item descriptions, generic routeings and generic pricing stuctures* can be defined

Generated product data. Based on the generic product data as described before, and with the aid of the options selected for a specific customer order by means of the product configurator the system *generates* the product data. The configuration can be done on-line during sales order processing. The systems checks on-line if the

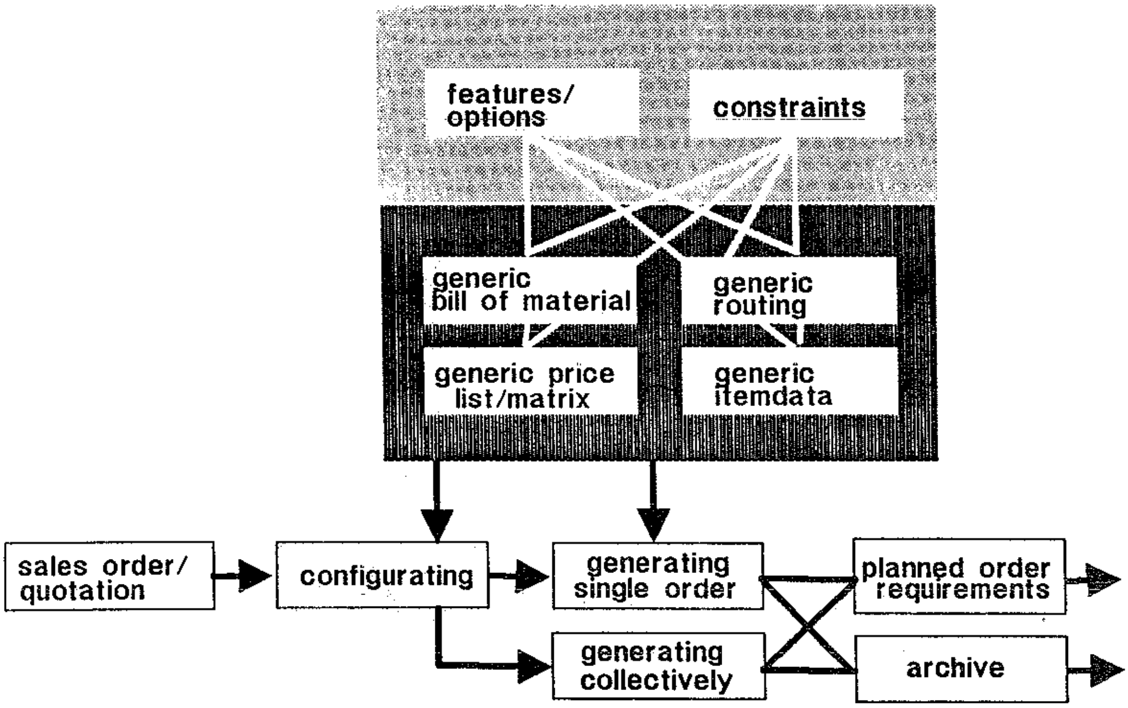

Figure 7 Architecture of the product configurator and generator

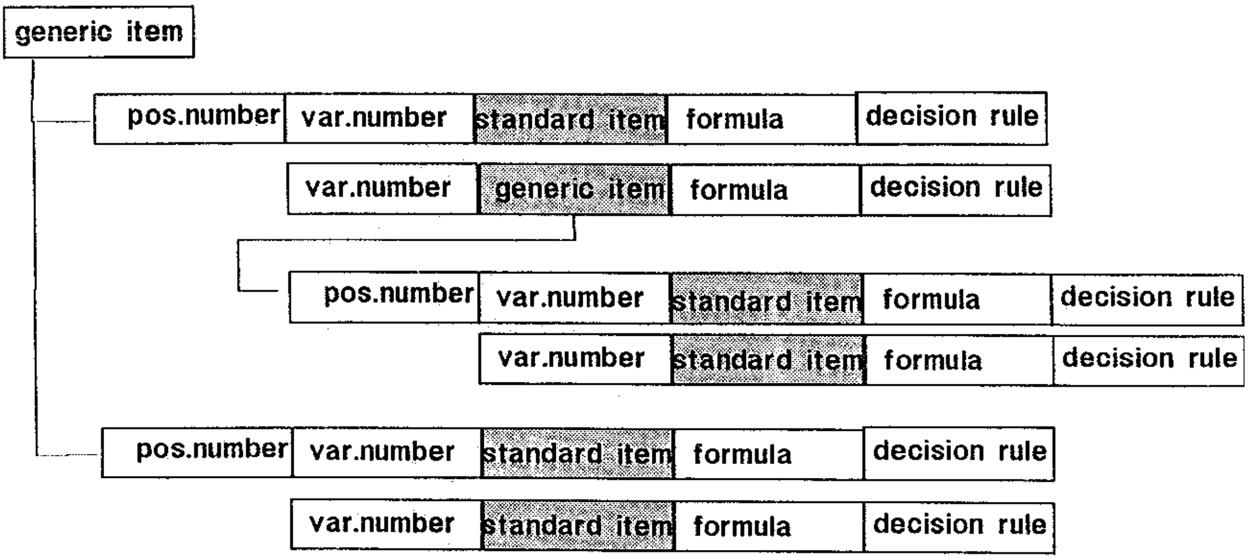

Figure 8 Example of a two-level generic BOM structure

selected options are allowed. It is even possible that the system only shows the options which are still possible, based on choices made earlier in the configuration process.

The generated product data is always linked to a customer order. Therefore it is handled as a separate entity in the system. It is possible to change the generated product data manually. The generated data includes generated (customer-specific) item codes, item descriptions, BOMs, routeings, and selling and/or purchase prices.

One detail might need some explanation: the generation of item codes. The background of this generated item code is that some assemble-to-order companies do have 'standard variants': often-sold variants for which it makes sense to produce them to stock. At the moment of configuring the product, the system user or the customer might not know that for the product in this specific layout, there is already a standard item available. In such cases, the system is able to use this generated item code to check if an identical standard item exists; it must have the same item code. If the system finds such an item, the generated (order-dependent) item will be automatically replaced by the identical standard item during the generation process, in order to be able to consume the stock of the identical standard item for this customer order. Furthermore, the generated item code can be useful for internal communication and statistical purposes.

Decision support: order requirements planning (ORP) For customer orders for which the product data has been generated by the product configurator and generator, the system calculates the material and capacity requirements. This function is called *order requirements planning* (*ORP*) and is comparable with final assembly scheduling in MRP II.

The requirements calculation by ORP is done up to the decoupling point, which allows for a direct check on availability of the CODP items, and is done primarily by customer order. All recommended production and/or purchase orders are linked to that customer order.

However, in view of the fact that, as stated in the first section, the position of the decoupling point can be quite flexible due to operational hybridity, some special options were added to the ORP function. This is illustrated in Figure 9. It provides the opportunity to have the system check the available stock of identical or similar standard items (right from the CODP) while calculating the requirement, and, if necessary, consume this stock. It means that ORP, except for the traditional recommendations for purchase and production, has a third type of recommended orders, called *stock orders*.

It is also possible to have the system perform a stock check at decoupling point level. If the stock is insufficient, the user can decide whether the system should generate an order advice to produce/purchase the uncovered requirements *to order*. Which means, 'behind the screen', that the system automatically copies the standard product data with all corresponding data to customer-

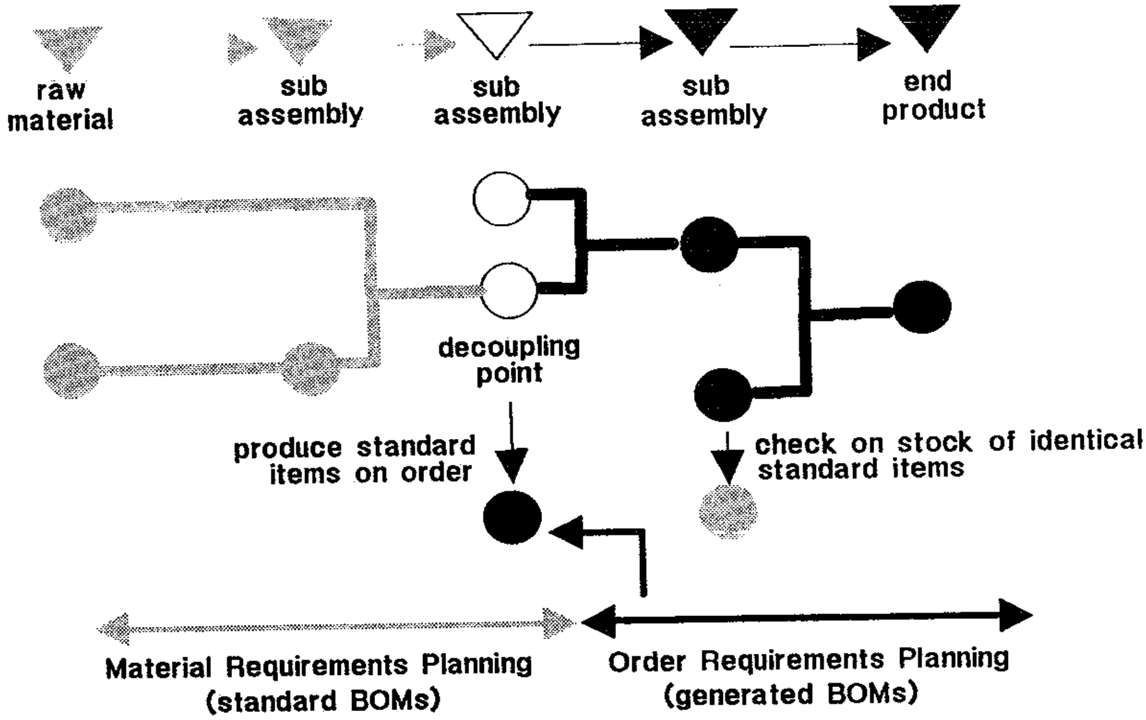

Figure 9. Order requirements planning (ORP)

specific product data linked to the order. This check can be repeated for each subsequent level.

Decision support: integration with master production schedule (MPS) A generic item (product family) can be defined as an MPS item. The MPS of the generic item is translated to the production forecast of MPS items (and, possibly, MRP items) at CODP level using the generic BOM. For the planning explosion, the generic BOM can act as a planning BOM.

5.3 *Engineer-to-order*

State-independent product data The characteristic feature of an engineer-to-order situation is that product data is, in principle, *state-dependent*. It is linked to customer orders, and will be recorded just after receiving the customer order and following the engineering process for that order. However, there are some exceptions. In the system three kinds of state-independent *reference data* are distinguished, which may serve as an aid for engineers. Firstly, standard BOMs and routeing linked to make-to-stock items can be copied to projects. Secondly, generic product data can be used to generate (parts of) the customer order-specific product structures of a project. Finally, product data of other projects can be copied to a new project.

Order dependent product data In the engineer-to-order situation the process of defining product data very often starts after receiving a request for proposal. To support this stage, *budget structures* can be recorded. The main purpose is the making of *budget calculations*, which are linked to *quotations*. These are often of a general nature, because not all details of the project are known at this stage. It is possible to make use of data from earlier projects or budget calculations, by copying this data to a budget structure. The layout of the budget structure is very flexible, because each company has its own practice in this area.

After the customer order has been received, the product data can be recorded. This starts with recording a *project*, with all related data like start date, end date, planner code, planning method, etc. In the case of complex projects, a hierarchy of projects can be defined. For this purpose, a project can be characterized as *single project*, *main project* or *subproject*. For each main project it has to be defined which subprojects belong to it.

Afterwards, the customer order-specific product data of the (sub)project can be recorded. This is called the *project structure*. Figure 10 shows the layout of a project structure, and its link with decision support system functions.

At the highest level, a (sub)project is divided into *modules*. Each module consists of a customer order-specific product structure, consisting of *customer-specific*

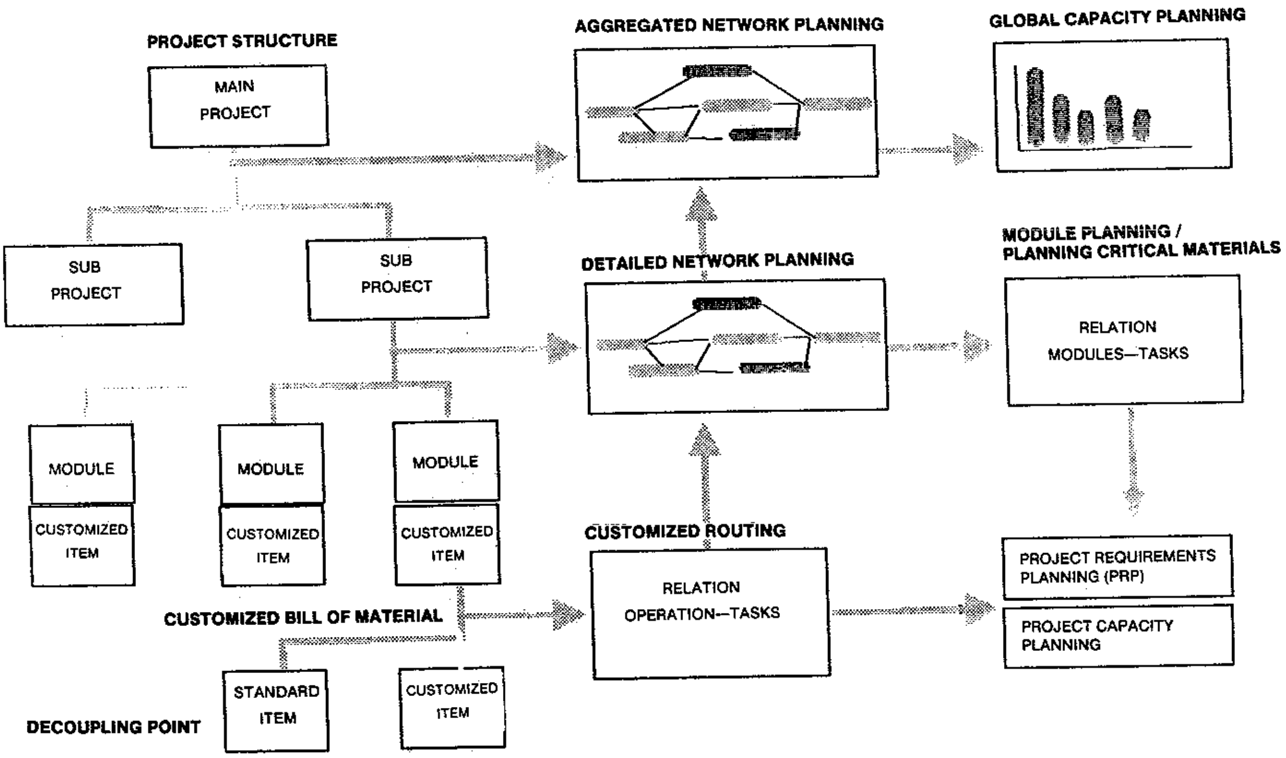

Figure 10. Project structure and project planning

items, BOMs and routeing. A number of typical prerequisites for these production situations were taken into account, including:

- modules can be linked to activities in the network planning of the project. In the following paragraph it will be explained how the system uses this relation to perform activity-based requirement calculations;
- the option of phased release of parts of product structures of a project, which is desirable because in these situations the engineering activities often run partially parallel with the production activities;
- facilities to record customer-specific product data as simply as possible (e.g. automatic numbering of customer-specific items);
- flexible calculation functions, like simple facilities to base calculations on actual prices.

As are generic BOMs, budget and project structures are defined up to the decoupling point. Or, in other words: a customer-specific BOM may contain standard items.

Decision support. project master schedule (PMS). For each (sub)project a *network* can be defined, consisting of multiple *tasks* or activities. The relation between the tasks has to be specified. These can be of the type *end-start, start-start* or *end-end*. The function which performs the network planning of main projects and subprojects is called the *project master schedule* (PMS).

It has already been explained that main projects can be divided into subprojects. Each project in this hierarchy may have its own network planning. The relations between the different network plannings have to be specified by defining for each subproject's network to which task(s) of the aggregated network it is related.

The network planning is the basis for determination of delivery dates, planning material and capacity requirements, monitoring progress and controlling actual cost for individual projects.

To the activities of the network planning, critical materials BOMs and critical capacity routeings can be linked. Planning of critical materials makes it possible to start the materials flow for certain critical materials, in anticipation of the definition of the project structure. Planning of critical capacities provides the facility to get a quick insight into the rough required capacity for a project.

Decision support: project requirements planning (PRP). With help of the *project requirements planning (PRP)* the planning of material and capacity requirements can be executed. Compared with ORP logic in the assemble-to-order situation, PRP has some extra functionality, due to the nature of these production situations.

- It is possible to perform PRP based on the activity network as defined for the project. To this end, modules of a project can be linked to tasks. The PRP plans task by task, and does an explosion of the customized BOM structure corresponding to the task.
- PRP takes into account the requirements on critical materials and capacities from PMS.
- Just as described for the ORP, requirements calculation is done up to the customer order decoupling point, and by project. Furthermore, again some options were added to be able to handle flexibility in the decoupling point position due to operational hybridity.

5.4. *Conclusion: dealing with hybridity*

In comparison with traditional MRP II packages, the system is relatively well capable of dealing with the different kinds of hybridity. Integrated production control for the different production situations (assortment hybridity) is possible. For each distinguished production situation, specific functionality has been added. Capacity and material interactions between these production situations can be handled.

Long-term hybridity can be dealt with using data handling functions, e.g. easy functions to copy (parts) of project structures to standard product structures. In particular, the order requirements planning and project requirements planning contain specific functions to deal with operational hybridity.

5.5. *Evaluation*

Since it was released to the market, a number of companies in different countries have now completely implemented the system. The types of companies which use the package, and the configurations in which it has been installed, differ markedly. They vary from distinct engineer-to-order situations (cranes, packaging lines, tools, steel constructions) to classical make-to-stock environments (ladders and cameras) and everything in between. (a.o. transport installations, furniture, kitchens, pliable doors, marquees).

The underlying concept of the package is not simple. Companies are not always aware of something like a 'customer order decoupling point', let alone its importance for the implementation of an information system.

The question could arise whether it is desirable to implement this kind of complex concept in standard packages for production control. Would it not be better to develop dedicated solutions for specific branches of industry or specific production situations? This is an important question. However, for two main reasons it could be stated that these concepts are necessary and desirable. The first reason is that hybrid situations are 'normal'. It appears that software packages for these types of companies meet a demand.

The second reason is that the state of current software technology makes it possible to distinguish between internal and external complexity. The software package discussed in this article was developed as a function library, containing a great many functions essential to various production situations. The system functions relevant to a specific company situation are selected with the aid of a product configurator. On that basis an information system is generated for a specific business situation. Furthermore, 4GL tools and parameter settings are used for fine-tuning purposes. In this situation, the user has only to deal with those sections of the function library which are vital to his situation. Moreover, 4GL tools enable him to provide the package with its own, recognizable face.

References

BERTRAND, J. W. M., WORTMANN, J. C., and WIJNGAARD, J., 1991, *Production Control. A Structural and Design Oriented Approach* (Elsevier Science Publishers, Amsterdam).

BERRY, W. L., VOLLMANN, T. E., and WHYBARK, D. C., 1988, *Manufacturing Planning and Control Systems* (Dow Jones-Irving).

EVERDELL, R., 1984, *Master Scheduling* (APICS).

GUERRERO, H. H., and KERN, G. M., 1990, A conceptual model for managing demand in the assemble-to-order environment. *Journal of Operations Management*, 9 (1).

HEGGE, H. M. H., and WORTMANN, J. C., 1990, Generic bill of material: a new product model. *Preprints 6th International Working Seminar on Production Economics*, February 1990.

VAN VEEN, E. A., 1991, Modelling product structures by generic bills of material. PhD. Thesis Eindhoven University of Technology.

WEMMERLOV, U., 1984, Assemble-to-order manufacturing: implications for materials management. *Journal of Operations Management*, 4 (4).