MASTER

A new planning and control concept for the 1065/5065 copier family build to customer order

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A new planning and control concept for the 1065/5065 copier family

Build to customer order

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Graduation report
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Integrated Supply Chain

RANK XEROX Manufacturing (Nederland) B.V.

Contents

Abstract

The ordering, distribution and production and its planning and control process of a family of copiers is described. Due to the planning and control process production is not able to react to customer demand. Build to order and "ship one build one" were suggested as alternatives and simulated. Build to order is recommended because of the lowest cost of capacity and stock. Also, its order leadtime is within market requirements.

Summary

In this report a new planning and control concept for the production of a copier family of RANK XEROX Manufacturing (Nederland) B.V. in Venray is investigated. RANK XEROX Venray is improving its goodsflow from parts supplier to customer. In a major project called Integrated Supply Chain these improvements are being realised by optimising the chain as a unity. That means that the flow from parts supplier to manufacturing plant to central warehouse (European Logistics Centre) to the national sales and service organisation (Operating Company) is approached integrally.

My assignment was part of this project and was to develop a planning concept for the 1065/5065 copier family that would make production more responsive to demand so that service level would increase and stock would decrease.

The current goodsflow starts with parts form the suppliers. The parts vary widely in leadtime: from 3 to 27 weeks (average 13 weeks). From these parts currently four product variants are made; three of them are used machines that are being recycled (on end product level). The variants have about 2/3 of their parts in common.

Used machines are first partly disassembled and cleaned. Then they are reassembled at the same line as the new machines. The throughput time of the assembly is 1.5 for new and 3.5 days for used machines on average.

The end products are stored at the ELC. The ELC also stores accessories made by other plants.

At the other end of the goods flow there is the customer. The customer orders a machine with the OpCo. In a contract the details of the order are defined. Most orders (85%) do not have a specified delivery date. The orders with a delivery date have an average delivery leadtime (from signature to delivery) of 5 1/2 weeks. The OpCo orders the machine that is necessary to satisfy the order from the ELC as late as possible. Some OpCo's keep stock and replenish products. The ELC generally ships the products that have been ordered within one day. The OpCo generally delivers and installs the products within 5 days

The customer demand is highly variable; 45 to 62% of the demand is in the last week of the month. Also, during the year demand is variable.

The quantity of end products to be produced in the next months is planned in the P3 process. In this process two forecasts of the demand are used. With these forecasts and the actual stock data production is defined in such a way that the projected stock will stay within specified control limits. During three months the plan is fixed because of the leadtime of the parts (only with crash actions changes can

be made). In the fourth month changes are possible due to hedging (overplanning) of material. The P3 plan is input for MRP which determines the material requirements. On a weekly basis fine-tuning of the plan is performed and used as input for final assembly.
The distribution process starts with a forecast of the required shipments to the OpCo`s for the next three months. Stock and future production is allocated to the OpCo`s. During the month the OpCo calls off the products within the allocation. An increase of the allocation can be rejected although other OpCo`s have remaining allocation.
This planning and control process could not respond to customer demand. MRP planning was not able to react flexibly to demand changes. Because of the leadtimes production was not in phase with demand. So stock at the ELC was necessary. The production of accessories was not in line with the production of main machines. Also, the allocation process constrained demand.
The information available for production was not demand. Customer order information was not available either at ELC or at Manufacturing. Orders were held at the OpCo. Necessary information like the customer delivery date was often not specified.
The problem was defined as follows: *the current production planning and control process is not able to react to customer demand within acceptable order-to-install time. Resulting service level and stock are not optimised integrally for the entire chain.*
Two alternatives were proposed: [1] a ship one build one concept, and [2] a build to order concept. In [1] the OpCo`s ordering and ELC delivery are as now. Stock at the ELC is immediatley replenised from Manufacturing. Current material and capacity planning are changed in order to increase flexibility. In [2] the OpCo`s transfer customer orders immediately to Manufacturing. Manufacturing starts production when capacity is available. Also, material and capacity planning is changed.
Materials should be planned with a statistical inventory rule. A s-S rule was recommended. In this rule a reorder level (when to order products) and a reorder maximum (upto what level to order) are defined. The stock on hand and on order are periodically compared with the reorder level. The levels are based on variance in demand and leadtime of the parts. This was applied for expensive parts.
Capacity is limited by the layout of the line. The output of the line was fixed on 32 machines per day. Manpower was assumed to be flexible. Because of the difference in processing time of new and used machines the choice of the capacity

mix is very important. Using exponential smoothing of the percentage of demand for new machines the capacity mix was determined.
This mix leads to a net capacity that is needed for the assembly of the products. The manpower needed for that mix was determined by adjusting the net capacity for illness, holidays and organisation losses. It was also recommended to abolish the summer shutdown. It was assumed that in that period the plant would work on half capacity.
A simulation model was made in order to determine consequences of the two concepts. Demand was based on the pattern in France. Some orders were given a delivery date. Capacity was defined as mentioned before. Also, a simulation with fixed capacity and summer shutdown was performed. The consequences for materials were also investigated. Stock at the ELC was taken into account.
In production order release priority was given to orders with a delivery date within standard leadtime. Second priority was on orders without delivery date. Consequences for leadtimes, stock, stock outs and capacity were analysed. The three simulated concepts were [A] build to order with fixed capacity, [B] build to order with flexible capacity and [C] ship one build one.
[A] gave the largest order leadtime (upto 30 days) especially after the summer shutdown, [B] gave leadtimes from 11 to 19 days and [C] gave the shortest leadtimes from 7 to 11 days. Material stock value was about the same for all three concepts. However, ELC stock was the largest for [C], namely three times as much as for [A] and [B]. In [C] ELC stock was unsold opposed to [A] and [B]. Stock outs for material were the highest for expensive parts (4%). They were about the same for all simulations (the alternative with the smallest material stock value had the largest stock out costs). Capacity cost was least for [A]. However, capacity cost per built product for [B] and [C] were marginally higher. Workforce varied between 44 to 55 people in [B] and [C].
[A] was rejected because leadtime was beyond market requirement. [B] and [C] were both within. Although [C] had the shortest leadtime it was not recommended because stock was larger (and unsold) and the balancing of the stock of more variants was a very difficult problem. A build to order concept with flexible capacity was recommended.
Finally some additional recommendations were made. First, it was advised to improve the order process. Orders should be available at Manufacturing immediately after order signature. Delivery dates that are in line with real market requirements should always be specified. Information sharing of order status is very important.

Material planning should be done using SIC rules. Also, they should be applied to accessories. Before starting with production on order material stock should be increased. Also, suppliers should be involved.
Capacity should be planned as suggested. However, also volume flexibility of the line should be improved. Manpower should be flexible in order to support this. One should be warned for negative consequences of a variable mix on space.
Last, it was discussed that resistance from OpCo`s, ELC and Manufacturing is likely. Information about all consequences of build to order should be communicated to them in order to overcome resistance.

Preface

During the period between June 1991 and March 1992 I performed my graduation assignment at RANK XEROX Manufacturing (Nederland) B.V. in Venray. I was stationed at ELC Projects, a project department. I joined the Integrated Supply Chain Team which is improving the logistic process from parts supplier to customer.
I experienced this period as very valuable. Not only because I had the opportunity to get to know real life processes and to apply my knowledge but also because I felt at home at this company.

I want to thank the people in Venray in Planning and Control, in Production, in Materials Operations, in Materials Control, in Manufacturing Engineering, in Frans Maas Oostrum, in ELC Operations, the people in France in Logistics, in Marketing, in Information Systems and in Customer Administration and the people in the UK in Equipment Supply Operations, in Central Marketing and in the OpCo for their information and willingness to help.
I also want to thank the people in ELC Projects for their support and their positive attitude. They really accepted me as one of their colleagues.
I want to thank Ton van Esch for offering me the assignment. Without him I would never have had this opportunity.
I want to thank Fred van Kampen, manager of the Integrated Supply Chain team, for his willingness to let me join the team.
Special thanks to the university coach J. Geurts who motivated me to put all my energy in achieving the best result possible.
Last but not least I want to thank Jos Hagebols. Jos was my coach in Venray. Without his advice, suggestions and the freedom he gave me I would never have accomplished this result.

If I have forgotten someone, then please forgive me. One always remembers the things people do but sometimes the things that have not been done are more important.

Chapter 1 Introduction to RANK XEROX

Introduction

This chapter will start the description of the assignment. Here, an introduction to the company and its market and product is given. The assignment is presented. Chapter 2 and 3 will discuss the goodsflow from production to customer. In chapter 4 and 5 the present planning and control of this goodsflow is discussed. Drawbacks of the planning and control will become clear. This will lead to the problem statement that is discussed in chapter 6. To overcome the problem two alternative planning and control concepts are suggested in chapter 7. Two important aspects of them are material planning and capacity planning. Both are similar for the alternatives. Material planning is described in chapter 8 and capacity planning in chapter 9. In order to decide which of the alternatives is best a simulation is performed. The simulation and the results are presented in chapter 10. In chapter 11 the choice for one of the alternatives is made. This report ends with recommendations for the implementation of the chosen alternative.
The meaning of used abbreviations are in the glossary on the last two pages of this report.
However, first an introduction to RANK XEROX is given.

The company

RANK XEROX is a company that manufactures and sells copiers, faxes and printers. It is part of the worldwide XEROX concern. RANK XEROX`s main market is Europe. Each West European country is supplied by a sales and service company, the Operating Company (OpCo). The products that the OpCo sells are distributed by the central warehouse in Venray, the European Logistics Centre (ELC).
Most products that are stored here are manufactured by three European plants. One of these plants is located in Venray, Manufacturing. The physical flow is summarised in figure 1.
My assignment was performed at the manufacturing plant in Venray. My assignment concerned a specific product that is sold to customers with specific requirements. The features of the product and the market are discussed in more detail. Attention is payed to the organisation and to the assignment.

The product

One of the Venray products is the 1065/5065 copier family. Venray only builds the processor (the plain copier) with input module (copier with part for loading orig-

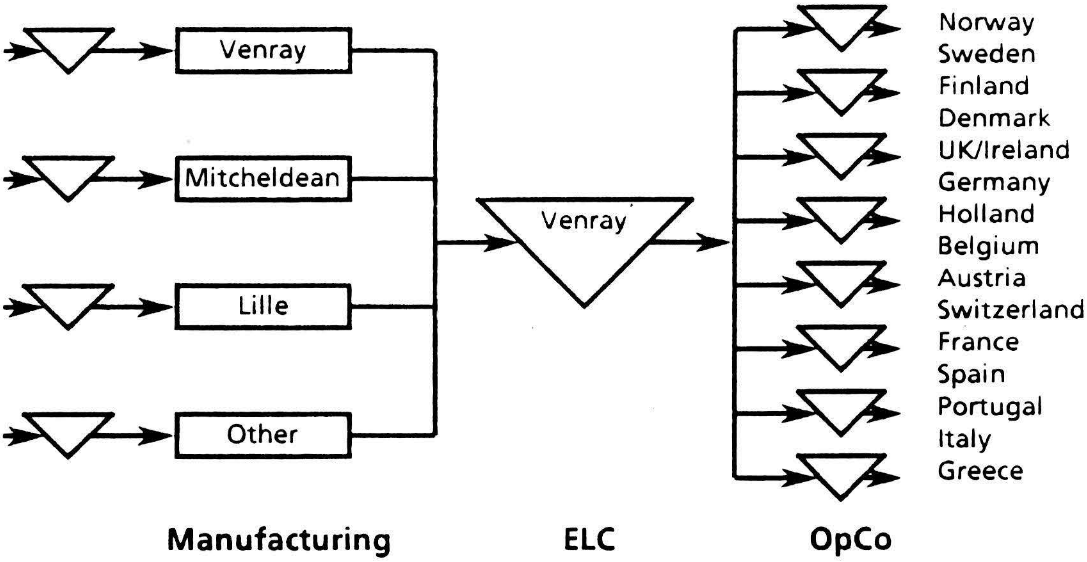

Figure 1 Rank Xerox in Europe

inals). Venray manufactures these processors in four configurations, one new processor (5065 with RDH) and three recycled ones (1065 with ADH, 1065 with RDH, and an upgrade, the 5065 Conversion with RDH).

The recycled machines are used machines that are cleaned, partly reassembled and tested.

These products are sold in the market with an output module (part that gathers the copies); also, country dependent items are added. This happens at the ELC. The product structure is summarised in figure 2.

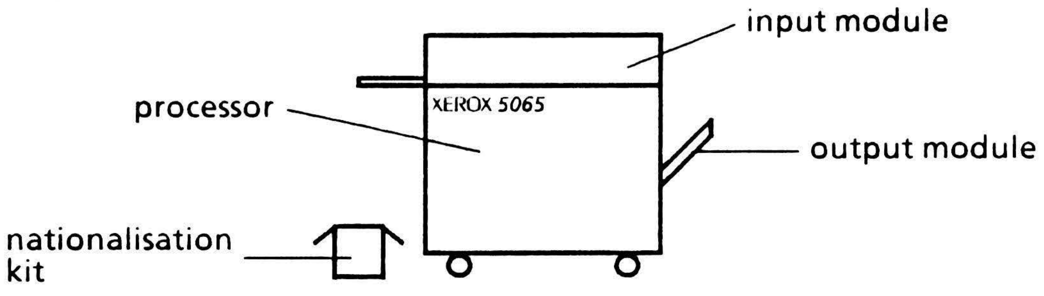

Figure 2 The structure of a 1065/5065 copier

An example of the product is in Appendix A.

The market

As mentioned before, each country in West Europe is marketed by an OpCo. Copiers are sold or leased to the customer. The 5065 copier is an exponent of the so called mid volume range. This means that the copier has a considerable capacity (20,000 to 50,000 copies per month).

In most cases the customer also takes a service contract together with the product. The customer requires a reliable and standby machine. Product quality is a very important customer requirement. This already starts with the product delivery. An OpCo desires a complete and tested machine that it only has to deliver and plug in.
The OpCo`s have a lot of different customers. The size is an important feature. Large customers require a different approach than small customers. This difference can be seen in the negotiation process.
This process is ended with the sale or lease. Contracts have to be filled in to confirm the order. However, in most cases no delivery date is defined. The OpCo assumes that most customers require a delivery lead time of three weeks.
In table 1 the requirements are summarised.

Table 1 Customer`s requirements

requirement	satisfier	realised through
capacity	wide range of copiers	various products
features	various accessories	configurations
reliable	product quality	reliable assembly process and quality control
reliable	fault free installation	engineering at installation
reliable	service	service contracts
delivery	throughput time	JiT call off

Source: RXF Marketing

The organisation

As was mentioned an OpCo is responsible for selling and servicing, the ELC is responsible for central distribution and the plant is responsible for manufacturing the products.
This organisation is supervised by a headquarters office in Marlow (UK). Here forecasts of market demand are made, plans for market strategy and sales are made and overall results consolidated and analysed. In my assignment the following Marlow departments are involded: Equipment Supply Operations (ESO) who is responsible for the allocation of central stock and for the forecast input of production planning, Worldwide Marketing who prepares market forecasts based on information of the OpCo`s and European Manufacturing Operations (EMO) who coordinates the production at the European plants. A summary is in figure 3.

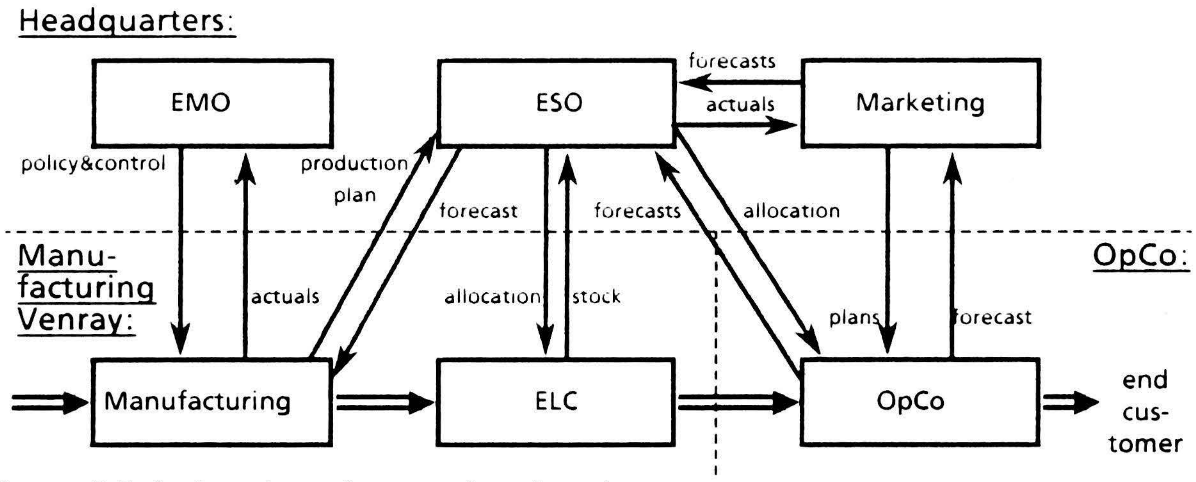

Figure 3 Relations in an international environment

Background of the assignment

RANK XEROX is trying to improve its goodsflow from parts to end customer. This effort is called the Integrated Supply Chain (ISC). The aim of the ISC is to make the goodsflow more responsive to the market requirements. The ISC will enable the achievement of RANK XEROX`s goals especially total customer satisfaction through low logistics costs, service level of 100% and a low asset level. This is summarised in figure 4.

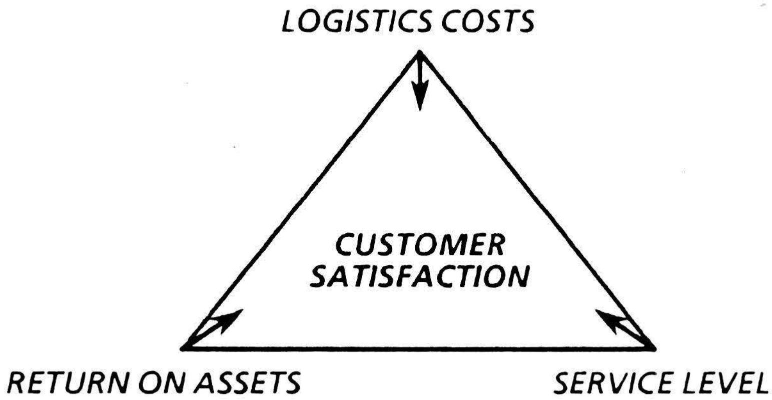

Figure 4 Rank Xerox`s goals

The ISC will be benefitial because it optimises the goodsflow as a unity. Instead of the currently used and independently operating Just in Time manufacturing and Just in Time distribution strategy the ISC will consider manufacturing and distribution together.

The assignment

In this environment I performed my assignment. I limited my analysis to one product family, the 1065/5065. My assignment was to develop and describe a production planning process for RANK XEROX Venray for the 1065/5065 product family.

The process to be developed should be responsive to customer demand. The process should decrease total chain cost (inventory, capacity, etcetera) and increase the service level to the customers.
This assignment leads to a problem statement that will be discussed in chapter 6. The problem investigated is that the present production and distribution planning is not able to respond on customer demand.

Chapter 2 Materials and production

Introduction

Now, the company is known. So the present planning process can be described. However, first a description of the process to be planned should be given. This will be done in this and the next chapter. The next chapter will discuss the ordering and distribution process. This chapter will describe the flow from parts to end product. Relevant characteristics like part lead time and assembly throughput time are discussed.
The data were gathered by monitoring the physical flow, by measuring the throughput times and by extracting part leadtime information out of XBMS, the MRP system used by RANK XEROX Venray.

Parts

The processor that is built at the Venray site consists of approximately 1200 parts. The entire family consists of about 1600 parts. These parts are sourced in Europe, America and the Far East. About 2/3 of the material value comes from America. This sourcing profile largely explains the variance in part leadtime which varies from 3 to 27 weeks. This is displayed in figure 5.

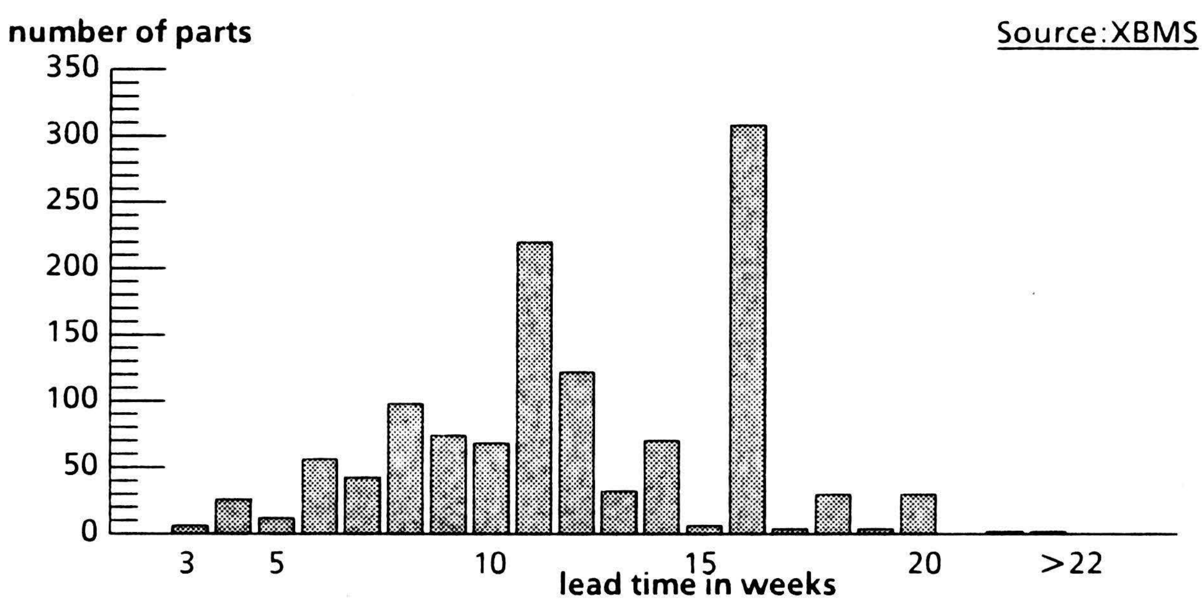

Figure 5 Distribution of the number of buy parts of a 5065 NB over the weeks

Parts come from two kinds of suppliers. Some parts come from other XEROX plants. Other parts come from independent suppliers.
The four product variants have about 2/3 of their parts in common. Despite the high commonality of parts the usage of parts differs per variant. Especially the

usage differs between new and used machines. In case of used machines some parts only have to be replaced partly. The usage ratio`s have been estimated on historical data of former recycling activities and machines in the field.
The most important input for recycling is a carcass. A carcass is a used machine that has been bought back from the OpCo`s and that is in such condition that recycling of the carcass into an "as good as new" machine is possible.
Reliability of the delivery from the suppliers is high. On average 98% (according to Operations Review Meeting reports) of the parts arrives on time.
The value of the parts varies from Dfl. 0.01 for a nut-hexagon steel to Dfl. 3,918 for an input module. The material represents 90 % of the cost price (called Manufacturing Transfer Price, MTP) in case of a new machine and about 75% for a used one. More about prices is in appendix B.
These parts are assembled; result is the processor.

Production

The parts are received at the storage area of the assembly building in Venray. The parts are keyed in into the stock system and put into the automatic store.
The operators in the assembly line order the parts using a terminal. Parts are provided within 4 hours after ordering. Parts are supplied in box pallets or tote-tins.
These parts are assembled into the processor. Some parts are assembled into subs. The subassembly occurs in line with the main assembly line for small parts and on a separate location for voluminous subs. In the last case the operator in the main line will fetch the subs himself.
On the main line four variants of the 1065/5065 are built. Three of them are used machines. These machines are first partly disassembled and cleaned at another building. After that the machine and the removed subassemblies are transported to the assembly line.
The new machines are assembled from part level. The used ones are checked, the removed subassemblies inserted and some parts replaced. In a test the copying quality of the machines is brought in line with the norms. After that the machines are covered and packed. Some products are checked at a quality audit function. The processors are scanned with a barcode reader and transported to the ELC. Here, the products are put into stock.
The ELC also stores the kits and the output modules. The output modules are manufactured in France and Brasil. The kits are built in the Netherlands.
The observed throughput times for new and used machines for the main assembly line are 1.5 and 3.7 days on average. The standard deviation of the processing

time is about 15% of the average value. The disassembly line has a throughput time of 1 day.
The difference between new and used machines occurs especially in testing. New machines need about 2 hours of testing while used ones need 6 hours. It is clear that a change in mix means a change in manpower requirement.
The line can produce up to 35 machines per day if sufficient manpower is available.
More data can be found in appendix C.

Chapter 3 Demand and distribution

Introduction

In the previous chapter the making of the copier was described. Now, the demand on the product and the distribution to the customer will be discussed. This will conclude the order and goodsflow description and will lay the basis for the analysis of the planning and control processes.
The information in this chapter was gathered by an analysis of the demand and distribution process of the french OpCo RANK XEROX France, RXF. The process description is based on interviews with the key players in France and in the ELC. Quantitive information is based on data that are stored in the information systems of RXF SOFIA (the customer administration system), ACCORD (the central logistics system) and RITA (distribution and installation system) and of the ELC SWORD (stock system).

Order and distribution process

The process starts with the decision of the customer to buy or lease XEROX. The customer demand is inserted into the customer administration system which records customer information, the product to be delivered and the quantity, the price and the delivery date. In about 85% of the orders the delivery date is not specified according to a sample out of SOFIA. An example is in appendix D. However, for mid volume copiers (of which the 1065/5065 is an exponent) the marketing department of RXF thinks that an order throughput time of three weeks is acceptable for the market. This view is supported by the fact that customers who ask for a delivery date want the products within 5½ weeks on average.
The order information is transferred to the logistics department. The orders for one product are accumulated daily. If there is no stock in the OpCo available (in case of France) an order (the JiT call off) is put on the ELC to deliver the products at the agreed drop point within one day.
The ELC will generate an internal order and a pick ticket. The requested equipment is picked and loaded into the truck. The forwarder (Frans Maas) will ship the product to the agreed droppoint according to a formal time table. From there the OpCo (read: the forwarder contracted by the OpCo) transports the product to the end customer or to a regional distribution point (different per OpCo). In France this local distribution takes about 4 to 5 days. After product delivery the product has to be installed. An engineering crew installs the machine: the machine is nationalised, the output module and accessories are added and the ma-

chine is made operative (the strategy is to centralise these activities - also known as customisation -; first, they are going to be done at a separate location; later, these activities will be integrated in the assembly line).

Demand pattern

The demand is not evenly distributed over the weeks. It turns out that the largest part of the demand occurs during the last days of the month. If the call off pattern would be regarded it turns out that 45 to 62% of the orders occur in the last week based on the call offs for 1991 registrated in ACCORD. An example is in figure 6.

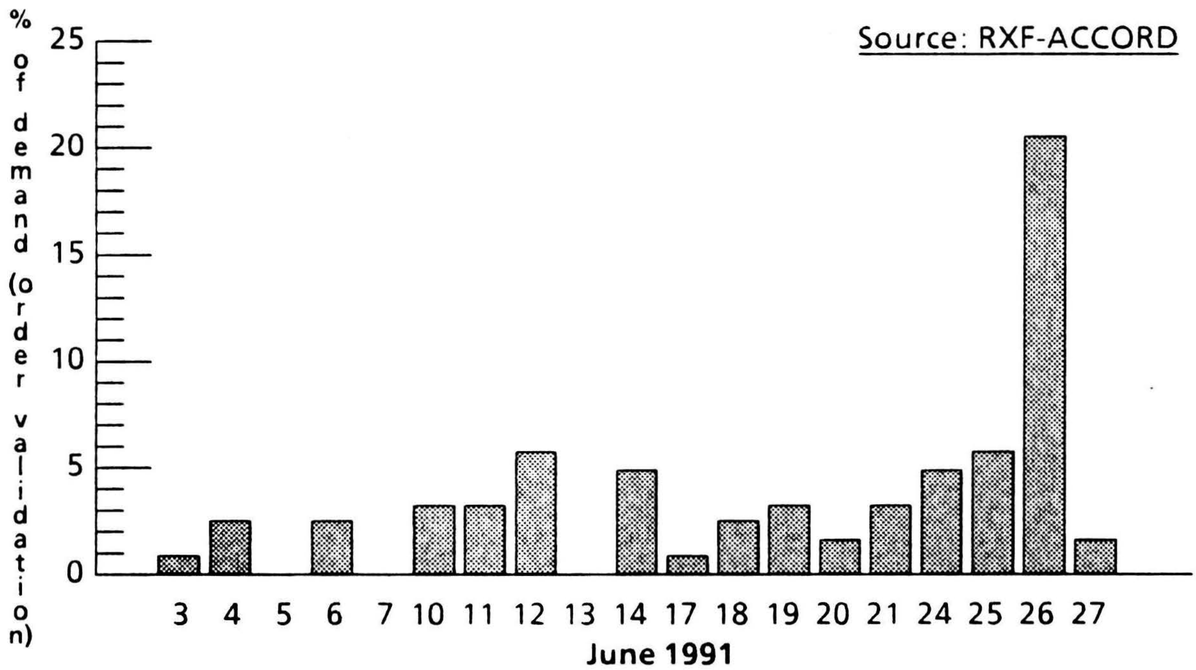

Figure 6 Example of the distribution of the orders over the month

Also, the demand is not evenly divided over the months. At the end of the quarters and especially at the end of the RANK XEROX year (November to October) the demand is at its highest level. An example is in figure 7.

This demand pattern has consequences for the delivery performance. The demand peaks are handled by the forwarders through extra manpower and extra trucks. The problems occur at the delivery and installation with the customer. First, the demand peak cannot be handled by the installation crew. About 40% of the orders is not delivered within the standard distribution time of RANK XEROX France (this is 4 days for the Paris area and 5 days for the rest of France). Second, 10% of the orders that cannot be delivered on the planned (by the subcontractor) delivery date are refused by the customer although the customer agreed with an

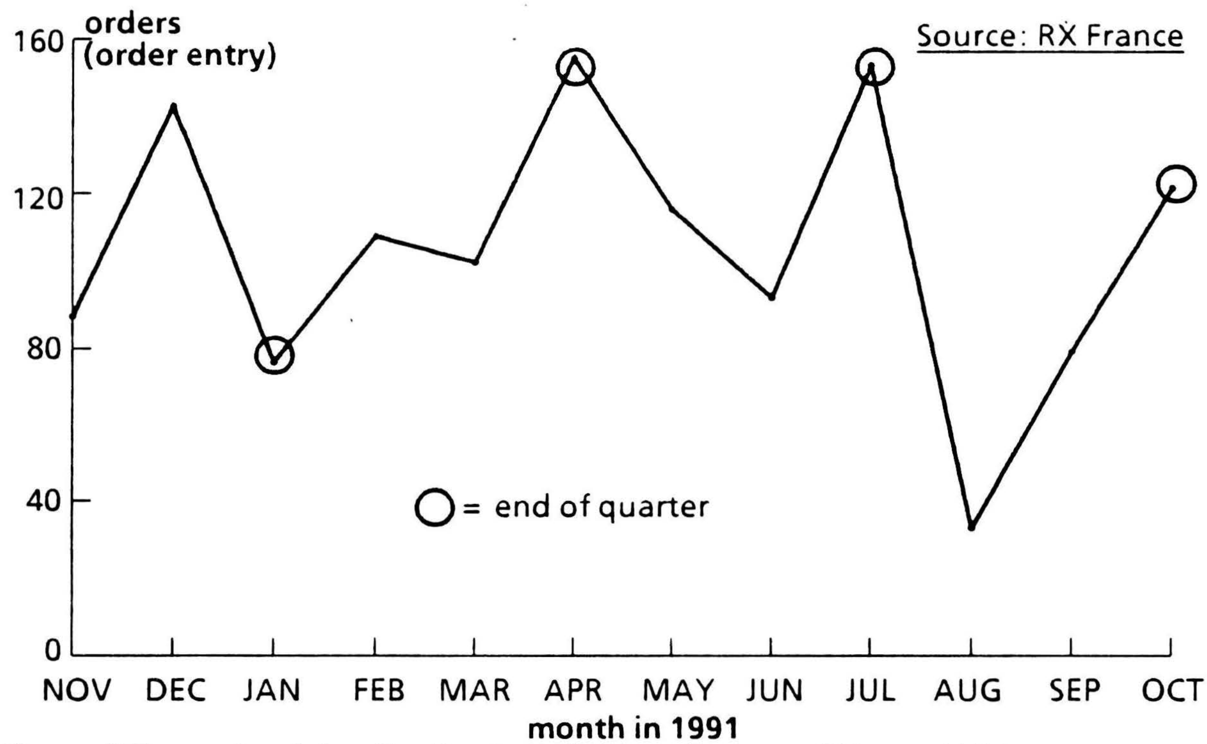

Figure 7 Example of the distribution of the orders over RX year 1991

"as soon as possible" delivery date. These percentages are based on the customer satisfaction reportings of RITA.

Chapter 4 Materials and production planning

Introduction

In the previous chapters the goods and order flow was presented. In the following chapters the planning and control of this flow will be discussed. First, the planning and control process is described. After that drawbacks of the process are discussed and summarised in the problem statement. The next chapter will described the planning of the demand and distributation. But first, in this chapter the planning of the parts and assembly of the product will be described. Relevant features will be shown.
The data are based on interviews with key players in the process and on process documentation.

The P3 process

The P3 (Production Planning Process) process determines what should be built in the following months in order to satisfy demand. The process uses the following information:

1. a forecast of the call offs of the OpCo`s for the next three months (also known as the EM3),
2. a forecast of the demand of the OpCo`s for the months after that three months (the shipment outlook),
3. a forecast per week based on the phasing of the demand during the last year, on the level of the demand in the last but one three months and on the special market deals (also called outlook with bias correction; this forecast is aggregated as a forecast for an entire month),
4. the actual stock at the ELC, the actual shipments and production,
5. the planned production for the next three months and
6. the proposed production for the months after.

The EM3 is a forecast that is made by the OpCo`s. The forecast is based on order information that is gathered 19 days before the start of the forecasted months. This forecast is consolidated by ESO in Marlow. The shipment outlooks are based on a forecast of Worldwide Marketing and translated into shipments by ESO. This forecast is based on forecasts of the OpCo`s. On the moment of this forecast the market has changed because of the long throughput time of making the forecast. Also, this forecast is not reliable (see ref. [1]).
So in the planning process three forecasts are used (EM3, shipment outlook and forecast with bias correction). In the P3 meeting - in which the new plan is

defined - the forecasts are interpreted by the participants (representatives of ESO, EMO and Venray).
The material plan for the next three months is fixed. This is because of the leadtime of the parts. For parts that have a longer leadtime than three months the quantity ordered on the supplier is higher than what is forecasted in the shipment outlook. This extra quantity is called a hedge. If the hedge is not required, the hedge is postponed to the following period.
The goal is to build so many machines that the projected stock (based on the bias correction forecast) over three months and later will be between the predetermined minimum and maximum levels. Within three months a minimum (read: safety) stock is kept. Also, a maximum stock level is defined. The stock levels are determined by the forecast error of the EM3. The minimum level is fixed on 1.49σ (σ = standard deviation of the forecast error of the EM3 over three months). This corresponds to a probability that stock is positive of 88% (RANK XEROX calls it service level; however, this is not a service level). The target level and maximum level are 2.23σ (service level 98%) and 2.98σ (service level 99%). If the projected stock (based on EM3) is near zero the planned production within leadtime will be increased. Extra costs like air freight and overtime have to be incurred. An example of the P3 plan is in figure 8. The detailed plan is in appendix E. Also, if it is possible to switch the plan between the configurations this is done.
In general the material plan will be the assembly plan. However, in a weekly outlook meeting some fine-tuning is done. The P3 plan is a monthly plan. It does not specify in which week the product should be built. This specification is done in the outlook meeting. Also, if the actual stock approaches the zero level the assembly plan will be increased by expediting material and by overtime.
The P3 process is summarised in figure 9.

Material requirements planning

The P3 plan will be input for the ordering of parts. The demand on parts is determined with Material Requirements Planning (MRP). The P3 plan is inserted into MRP as the weekly demand on end products. The date of receipt of the parts is planned at three days before the production output date. MRP explodes the demand on part level based on the bill of materials (BOM). In case of used machines not all parts have to be replaced so that usage is expressed as a percentage in the BOM. The explosion run is performed weekly at the week-ends. The resulting part requirements plan is analysed and translated into orders by material analysts. Depending on the value, volume and supplier reliability of the parts the analysis is

performed from once a week to once a month. Based on an A-B-C classification the delivery frequency of the parts is determined.
MRP generates work orders for the next two or three weeks in order to reserve material for production. A work order does not commit material to the assembly of a specific configuration. That means that a work order is not linkend to an assembly order for a product. Using these work orders a special group (Expediting) checks whether material has been delivered. If not, material is expedited.

Production planning

In the weekly outlook meeting the production plan for the next and ongoing week is discussed. The week plan is communicated to the unit managers of the assembly line so that they know what should be assembled. Also the ELC knows how many carcasses should be shipped to the disassembly line and this line knows how many cleaned carcasses should be shipped to the main assembly line.
The amount of carcasses available at the ELC and OpCo`s exceeds present demand. The carcass flow is being improved because recycling of carcasses only starts when a large amount of carcassses is available. Ideally recycling should start when the first machine returns from the customer. In a project this problem is tackled.

Remarks

Planning of kits and of output modules is not done in this P3 process. Goal is that the planning of output modules will be integrated in the P3 process. Planning of kits is being improved. In a project the availability of kits is being increased as a first step. This is done by presenting OpCo`s alternative kits if a specific kit is not available. Result is that customer demand still can be satisfied. Finally, kits planning will be integrated in the normal material planning. These processes are beyond the scope of my assignment.

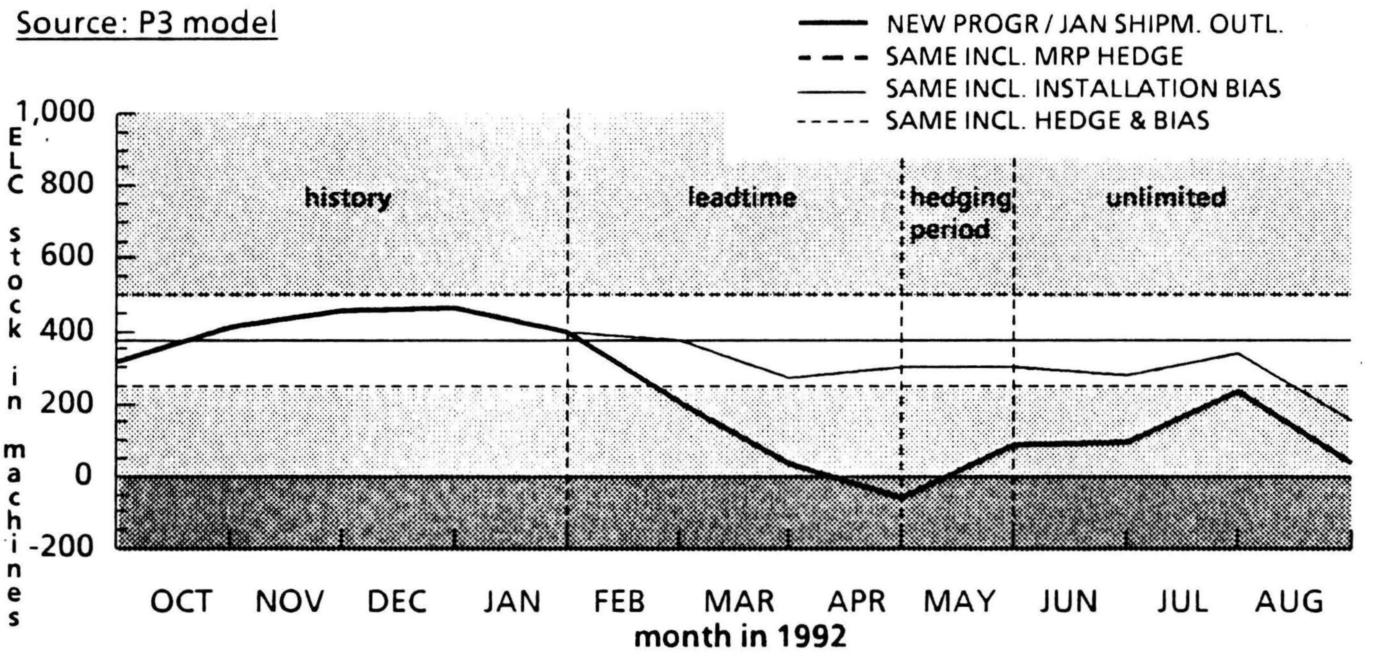

Figure 8 P3 planning chart for the 1065/5065 product family (destination RXL)

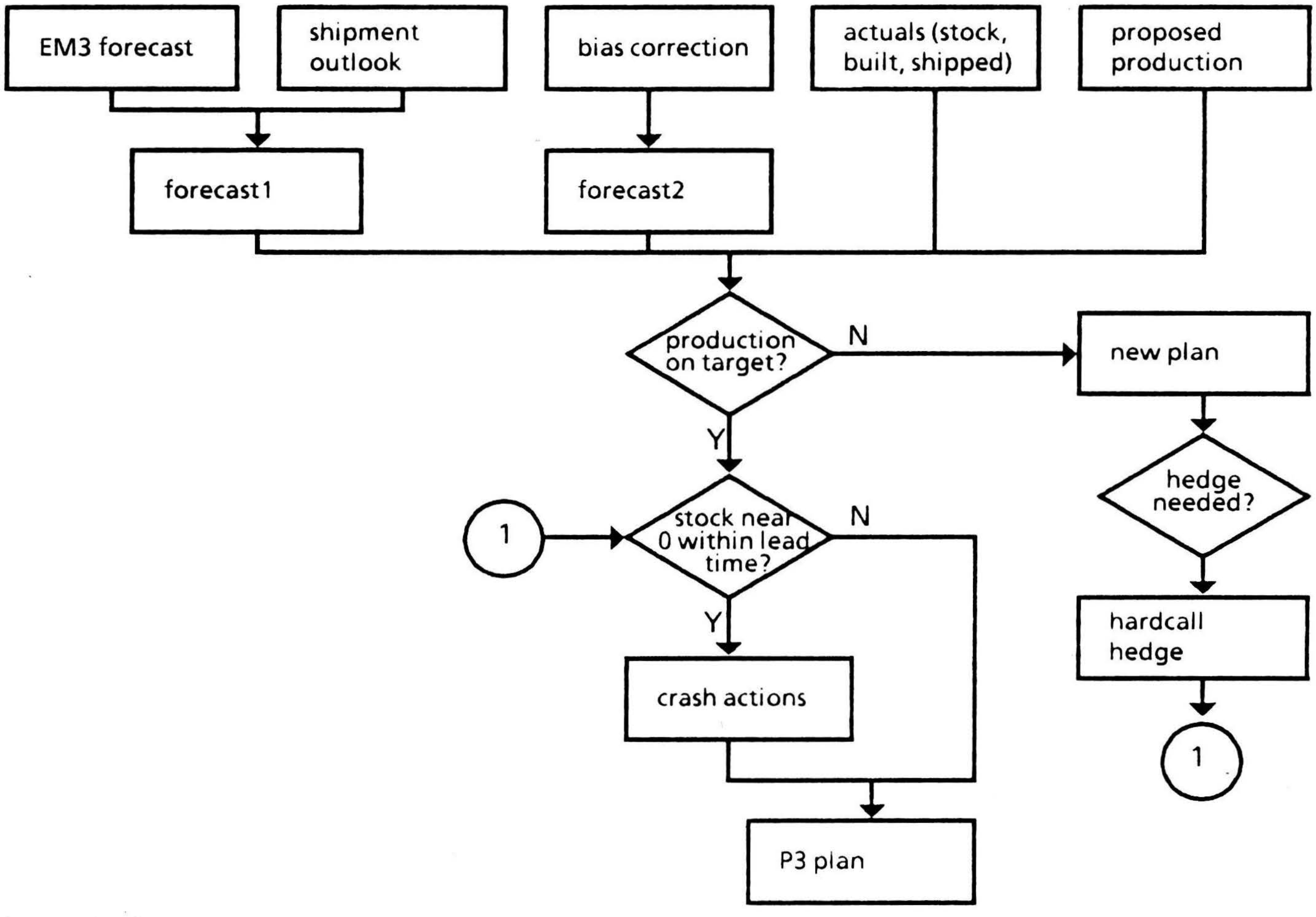

Figure 9 P3 process

Chapter 5 Demand and distribution planning

Introduction

In the previous chapter one aspect of the planning and control process was discussed: the planning of materials and production. This determines the supply side: the available products. In this chapter the other aspect of the process will be described: the planning of ordering and distribution. This is the demand side. This will complete the input for the problem statement.
Data presented in this chapter are based on interviews with key players in Venray, Marlow and France and on process documents.

The EM3 - JiT call off process

In the previous chapter the EM3 forecast was introduced. This forecast is originated by the OpCo`s. This forecast is sent to ESO in Marlow. Here, it allocates available stock and future production to the OpCo`s. This is called the EM3 allocation. The allocation defines the limit of the machines that an OpCo can order on the ELC in a month. If the OpCo finds that its demand is higher than the allocation an OpCo can ask for an increase of the allocation in that month. If there is stock an OpCo will receive a raise of allocation. If the raise is rejected it still can happen that at month end stock is remaining because other OpCo`s did not entirely call off their allocations. An OpCo is not obligated to call off its allocation. Also, the moment of call off of the allocation is not defined. In principle, the allocation is allowed to be called off at the first day of the month (for EM3 forecasting see ref. [1]).
The OpCo will order the machines on the ELC (the JiT call off) if there are customer orders or if they regard their stock (not applicable to RANK XEROX France) as too small. In case of a delivery date that is beyond the OpCo`s leadtime the OpCo will put the order on hold and wait until the order`s due date is within leadtime before calling off. If the machines are available at the ELC, the ELC will inform the OpCo of the despatch and the product will be shipped to the agreed destination according to a formal time table (see appendix F). If there is no stock, the OpCo`s call off will be denied and the OpCo will have to reorder. The ELC will also bill the OpCo`s for the products that have been shipped.
The OpCo will be responsible for the transport to the customer. The transport and installation planning differs per OpCo and is beyond the scope of this report.
The process is summarised in figure 10.

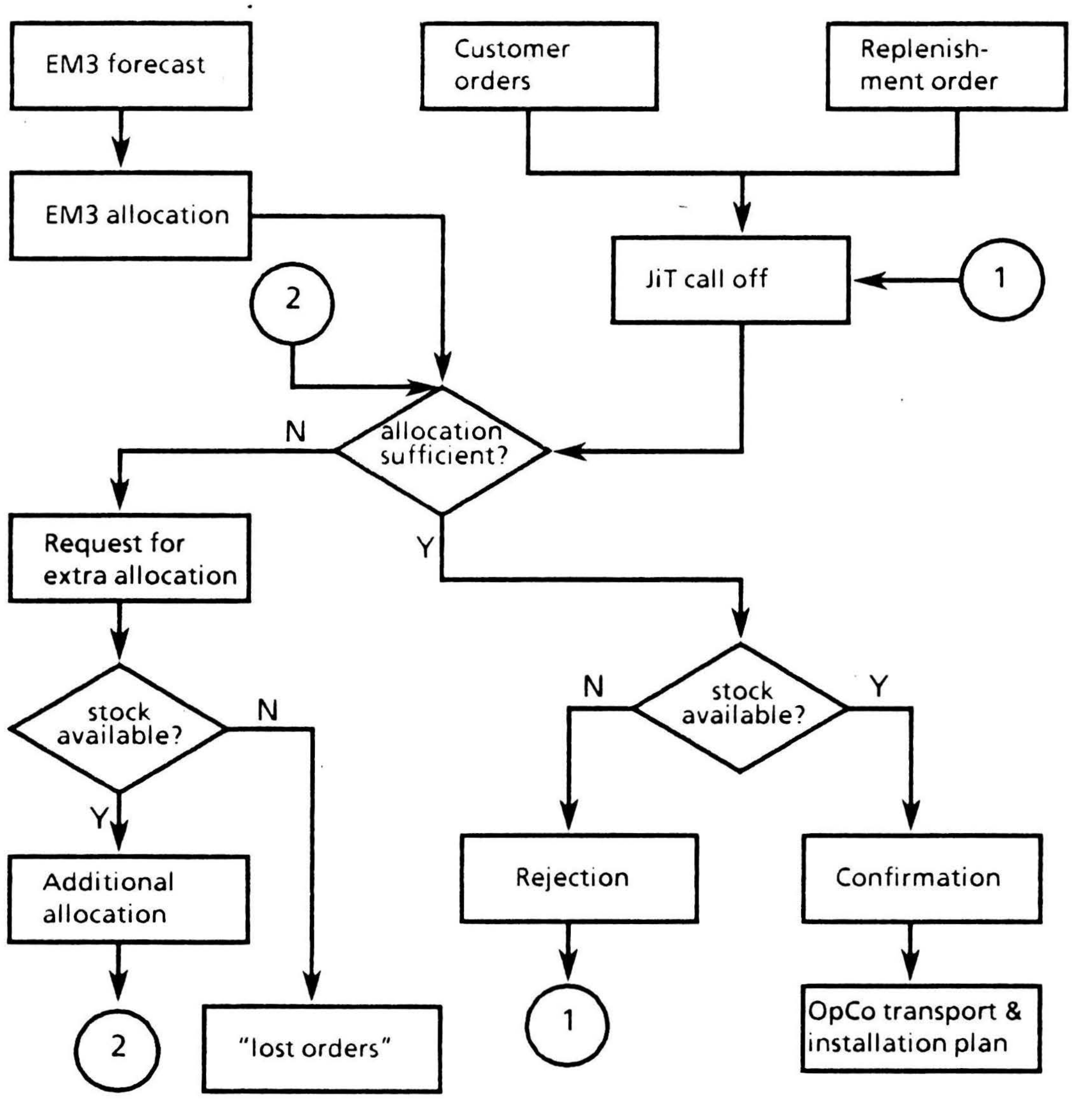

Figure 10 The EM3 - JiT call off process

Chapter 6 Problem statement

Introduction

In the previous chapters the goodsflow of the 1065/5065 family and its planning process were described. In this chapter the actual state and the desired one will be compared. It will be shown that the current process does not comply with the desired state of a planning process that is in line with RANK XEROX`s goals.
This will lead to the problem statement. In the remaining chapters this problem will be tackled.

The desired state

The Integrated Supply Chain is the desired state. This means that service level to the customer should be 100%. The production should react to customer demand with the smallest reation time possible. The planning and control concept should enable a fast reaction to demand. Also, the cost of achieving this should be as low as possible. This state can be achieved when the supply chain from parts supplier to customer is approached as a unity. Stock is regarded at all levels and as such optimised on an overall basis.

Variance between actual and desired state

Reaction on demand signals

With the current process production is adapted to a forecast of the demand. This would be no problem if the demand would be the same as the forecast. However, this is not as was mentioned in a previous chapter. In order to react on actual demand stock of finished goods is necessary. Despite the stock it is impossible to match the composition of the stock to the actual demand.
Also, the allocation of stock process again assumes that the forecast of the OpCo is the same as the actual demand. Again, the allocation of stock is not matched to the actual demand. If an OpCo has not sufficient allocation it can happen that this OpCo cannot satisfy demand while other OpCo`s have open allocation.
The P3 process plans and controls the goodsflow taking notice of the forecast accuracy. But still with changes in demand extra effort (for example air freight) has to be incurred to satisfy this demand. If the change is structural, the actual response time on demand is the product lead time of three months and definitely not the delivery lead time or order-to-install time of three weeks (as required by the market).

- In order to satisfy demand all components (processors, output modules, kits, accessories) that are needed to form a system must be available at central stock. To guarantee this the planning of the production of these components should be coordinated. However, now the planning of these components is performed by separate plants; there is only marginal tuning of the different plans and there is no feedback. In most cases when call off`s from the OpCo`s cannot be satisfied this occurs because only one component of the system is not available.

Reaction to true demand signals

The current planning process is not able to react on true demand signals because these signals are not known at RANK XEROX Venray.
Currently, the demand information that is available is the call off`s from the OpCo`s. However, in some cases this call off is based on the desired replenishment of the OpCo`s stock. In that case the call off does not correspond with true demand signals. In other cases the call off is a real customer order. But the OpCo knows the order much earlier if the customer has asked for a delivery date. It keeps the order on hold and releases it (call off on ELC) when the delivery date is within their product delivery and installation leadtime. The demand signal is not available at Venray at the right time (when the demand is generated).
In many cases the delivery date is not specified. The customer order regards the delivery as soon as possible. However, there is not an agreement on expected leadtime either. The current process moves the product from the ELC to the customer with the highest speed possible. However, some customers refuse to accept the product delivery because the product comes earlier than expected. So, the customer order without specified delivery date does not represent true customer demand because actual delivery leadtime is not in line with the customer`s expectations (and not with the leadtime that marketing regards as acceptable).

Service level

The P3 process tries to achieve a specified service level. However, this service level is based on the demand of the OpCo. So, the current service level (of about 98%) for processors measures whether call offs are satisfied within one day. The process should not achieve a service level to the OpCo but to the customer. The end customer determines whether the product is delivered according to agreed conditions. So with the current process it is not known whether service level is good and whether the parameters of the process (minimum, target and maximum stock level) are set at the right values.

Stock

Currently, OpCo`s have stock. However, stock at the OpCo`s cannot be used for every demand. The current process of allocation and call off does not contain any thrive for preventing OpCo`s stock. However, the strategy is to have central free stock only (an example of stock reporting is in appendix G).
The current material planning process orders material using the MRP concept. MRP assumes that the future demand is completely known and as such it will adjust supply to demand. In our case MRP calculates the quantity of parts that is needed to satisfy the forecast. However, it does not take notice of the forecast accuracy. Although safety is increased using safety time (longer leadtimes) the MRP concept will never be able to deal with a safety stock. MRP is not able to deal with a safety stock because it is not recognised as such (see ref. [2] and [3]).

Problem statement

In the previous paragraph it was shown that the current planning and control process is not able to react on customer demand signals. It is not able to guarantee a high service level to the end customer. Stock is not divided wisely over the entire supply chain in order to achieve a high service level.
This can be summarised in the following problem statement:
The current production planning and control process is not able to react on customer demand within the acceptable order-to-install time[1]. Resulting service level and stock are not optimised integrally for the entire supply chain.
In the remainder of this report this problem is tackled. With the current process true demand responsiveness can never be achieved. Some major changes in the process have to be made. These changes will require a new way of looking at the goodsflow.

Remarks

Before discussing the solution of the problem some remarks should be made first. The goodsflow has some features that currently are unused opportunities. The current throughput time of assembly is not used. If one would add this time to the transport time from ELC to OpCo`s drop point and the delivery and installation time with the customer one could conclude that the total physical lead time would be about 9 days and definitely within the acceptable order-to-install time.

[1] the order-to-install time is the time between the date of order signature by the customer and the date of installation of the product at the customer

Also, order information is available at the OpCo`s. Often this information is stored in their own order database. In other cases the order is kept in the "salesman`s briefcase". Now, no optimal use is made of this information.

Chapter 7 Alternatives

Introduction

The problem is known. Next step is to solve it. What alternatives do apply? How does the material and capacity planning of each alternative work? What are the impacts of each alternative on stock, leadtime and capacity? The answers will be given in the remainder of this report.
In this chapter two alternative solutions to the signalized problem are introduced. A more detailed description and analysis will be made in the next chapters. Also, it is explained why statistical inventory control has been chosen.

Alternative one: ship one build one

This alternative can be considered as a replenishment system. Customer orders are transferred to the ELC just as in the call off process. The call offs are aggregated customer orders. From here the products are shipped to the drop points of the OpCo`s. It is similar to the current process of ordering and distribution.
However, stock in the ELC is replenished immediately after the moment a call off from the OpCo occurs. The replenishment order is transferred to the manufacturing plant and built on the earliest day possible. Manufacturing will translate these orders into assembly orders. If the capacity load of the replenishment order exceeds available capacity the remainder of the order is postponed to the next day.
To ensure fast delivery to the customer stock level in the ELC is based on fluctuations in demand during the time between replenishment order and receipt of the products from Manufacturing.
In order to guarantee material availability material is controlled using a statistical inventory control (SIC) rule. This rule ensures that a safety stock is available that is large enough to satisfy demand fluctuations during the part leadtime. More will be explained in the next chapter.
Immediate delivery after OpCo call off can be achieved in most cases. However, stock at the ELC is still needed. Also, there is a risk that demand fluctuations are not correctly translated into parts demand (the Forrester effect - see ref. [4]). Another difficulty is the balancing of the stock of the variants.
The results of a simulation of the ship one build one concept are discussed in one of the next chapters.

Alternative two: build to order

This alternative reacts directly and completely on customer demand. Daily customer orders are transferred from the OpCo`s to Manufacturing. These orders are transferred by the OpCo immediately after clearance and validation of the order.
Orders with a delivery date are planned in such a way that delivery will occur on time and that time between order release for production and delivery with the cutomer is at least equal to the physical leadtime for production, distribution and installation. Orders without a delivery date ("as soon as possible" orders) are built and delivered "as soon as possible" (that means that priority is on orders with a due date). Their throughput time (from order entry to installation) will vary.
The throughput time from Manufacturing to customer largely depends on the variation of the quantity of orders per day. Availability of capacity has a major impact on "on time delivery". In this alternative there is no free stock at the ELC. The ELC is responsible for the cross docking of products from Manufacturing to the OpCo`s. ELC stock that occurs is caused by orders with a delivery date beyond standard leadtime.
Also, in this alternative material availability is a prior condition. Again, a statistical inventory control rule for ordering parts is recommended. However, in this case the material replenishment orders are based on true demand signals.
For this alternative also a simulation was performed.

Why statistical inventory control?

In both alternatives SIC was chosen for the replenishment of material. SIC does not match supply with demand but it recognizes that demand is not known before hand. That is why safety stock is kept.
MRP tries to match supply with demand. However, demand is not known when the MPS (master production schedule, production plan) is determined. So a difference between actual demand and MPS occurs. In order to satisfy this demand safety stock at MPS level is necessary. MRP however does not know how to deal with it.
SIC however is able to deal with safety stocks. It does not require a complex forecasting method. It is able to deal with demand uncertainty. The unbalance of stock is not likely because material is replenished directly based on customer demand. A broad discussion is in ref. [5].

Chapter 8 Material replenishment

Introduction

In the previous chapter two alternative planning and control concepts were introduced. Both pretend to be responsive to true customer demand. Both concepts have some things in common: they use a statistical inventory control (SIC) rule for the replenishment of material and they use flexible capacity. The lather will be discussed in the next chapter. The former will be discussed in this chapter. A replenishment rule will be explained and applied for the build to order concept.
These two chapters will discuss aspects that will be used in a simulation that analyses the effects of the alternatives on leadtime, stock and capacity. The simulation will be discussed in chapter 10.

A SIC rule: s-S

A statistical inventory control rule (see ref. [6] and [7]) replenishes material if the quantity on stock and on order decreases under a specified limit (reorder level). The quantity to be ordered will either be a fixed quantity (a batch) or a variable quantity (this means that one orders a quantity that will increase the amount on stock and on order upto a specified maximum). Also, there is a difference in the review interval of stock. In one case the stock will be reviewed continuously (and material will be reordered instantly); in the other case stock will be reviewed on fixed intervals (for example weekly).
All rules consider demand fluctuations. The reorder level considers the variance of the demand during the lead time of the part. With a specified service level stock will be large enough to satisfy demand. The service level measures the percentage of time that there is no physical stock. In this case it is a good measure because it expresses the fact that a lack of materials will delay production and (more important) will increase the order throughput time.
In this case the s-S rule is used. It reviews stock on fixed intervals. The order size is variable. It is valid for a service level that measures the time that stock is not available. Also, demand arrives as separate orders. In this case that is true because customer orders arrive separately and are not ordered in batches.

The following parameters are used (see [6]):

- m = the review interval
- t = the part lead time
- v = inventory cycle (a multiple of m, order interval)
- μ = average demand per period

σ^2 = the variance of demand per period
k = the safety factor based on a specified service level
Q = fixed batch size in case of a s-Q rule

The variance of available stock at an arbitrary moment is (in case of a s-Q system; fixed batch size):

$$V_1 = m*\sigma^2/2 + \mu^2*m^2/12 + t*\sigma^2 + v^2*\mu^2/12$$

The variance of available stock at an arbitrary moment is (in case of a s-S rule):

$$V_2 = t*\sigma^2 + v*\sigma^2/2 + \mu^2*v^2/12$$

If one assumes that $v*\mu$ is equal to Q the reorder level that applies to a s-Q rule also applies to a s-S rule:

$$s = (t + m/2)*\mu + k*\sqrt{V_1} - \mu*v/2$$

The maximum level can be specified as follows:

$$S = (t + v/2)*\mu + k*\sqrt{V_2}$$

The procedure is then as follows:

1. At each time 0, m ,2m, 3m, ... determine the stock level and the outstanding orders
2. Determine whether this total is larger than the specified reorder point; if the total is larger perform step 1 again on the next review time; else perform step 3
3. Order the difference between maximum level and on stock plus on order; review stock on the next review time
4. Parameters should be updated if changes occur.

This model assumes that at least the average and variance of the demand are given.

Application

An A-B-C classification

Not all parts have an equal value of turnover. Not all parts are equally voluminous. The SIC rules should be applied sensibly. That means that parts with a large turnover (and voluminous ones) which have a large impact on stock should be controlled more intensively than parts with a small turnover. That is why an A-B-C classification is applied. A-items have a large turnover value and are controlled continuously. A-items are always a small amount of the total parts. B-items are controlled less frequently and form a large part. C-items have a very small turnover value and form the largest part. In this case classification was done on the expected annual turnover per part (volume of the part was not considered). Premise was the A-B-C-classification used by RANK XEROX. However, the number of classes was reduced from 8 to 3. The new class A was formed by RX classes A, B and C (new B = D, E and F; new C = G and H). The new ordering policy was also based on the given classification. For each new class the least frequent ordering policy of the old ones was chosen. Results are in table 2.

Table 2 A-B-C classification (example for NB 5065)

Item class	Classification criterion (expected annual turnover)	Number of parts	Value of annual turnover in Dfl.
A-item	Turnover ≧ Dfl. 80K	140	12,538.22
B-item	Dfl. 10K ≦ Turnover < Dfl. 80K	355	2,959.30
C-item	Turnover < Dfl. 10K	708	373.21

Source: XBMS

Definition of the parameters

Per item class an order and stock review policy was determined. A-items will be reviewed and ordered weekly, B-items once per four weeks and C-items once per twelve weeks. Safety factor is different per item class. The highest service level is chosen for C-items because extra safety at these parts has only a marginal influence on stock value. Service level is the smallest for A-items. These have the highest turnover. Also, if there would occur a stock out this should be monitored first for A-items; they are reviewed most frequently and extra effort to prevent negative influences of a stock out will be limited to a selected quantity of parts.
Average demand and variance should also be calculated. However, no customer demand was available. The call offs on the ELC were assumed to represent fluctuations and level of demand. One should realise that this is biased information. The call off information per week in 1991 was supplied by FMO and is stored in SWORD.
The safety factor was determined by using the student`s t distribution. With the given service level this factor could be easily found in a given table (Ref. [8]).
Parameters are set in table 3. Per item the used parameters are specified.

Calculation of the reorder level and reorder maximum

The end products have a lot of common parts. This means that the demand for the four end products has to be translated into demand per part first. With the usage ratio that is given in the bill of materials the demand per part is calculated. This calculation was done on a spreadsheet model. With the given parameters the model also calculates the reorder level and maximum. This calculation was only

Table 3 Parameter setting for reorder level and maximum

Variable	A-item	B-item	C-item
Review interval m (in weeks)	1	4	12
Inventory cycle v (in weeks)	1	4	12
average NB[a] demand μ_{NB} (qty / week)	80	80	80
variance NB demand σ_{NB}^2 (qty / week)	1434	1434	1434
average RDH[a] demand μ_{RDH} (qty / week)	20	20	20
variance RDH demand σ_{RDH}^2 (qty / week)	131	131	131
average ADH[a] demand μ_{ADH} (qty / week)	9	9	9
variance ADH demand σ_{ADH}^2 (qty / week)	32	32	32
average[b] CNV[a] demand μ_{CNV} (qty / week)	29	29	29
variance CNV demand σ_{CNV}^2 (qty / week)	267	267	267
safety factor k	2.2	2.9	3.3
service level corresponding with k (%)	98	99.5	99.9

Source: SWORD (for demand data)

[a] NB = NB 5065, RDH = RC 1065 + RDH, ADH = RC 1065 + ADH, CNV = CONVERSION 5065
[b] history of CONVERSION 5065 started in June 1991

performed for all A-items. A sample of fifteen B-items and ten C-items was drawn. For this sample the calculation was also performed.

For analysis purposes all B-items and all C-items were regarded as one B-item and one C-item.

The usage ratio`s of the A-items are in appendix H. The reorder levels and maxima are in appendix J.

Remarks

This replenishment method could also be applied to kits and output modules. The calculation method is the same. In the remainder kits and output modules will not be regarded. However, planning of these parts should be done by the same department as the planning of parts for processors.

Carcasses are the input for recycling. Availability of carcasses is influenced by many factors that are out of the control of Manufacturing. It is assumed that the availability of carcasses is no problem. Presently there are far more carcasses available than demand. It is also assumed that the disassembly activities are not directly controlled by customer orders but that a buffer is maintained between the disassembly line and main assembly line.

Chapter 9 Capacity planning

Introduction

In the previous chapter the material aspect of the alternatives was discussed. Now the capacity aspect is regarded. Both aspects will be applied in a simulation of the alternatives that is presented in the next chapter.
Both alternatives need flexible capacity. Both alternatives use the same capacity planning method. It is applied to the build to order concept.

Capacity mix flexibility

Available capacity is limited by manpower and assembly line (physical layout, equipment, etc.). In this case the assembly line is given. It is assumed that this cannot be changed.
However, manpower is still a variable. But the manpower needed for the assembly of the 1065/5065 product family has to be skilled (large work packages, different elements, technical knowledge). That is why no flexible manpower like temporary employees can be used on this line. However, the manpower of the 1065/5065 can be switched to other jobs. So they could fulfill a temporary job at a different line. It is assumed that this kind of flexibility can be used on a weekly basis.
The amount of manpower needed is determined by the capacity requirements of the products. The layout of the assembly line limits the amount of machines that could be made on the line to 32 machines per day. It does not matter whether these machines are new or recycled. The manpower required should be based on this output so that manpower does not constrain capacity. However, the 32 machines per day consist of four variants. And these variants (new versus used) differ significantly in processing time (mainly due to testing which occurs at parallel work stations). So the manpower has to vary in order to be able to build a specific mix of products.
Although the line could produce 32 machines a day, available manpower limits the mix that can be assembled. So, determining capacity also means determining the mix of products that can be made. In order to determine the mix, a forecast should be made of this mix. Exponential smoothing is used to determine the mix of new and used machines (see ref. [7], [9] and [10]). The capacity must be available in a mix that is in line with end customer demand. The size of demand is not of concern because capacity is constrained to 32. The procedure is as follows:

The following variables are used:

$d(t)$ = demand for new and used machines on Manufacturing at day t
$d_N(t)$ = demand for new machines on Manufacturing at day t
$p_N(t)$ = ratio of demand for new machine and total demand at day t
$p_N(t,t)$ = forecast of ratio of new machines to total demand at day t made at the end of day t-1
α = exponential smoothing parameter
$C_N(i)$ = net available capacity of new machines per day for week i
$C_U(i)$ = net available capacity of used machines per day for week i

The following equations apply:

$p_N(t) = d_N(t)/d(t)$ (1) determining the actual ratio
$p_N(t,t) = \alpha * p_N(t-1) + (1-\alpha) * p_N(t-1,t-1)$ (2) exponential smoothing
If t-1 is last day of week i-1 then:
$C_N(i) = 32 * p_N(t,t)$ (3) determining the new capacity mix for week i
$C_U(i) = 32 - C_N(i)$

According to this mix the manpower requirements are determined.

Manpower determination

In the previous paragraph the net available capacity per week was determined. However, in order to get net capacity gross capacity is needed. Gross capacity does not consider losses like illness, holidays and organisation losses. Manpower should be based on gross capacity. So the net available capacity per week should be corrected with these losses in order to determine the required manpower. The losses are the same as assumed in the 1991 control plan. A check of the actual losses proved that the assumed figures are representative.

The following variables are used:

$C_N(i)$ = net available capacity of new machines per day for week i
$C_U(i)$ = net available capacity of used machines per day for week i
o = organisation losses in %
z = illness in %
$M_H(i)$ = required manpower (on pay roll) in week i in hours
$M_P(i)$ = required manpower (on pay roll) in week i in amount of people
$x(i)$ = available working days in week i
A_S = available hours per year with a summer shutdown
A_N = available hours per year with "half" summer shutdown
A_M = net available hours per man per year (without holidays)

S_{NB} = standard time-in hours for the main assembly of a new machine
S_{RC} = standard time in hours for the main assembly of a recycled machine

Also, values of table 4 should be used.

Table 4 Capacity and its parameters

Parameter	Value
Illness percentage	12 %
Organisation losses	3 %
Available production hours (summer shutdown)	1792 hrs
Available production hours ("half" summer shutdown)	1936 hrs
Available hours per man (without holidays)	1704 hrs
Available hours per day	8 hrs
Standard processing time for new machines	7.0 hrs
Standard processing time for used machines	13.1 hrs

Source: Control Plan 1991

The following equations are used:

$$M_H(i) = \{C_N(i)*S_{NB} + C_U(i)*S_{RC}\}*x(i)/\{1-(o + z)/100\}*(A_S\#OR\#A_N)/A_M$$

$$M_P(i) = \text{INTEGER}(M_H(i)/\{x(i)*8\}) + 1$$

With this equation the required manpower is determined. This formula applies to the main assembly line. In a similar way the required manpower for subassembly and disassembly can be defined. However, this aspect is not regarded.

Remarks

At present there is a summer shutdown period of three weeks. In the new concept this is unacceptable because orders that are taken in this period will be delayed with three weeks. That is why some capacity should be available in order to prevent a large delay of customer orders. In the remainder it will be assumed that during the previous summer shutdown the assembly line will operate on half capacity. How to organise this is not regarded. However, it is acceptable to RANK XEROX not to close the plant in the summer. First, the ELC is not closed during summer. Second, RANK XEROX recently implemented flexible holiday planning for its employees.

The available capacity of 32 machines per day was given. This is a long term decision. However, if the level of demand changes also the available capacity should change. The capacity should always be larger that the demand level. In this case the capacity of 32 machines per day is more than the average demand level of 26 machines per day. This means an overcapacity of 23 %. Overcapacity should be maintained in order to be able to respond on customer demand. The required overcapacity has not been investigated because it is a long-term decision.

Chapter 10 Simulating the alternatives

Introduction

In the previous chapters the capacity and material aspects of the alternatives were discussed. Both alternatives were the same with regard to these aspects. However, there are differences. In this chapter the alternatives are analysed with regard to impact on stock and on throughput time. The results will be compared in the next chapter and will lead to the choice of one alternative.
The results were achieved through a simulation model that was made with the spreadsheet package VP-Planner (see ref. [11]).

The preparation of the simulation

A simulation model was made of a build to order and a ship one build one concept. The model consisted of three spreadsheets: the planning of orders, the replenishment of material and the definition of capacity. The model considered orders on a day by day basis for a full year.

Demand

First step was to determine customer demand. Only the weekly call off pattern of all OpCo`s was available. However, the demand (order entry in ACCORD) of the OpCo in France was available on a daily basis. Also, a sample of orders with a specified delivery date was available in France.
It was assumed that the demand pattern in France per day was representative for all OpCo`s. To estimate the demand of all OpCo`s the demand of RXF was divided by its share in the demand of all OpCo`s per week (based on SWORD data).
It was also assumed that the OpCo`s have a similar delivery date specification as in France. It was assumed that 85% of the orders had no delivery date and the rest had a delivery date distribution as in figure 11.
With a random generator first the orders with a due date were calculated per day. After that based on the distribution of figure 11 and a random generator due dates for these orders were drawn. The daily demand is in appendix I.

Capacity

The capacity per day was set on 32 machines per day. The capacity mix was the same for the two alternatives. It was based on the exponential smoothing forecast as was expressed in the previous chapter. The same holidays were applied as

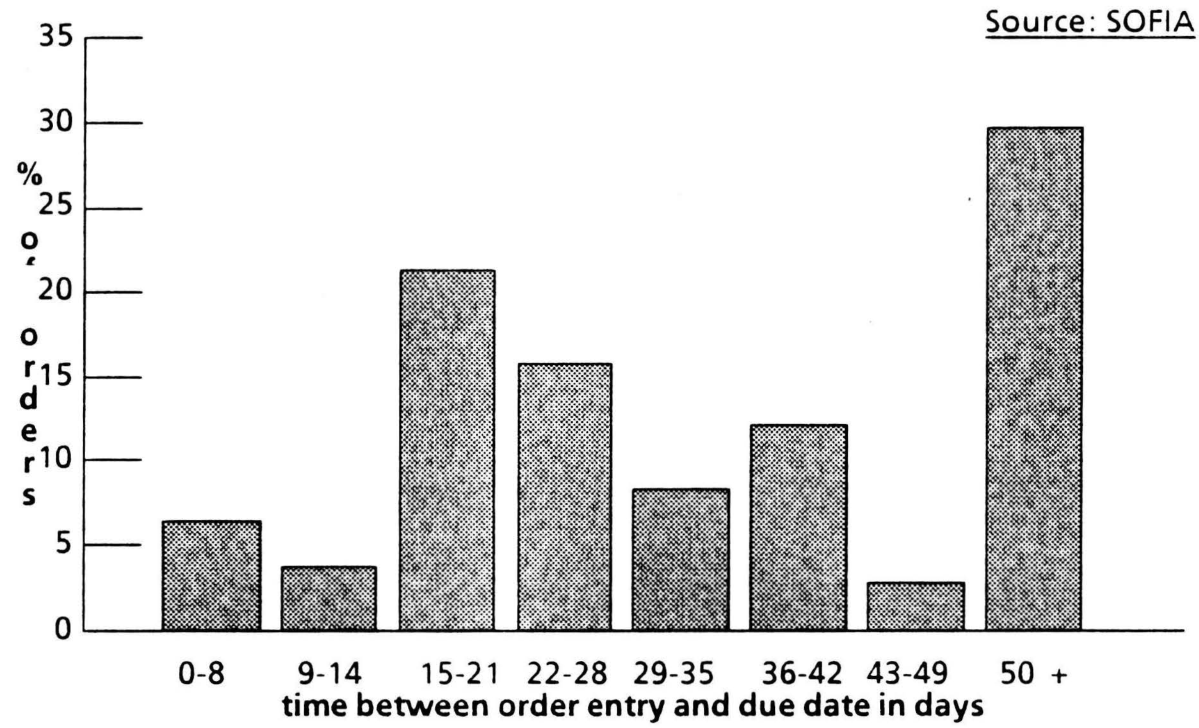

Figure 11 Distribution of the delivery leadtimes of orders which have a delivery date

in 1991 by Manufacturing. However, in case of the summer shutdown period the capacity was set on 16 machines per day.

In case of the build to order concept another capacity alternative was investigated. This alternative was used to show the consequences of mix flexibility and summer shutdown. In this alternative the capacity was set on 32 machines a day with a fixed mix of 17 new and 15 used machines (fixed work force). Also, the summer shutdown was maintained.

Capacity is given in appendix I.

Material

Material reorder levels were determined in chapter 8. All A-items and a sample of B-items and C-items were investigated. For the A-items the replenishment was done on a weekly basis. Therefore, it was assumed that all demand of that week occurs at the beginning of that week and that all orders are received at the beginning of that week. Also, a part with lead time $\underline{t}$ that is ordered in week $\underline{i}$ is received in week $\underline{i+t+1}$.

Also, an opening stock of material was assumed. By trial and error it was set on such a level that at first review immediately an order had to be placed but that this order was in line with the average demand.

Stock level

In case of the ship one build one concept free stock at the ELC is kept. This stock is based on the demand uncertainty (call off pattern of 1991 as registered in SWORD). The calculation rule is as follows:

σ_N = standard deviation of demand for new machines = 67 machines/week
σ_R = standard deviation of demand for used machines = 49 machines/week
k = safety factor based on normal distribution = 2.0
SL = service level corresponding with k = 97.5 %
lt = manufacturing leadtime

The leadtime of manufacturing is set on 1 week. The stock is calculated as follows:

I_N = stock of new build = $k*\sigma_N*\sqrt{lt}$ = 135
I_R = stock of recycled = $k*\sigma_R*\sqrt{lt}$ = 100

In case of the build to order concept no free stock is kept. However, if there is capacity left and if there are orders with a due date beyond the lead time these orders are built and stored at the ELC. So there results stock which is however sold.

Order release

Alternatives are summarised in table 5.

Table 5 Description of the alternatives

Sequence	Name	Description
1	Simulation 1	Build to order / fixed work force / summer shutdown
2	Simulation 2	Build to order / mix flexibility / half capacity in summer
3	Simulation 3	Ship one build one

The physical leadtimes are set on 10 working days for new and 12 days for used machines (7 days in case of simulation 3). There is also minimal one day between order entry and order release. The specification is in figure 12.

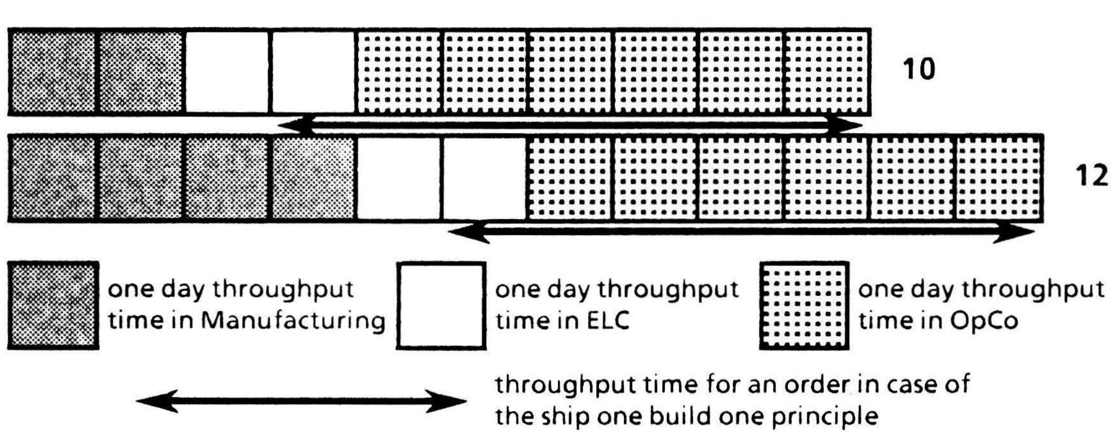

Figure 12 Standard physical leadtimes for new and used machines

With these leadtimes the following order release functions were used:

Simulation 1: *Build to order, fixed capacity, summer shutdown*

1. plan all orders with a due date of which the due date is equal to or less than the current date plus the leadtime; if capacity is fully planned, then start with step 1 on next day; else, go to step 2
2. if there is capacity left then plan the orders without the due date; priority is on the orders with the earliest order entry date; if capacity is fully planned, then start with step 1 on next day; else, go to step 3
3. if there is still capacity left then plan the remaining orders with due date; priority is on orders with the earliest due date; if capacity is fully planned, then start with step 1 on next day; else, accept unused capacity and start with step 1 on next day

Simulation 2: *Build to order, mix flexibility, half capacity in summer*

1. plan all orders with a due date of which the due date is less then the next working day plus the leadtime; if capacity is fully planned, then start with step 1 on next day; else, go to step 2
2. if there is capacity left then plan the orders without due date; priority is on the orders with the earliest order entry date; if capacity is fully planned, then start with step 1 on next day; else, go to step 3
3. if there is still capacity left then plan the remaining orders with due date; priority is on orders with the earliest due date; if capacity is fully planned, then start with step 1 on next day; else, accept unused capacity and start with step 1 on next day

note: orders are in principle released according to the planned mix

Simulation 3: *Ship one build one*

1. orders are directly shipped if stock is available
2. due dates are of no concern (like in JiT call off process) demand is directly transferred as a replenishment order to manufacturing
3. orders are released in sequence of order entry date and in the preferred mix

note: only the aggregate stock of respectively new and used machines are regarded; the real stock will be higher because of the four variants and the real throughput time will vary more!

The simulation

First, the generated orders were planned on the available capacity. A seperate spreadsheet for orders with a due date determined whether they should be released. Another spreadsheet was used for the orders without due dates. This one calculated the time between order entry and order release. Both spreadsheets resulted in order releases. The order releases were gathered in another spreadsheet that determined the capacity use per day and per week. The weekly capacity use was input for another spreadsheet that simulated the material replenishment. It calculated per item the average stock during the year and the amount of stock outs.

In case of simulation 3 all demand was directly inserted into a spreadsheet which determined available stock at the ELC, the production plan of orders and the manufacturing throughput times.

The output of the various spreadsheets was used to determine the results of the simulations. The simulation process is summarised in figure 13.

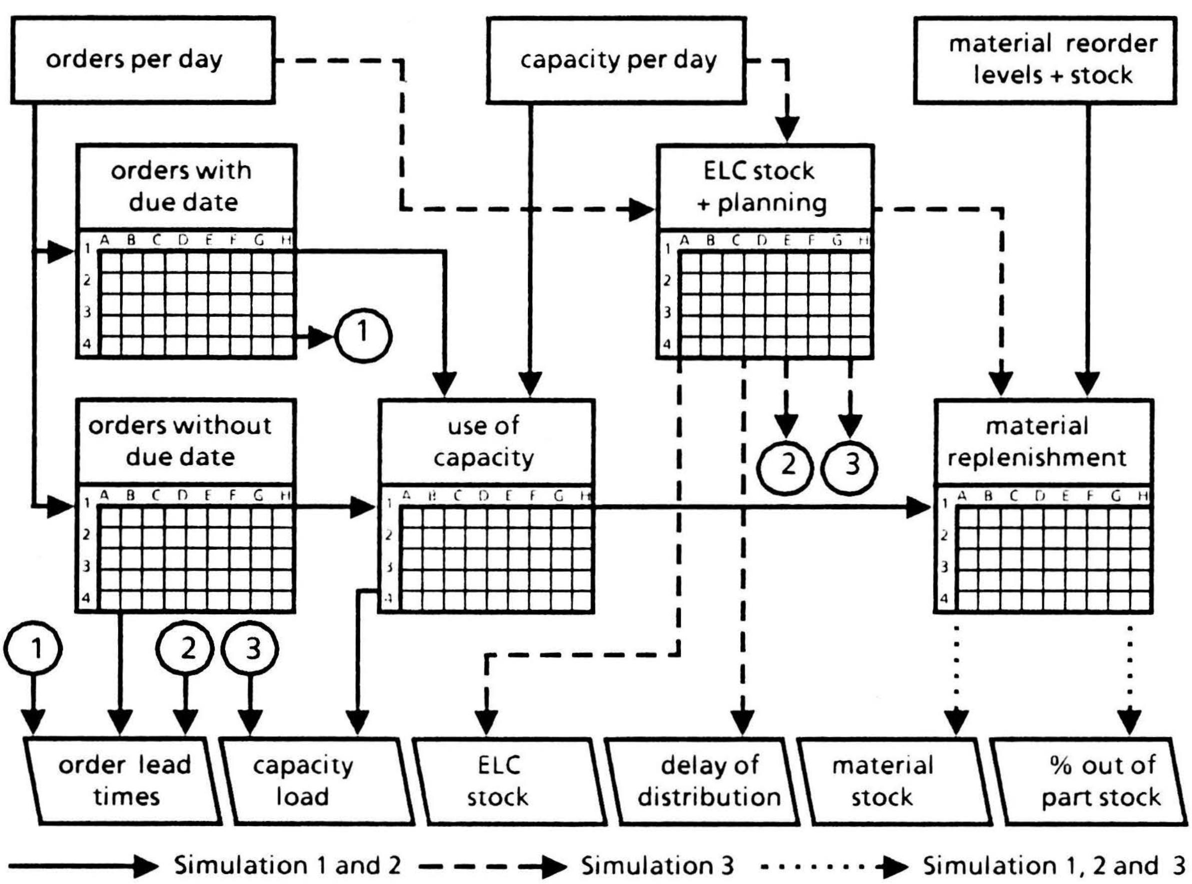

Figure 13 The simulation process

Results

The results of the simulations can be divided into the categories throughput time, stock, stock outs and capacity. In this paragraph these categories are investigated.

Throughput time

In figure 14 and 15 the throughput times (from order entry to installation) of orders without due date are compared for the three simulations.
As can be seen the impact of a summer shutdown period on order throughput time is large. Also, the impact of mix flexibility is large. In simulation 1 the orders for used machines have a large throughput time at the end of the year due to lack of mix flexibility and summer shutdown.
If there is stock at the ELC the throughput time is the shortest.
For orders with a due date the orders should be released on time. However, there could be circumstances that the due date could not be made. In case of orders with a due date within physical lead time these orders are of course always too late (of course this should be prevented in a build to order concept). This should be considered if the lateness is interpreted. The order release function has a large impact on the on time delivery.
Results are in table 6.
As can be seen the impact of mix flexibility is large. There is balance in the lateness of orders for new and used machines. Also the impact of a summer shutdown is enormous. The lateness increases significantly. Mix flexibility and "half "summer shutdown are necessary to prevent delay of the orders. Third, the order release funtion has an impact on the lateness. In simulation 2 the order release rule plans orders <u>now</u> if the order would be delayed when release is on the following working day.

Stock

Another impact of the alternatives is on stock. Only stock of material and end products at the ELC are regarded. In case of build to order there will be no <u>free</u> stock at the ELC. However, stock occurs at the ELC because some orders have been made earlier than the due date. In case of ship one build one the stock at the ELC is only <u>free</u> stock, it is not sold yet. Results are summarised in table 7. Detailed data are in appendix J and K.

Stock outs

Although parameters are chosen in such a way that a stock out for material does not happen very often it still does. In practice it does not have to mean that material is not available. With special effort a real stock out can be prevented. How-

Source: simulation model

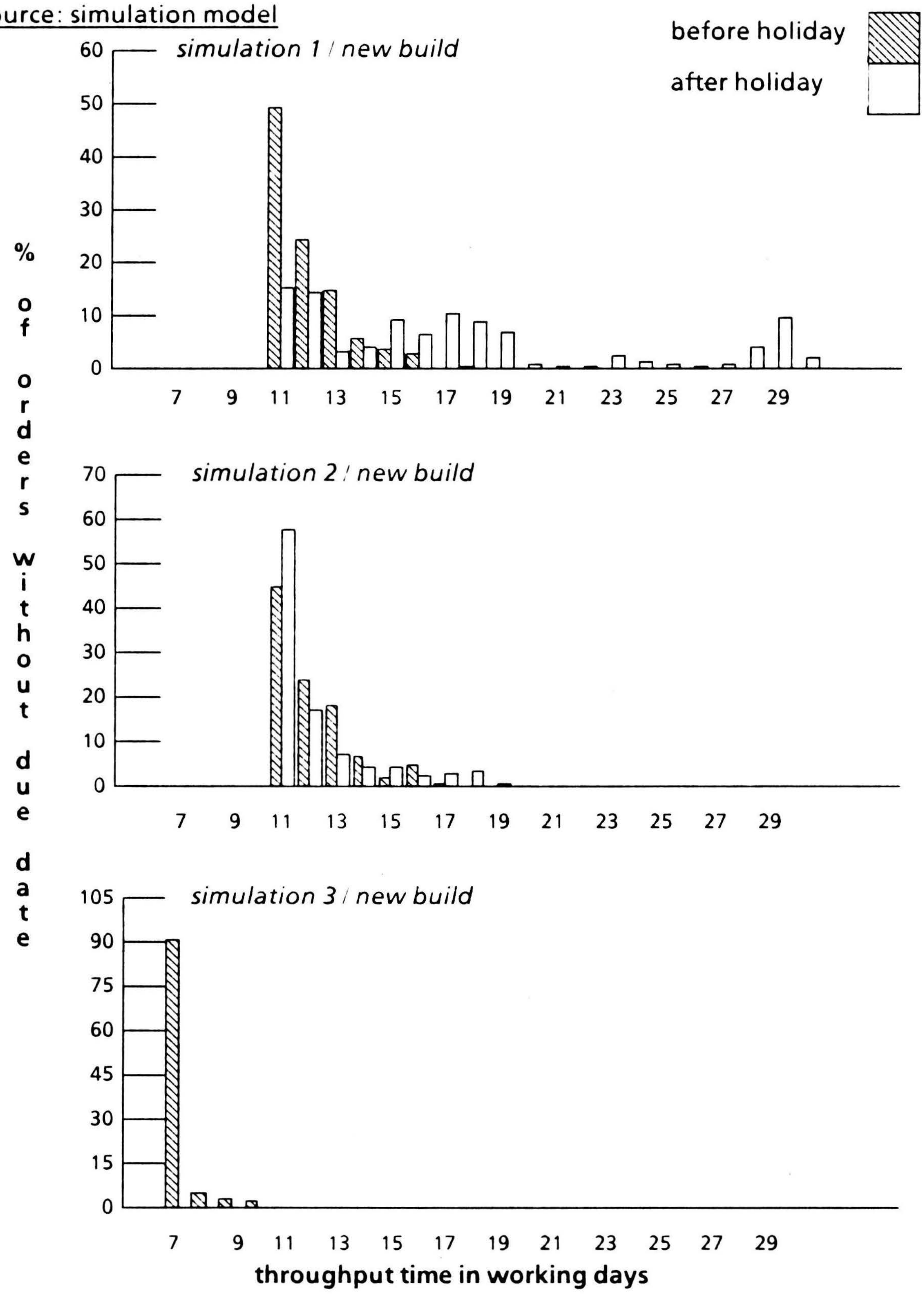

Figure 14 Order throughput time in working days for new machines

ever, extra costs like air freight and courier services have to be incurred. So although a stock out does not occur stock out costs do! In appendix L these costs are estimated. The stock outs are based on the material replenishment simulation for

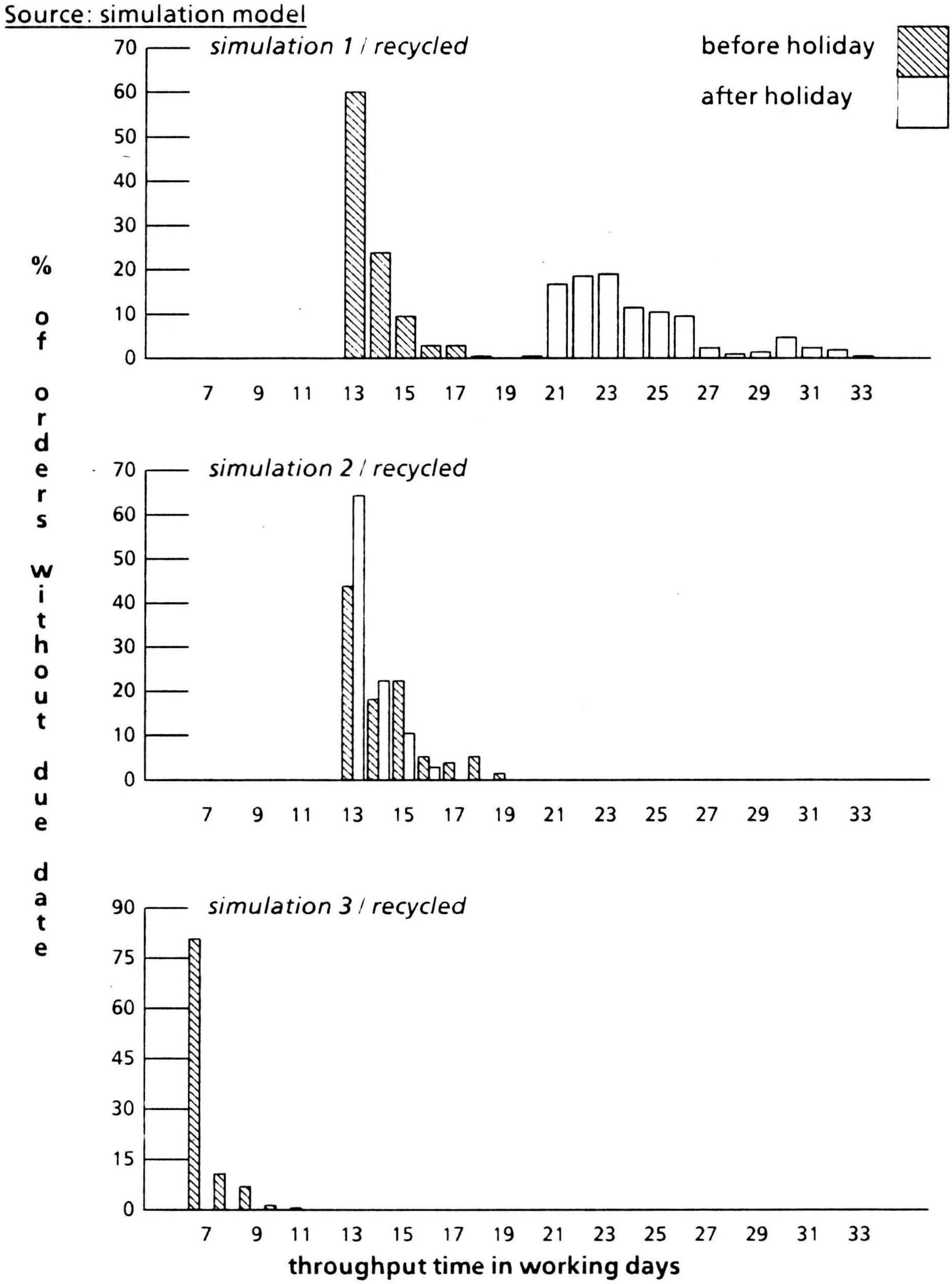

Figure 15 Order throughput time in working days for used machines

all A-items and for the sample of B-items and C-items. Results are summarised in table 8. More data are in appendix J.

Table 6 Results for orders with a due date

	Criterion	Performance new build			Performance recycled		
		Overall	Before holiday	After holiday	Overall	Before holiday	After holiday
Simulation 1	% orders on time (of orders with due date)	79.8	85.3	47.2	67.2	75.5	54.9
Simulation 1	% orders too late (of orders with due date)	20.2	14.7	52.8	32.8	24.5	45.1
Simulation 1	% orders with due date within lead time (of orders with due date)	10.3	9.2	16.7	9.0	9.0	9.2
Simulation 1	% orders too late (orders with due date beyond lead time)	11.0	6.0	43.3	26.1	17.1	39.5
Simulation 1	average throughput time in calendar days	25.4	27.1	15.4	19.9	21.1	18.1
Simulation 2	% orders on time (of orders with due date)	90.5	91.6	86.4	91.0	89.5	92.9
Simulation 2	% orders too late (of orders with due date)	9.5	8.4	13.6	9.0	10.5	7.1
Simulation 2	% orders with due date within lead time (of orders with due date)	8.2	7.7	10.0	7.7	8.6	6.6
Simulation 2	% orders too late (orders with due date beyond lead time)	1.5	0.7	4.0	1.4	2.1	0.6
Simulation 2	average throughput time in calendar days	28.7	28.3	30.3	24.3	22.2	26.7

Source: simulation model

Remarkable is that the resulting service level is smaller than the chosen one. The reorder levels are based on shipments that do not reflect the variance that occurs in case of real demand. Also, the demand of the simulation is slightly larger (2 %) than the realised shipments. This causes the reorder levels to be smaller than required. Also, the opening stocks were assumed. The difference can also be ex-

Table 7 Impact on stock

Alternative	Value A-items (in Dfl.)	Value B-items (in Dfl.)	Value C-items (in Dfl.)	Value ELC stock in MTP (in Dfl.)	Value total stock (in Dfl.)
Simulation 1	3,318,792	1,724,940	625,951	464,204[a]	6,133,887
Simulation 2	2,910,282	1,477,945	569,694	664,583[a]	5,622,504
Simulation 3	2,942,831	1,588,551	587,881	1,528,670[b]	6,647,933

Source: simulation model

[a] stock is sold [b] stock is free (unsold)

Table 8 Material stock outs

Alternative	% stock out A-items	% stock out B-items	% stock out C-items	Total stock out costs
Simulation 1	4.1	0.15	0	Dfl. 32,700
Simulation 2	4.7	1.1	0.3	Dfl. 72,100
Simulation 3	4.0	0.85	0	Dfl. 46,000

Source: simulation model

plained by the starting effects. At the start of the simulation outstanding orders are not generated by the replenishment rules yet. If a longer horizon for the simulation could be used probably a more reliable service level would occur. Also, a more honest service level occurs if the reorder levels are based on real customer demand!

Capacity

The alternatives also have impact on the capacity. In simulation 1 the capacity was fixed, in 2 it was variable. This has consequences for the work force that has to be avaiblabe and the related costs.

In figure 16 the capacity use against net available capacity per week is displayed. Detailed information is in appendix M. In the first weeks of the simulation the use of capacity is low. This is partly caused by starting effects of the simulation. There are no outstanding orders at the beginning of the simulation.

If there is a flexible capacity mix the use of capacity is much better because the capacity is adjusted to the mix in customer demand.

Also of concern is the cost of capacity. The theory was explained in chapter 9. The net available capacity is translated into required manpower hours and people. These are multiplied with the cost of manpower (Dfl. 28,51 per hour). In case of flexible capacity it is assumed that the workforce can be rescheduled to replace temporary employees. The results are in table 9 and figure 17.

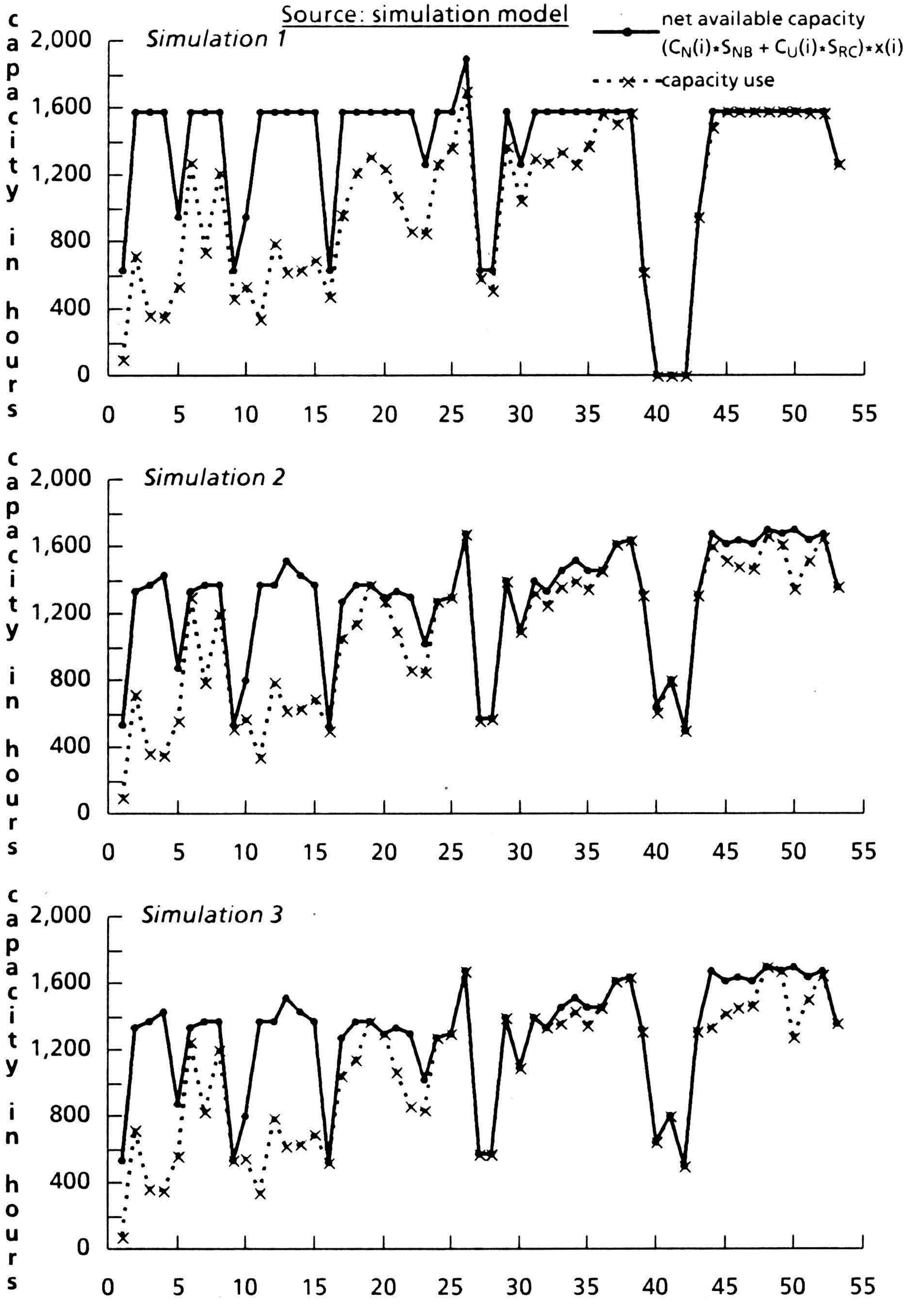

Figure 16 The use of the net available capacity per week

In case of ship one build one a buffer stock is kept at the ELC. The available capacity does not have to be as fexible as in the case of build to order because of this buffer. However, this is not investigated in the simulation. The capacity costs of ship one build one will be lower than assumed in the simulation. However, the costs will be only a small fraction lower because a rather small stock is kept at the ELC. The reaction time is small. As can be seen in the simulation of build to order flexible capacity is only slightly more expensive than fixed capacity. In case of ship one build one the calculated capacity costs are expected to be marginally higher than when capacity is less flexible. Also, a less flexible capacity will lead to higher variance of leadtime.

Table 9 Capacity effects

Alternative	Required manhours for entire year	Average manpower per working day	Capacity cost for entire year (in Dfl.)[a]	Produced quantity (NB + RC)[b]
Simulation 1	87,438	44.0	2,492,858	6,051
Simulation 2 and 3	91,704	46.0	2,614,481	6,264

Source: simulation model

[a] one manhour costs Dfl. 28.51 (control plan 1991) [b] only simulation 1 and 2

In case of build to order and mix flexibility the required capacity increases 4.9 % compared with no mix flexibility. So the actual mix flexibility costs are minimal.

Summary

Three alternatives were compared. Simulation 1 and 2 concerned build to order and simulation 3 ship one build one. Impacts on throughput time, stock, stock outs and capacity were analysed.
Ship one build one gave the shortest throughput times, and the least variance. Simulation 2 was the best alternative in case of build to order, simulation 1 could lead to an order throughput time up to 6 weeks.
Simulation 2 gave the least costs for stock. Simulation 3 gave the most stock. In that case unsold stock of finished products had to be kept. Build to order seemed to be the best alternative with regard to stock.
Related to stock are stock outs. The three alternatives differed with regard to stock outs. Especially the estimate of stock outs for C-items had a large impact on costs. The estimate of 0 % stock outs in case of simulation 1 and 3 is not likely to occur in real life.
Remarkable was that the resulting service level was smaller than the chosen one. Explanations were the starting effects and the biased information that was assumed to represent demand.

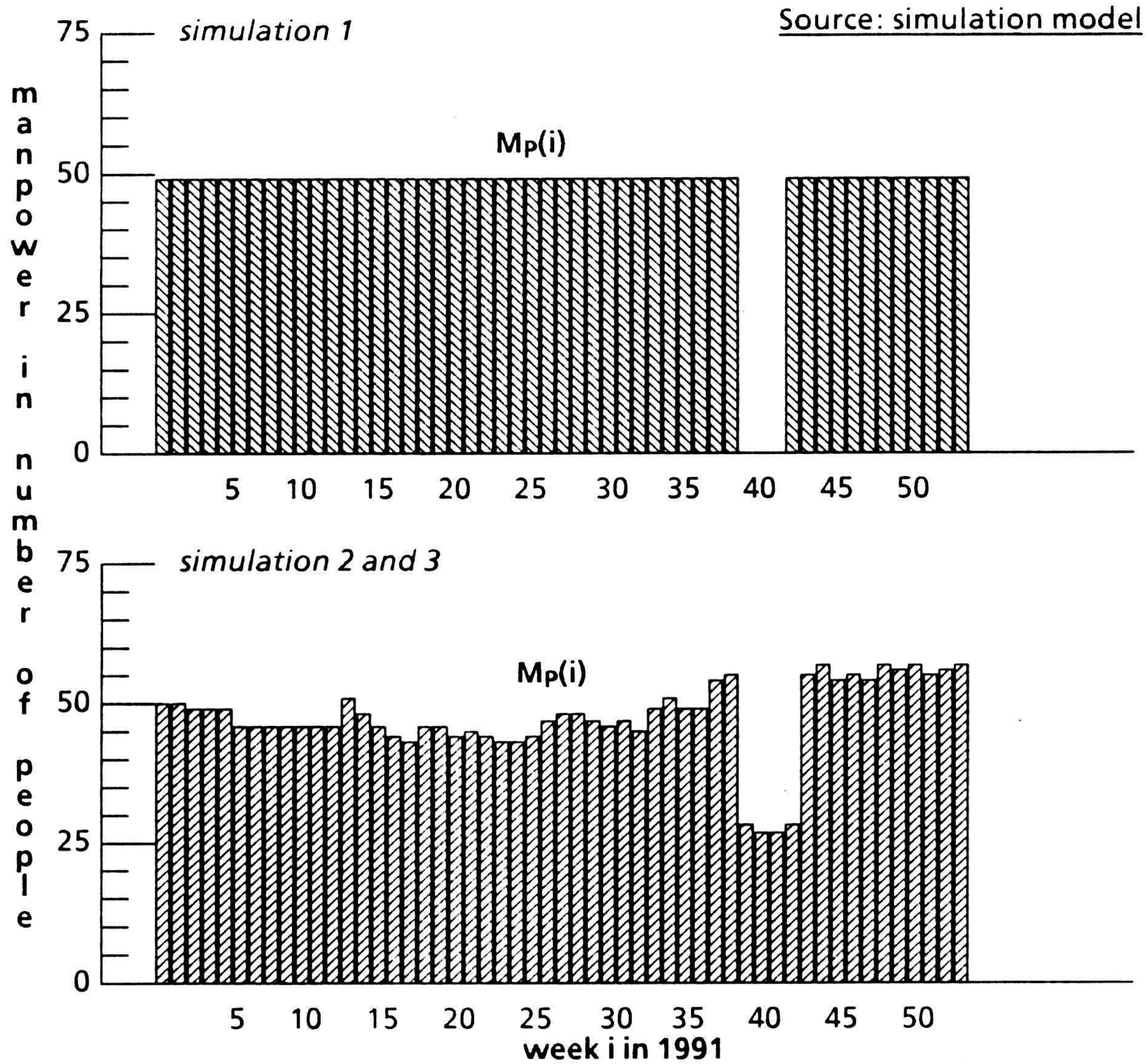

Figure 17 The presence of manpower at the assembly line in a specific week

The impact of mix flexibility is small on capacity costs but large on the throughput times. In case of simulation 2 compared with simulation 1 the maximum throughput time is reduced from 30 to 19 working days for new machines and 33 to 19 working days for used ones. In case of ship one build one it was stated that the calculated capacity costs were overestimated.

All impacts have been discussed. A choice still has to be made.

Chapter 11 Choice of the alternative

Introduction

In the previous chapter the various impacts of the alternatives were discussed. However, no overall conclusion was made. In this chapter it will be made and as a consequence one of the alternatives will be proposed. Recommendations for the implementation of the proposed alternative are made in the next chapter.

An overall picture

The various impacts of the alternatives were expressed into dutch guilders. Stock costs are based on the inventory carrying costs used by RANK XEROX. They are summarised in appendix N. Note that the provisions percentage to account for risk is 0 in case of sold products. Impacts are summarised in table 10. This table shows an accuracy of the numbers that should not be interpreted as such. These numbers mainly summarise the weight of each impact. For that reason the numbers for the present situation are not included because that would mean a relationship that is not existent.

Table 10 Impacts of the alternatives

Cost element	Build to order fixed capacity	Build to order flexible capacity	Ship one build one
Inventory costs material	Dfl 1,417,421	Dfl 1,239,480	Dfl 1,279,816
Inventory costs ELC	Dfl 97,483	Dfl 139,563	Dfl 382,168
Inventory costs OpCo	Dfl 0	Dfl 0	Dfl 0
Stock out costs	Dfl 32,700	Dfl 72,100	Dfl 46,000
Capacity costs	Dfl 2,492,858	Dfl 2,614,481	Dfl 2,614,481
Total cost	Dfl 4,040,462	Dfl 4,065,624	Dfl 4,322,465

Source: simulation model

Together with the financial impacts the impacts on order throughput time should be regarded. As was shown in the previous chapter the ship one build one concept gave the smallest throughput time. The build to order with fixed capacity has the largest throughput time. Because of the desired throughput time of three weeks this concept is not feasible. The build to order concept with flexible capacity is able to build and deliver 94% new machines and 97% used machines within

three weeks and all machines are built and delivered within four weeks. So this alternative should not be rejected because of the desired throughput time.
Compared with the ship one build one concept its costs are similar apart from the ELC stock. The choice is limited to these two concepts.

The actual choice

Based on throughput times the ship one build one concept is favourable. However build to order has good and acceptable results. The short throughput time in case of ship one build one offers more than the market requires.
The ship one build one concept still has free stock at the ELC. A problem that has not been discussed yet is that this stock has to be balanced. So for each product variant a separate stock is necessary. This was neglected in the simulation because it regarded aggregate stock of recycling machines. The real stock has to be larger than assumed. The demand uncertainty for each product variant is higher than the demand uncertainty of the aggregate products. This means that the safety stocks for three variants is higher than the aggregate safety stock.
Another problem is that a change in mix is difficult to deal with. This means that also the individual stock norms have to change. The principle ship one build one looks simple but a shipment of variant x does not necessarily mean that the production of x has to start. Maybe variant y should be made. So its demand responsiveness is rather precarious. The balancing of end product stock becomes more difficult if the number of product variants increases and demand becomes more variable.
Furthermore, the concept can be fitted in the call off process that is used now. So, the risk of replenishment orders for end products by the OpCo`s is still likely. It does not force OpCo`s to transfer their customer orders to Manufacturing or the ELC.
The build to order concept does not have that problem because production is based on real customer orders. Also, this concept has the least stock costs because it does not have free ELC stock. Most important, the build to order concept has the highest demand responsiveness. Demand responsiveness was the most important weakness of the current planning process. With demand varying and the number of product variants increasing production of the variants on customer order is the only way to prevent unbalanced and obsolete stock. Smaller capacity costs of ship one build one will never offset its costs of unbalanced stock. Based on these arguments the build to order concept with use of flexible capacity is recommended.

Chapter 12 Recommendations

Introduction

In the previous chapter a build to order concept with flexible capacity was recommended as the planning concept that would make production of the 1065/5065 product family responsive to customer demand. In this final chapter recommendations for using this concept are made.

Order process

The concept uses real customer orders. So, the OpCo`s should transfer the orders immediately after they have received it to the manufacturing plant. In this case OpCo`s should put effort in improving the process from order signature to order entry in their administration system. It should be analysed why a salesman does not transfer his orders immediately to the administration department in the OpCo (for example: he postpones the job of doing the paperwork; the rewarding process fosters this delay). If causes are known measures should be taken to prevent them. One should realise that every day that an order arrives later at the plant the possibility to smooth capacity use decreases.
The OpCo should define the required (by the market) order throughput time. Now, it is not clear what is acceptable to the market. A salesman should be stimulated to settle a delivery date (that is acceptable for the customer and realisable for manufacturing).
The OpCo should be able to get on time information on the order status. Only then an OpCo can track the progress of the order and signal problems with current and future orders. In that case the OpCo can take the right actions to improve service level.

Material replenishment

Material replenishment should be designed as was discussed in chapter 8. However, effort should be used to find real customer demand. This is needed as input for the determination of reorder levels and maxima.
For output modules and kits the same replenishment method should be applied. This replenishment should be done centrally by the plant that also receives the customer orders. The production plans of the different plants will then be coordinated. These accessories should be treated as normal parts.
Carcass replenishment is impossible. Therefore a buffer of carcasses needs to be kept. This is not possible if supply of carcasses is constrained. The only thing left to

do in that case is to warn the OpCo's that orders for used machines should be limited. Orders could be switched to new machines.
As was mentioned before, material should be available in order to build a product on order. If the build to order concept is to be implemented, the material stock should be increased before the actual start of the production on order. Otherwise, the first orders would be delayed and the OpCo's and customers dissatisfied. This would ruin the support for build to order.
It is very important that material stock information is reliable. Presently, it is and it should be so in the future. Only then a SIC rule can function satisfactorily.
The customer demand and its variance should be tracked and analysed. If there is a structural change in demand the reorder levels have to change, too.
Inherent to the replenishment rule is the variable order size. This means that work load for order receipt and the use of the storage will vary. These impacts have been disregarded. However, the impacts should be quantified and if necessary additional measures should be taken to prevent any problems. Also, the suppliers should be involved.

Capacity

Capacity should be flexible. Mix flexibility has been discussed. But also volume flexibility should be used. If there exists volume flexibility the variance of the order throughput time will decrease. The ideal state regarding leadtime would be that the difference between a build to order concept and a ship one build one concept is only the assembly time (if it is constant and small).
The consequences for the assembly line of a varying mix were not analysed. It is known that the line can handle a wide mix within a given quantity (if capacity is available). But changing mix also means that the amount of unique voluminous parts that lie in the line varies. With the limited space this can give problems.
It was discussed that a summer shutdown cannot be maintained. It was regarded in the manpower calculation. However, it has not been discussed how to implement it. It is not known whether it is acceptable to the employees. And if it is, a holiday planning should be implemented. It would be sensible to investigate the summer holidays of the OpCo's so that plant's holidays (and its capacity) are adapted to the OpCo's holidays (and customer demand).
Last, due to build to order available capacity may not be completely used. It will occur that manpower does not have orders to work on. These people could be sent home or put on a special training for the rest of the day.

Motivation

The build to order concept experiences resistance throughout the company. The OpCo's are reluctant because they cannot imagine that the manufacturing lead-time will be about two weeks instead of the present product leadtime of three months. OpCo's have to cooperate because their order information is necessary. However, the build to order concept is beneficial for the OpCo's. First, the production is for real orders. The OpCo's demand will not be constrained. Second, throughput time is acceptable. Third, build to order opens the possibility to customise a product at manufacturing; this means the delivery of a complete system which will reduce installation effort. It is necessary to convince OpCo's of the benefits of build to order.
Also, in the ELC resistance is likely. Now, the ELC does not plan activities; product delivery is triggered by a call off. With build to order the ELC should plan transport before the product is even at the warehouse. Planning and preparation of the invoice can start when assembly has started. Also, products are not stored but cross docked (transshipped). In case of orders with a due date some products have to be stored. Then the ELC has to generate the trigger for order picking and delivery itself. It is not likely that the ELC will accept these changes enthusiastically.
Also, the manufacturing plant is likely to show resistance. The days of a fixed plan will be gone. Also, one should accept the "lost hours" that occur if there are not any orders. Measurements should take notice of this. Also, material management will have to change enormously. Instead of the MRP concept that wants to prevent material stock a concept is chosen that will increase stock!
So throughout the company there will be aversion and resistance. Build to order will only succeed if this resistance is taken away.

Remarks

This report tries to contribute to the achievement of the Integrated Supply Chain. The recommended build to order concept really makes production responsive to demand.
Many aspects however could not be regarded. With the implementation of the concept they should be. But this report shows the most important impacts of the build to order concept. As such it hopes to increase support for the build to order concept and to take away some resistance.

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Glossary

ACT	actual
ADH	Automatic Document Handler
AV.CAP.	Available capacity
BOM	Bill of Materials
CAL.DAY	Calendar day sequence number
CNV	Conversion
CONV	Conversion
corr.	correction
DAYNR.	Working day sequence number
Dfl.	Dutch guilders
DOS	Days Of Supply
ELC	European Logistics Centre
EM3	Equipment Management forecast for 3 months
EMO	European Manufacturing Operations
ESO	Equipment Supply Operations
FIN	Finisher
FMO	Frans Maas Oostrum
hrs	hours
ICC	Inventory carrying costs
ICTP	InterCompany Transfer Price
Incl.	Including
Inv.	Inventory
ISC	Integrated Supply Chain
JiT	Just in Time
MNFG.	Manufacturing
MRP	Materials Requirements Planning
MTP	Manufacturing Transfer Price
NB	New Build
OCT	Offset Catch Tray
OL.	Outlook
OpCo	Operating Company
Outl.	Outlook
P3	Production Planning Process
Progr.	Programme
Qty	Quantity
RC	Recycling

RDH	Recyle Document Handler
REC	Recycling
Ref.	Reference
RPP	Rolling Production Programme
RX	RANK XEROX
RXF	RANK XEROX France
RXL	RANK XEROX Ltd.
RXLO	RANK XEROX Logistics Operations (Headquarters` department)
Shipm.	Shipment
SIC	Statistical Inventory Control
Sim	Simulation
SWORD	Supply Warehousing and Operations from Receipt to Despatch
UK	United Kingdom
XBMS	XEROX Business Management System