Production and inventory control at ABB Motors and Volvo Wheel Loaders, two examples of MRP in practical use

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Keywords Material requirements planning, master production schedule, aggregate planning, planning bills, available-to-promise, accumulative lead-time

Abstract. The paper presents the main routines of production and inventory control at ABB Motors, Västerås and Volvo Wheel Loaders, Eskilstuna. The primary interest is to present how Material Requirements Planning (MRP) is used in these two companies. If the number of end items is large, the company assembles-to-order or makes-to-order then additions to pure MRP seem to be necessary. ABB Motors and Volvo Wheel Loader use: planning bills, a normal bill of materials with 'adding bills of materials', a master production schedule planning system with an available-to-promise function and a home-made 'system' for modules available-to-promise. One important measure for the both companies is the accumulative lead-time. An increase of the Master Production Schedule in a shorter time than the accumulative lead-time is avoided, because it will lead to suggestions of purchase in past time periods and therefore most probably to future material shortages.

1. Introduction

Material requirements planning (MRP) is a basic tool for carrying out the material planning function in the manufacture of component parts and their assembly into finished products. Ever since the 1970s MRP has been a popular multilevel inventory control method in computer systems for materials and production control (MPC). From forecasts of the end items, MRP uses the bills of materials and the lead times of the items to calculate the required quantity and the due dates for each subassembly and component item. Total requirements for an item are matched (or netted) against inventory on hand and scheduled receipts. This determines whether or not any already open orders should be rescheduled or cancelled, whether or not any planned orders should be added, and if any orders should be released. The calculation starts with the items on the highest level in the product structure and is performed one level at a time down to the lowest level. The lowest level on which an item is used determines in which structure level the item takes part in the net calculation. Orlicky (1975) presents a thorough description of MRP still applicable to practical problems and theory. But most of the MRP users of today have probably been educated by APICS's certification review courses (cf. St. John, R. E. 1993) or textbooks (in logistics and operations management) from undergraduate and graduate courses. Orlicky points to the advantages of MRP compared with an ordinary reorder point system:

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MRP considers future demand, even if it varies; considers the relationships between items according to the bill of materials; produces a basis for future work loads. Segerstedt (1996) presents the algorithm of the MRP-calculation with formulas. As described in e.g. Nahmias (1997), the MRP calculated quantity of planned orders can be determined by fixed EOQ or several lot-sizing techniques, such as Silver-Meal, Least Unit Costs, Lot for lot (L4L) etc.

This paper contains two studies of how MRP is used in two different companies, ABB Motors and Volvo Wheel Loaders. To make a complete documentation of the production and inventory control systems in one company would almost require a book, so in this article what additions and specialties the two companies use around MRP is concentrated on. It is assumed that the reader is well informed about MRP from practical experience or literature, the reader should be familiar with Orlicky (1975).

2. ABB Motors

ABB Motors in Västerås produces seven main sizes of different electrical motors in aluminium. Figure 1 shows three main sizes, the size is determined by the height of the shaft (above the floor). About 300 different motors (end items) are kept in a finished goods inventory allowing delivery to the customers (within Europe) in 24 hours. In total about 2000 different types of motors are produced per year. Those items not in the finished goods inventory are manufactured when the customer order arrives. This takes some 3–4 weeks. But the main volume delivered to customers is standard motors, which pass the finished goods inventory.

Most of the main components, shields, rotors, stators etc. are produced in their own facility, and standard components such as bearings, aluminium bars and iron plates are bought from suppliers. Figure 2 shows the manufacturing flow in the production facility and it

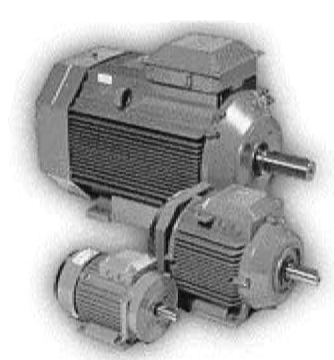

Figure 1. Electric motors from ABB Motors.

also marks that the number of levels in the product structures is only three or four. The production facility is divided into two sections: Division Production and Division Assembly. Division Production also delivers stators and rotors to other assembly facilities within the ABB Motor group. The semimanufactured inventory consists of about 400 different items.

The marketing manager calls the CEO (chief executive officer), the executive officers of the divisions and the manager of the aggregate planning to the *marketing meeting* (see figure 3). The marketing meeting often takes place on a Monday, and then the *preliminary meeting* takes place on Friday and the *executive meeting* on Wednesday the week after. Figure 3 shows which matters are essential in the different meetings. Three hundred end-items, that are kept in stock, and complemented with special end-items currently produced on special customer order, is too much information to handle and keep track of during these meetings. Therefore during these meetings the discussions use an aggregate plan consisting of how many units of the main motor sizes will be produced per production day (level 1 in figure 4). The aggregate plan consists of the seven main motor sizes: 112 (where 112 is the height of the shaft in millimetres between the shaft and the 'floor' (see figure 1)) and 132 assembled in the M1 production line; 160 and 180 assembled in the M2-production line; 200, 225 and 250 assembled in the M4 production line. The 'process' in figure 3 is 'owned' by the aggregate-planning manager, i.e., he is responsible for seeing that the results of the different meetings in the end lead to an acceptable master production schedule. A fictitious product structure, a planning bill (see figure 4) helps to transform these aggregated plans to plans for real item numbers.

Level 3 consists of the real end-items sold to customers. All motors of size 112 produced in the wiring machine AMT is on level 2 aggregated to the 'item'-number 112-AMT. The real end-item 3GAA112001-ADA is estimated to constitute 2% of the total amount of 112-AMT. The real end-item 9XXX112999-XXX1 is estimated to constitute 1.5% of the total amount of 112-AMT. 112-AMT consists of a lot of different real motors of size 112 produced in the machine 112-AMT. The aggregated product 112-AMT is estimated to constitute 80% of the total amount of size 112. The 'items' on level 2 produced in the four different wiring machines is on level 1 aggregated to size 112.

The decided production rate from the executive meeting in units per production day is transformed to batches per week and registered in a special Master Production Schedule Planning (MPSP)-system (a computer routine). This system 'explodes' the forecast (by the planning bills described in figure 4) to level 2 and 3. In the MPSP-system is also incorporated the 'external' demand of two of the

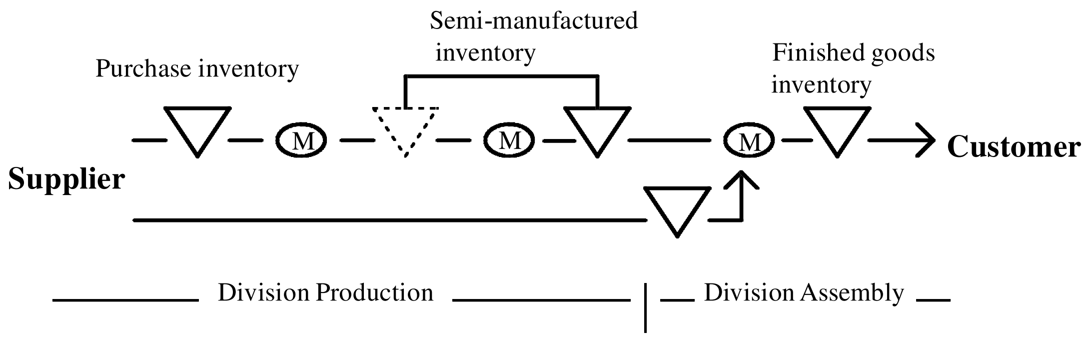

Figure 2. Manufacturing flow ABB Motors.

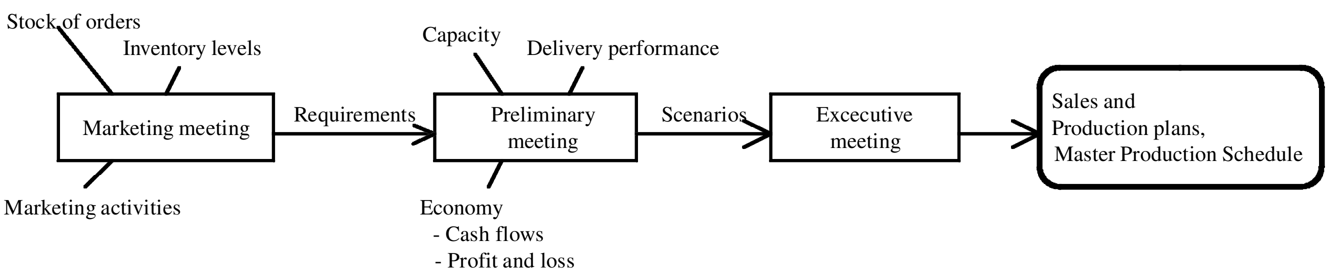

Figure 3. Overall planning cycle, every month, at ABB Motors.

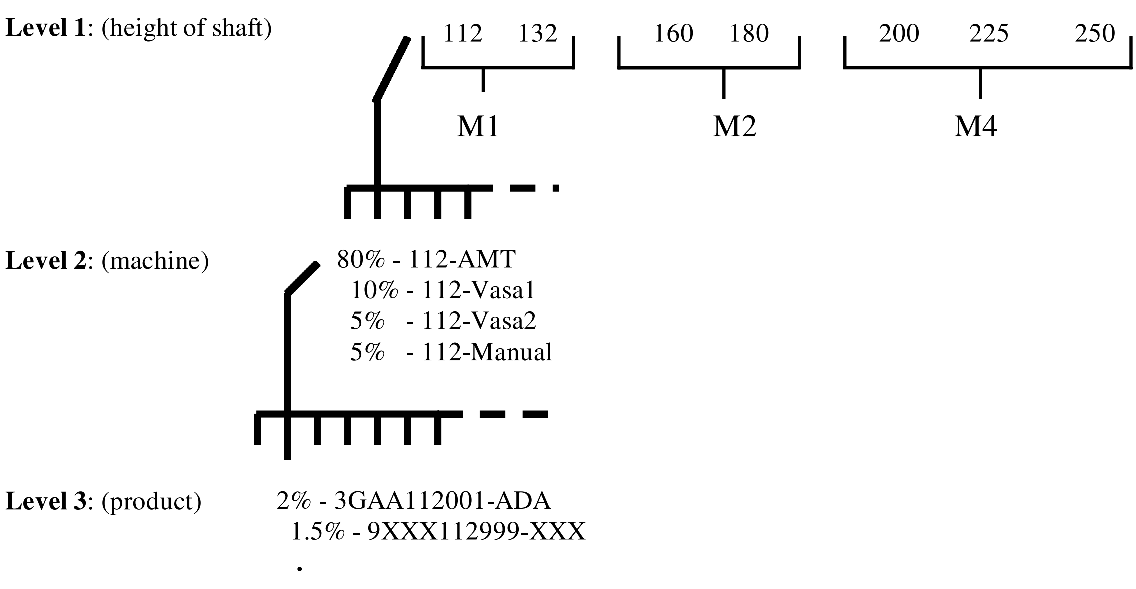

Figure 4. Bill of materials for planning, an example.

main components of the motor, stators and rotors. This is because the production division also manufactures stators and rotors for other assembly plants in the ABB-group. Then the production division can obtain the complete demand; both internal and 'external' demand.)

The MPSP-system has an available to-promise function. From the information in table 1 delivery dates for customer orders of real products are promised, and the MPS that will be the input to the MRP calculation is settled. *Forecasted demand* (in table 1) is the demand exploded from the production plan on level 1 (in the

Table 1. An example of the possible booking situation for a motor.

Row		Week	44	45	46	47	48	49	50
(1)	−	Forecasted demand	25	25	20	25	20	20	20
(2)	−	Other requirements	5		5				
(3)	−	Customer orders booked	27	28	22	14	5	0	2
(4)	+	Scheduled receipt (MPS)	48						
(5)	+	Planned receipt (MPS)			48		48		48
(6)	=	Projected on-hand inventory	33	5	26	1	29	9	37
(7)		Available-to-promise	5		12		43		46

planning bill). *Other requirements* can be interplant orders for service parts and orders for filling up inventories within the ABB-group. *Customer orders booked* show the amount already promised for delivery. *Scheduled receipt* is already decided and registered manufacturing orders for replenishments. The MPSP-system automatically suggests a *planned receipt* as replenishment so as to avoid *projected on-hand inventory* becoming negative.

The inventory on-hand in the beginning of period 44 is 17. The following mathematical expression is used in table 1:

$$\begin{aligned}&\text{Projected on hand inventory}_t\\&\quad= \text{Projected on hand inventory}_{t-1}\\&\qquad - \max\,(\text{Forecasted demand}_t, \text{Other requirements}_t\\&\qquad + \text{Customer orders booked}_t) + \text{Receipts}_t\end{aligned}$$

Available-to-promise for delivery in week 46 and 47 is 12 units ($= 48 - 22 - 14$). If no new customer orders are booked in week 44 and 45, it is possible to promise for delivery in week 46 and 47 totally 17 units ($= 5 + 12$). Observe that the information in table 1 can be aggregated and presented for all 'items' (both on level 1, 2 and 3) in figure 4, but only the MPS quantities on level 3 is used in the next MRP-calculation. (Both Vonderembse and White (1996) and Vollman *et al.* (1997) present discussions of a similar MPSP-sytem.) The receipts (MPS in table 1) (from level 3) are then exploded, through the real product structure, to their components by the real MRP-calculation.

The assembly of motors on production lines M1 and M2 is performed in two-week cycles; i.e. the order quantity of a motor assembly should at least cover the next 10 working days. In M1 first size 112 is assembled then size 132, and it takes at least 10 days before the same model is produced. Just recently the production cycle in production line M4 has been decreased to three working days. About 20 different variants of the same size are produced every cycle. The operators in the assembly line decide in what sequence the current amount of different assembly orders (two weeks of future requirements) should be expedited in order to minimize set-up times. The set-up times are dependent on the chosen sequence of orders. The same two week cycle is used for the manufacture of components despite their generally having longer set-up times and higher volumes than the different end items. (A variant of a motor size has often a low volume compared to the components, which are mostly used in several variants.) The planned orders from the MRP-calculation for purchase items of the motors have just recently started to be used as a signal for replenishment. For raw materials to components, on the other hand, manually decided reorder levels are used. ABBM uses a program package from Triton/Baan for its material- and production control. The MRP-calculation is performed every day with a planning horizon of 15 months.

The operators at division Assembly are called 'motor constructors'. They have all like 'white collars' a fixed monthly salary. The size of the payment depends on how many different tasks in the production line the person in question can handle.

3. Volvo Wheel Loaders

Volvo Wheel Loaders in Eskilstuna assembles the wheel loaders, Volvo L50 and Volvo L70 (see figure 5). Volvo Wheel Loaders (VWL) also has a plant in Arvika, Sweden, where another five models of wheel loaders are assembled. VWL belongs to the Volvo Construction Equipment (VCE) group within the Volvo concern. In Eskilstuna Volvo Construction Equipment Components AB, another company in the VCE Group, manufactures components such as axles, transmissions and frames for wheel loaders and other products (mostly trucks). Batches of material are also delivered for assembly in factories of the VCE Group in Brazil and USA. That means that the total bill of materials of a wheel loader 'belongs' to the VCE Group but it is divided so that

Figure 5. A Volvo wheel loader.

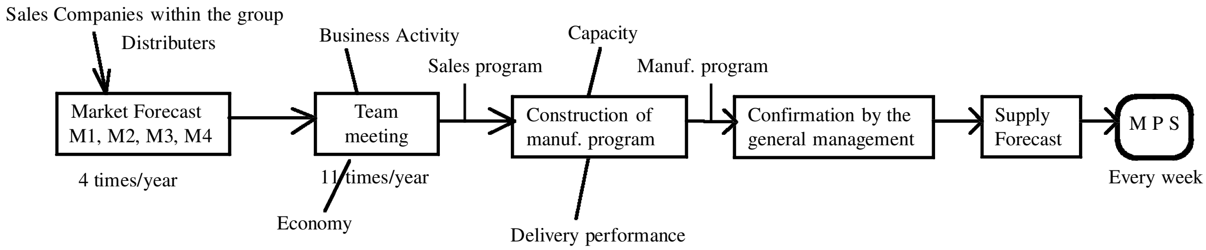

Figure 6. Overall planning system VWL and VCE.

different companies manufacture different parts and are responsible for the supply of different external components.

Figure 6 shows a schematic picture of the overall planning system at VWL and VCE. Four times per year the market department makes a new *market forecast* with a specified end product (Volvo L50, Volvo L70 and for the five models produced in the Arvika plant), from estimates made by the selling companies and the distributors within the group. The sales forecast covers 15 months ahead. Every month (11 times per year) this sales forecast is reworked into a delivery plan or a *sales programme*. The team meeting usually consists of seven people: three from the VCE marketing department (the manager of the forecast group and one of his assistants and a specialist on business activity); two from Volvo Wheel Loaders (the managers of the aggregate planning in the two plants Eskilstuna and Arvika); one from Volvo Construction Equipment Cabs AB in Hallsberg where the cabins and the hydraulic cylinders are produced; and one business controller.

The building activity in North America influences the demand for wheel loaders. It is also important to estimate the influences that a financial crisis in South East Asia has on the demand for the wheel loaders. The team meeting establishes a sales programme (or a delivery programme) for the different wheel loaders specifying an expected quantity per month. The decisions of the team meeting will have considerable influence on the future economic result so naturally the business controller also takes part in the meeting. From the delivery programme a *manufacturing programme* is constructed by the manager of aggregate planning taking into consideration the number of working days, a high utilization of the assembly crew and a possible buffer of finished inventory. The general management confirms the manufacturing programme. Thereafter the manufacturing programme works as a *supply forecast*. Every week the manufacturing program is reworked into a concrete *master production schedule* based on week batches.

Some of the components for the assembly of wheel loaders arrive assembled, in many structural levels, from other factories within the group, e.g. (steering) cabins and lifts. The product structures are much 'deeper' for wheel loaders than the product structures for ABB Motors (cf. figure 2, four levels). Every wheel loader model can be assembled in hundreds of different variants. The wheel loaders differ as to air conditioning, seats, hydraulic equipment, transmissions, load buckets etc. For handling these several variants VWL uses a special facility or routine in their MRP-system. The Master Production Schedule (MPS) consists of the two main end items and several hundreds of pieces of special equipment ('9-numbers'). These '9-numbers' are product structures for some special equipment or option. However, they also contains a credit quantity of the item it is supposed to replace in the ordinary end product structure (see figure 7), thus avoiding material requirements both for the components of the ordinary end items and the components of the variants.

The problem with these changeable product structures is that it is sometimes difficult to avoid a double reservation of material. For instance there is an option making it possible to move the load bucket horizontally according to the grip arms, and also one option to move the bucket vertically. Both options need a fastening plate assembled on the grip arm, but if the customer wants both options only one fastening plate is required and not two! Sometimes, but less frequently, a double credit quantity is also executed when the correct handling should only be one credit quantity. VWL solves this problem by a

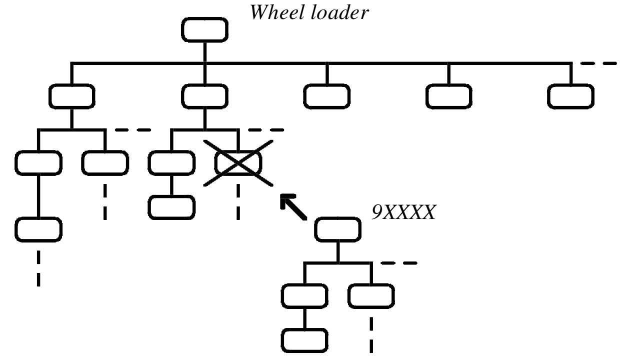

Figure 7. Changeable product structures, VWL and VCE.

manual deleting (or adding) of the wrong inventory record.

The forecasts of the different options are considered and kept track of with a kind of a homemade available-to-promise system, in the way the following example, in Tables 2, 3 and 4 describes. Suppose that the cumulative (total) lead-time for option 9XX10 is 10 time periods. Then, if the forecast of the option is increased during the total lead-time of the option, the MRP calculation will suggest purchase of components in past time. (It will take 10 time periods from today until now increased order quantities of components will lead to an expanded outflow of their option, due to the normal lead times from suppliers and from the manufacturing lead times in their own facilities.) To take account of this a new MRP-calculation is prepared in the beginning of period 4, according to table 2. 'Forecasted balance' is previous forecasted quantities so far not consumed by real orders but still used as a part of the master production schedule in the MRP-calculation. The MPS quantity in period 4 is therefore $2 + 1 = 3$. The MPS up to period 13 is principally fixed, because an increase of the total amount will lead to suggestions of purchase in past time (and also to delays in customer deliveries if customer orders are promised in accordance with such an increased MPS and if planned lead times are in accordance with real lead times.)

Table 2. Option 9XX10, Period 4.

Time period	4	5	6	7	8	9	10	11	12	13	14	15	...
Forecasted balance (MPS)	2												
Forecast (MPS)	1	2	3	1	4	6	0	2	3	2	4	0	
Real orders	0	1	–	–									

Table 3. Option 9XX10, Period 6.

Time period	6	7	8	9	10	11	12	13	14	15	16	17	...
Forecasted balance (MPS)	4												
New forecast (MPS)	3	1	4	6	0	2	3	2	4	0	3	1	
Real orders	3	0	–	–									

Table 4. Option 9XX10, Period 8.

Time period	8	9	10	11	12	13	14	15	16	17	18	19	...
Forecasted balance (MPS)	3												
New forecast (MPS)	4	6	0	2	3	2	4	0	3	1	2	3	
Real orders	–	–											

If the real orders for the option became zero in period 4 and one in period 5, then when at the beginning of period 6 the situation in table 3 occurs. From period 4 the 'Forecasted balance' increases by $(1 - 0 = 1)$ and from period 5 it increases by $(2 - 1 = 1)$. Observe that due to the forecasted balance it would have been possible to promise real orders for delivery in period 4 with the amount of 3 instead of 1. However, according to the real orders the possible forecasted balance in period 6 is 4. The executive planner must now decide if this balance is a proper 'buffer' or if it is too large. A larger buffer than necessary leads to a surplus of capital invested in work-in-process and inventory. A too small buffer will lead to worse customer service than necessary. However the planner cannot increase the forecasted balance; this will lead to suggestions of purchase in past time. If the planner at the same time decreases a future forecast, the suggestion of purchase in past time can possibly be avoided, but then there will probably be a late delivery of a promised real order due to components not yet ready for assembly.

It is assumed that the planner keeps the forecasted balance equal to 4. Time passes and the real orders in period 6 become 3 and zero in period 7. Then in the beginning of period 8 the forecasted balance is 5. However now the planner thinks this is too large a buffer and reduces it to 3 according to table 4. With this MPS according to table 4 the requirement in near future has diminished compared to the last MRP-calculation. This will in turn lead to the suggestion that previous planned orders, and even open orders, should be postponed.

The planned orders from the MRP-calculation with a start date within the next six days are released to open orders. The assembly of a wheel loader is mostly performed for a special customer order; the assembled wheel loader only in exceptional cases has to wait in an inventory of finished goods.

The operators are paid monthly with a fixed salary; the size of the salary depends on knowledge, experience and flexibility for different working tasks, instructor capacity etc. VWL has a profit share system where all the employees have a share of the company's profit. Working time per day is usually eight hours. The difference between 'white collar jobs' and 'blue collar jobs' has diminished. Today 'blue collars' perform a lot of tasks, which used to be performed by 'white collars'. There are four different working unions, one 'blue collar' (Metall) and three 'white collar' (CF, SIF, Ledarna). The operators at VWL (the assembly of the finished wheel loaders) are working one shift per day. An extra shift for the final assembly is expensive as most of the work is manual, and there is a lot of wage-increment working time when it is not ordinary daytime. Often it is not possible to keep the same efficiency during two shifts of assembly as can be done during one shift, due to lower service, e.g., present expert skills during the second shift. However, the manufacture of components (VCE) is performed during two to three shifts per day. In this production it is important to realize a high utilisation of the expensive production equipment.

VWL uses the program package Mapics, with a lot of special arrangements, for its material- and production control. The MRP-calculation is performed every week with a planning horizon of 15 months.

4. Concluding discussion

The master production schedule (MPS) can consist of the following possible alternatives:

- *end items*, the 'top' item in the bill of materials
- *modules*, items below the end item in the bill of materials
- *customer orders*

The customer order is an end item, by definition, but it is mentioned separately here because it is a natural 'gross requirement' in the MRP-calculation. The customer orders represent the real requirements and in many practical installations, the computer packages let the customer orders take part in the MRP-calculation to prevent their being forgotten. External demand of a specified quantity in a certain future time period is precisely what the MPS specifies. Some of the future external demand is known customer orders with specified future deliveries and some are pure forecasts. To avoid production of the old forecasts and new customer orders, if the customer orders take part in the MRP-calculation, a continuous adjustment (reduction) of the MPS is necessary.

However, in this study the customer orders do not automatically take part in the MRP-calculation. At ABBM the MPSP-system helps to convert aggregate forecast and real customer orders into a required MPS-quantity. At VWL every week the manufacturing programme is reworked into a concrete master production schedule based on week batches. The MPS-quantities and their due dates are manually established with the same configuration (bill of material) as current customer orders (as if the customer orders took part in the MRP-calculation).

Heizer and Render (2001) suggest that it is natural that the MPS consists of: *end-items* in a *continuous* (make-to-stock) company; *modules* in a *repetitive* (assemble-to-stock) company; and *customer orders* in a job shop (make-to-order) company. For a make-to-order company the problem is that if they are to be able to present a delivery time to the customer shorter than the cumulated lead time, they must use some sort of forecast. VWL, mainly a make-to-order company, then need a forecast for the end item, but they have so many different end -items, they can never be sure what end item the customer will require. Therefore VWL work with two standard end items and the related options, which is a type of module system. ABBM is mainly a make-to-stock company (the great sales volume is on the standard 300 end-items and not on the 1700 non-standard end-items) and they use end items in their MPS. However, ABBM finds 300 end items too much to handle with separate forecasts so they use their available MPSP-system, in the Baan/Triton package, to explode the aggregate forecasts of the seven main product sizes to real end items.

VWL shows that a problem with using modules as MPS in the MRP-calculation, is to keep track of which options are really used in the real customer orders. VWL cannot use the same type of planning bill as ABBM, which handles aggregates to real products. VWL needs a system, and has a system, for checking that new customer orders are available-to-promise according to previous forecasts of modules. This is a bit more difficult as the customer order must be checked against a number of different modules (options), and different customer orders requiring different modules. Consequently using modules in the MPS is bit difficult to do in a practical application and it mostly requires some 'help-addition'. (Cover-Time Planning, a less complex alternative to MRP, keeps the used forecast completely separated from 'real' open orders. This eliminates many of the problems around modules and customer order production (cf. Segerstedt 1998)).

Every MRP-calculation presents a signal report presenting all open orders whose due date should be *rescheduled*, postponed or finished earlier. As in other MRP-installations, the volume of rescheduling signals is extensive. Therefore, both VWL and ABBM can only react on a very few of the recommendations and then mostly the suggestions for an earlier start to avoid future material shortages. This is in line with a study of Euwe *et al.* (1998).

The purpose of *rough-cut capacity planning* (mentioned in most textbooks) is to determine quickly whether approximately enough capacity will be able to meet the MPS. Thus one will not be concerned with developing the exact figure. One common method many companies use because of its ease and simplicity is 'the method of overall factors' (cf. Vonderemse and White 1996). This method relies on experience and historical accounting information to determine how many standard hours are required per unit of each product (end item). By multiplying this figure by the number of units planned for production each time period (according to the MPS) an overall capacity requirement can be determined. These requirements are mostly broken down to individual bottleneck work centres. However, at ABBM and VWL, rough-cut capacity planning is done in a slightly different way. At VWL there are only two different main products and a rough-cut analysis can be based on just the number of wheel loaders. VWL 'knows' that too many wheel loaders (per week) are not possible, and needed capacity is directly proportional to the number of wheel loaders. Almost the same type of rough-cut analysis is made at ABBM. The planning bill, with its connections to different machines, therefore also functions as a type of a rough-cut planning tool. ABBM knows from previous experience what numbers per day of the different sizes is possible to manufacture.

Both companies seem to be rather satisfied with their installation of MRP. VWL would like to find some solution to double material reservation due to two different modules needing the same component. ABBM would in the future like to see 'available-to-promise' also for aggregates of the different motor products with other classifications than the existing planning bill (without changing the planning bill which is connected to the machines). Both installations of MRP must be considered as MRPII installations; inventory data is augmented by labour hours, by material cost, by capital cost and other resources (Heizer and Render (2001) define MRPII in this way). Krajewski and Ritzman (1999) say that MRPII enables managers to test 'what if' scenarios. Management can project the dollar value of shipment, product costs, overhead allocations, inventories, backlogs, and profits. ABBM and VWL are not advanced users of that kind. But the benefits and solutions coming from advanced computer MRPII scenarios would probably not counterbalance the cost of such an operation, because it will be based on planned orders that will not coincide with real future (open) orders (a cost effective 'what if' scenario can be created in a rough-cut analysis manner with a simple spreadsheet model, avoiding the details from thousands of planned orders).

Krajewski and Ritzman (1999) mention that 'changes to the MPS can be costly, particularly if they are made to MPS quantities soon to be completed. Increases in an MPS quantity may cause delays in shipments to customers or excessive expediting costs because of shortages in material. Decreases in MPS quantities can result in unused materials or components (at least until another need for them arises) and consumption of valuable capacities for something not needed. Similar costs occur when forecasted need dates for MPS quantities are changed'. For these reasons they mean that many companies 'freeze', or disallow changes to, a portion of the master production schedule. Also Vollman *et al.* (1997) discuss a *demand time fence*, during which few, if any changes can be made and a *planning time fence*, which covers a longer period than the demand time fence. The master scheduler, but not the computer, can make changes to the MPS quantities during the planning time fence. These types of fences are not apparent or used at ABBM or VWL. The important time fence for both is the accumulative (or total) lead-time. An increase of the MPS in a shorter time than the total lead time will lead to suggestions of purchase in bygone time periods and therefore to most probably future material shortages. However, a quick response to a changed customer demand is an important action for performing high services to customers and keeping up the sales figures. It is very important to be able to deliver what the customer requires with a short delivery time. Decrease of the MPS in a shorter time than the total lead-time will lead to excess work-in-process and inventory. Excess inventory and work-in-process do not only create cost, it can also be a buffer for allowing a short delivery time (even if the customer demand changes) and it can make possible small changes of the MPS within the total lead-time without material shortages.

Previously both ABBM and VWL have had piecework for 'blue collars'. Today they are paid monthly with a fixed salary without bonus payments, like 'white collars'. The differences in salary between the 'blue collars' depend on proved skill, education, and number of years in the company. The differences between 'white collar' jobs and 'blue collar' jobs seem to disappear more and more. The reasons for this may be that to be competitive all resources in a company must be focused on effectively producing what the customer asks for. It is today a sub-optimization to let the worker concentrate on one task, which is what piecework mostly give preference to, i.e., to manufacture as many components as possible in as short time as possible. Instead the capability of the operators is needed for solving all kinds of problems in a complex production facility.

In this study the companies are not compared according to inventory turnovers, precision in deliveries, delivery times etc. It is not appropriate because the two companies have completely different situations, e.g., VWL has much deeper product structures (more structure levels) than ABBM; a wheel loader has a greater number of components than an electrical motor; the production equipment differs; the amount of variation in demand differs etc. (cf. Williams *et al.* (1992) and Oliver *et al.* (1994), they point to the difficulty in evaluating different 'paradigms' in production management). The explanation for fast inventory turnovers is not only a 'good' or 'bad' MRP-installation (ABBM and VWL do not either want to show production figures in public). It is also very difficult to estimate and compare what costs ABBM and VWL spend on their planning system, some are manual jobs done by own personnel, some are computer and software cost, some resources are owned and some resources are hired etc. Both companies agree that the planning and computer costs are high, but necessary. If the computer system is 'down' the manufacturing process both for ABBM and VWL will be set backed and after while even interrupted. However a delayed MRP-calculation does not cause this effect, but it is an important part in a very vital system for the companies.

The main conclusions from ABBM and VWL are:

- In an MRP application, if the number of end items is many, the company assembles-to-stock or makes-to-order, then *additions seem to be necessary*. Additions which help MRP to handle the situation suitably, such as a planning bill for ABBM, a normal bill of materials with 'adding bills of materials' for VWL, a master production schedule planning system with an available-to-promise function for ABBM and a home-made 'system' for available-to-promise modules for VWL.
- The *accumulative lead-time*, the longest lead-time through the product structure, is a very important measure and parameter, because an increase of the Master Production Schedule in a shorter time than this time period will lead to suggestions of purchase in past time periods and therefore most probably to future material shortages.

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