INTRODUCTION TO MULTI-PLANT MRP

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WP # 1486-83 October 1983

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Abstract

A large number of papers have appeared in the literature, in recent years, concerning Material Requirements Planning (MRP) systems. The rapid increase in the performance/price ratio of digital computers has made this method of materials management feasible for many firms. Most of the literature however, pertains to the methodology and implementation of MRP in a single plant environment. There has been little written about the design of an MRP system for a firm with multiple plants, especially when certain parts are produced in more than one location (multi-sourced parts).

If a firm has few interactions between plants and measures and controls each plant as an investment or profit center, implementing a standard, single-plant MRP system at each plant location may provide good results. But, if a firm has many interactions between plants, measures and controls each plant as a cost center, and desires to plan and control material requirements on a corporate-wide basis, a single-plant MRP system is not appropriate. Efficiencies, including shorter lead times and lower inventory levels, can be obtained with a more complex, multi-plant system.

This paper examines the reasons that make a single-plant MRP system inappropriate for a firm, in the second case above, and describes in detail one possible methodology for designing a multi-plant MRP system. The ideas presented here are relevant to any firm (or division of a firm) that has interdependencies between its plants, and desires to plan and control material requirements on a company-wide basis in order to increase the efficiency of its operations.

1. Introduction and Purpose

Material Requirements Planning (MRP) is the component of a total manufacturing control system which is designed to manage inventory and plan orders for parts and materials with dependent demand (demand derived from the demand of other items). Most of the literature on MRP systems deals with the methodology and implementation of MRP in a single plant environment. Most of the MRP systems and software currently in use are single-plant systems. This paper assumes that the reader is familiar with such methodology. There is an extensive literature concerning single-lant MRP and some references are listed for those who would like to examine the topic in detail, [2],[3],[4], [5],[6], and [8].

If a firm has multiple manufacturing plants and each one is treated as an investment/profit center, each plant could generate its own master schedule and a single-plant MRP system can be implemented at each facility. But, if a firm treats each plant as a cost center and plans and controls material requirements on a corporate-wide basis, treating the corporation as a single facility and applying a single-plant MRP system can create severe problems. The reason is that optimal shipping routes must be considered when assigning material requirements to each plant location, so that producing (supplying) plants ship to requiring (demanding) plants in an economical manner. Implementing an independent single-plant MRP system at each plant location can also create severe problems, because schedule interdependencies between plants will not be considered. Efficiencies can be obtained by considering these interdependencies within a more elaborate system.

Measuring and treating the plants in a firm as profit centers requires that each facility has the freedom of developing its own forecasts, manufacturing plans, and schedules. The profit center approach works best in situations in which the manufacturing plants are organized to support specific product lines.

This type of organization usually reduces schedule dependency between plants. But if the plants in a firm are organized more along the lines of the stages in the manufacturing process such as fabrication, assembly, and final testing, these plants are all dependent upon the final assembly schedules. The plants organized in this fashion can be more effectively managed as cost centers with a centralized control of material requirements. In such cases, it is possible to measure the performance of each plant on the basis of how well it meets its corporate-determined schedule.

Thus, the concept of multi-plant MRP is relevant to any firm that has multiple manufacturing plants organized as cost centers, and where corporate control of material requirements is desired. A multi-plant MRP system should recognize that parts are produced in different plants, make offset calculations for intransit lead times, and consider transportation costs when establishing production requirements and shipping routes for parts that are produced in more than one location (multi-sourced parts). The objective of multi-plant MRP is to communicate the current master schedule for finished products (or highest level assemblies) to all the plants and to all the vendors in one planning cycle. That is, beginning with the master schedule for top level finished products, the objective is to develop time-phased planned order release schedules (term defined below) and shipping or delivery schedules, for each manufacturing plant producting components for the finished products.

Demand forecasting and setting the master production schedule is done only at the corporate (or divisional) headquarters with a multi-plant MRP system, and not at each plant location. The plant production schedules are dependent upon the corporate master schedule. The major benefits of this type of a system and cost center organizational structure are shorter lead times, and lower inventory levels due to the effective coordination of the operations. Each plant will be shipping the required components to the correct demanding plants at the correct time. The main disadvantages of this structure are the reduction of the role of the plant manager, and the additional complexity of the system. Thus, strong corporate support of the cost center organizational structure and operating philosophy is required before a firm can attempt to implement a multi-plant MRP system.

The purpose of this paper is to describe one possible methodology for designing a multi-plant MRP system. Some preliminary details will be discussed first, including the introduction of the terminology that will be used, further background on multi-sourcing decisions, and the basic framework of a multi-plant MRP system. A simple example will then be described and worked through in detail to illustrate the multi-plant MRP methodology. Refinements necessary to operationalize this initial, simplified framework will be indicated, but not described in detail. These are presented in another paper [1].

We have coded a prototype computer program of the multi-plant MRP system presented in this paper, to ensure feasible implementation of the system. However, this prototype program will not be described here due to space limitation.

2. Preliminary Details

The multi-plant MRP system is designed to be an enhancement to a standard, single-plant MRP system. Its main feature is that a transportation algorithm is incorporated within the context of single-plant MRP calculations to handle the multi-sourcing decisions (the production requirements and shipping routes for parts made in more than one location).

Low level coding must be applied in a multi-plant MRP system, and explosion must take place across all finished products on a level by level basis, as opposed to exploding one finished product completely before beginning to explode another. Low level coding means that in the level by level requirements-computation process, the processing of a component is delayed until the lowest level on which it appears is reached, and all of the requirements from higher-level parts have been established. In addition, the system that will be described is regenerative as opposed to a net change. In a regenerative system, all requirements are completely exploded from the master schedule down to the purchased parts for all items each time the system is run. In a net change system, a limited explosion is made only for the items that are affected by a change in the master schedule, inventory records, or open order records.

The following are definitions of the basic MRP terminology that is employed throughout this paper. Additional terminology will be defined as it is encountered in the discusion.

2.1 Stock Status Terminology

- Balance on Hand (BOH) - the quantity of a part currently in stock at a particular plant (we will assume that each part is stocked in at most one stocking location in a plant, or that this BOH figure is the total of a part's several stocking locations in that plant).

- Intransit (IT) - the quantity of a part currently in transit between the producing plant and the receiving plant, or currently in the receiving area of the receiving plant. This figure is always zero if a part is made and used at the same plant.

- Safety Stock (SS) - stocking quantity needed to cover uncertainty in supply lead times and delivery quantities. SS may be held for any component part at any level in the bill of material structure.

- Net BOH (of a part at a plant) = BOH + IT (to this plant) - SS.

Note: This list of stock status items is intended to be illustrative, rather than exhaustive.

2.2 MRP Calculation Terminology

- Dependent Demand - the derived demand or requirements for a component part.

- Independent Demand - for finished products it is the demand forecast. For all other parts it is field service spare parts demand or the external demand of the part as an end product.

The Dependent and Independent Demand for a particular part must be offset for intransit lead time (ITLT). ITLT includes inspection time at the receiving plant. The offset calculation is explained below.

- Scheduled Receipts - open orders or work in process.

- Net Requirements - the sum of the Dependent and Independent Demands after subtracting out the Net BOH and the Scheduled Receipts.

- Planned Order Release - the Net Requirements line offset for manufacturing lead time (MLT). It displays when to schedule an order to begin production of the component or to purchase from a vendor.

The terminology introduced here is similar to that used for single-plant MRP, except for the intransit inventory record and the need to offset the dependent and independent demand lines for any intransit lead time. The terminology will become clearer as some examples are worked through.

2.3 No Multi-Sourced Parts

As mentioned above, the multi-plant MRP system is designed to be an enhancement to the standard, single-plant MRP logic. If a firm has no parts that are produced in more than one location, the enhancement to a single-plant MRP system to handle a multiple plant situation would be simple. With every part single-sourced, a facility that requires a certain part can receive it from only one location, and transportation costs would not be an issue when planning material requirements. The only adjustment required to a single-plant MRP system would be to recognize the plant code for each part and to make an offset calculation for intransit lead time when necessary. To illustrate:

Suppose Part X requires 2 units of Part Y and both parts are produced in Plant A.

If Part X's Planned Order Release line is:

Part X	Past Due	Wk1	Wk2	Wk3	Wk4	Wk5	...
Planned Order Release	0	0	10	10	15	15	

(Note: The Past Due (PD) time bucket represents a lack of planned performance or is a result of the lead time exceeding the available time.)

Then Part Y's Dependent Demand line becomes:

Part Y	Past Due	Wk1	Wk2	Wk3	Wk4	Wk5	...
Dependent Demand	0	0	20	20	30	30	

But if Part Y is in Plant B and there is one week intransit lead time from Plant B to Plant A, Part Y's Dependent Demand line would be:

Part Y	Past Due	Wk1	Wk2	Wk3	Wk4	...
Dependent Demand	0	20	20	30	30	

Part Y's Dependent Demand line has now been offset for intransit lead time. It would be very easy to add this logic to single-plant MRP software. This enhanced logic breaks down though, when multi-sourced parts are introduced. How this occurs is explained in the following section.

2.4 Multi-Sourced Parts

Multi-sourcing means producing a particular part in more than one facility location. Some of the reasons why a firm would multi-source certain parts include capacity restrictions in its producing plants, transportation economies, and not wanting to be dependent upon one facility for all of the production of a part. For example, although the most cost efficient plants may be located in foreign countries, a firm may still want to maintain a small percentage of the requirements of certain key parts in a backup domestic plant, with the necessary equipment, tools, and a properly trained workforce in place. If any emergencies or problems develop in one of the foreign plants, the backup plants will be able to produce higher volumes of these parts in a relatively short time. The firm may also use backup plants in order to maintain domestic repair facilities for various parts.

Multi-sourcing decisions are often implemented by specifying multi-sourcing rules for each part that is produced in more than one location. For example, a part that can be manufactured in two plants may be assigned a 75-25 rule. This means that 75% of the part's requirements will be produced in the lower cost plant, while 25% will be produced in the backup plant. These multi-sourcing rules are flexible and are changed by materials management as necessary. They are an input to the MRP system.

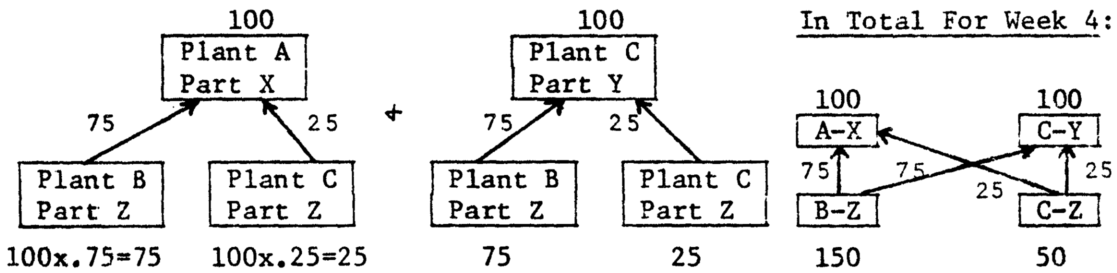
As mentioned above, standard single-plant MRP logic could easily be enhanced to recognize a part's plant code and to make an offset calculation for intransit lead time when necessary. It can also be adapted to split requirements by multi-sourcing rules. But, this enhanced single-plant MRP logic will break down with multi-sourced parts because optimal shipping routes must be considered when assigning material requirements to each plant location. If transportation costs are not considered, supplying plants will be shipping to demanding plants in a non-economical manner. This is illustrated by a simple example in Exhibit 2.1.

From this brief example it can be seen that the main enhancement is the incorporation of a transportation or network flow algorithm [7] within the context of the single-plant MRP calculations to handle the production requirements and shipping routes for multi-sourced parts. It can also be seen why low level coding must be employed in a multi-plant MRP system. All of the requirements from higher level parts (and corresponding plants) must be established

Exhibit 2.1 Failure of Single-plant MRP Logic

Suppose that in week 4, 100 units of Part X and 100 units of Part Y are required by higher level parts. Part X is made in Plant A and Part Y in Plant C. Also suppose that each unit of Part X requires 1 unit of Part Z and each unit of Part Y requires 1 unit of Part Z. Part Z can be made in Plants B or C, with a current multi-sourcing rule set at 75% of Part Z's requirements to be made in B and 25% in C.

If transportation costs were not considered, our enhanced single-plant MRP system would set Part Z's requirements and shipping routes like this:

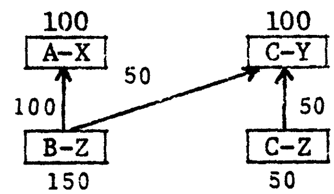


Thus Plant C makes 25 units of Part Z for Plant C (Part Y) and 25 units of Part Z for Plant A (Part X). But this clearly does not make sense in terms of transportation efficiency, because the 25 units of Part Z that are being shipped to Plant A are needed right in Plant C and are currently being supplied by Plant B.

The total requirements for Part Z must be looked at together and the transportation problem solved, before material requirements and shipping routes for Part Z are set. This would result in:

Total week 4 requirement
For Part Z = 200
Thus:
Plant B = 200x.75=150
Plant C = 200x.25=50

Now solve the
transportation
problem →
Suppose cost/unit:
B-A = \$5; B-C = \$8
C-A = \$6; C-C = \$0



Notice that Plant B and Plant C still produce the same proportion of week 4's requirements, but now Plant C is no longer shipping Part Z out when it is needed right in Plant C. Of course the transportation issues become more complicated than this, with several supplying plants and several demanding plants.

before solving the transportation problem, to determine shipping routes and the proper intransit lead time offsets needed to calculate a multi-sourced part's dependent demand. This will become clear in the detailed example that follows.

3. Detailed Example of Multi-Plant MRP

This example explicitly illustrates how multi-plant enhancements can be fit into a standard MRP framework. Based on given input data, all the MRP calculations are worked out for a very simple bill of material for one finished product. The transportation and intransit offset calculations are explained and two summary reports are constructed illustrating how a final production schedule by plant, and a final delivery schedule by plant might look with a multi-plant MRP system. The example contains the following features and assumptions:

- In order to pick a starting point, we will assume that the system has just been implemented and that this is the first MRP run.

- Only one finished product bill of material is exploded. If many finished products are considered the same logic would apply, and there would be more requirements to gather and more calculations to make. In addition, we will look at a planning horizon of only 14 weeks for the one finished product.

- There are three manufacturing plants in the example. A field service (FS) division independent demand for spare parts is also considered.

- A multi-sourced part is included in the example (part 5-0827) to illustrate how the transportation algorithm fits into the calculations. A 75-25 multi-sourcing rule is assigned to this part.

- Lot for lot ordering is the lot sizing technique employed in the example.

The following exhibits contain the details for this example:

Exhibit 3.1 - Example Bill of Material Structure and Related Data

Exhibit 3.2 - Input Data

Exhibit 3.3 - Multi-Plant MRP Calculations

Exhibit 3.4 - Transportation Algorithm and ITLT Offset Calculations

Exhibit 3.5 - Summary Report: Planned Order Releases by Plant

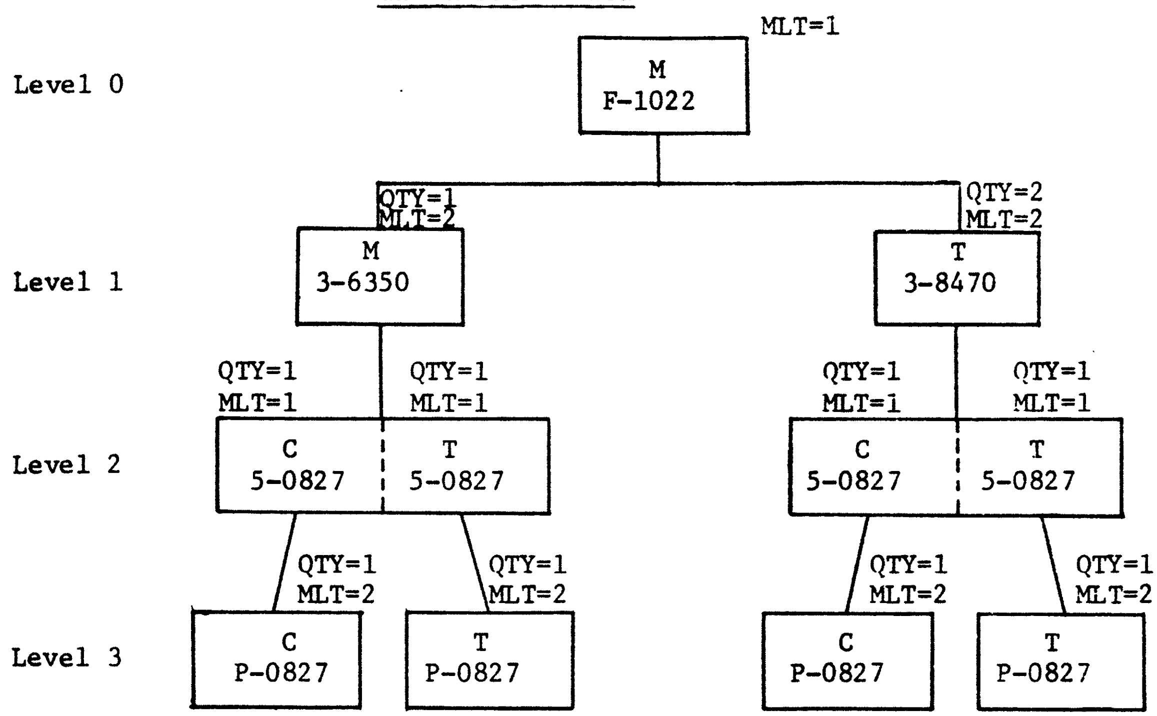
Exhibit 3.6 - Summary Report: Delivery Schedule by Plant.

3.1 Input Data

Data extracted from various feeder systems is required as input for any MRP system. This data includes the bill of material structure, completed parts stock status data, work in process data, independent demand forecasts, manufacturing lead times (MLT), and in the multi-plant MRP system, also intransit lead times (ITLT), transportation costs, and stock status data in each plant.

Exhibit 3.1 provides the very simplified bill of material structure for the one finished product that this example is based on. Each part in the example structure has information on the plant at which it is manufactured (or purchased), its MLT, and the quantity required of that part for each unit of the higher-level requiring part. Part 5-0827 is the multi-sourced part and it is required by two higher-level parts. P-0827 is the only purchased part and it is purchased locally by each plant that requires it. The intransit lead times and transportation costs between each plant are also displayed in this exhibit. In the example, these transportation costs are assumed to apply to all parts. In addition, note that we assume zero lead time and the same cost to ship to meet field service division demand from each of the manufacturing plants. This is done only to simplify the optimal shipping decisions, so that the reader can easily follow the transportation algorithm calculations.

Exhibit 3.1 Example Bill of Material Structure and Related Data



Key

M= Massachusetts Plant
C=California Plant
T=Texas Plant
FS=Field Service Division

MLT=Manufacturing Lead Time (weeks)
QTY=Quantity per higher level part
•Part P=0827 is purchased locally by C and T
•Multi-scourcing Rule For Part 5-0827 } 75% produced in T, 25% produced in C

Intransit Lead Times (weeks)

	M	T	C	FS
M	0	1	2	0
T	1	0	1	0
C	2	1	0	0

Transportation Costs ($/unit)

	M	T	C	FS
M	0	5	10	1
T	5	0	5	1
C	10	5	0	1

Note: We will assume that the FS Division has regional warehouses near each of these plants so that intransit lead time is only 1 day (which is rounded to 0 weeks). This will allow us to easily solve each transportation problem by inspection for presentation purposes.

Exhibit 3.2 displays the completed parts inventory status at each plant (remember that we are assuming that each part is stocked in at most one stocking location in a plant, or that each balance on hand figure represents the total of a part's several stocking locations in the plant). Note that we must keep track of the inventory of each part at its producing plant(s) and at any other plants that may require it. The exhibit also gives the scheduled receipts or work in process data, and the independent demand forecast for the demand of the finished product and for the component part's field service (FS) spare parts demand. All of the terms appearing in this exhibit were defined earlier.

3.2 MRP Calculations

We have now obtained the necessary input data from the feeder systems and are ready to generate the multi-plant MRP calculations. Materials management policy decisions including multi-sourcing rules and lot-sizing rules have been stated (the 75-25 rule for part 5-0827 and lot for lot production of each part). We can now calculate the planned order release schedule and the delivery schedule for each part in our example bill of material structure. Exhibit 3.3 contains the multi-plant MRP calculations.

The calculations for the first three parts, F-1022, 3-6350, and 3-8470 are straightforward. Two terms, dependent gross requirements and dependent net requirements have been added for ease of presentation. The rest of the terminology was defined above. The dependent gross requirements line simply displays the higher-level parts that require the component part being calculated. It is each higher-level part's planned order release line extended by the quantity of the component part per unit of the higher-level part. The dependent net requirements line displays each gross requirement listed, netted by the higher-level net BOH. This quantity is the net amount of the component part on hand

Exhibit 3.2 Input Data

Stock Status Data (Beginning of week 1)

Part #	Stocking Plant	BOH	IT	SS	NET BOH
F-1022	M	22	0	15	7
3-6350	M	20	0	12	8
3-8470	T	30	0	5	25
	M	52	0	30	22
5-0827	C	27	0	8	19
	T	55	0	23	32
	M	20	0	10	10
P-0827	C	15	0	9	6
	T	29	0	20	9

Scheduled Receipts

Part #	Past Due	1	2	3
F-1022	0	16	0	0
3-6350	0	25	0	0
3-8470	0	26	42	0
5-0827C	0	18	0	0
5-0827T	0	44	0	0
P-0827C	0	32	0	0
P-0827T	0	30	30	0

Independent Demand Forecast

Part #	PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Finished Product Demand:															
F-1022	0	10	20	20	22	22	18	18	18	18	22	22	23	23	23
FS Spare Parts Demand:															
3-6350	0	0	0	0	20	0	0	0	20	0	0	0	20	0	0
3-8470	0	0	8	8	0	0	10	10	0	0	10	10	0	0	10
5-0827	0	10	10	10	10	10	10	12	12	12	12	12	12	12	12
P-0827	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Exhibit 3.3 Multi-plant MRP Calculations

	PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
F-1022 (Plant = M • Net BOH = 7 • MLT = 1)															
Dependent Demand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Independent Demand	0	10	20	20	22	22	18	18	18	18	22	22	23	23	23
Scheduled Receipts	0	16	0	0	0	0	0	0	0	0	0	0	0	0	0
Net Requirements	0	0	7	20	22	22	18	18	18	18	22	22	23	23	23
Planned Order Release	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
3-6350 (Plant = M • Net BOH = 8 • MLT = 2)															
Dep. Gross Req:															
-From M - F-1022	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
Dep. Net Req.:															
-Higher Level Net BOH=0	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
Dep. Demand - offset - ITLT	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
Indep. Demand - offset - ITLT	0	0	0	0	20	0	0	0	20	0	0	0	20	0	
Scheduled Receipts	0	25	0	0	0	0	0	0	0	0	0	0	0	0	
Net Requirements	0	0	0	16	42	18	18	18	38	22	22	23	43	23	
Planned Order Release	0	16	42	18	18	18	38	22	22	23	43	23			
3-8470 (Plant = T • Net BOH = 25 • MLT = 2)															
Dep. Gross Req.:															
-From M - F-1022	0	14	40	44	44	36	36	36	36	44	44	46	46	46	
Dep. Net Req.:															
-Higher Level Net BOH=22	0	0	32	44	44	36	36	36	36	44	44	46	46	46	
Dep. Demand - offset - ITLT	0	32	44	44	36	36	36	36	44	44	46	46	46		
Indep. Demand - offset - ITLT	0	20	8	8	0	0	10	10	0	0	10	10	0		
Scheduled Receipts	0	26	42	0	0	0	0	0	0	0	0	0	0		
Net Requirements	0	0	0	43	36	36	46	46	44	44	56	56	46		
Planned Order Release	0	43	36	36	46	46	44	44	56	56	46				

Exhibit 3.3 (Continued)

	PD	1	2	3	4	5	6	7	8	9	10	11	12	13
Intermediate Step for 5-0827 • multi-sourced														
Dep. Gross Req.:														
-From M-3-6350	0	16	42	18	16	18	38	22	22	23	43			
-From T-3-8470	0	43	36	36	36	46	44	44	56	56	46			
Dep. Net Req.:														
-Higher Level Net BOH=10	0	6	42	18	18	18	38	22	22	23	43			
-Higher Level Net BOH=0	0	43	36	36	46	46	44	44	56	56	46			
Independent Req.	0	10	10	10	10	10	10	12	12	12	12			
Total Net Req.	0	59	88	64	74	74	92	78	90	91	101			
-75% Plant T	0	44	66	48	56	56	69	59	68	68	76			
-25% Plant C	0	15	22	16	18	18	23	19	22	23	25			
(TO TRANSPORTATION ALGORITHM - See Exhibit 3.4)														
5-0827T (Plant=T • Net BOH=32 • MLT=1)														
Dep. Demand - Offset - ITLT	1	43	36	36	46	46	44	44	56	56	46			
		+30	+12	+10	+10	+25	+15	+12	+12	+30				
Indep. Demand - Offset - ITLT	0	0	0	0	0	0	0	0	0	0	0			
Scheduled Receipts	0	44	0	0	0	0	0	0	0	0	0			
Net Requirements	0	0	46	46	56	71	59	56	68	86	46			
Planned Order Release	0	46	46	56	71	59	56	68	86	46				
5-0827C (Plant=C • Net BOH=19 • MLT=1)														
Dep. Demand - Offset - ITLT	5	6	8	8	13	7	10	11	13					
	+12													
Indep. Demand - Offset - ITLT	0	10	10	10	10	10	10	12	12	12	12			
Scheduled Reciepts	0	18	0	0	0	0	0	0	0	0	0			
Net Requirements	0	0	14	18	23	17	20	23	25	12	12			
Planned Order Release	0	14	18	23	17	20	23	25	12	12				

Exhibit 3.3 (Continued)

	PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P-0827T (Plant T • Net BOH = 9 • MLT = 2)															
Dep. Gross Req.: -From T - 5-0827T	0	46	46	56	71	59	56	68	86	46					
Dep. Net. Req.: -Higher Level Net BOH = 0	0	46	46	56	71	59	56	68	86	46					
Dep. Demand - offset - ITLT	0	46	46	56	71	59	56	68	86	46					
Indep. Demand - offset - ITLT	0	0	0	0	0	0	0	0	0	0					
Scheduled Receipts	0	30	30	0	0	0	0	0	0	0					
Net Requirements	0	7	16	56	71	59	56	68	86	46					
Planned Order Release	23	56	71	59	56	68	86	46							
P-0827C (Plant C • Net BOH = 6 • MLT = 2)															
Dep. Gross Req.: -From C - 5-0827C	0	14	18	23	17	20	23	25	12	12					
Dep. Net Req.: -Higher Level Net BOH=0	0	14	18	23	17	20	23	25	12	12					
Dep. Demand - offset - ITLT	0	14	18	23	17	20	23	25	12	12					
Indep. Demand - offset - ITLT	0	0	0	0	0	0	0	0	0	0					
Scheduled Receipts	0	32	0	0	0	0	0	0	0	0					
Net Requirements	0	0	0	17	17	20	23	25	12	12					
Planned Order Release	0	17	17	20	23	25	12	12							

at the plant at which the higher-level requiring part is made. The term is relevant only when the demand plant (where the higher-level part is made) is different than the supply plant (where the component part is made). If the demand plant and the supply plant are the same, then the higher-level net BOH is zero. These two terms, dependent gross and net requirements, have been added to try to clarify how the derived or dependent demand is calculated. To ensure clarity, the following is an explanation of the MRP calculations for part 3-8470.

Part 3-8470 is produced in plant T and there is currently a net BOH of 25 of part 3-8470 at plant T per the stock status data. Part 3-8470 is required by only one part F-1022, which is produced in plant M. There is currently a net BOH of 22 of part 3-8470 at plant M. This 22 is the higher-level net BOH, the net BOH of the component part at the plant were the higher-level requiring part is made.

Thus the dependent gross requirements line for 3-8470 is the planned order release line of F-1022 multiplied by 2 (the quantity of 3-8470 per unit of F-1022). The net requirements line then subtracts out the higher-level net BOH of 22 from the gross requirements line. This line is then offset by the intransit lead time (1 week in this case) to yield part 3-8470's dependent demand line. Thus in a multi-plant MRP system, relevant plant inventory balances and intransit lead times must be considered when determining a lower-level part's dependent demand from the higher-level part's exploded planned order release.

Part 3-8470's independent demand line is exactly the same as the demand forecast for FS spare parts, since ITLT from plant T to FS is zero in this example. Part 3-8470's net BOH of 25 at plant T and the scheduled receipts are then subtracted out from the sum of the dependent and independent demands to yield the net requirements line. The scheduled receipts cannot be subtracted out of the demand requirements before the week in which they are scheduled to be completed. The net requirements line is then offset by the manufacturing lead time (2 weeks in this case) to yield part 3-8470's planned order release line. This completes the requirements computation process for 3-8470.

These calculations are the same as those for single-plant MRP, except for the need to account for the higher-level BOH and intransit lead time when the requiring or demanding plant is different than the producing or supplying plant. Notice that for part 3-6350 which is produced in plant M, the requirements computation process is the same as that of single-plant MRP. Since 3-6350's only requirement comes from part F-1022 which is also produced in plant M, F-1022's planned order release line falls right through to 3-6350's dependent demand line. There is no calculation for higher-level net BOH and intransit lead time.

The calculations for the fourth part, 5-0827, are more complicated. Part 5-0827 is multi-sourced. It must appear as two part numbers in the system, part 5-0827T and part 5-0827C. The suffix indicates the plant where the part is manufactured. The multi-plant MRP system must go through the requirements computation process for each plant in which a multi-sourced part is made. Thus in this example, there is a similar set of calculations for parts 5-0827T and 5-0827C. The details of the multi-sourced part algorithm are explained in the next section.

Before examining this algorithm, look at the final part, P-0827. Since it is purchased locally at both plant T and plant C, it must also appear as two part numbers in the system. There is a separate set of requirements computations for part P-0827T and P-0827C. Notice that each of these parts obtain their requirements from a part produced in the same plant that purchases it. Thus the calculations are the familiar single-plant MRP calculations. Also note that the parts will not be physically labeled as two different part numbers, but only recognized as two different part numbers by the MRP system in order to establish requirements computations for each plant.

3.3 Multi-Sourced Part Algorithm

A transportation or network flow algorithm must be incorporated into the MRP calculations for a multi-sourced part. Look at part 5-0827 in Exhibit 3.3. The intermediate step establishes the necessary supply and demand inputs for the transportation algorithm, and then the transportation algorithm output is used to establish the dependent and independent demand lines for parts 5-0827T and 5-0827C.

The first stage of the intermediate step is to obtain the dependent gross requirements from each user plant. The net BOH of part 5-0827 at each user plant (the higher-level net BOH) is then subtracted from the gross requirements to yield the net requirements. Note that the net BOH of 32 at plant T is not applied at the higher level (the higher-level net BOH at plant T is zero), but is applied when the requirements computations for part 5-0827T are made. Plant T is both a demand (user plant) and a supply plant in this case, and thus the higher-level net BOH is zero.

The dependent net requirements along with the FS independent requirements provide the demand inputs for the transportation algorithm. These requirements are then summed and split by the multi-sourcing rule to each supply plant (75% to T and 25% to C in this case). This provides the supply input for the transportation algorithm. The transportation problem is then solved separately for each week in the planning horizon. The optimal shipping routes to meet each week's demand requirements are determined by the transportation algorithm, and these shipping route flows are then offset by the corresponding intransit lead times to determine the dependent and independent demand lines for parts 5-0827T and 5-0827C. Once the transportation problem has been solved for each week in the planning horizon, these demand lines are completely determined and the MRP calculations continue in the normal sequence to produce the planned order release lines for parts 5-0827T and 5-0827C. Exhibit 3.4 provides details for all of the tranpsortation algorithm calculations and intransit lead time offsets.

Solving the transportation algorithm on a week by week basis is a reasonable approach when requirements are produced lot for lot. It is important to realize that this solution is a local optimum and that it depends on the multi-sourcing and lot-sizing rules that have been set by materials management policy. The algorithm does not establish policy rules that minimize production and transportation costs over the entire planning horizon. For each multi-sourced part, it only establishes the opitmum shipping routes to minimize transportation costs to meet that part's weekly requirements, within the context of the MRP calculations.

3.4 Summary Reports

There are two major summary reports that result as output from the multi-plant MRP calculations. They are:

- Planned Order Releases by Plant (Exhibit 3.5) - this report displays the time-phased planned order releases for each part made in each manufacturing plant. The report is to be used by each plant's production and purchasing departments, and will tell the plant manager how much to produce (or to order from a vendor) and when to begin production (or to place an order) for every part. For example, plant M must release an order to begin production of 16, 3-6350's in week 1.

- Delivery Schedule by Plant (Exhibit 3.6) - this report details for each part made or purchased in each manufacturing plant, how much, when, and to where that part must be shipped. This report would be used by each plant's distribution department. For example, plant T must ship 32, 3-8470's to plant M in week 1.

Exhibit 3.4 Transportation Algorithm and ITLT Offset Calculations

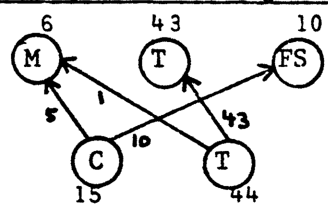
In this example, there are 3 demand locations - Plant M, Plant T, Field Service, and 2 supply plants - Plant T and Plant C. The net demand requirements and supplies for each week in the planning horizon have been determined in Exhibit 3.3. The transportation problem is solved each week to determine weekly optimal shipping routes in order to determine the delivery schedule. These shipping route flows are then offset by the corresponding intransit lead times to determine the dependent and independent demand lines for parts 5-0827T and 5-0827C back in Exhibit 3.3. Once these demand lines are filled, the MRP calculations continue in the normal sequence. The transportation problem and offset calculations will be shown in detail for weeks 1 and 2, and in less detail for weeks 3 through 10.

Week 1

Demand Req.
M = 6
T = 43
FS =10

Supply
C = 15(25%)
T = 44(75%)

Transportation Algorithm



Distribution
T → M = 1
T → T = 43
C → M = 5
C → FS = 10

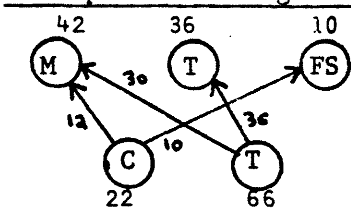
ITLT Offset
To 5-0827T Dep. Dem. line - PD column
To 5-0827T Dep. Dem. line - Wk 1 column
To 5-0827C Dep. Dem. line - PD column
To 5-0827C Indep. Dem. line - Wk 1 column

Week 2

Demand Req.
M = 42
T = 36
FS = 10

Supply
C = 22(25%)
T = 66(75%)

Transportation Algorithm

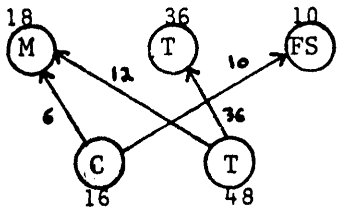


Distribution
T → M = 30
T → T = 36
C → M = 12
C → FS = 10

ITLT Offset
To 5-0827T Dep. Dem. line - Wk 1 column
To 5-0827T Dep. Dem. line - Wk 2 column
To 5-0827C Dep. Dem. line - PD column
To 5-0827C Indep. Dem. line - Wk 2 column

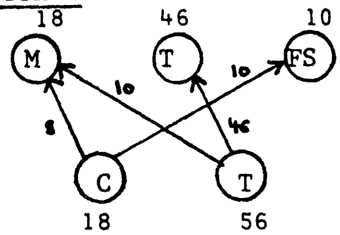
Exhibit 3.4 (Continued)

Week 3



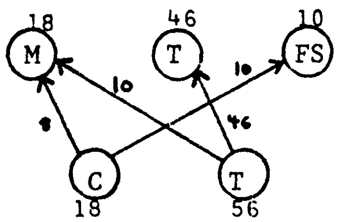
12 → 5-0827T Dep. Dem. line - Wk 2
36 → 5-0827T Dep. Dem. line - Wk 3
6 → 5-0827C Dep. Dem. line - Wk 1
10 → 5-0827C Indep. Dem. line - Wk 3

Week 4



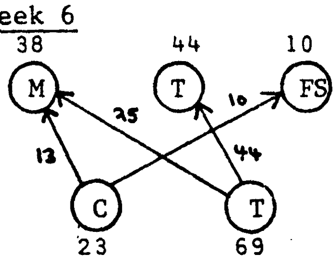
10 → 5-0827T Dep. Dem. line - Wk 3
46 → 5-0827T Dep. Dem. line - Wk 4
8 → 5-0827C Dep. Dem. line - Wk 2
10 → 5-0827C Indep. Dem. line - Wk 4

Week 5



10 → 5-0827T Dep. Dem. line - Wk 4
46 → 5-0827T Dep. Dem. line - Wk 5
8 → 5-0827C Dep. Dem. line - Wk 3
10 → 5-0827C Indep. Dem. line - Wk 5

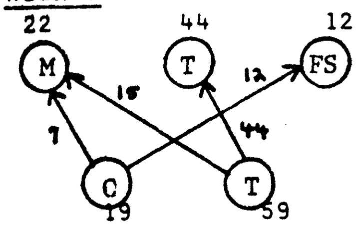
Week 6



25 → 5-0827T Dep. Dem. line - Wk 5
44 → 5-0827T Dep. Dem. line - Wk 6
13 → 5-0827C Dep. Dem. line - Wk 4
10 → 5-0827C Indep. Dem. line - Wk 6

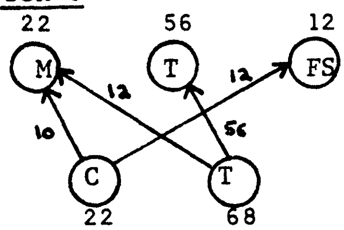
Exhibit 3.4 (Continued)

Week 7



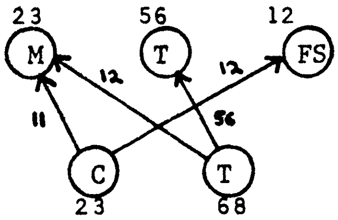
15 → 5-0827T Dep. Dem. line - Wk 6
44 → 5-0827T Dep. Dem. line - Wk 7
7 → 5-0827C Dep. Dem. line - Wk 5
12 → 5-0827C Indep. Dem. line - Wk 7

Week 8



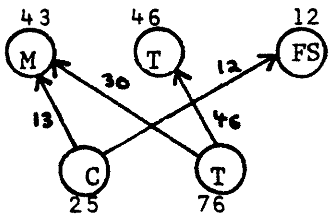
12 → 5-0827T Dep. Dem. line - Wk 7
56 → 5-0827T Dep. Dem. line - Wk 8
10 → 5-0827C Dep. Dem. line - Wk 6
12 → 5-0827C Indep. Dem. line - Wk 8

Week 9



12 → 5-0827T Dep. Dem. line - Wk 8
56 → 5-0827T Dep. Dem. line - Wk 9
11 → 5-0827C Dep. Dem. line - Wk 7
12 → 5-0827C Indep. Dem. line - Wk 9

Week 10



30 → 5-0827T Dep. Dem. line - Wk 9
46 → 5-0827T Dep. Dem. line - Wk 10
13 → 5-0827C Dep. Dem. line - Wk 8
12 → 5-0827C Indep. Dem. line - Wk 10

Exhibit 3.5 Summary Report: Planned Order Releases by Plant

	PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PLANT M															
F-1022	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
3-6350	0	16	42	18	18	18	38	22	22	23	43	23			
PLANT C															
5-0827	0	14	18	23	17	20	23	25	12	12					
P-0827	0	17	17	20	23	25	12	12							
PLANT T															
3-8470	0	43	36	36	46	46	44	44	56	56	46				
5-0827	0	46	46	56	71	59	56	68	86	46					
P-0827	23	56	71	59	56	68	86	46							

Exhibit 3.6 Summary Report: Delivery Schedule by Plant

Ship in week:	PD	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PLANT M															
F-1022 (M→FP Whse)	0	10	20	20	22	22	18	18	18	18	22	22	23	23	23
3-6350 (M → M)	0	7	20	22	22	18	18	18	18	22	22	23	23	23	
(M → FS)	0	0	0	0	20	0	0	0	20	0	0	0	20	0	
PLANT C															
5-0827 (C → M)	17	6	8	8	13	7	10	11	13						
(C → FS)	0	10	10	10	10	10	10	12	12	12	12				
P-0827 (C → C)	0	14	18	23	17	20	23	25	12	12					
PLANT T															
3-8470 (T → M)	0	32	44	44	36	36	36	36	44	44	46	46	46		
(T → FS)	0	0	8	8	0	0	10	10	0	0	10	10	0		
5-0827 (T → M)	1	30	12	10	10	25	15	12	12	30					
(T → T)	0	43	36	36	46	46	44	44	56	56	46				
P-0827 (T → T)	0	46	46	56	71	59	56	68	86	46					

4. Summary

This paper presents a framework of a system for performing MRP calculations in an environment with multiple plants and multi-sourced parts where corporate control of material requirements and production scheduling is desired. To become operational however, this simplified framework must be refined to handle the more complex aspects of a multi-plant network. These complexities include the treatment of requirements that are not shipped on time and the regeneration of new MRP schedules. We have also observed that the solution to the transportation problem as described above, is affected by the lot-sizing rules employed. In addition, there are several important issues and decisions that confront a firm when implementing a multi-plant MRP system. The implementation issues and the system refinements required to manage the complexities are addressed in another paper [1].

Acknowledgement

The authors are grateful to Jack Reeve and Joan Hamm for their helpful suggestions and comments during the development of this study.

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