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Improving Application Software by Integrating Master Scheduling with Material Requirements Planning in Supply Chain Management

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Abstract:
Supply chain management planning systems begin with supply network planning. As a next step, in order to fulfill production requirements, each production facility makes decisions about master production schedules (MPS) for all products and, subsequently, material requirements planning (MRP) and capacity requirements planning for all subassemblies and components made in the production facility. Currently, these decisions are made iteratively and by trial and error methods, resulting in inefficient and suboptimal decisions. A linear programming model is proposed in this paper that can assist planners in making the decisions in an integrated model to avoid iterative loops. The proposed model is illustrated with the formulation and solution of an example problem.

Keywords: Supply chain management, material requirements planning, linear programming models

1. Introduction

Supply chain management systems such as those developed by SAP (2014) begin with supply network planning to determine product allocations, production schedules for all production facilities, warehouse allocations, and optimal transportation lanes for product shipment. These tasks are performed with the goal of meeting customer requirements in a timely manner and at minimum cost. Production allocations and targets form the basis of the next module for production planning and detailed scheduling in the SAP-SCM software (2014). In this paper, we focus on production planning and scheduling decisions.

Production planning for a manufacturing organization is usually implemented in a hierarchical framework (Jacobs *et al.*, 2011, and Stevenson, 2018). Sales and operations plans (SOP) are prepared based on demand forecasts and customer orders. At the next stage, the plans are broken down into master production schedules (MPS) for individual end items. Then, MPS becomes the basis for material requirements planning (MRP) of raw materials, component items, and subassembly or module items. Several iterations are necessary to ensure that MRP, MPS, and SOP decisions are feasible within available resources of materials and capacities.

Sequential decision making is explained in Figure 1 (Jacobs *et al.*, 2011) below. These decisions are linked with feedback and iterative loops so that all the decisions are consistent and realistic. MPS feasibility is checked by rough-cut capacity planning. MRP feasibility is determined by the technique of capacity requirements planning. MPS may have to be revised if there are material or capacity problems after MRP calculations of planned orders.
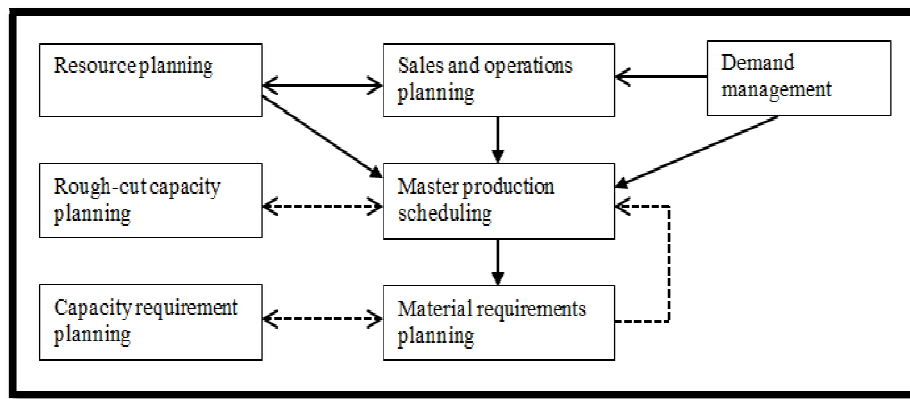
Figure 1: Framework of Hierarchical Decision Making

The sequential mode of making decisions is inefficient and gives suboptimal results. Managers need to spend considerable time and effort so that decisions are consistent and reliable. We develop a linear programming (LP)-based algorithm so that MPS, MRP, and capacity requirement planning decisions are made in an integrated model. This algorithm avoids feedback loops and iterative steps in the process. All of these decisions (SOP, MPS, and MRP) are typically made with the help of enterprise resource planning (ERP) software (SAP, 2014). The algorithm developed in this paper can be embedded in ERP software to assist managers in making decisions more efficiently and optimally. Database and computational resources can thus be better deployed with the proposed model.

Model development is discussed in the next section. In the proposed algorithm, MRP planned orders are calculated in terms of MPS unknown quantities (variables). MRP production order variables are then inputted into the linear programming formulation. Mathematical formulations are discussed, in addition to the underlying assumptions of the formulations. An example problem is shown to demonstrate the application of the model. The example problem is solved with the LP software of LINDO. Finally, in the last section, the relevance of the model in industry is highlighted. We also believe that the model can be very useful in teaching MPS and MRP concepts in supply chain management courses.

This paper suggests further improvements on an earlier model proposed by Bahl and Bahl (2013). First, it is shown how the linear programming model can be embedded in supply chain software such as SAP (2014). Components of SAP software are discussed, and improvements to the decision-making process are highlighted. Second, the proposed model removes the period order quantity restrictions from the earlier model. Lot sizing decisions are made based upon the capacity limitations in the proposed model. Setup times are incorporated with run times as proposed in Jacob *et al.* (2011).

2. MPS and MRP Model

MPS, MRP, and capacity requirements planning are integrated in the mathematical model discussed below. We then solve an example problem as an illustration in the next section. Storage (inventory) costs for end-items, storage costs for component and subassembly items, costs of regular time of all work centers, and overtime costs are all included in the objective function. Capital letters are used to show model variables, and lowercase letters are used for the known coefficients or constants.

	T N **T W** **T W**		
Minimize	$Z=\sum\sum I_{it}.c_{it}+\sum\sum E_{wt}.a_{wt}+\sum\sum F_{wt}.b_{wt}$		(1)
	$t{=}1\ i{=}1$ $t{=}1\ w{=}1$ $t{=}1\ w{=}1$		
Subject to			
	$I_{it}-I_{i,t\text{-}1}+X_{it}=d_{it}$ M	$i\in M$ $t\in$	(2)
	$I_{yt} - I_{y,t\text{-}1}+C_{yt}=\sum_{i=1} R_{it}$	$y\in(N-M)\ t\in$	(3)
	$\sum\sum X_{it}p_{y,w,t\text{-}l}\leq E_{wt}+F_{wt}$ $y{=}1\ i{=}1$	$w\in W$ $t\in T$	(4)
	$E_{wt}\leq g_{wt}$	$w\in W$ $t\in T$	(5)
	$F_{wt}\leq h_{wt}\ E_{wt}$	$w\in W$ $t\in T$	(6)
	$X_{it}, I_{it}, E_{wt}, F_{wt}\geq 0$	$i\in N$ $w\in W$ $t\in T$	(7)

Table 1

The notations used in the model are described below:
- N   Set of all items including end-items, subassemblies and components in the bill of materials.
- M   Set of all end-items (or products).
- W   Set of work centers.
- T   Set of time-periods in the planning horizon.
- IIT   Inventory level for product i at the end of period t.
- IYT   Inventory level for component y at the end of period t.
- XIT   Master production schedule quantity for product i during period t.
- EWT   Regular time capacity in hours used by work center w in period t.
- FWT   Overtime capacity in hours used by work center w in period t.
- CYT   Production quantity of component y in period t.
- RIT   Requirements of component y from all of the end items.
- CIT   Storage cost for product i at the end of period t.
- AWT   Regular time cost per hour for work center w in period t.
- BWT   Overtime cost per hour for work center w in period t.
- DIT   Forecast demand for product i in period t.
- HWT   Fraction of regular hours of work center w in period t so that hwt gwt gives the upper limit on overtime hours.
- PY,W,T-I Total operation time (setup time and processing time) required by component y on work center w at I period offset of lead time for making one unit of product in period t.

Inventory balance constraints for products are shown in constraints (2) and corresponding constraints for components are shown in constraint set (3). Constraints (4) impose the limits on the capacity used by the components at a work center. Constraints (5) restricts regular time capacity available to its upper limit. Constraints (6) limits the overtime to a percentage of the regular time limit at a work center.

Typical MPS and MRP data in industry such as bill of materials, product demands, storage costs, capacity limits, and the relevant costs are all modelled in the proposed mathematical model. Setup times are considered in capacity needs as an average for each item along with the processing time for an item. This assumption is consistent with similar frameworks in Jacobs *et al.* (2011) and Orlicky (1975). Berry (1972) and Jacobs *et al.* (2011) have demonstrated that the lot-sizing method of a fixed number of periods provides approximate good solutions in minimizing the setup costs and inventory carrying costs.

We also make the assumption that MPS decisions are typically made beyond the planning time fence. In industry, it is common practice (SAP-SCM, 2014, & Stevenson, 2018) that the beginning periods of MPS covering the product lead time are frozen in the planning horizon. For example, MPS may be planned on the first of November for the periods January 1 to June 30 for a product with a lead time of two months and with planning horizon of six months.

3. An Example Problem Information and its Solution

We now will discuss the concepts and the mathematical model with an example problem. Data for the problem are shown in Figure 2. We have assumed some data figures for the resources, products, and components. An LP model as discussed above was formulated with its objective function and constraints. We then solved it with the help of well-known LINDO software. There are only two products (PROD-A and PROD-B) for simplicity, and each has only one component (COMP-A for PROD-A and COMP-B for PROD-B). Lead time (LT) is also taken as one period for each item.
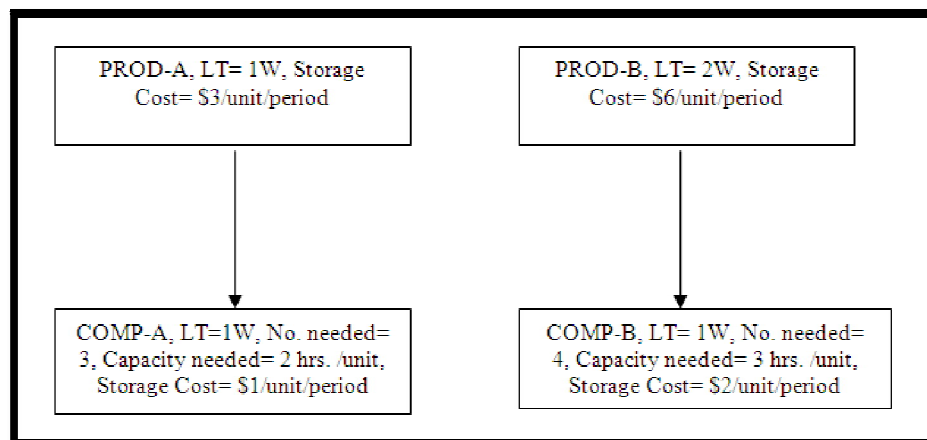

Figure 2: Bill of Materials Data

Demand for the PROD-A is 25, 30, 40, and 30 in four periods after the planning fence and for PROD-B is 15, 20, 30, and 40. To keep the example simple, it was assumed that there is only one resource, and its available capacity in each of the four periods is assumed to be 600, 400, 400, and 400.

MRP calculations are done and planned orders are computed with the bill of materials and items data given in the above figure. MRP calculations are carried out in terms of the MPS variables. MRP calculations for planned order releases are shown in Table 2 below.

Week #	-2	-1	1	2	3	4	-3	-2	-1	1	2	3	4
Forecast Demand			25	30	40	30				15	20	30	40
Master Production Schedule			a1	a2	a3	a4				b1	b2	b3	b4
POR for Assembly		a1	a2	a3	a4			b1	b2	b3	b4		
Gross Requirements for Component		3a1	3a2	3a3	3a4			4b1	4b2	4b3	4b4		
POR for component	3a1	3a2	3a3	3a4			4y1	4y2	4y3	4y4			
Capacity Requirements	6a1	6a2	6a3	6a4			12y1	12y2	12y3	12y4			

Table 2: Computations for MRP

The decision model for MPS and MRP is now formulated with the objective function and constraints discussed above. Example problem data were inputted into the LINDO software. The results obtained are given in Table 2 below. The linear programming results achieve minimums of product inventories costs, component inventories costs, regular time costs, and overtime costs and give an optimal solution within the available capacity. The example solution provides an MPS solution, planned orders as computed in MRP and capacity used. We thus avoid iterations and feedback loops in MPS and MRP decisions.

LP Optimum Found at Step	21	
Objective Function Value		
1 22320.00		
Variable	Value	Reduced Cost
E11	0.000000	3.000000
E12	13.333333	0.000000
E13	26.666666	0.000000
E14	0.000000	75.000000
E21	0.000000	6.000000
E22	15.000000	0.000000
E23	0.000000	0.000000
E24	0.000000	150.000000
Component Inventories		
C11	0.000000	1.000000
C12	0.000000	2.000000
C13	0.000000	0.000000
C14	0.000000	25.000000
C21	140.000000	0.000000
C22	0.000000	0.500000
C23	0.000000	0.500000
C24	0.000000	38.000000
Regular Time Capacity		
R11	600.000000	0.000000
R12	208.000000	0.000000
R13	400.000000	0.000000

LP Optimum Found at Step	21	
R14	400.000000	0.000000
Overtime Capacity		
O11	150.000000	0.000000
O12	52.000000	0.000000
O13	100.000000	0.000000
O14	100.000000	0.000000
End Items Production		
P11	25.000000	0.000000
P12	43.333332	0.000000
P13	53.333332	0.000000
P14	3.333333	0.000000
P21	15.000000	0.000000
P22	35.000000	0.000000
P23	15.000000	0.000000
P24	40.000000	0.000000
Components Production		
Q11	75.000000	0.000000
Q12	75.000000	0.000000
Q13	160.000000	0.000000
Q14	10.000000	0.000000
Q21	200.000000	0.000000
Q22	0.000000	0.000000
Q23	0.000000	0.000000
Q24	160.000000	0.000000
Row	Slack Or Surplus	Dual Prices
2	0.000000	-66.000000
3	0.000000	-66.000000
4	0.000000	-69.000000
5	0.000000	-72.000000
6	0.000000	-132.000000
7	0.000000	-132.000000
8	0.000000	-138.000000
9	0.000000	-144.000000
10	0.000000	-22.000000
11	0.000000	-22.000000
12	0.000000	-23.000000
13	0.000000	-24.000000
14	0.000000	-33.000000
15	0.000000	-33.000000
16	0.000000	-34.500000
17	0.000000	-36.000000
18	0.000000	11.000000
19	0.000000	11.000000
20	0.000000	11.500000
21	0.000000	12.000000
22	0.000000	0.000000
23	192.000000	0.000000
24	0.000000	0.625000
25	0.000000	1.250000
26	0.000000	-4.000000
27	0.000000	-4.000000
28	0.000000	-3.500000
29	0.000000	-3.000000

Table 3: LINDO Software Results for the Example Problem
No. Iterations = 21

The example problem shown above has very limited data to demonstrate the main ideas of the mathematical model (that is, those MRP computations for planned orders can be done in terms of the variables of MPS). In the industry setting, multi-level bills of materials, numerous products and numerous components, many work centers, relevant lot sizes, and various types of capacity resources can all be included in the mathematical model.

4. Conclusion

The algorithm developed will be invaluable in assisting managers avoid subjective iterative decision-making for MPS, MRP, and capacity requirements planning. The proposed LP model formulates these decisions in an integrated model. We demonstrated the applicability of the model by solving a sample problem. The model formulation is also helpful for supply chain management students in understanding integrated methods for making MPS, MRP, and capacity requirements decisions in manufacturing environments.

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