Chapter 2
Supply Chain Management

Abstract Supply chain management deals with decisions on new facility locations, quantities to manufacture, modes of transporting the manufactured goods, and information systems to use. Material and manufacturing requirements planning are conducted in a hierarchical manner. In other words, bill of materials and master production schedule is constructed and then manufacturing orders are released to satisfy the varying demands of the periods that are thought to be deterministic. This chapter presents some of the important topics in supply chain management.

Keywords Supply chain management · MRP · EOQ · Transportation

The term *supply chain management* (SCM) is attributed to Proctor and Gamble (P&G). P&G used the term for tracking the flow of Pampers diapers through the distribution channel [3]. As mentioned in the Chap. 1, supply chain management deals with integration and coordination of location of facilities, production, inventory control, and transportation of materials and products. This chapter deals with key supply chain management decisions and planning throughout the supply chain.

2.1 Key Supply Chain Decisions

Location of plants, warehouses, distribution centers (DCs), manufacturing quantities, order dates, inventory policies, and transportation related decisions are very important for supply chain success. Information system employed for the supply chain is also a key in successful implementations. These decision problems need to be elaborated in detail.

Manufacturers face the problem of shortage in production capacity as the demand for an item increases. The cost of outsourcing might be more than the cost of opening a new facility or increasing the capacity of the current one by extra labor, equipment etc. in the long run that makes opening a new facility, increasing

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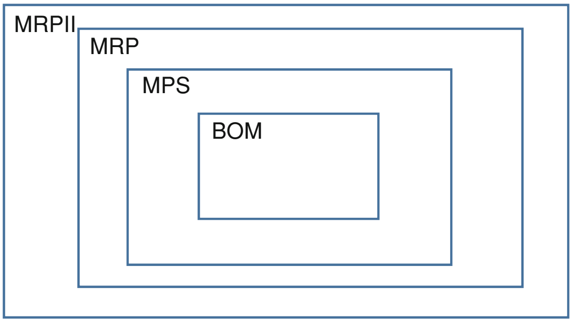

Fig. 2.1 Hierarchical relationship from BOM to MRPII

the capacity of the manufacturing plant more reasonable compared to outsourcing. Installing new machines, employment of new workers, facilitating new equipment, transportation vehicles might be necessary. Even opening a distinct plant might be compulsory. Decision on the location of the new plant based on the outbound transportation costs, operational costs within the new plant will be considered as well then. Some of the optimization problems and solutions to these problems that will lead to management decisions are reviewed in Sect. 4.2.

Location decision is a strategic one. On the other hand, manufacturers need to decide on the production quantity at operational level. Before operations level planning, aggregate planning should be achieved. Aggregate planning spans yearly plans of productions. These plans are decomposed into shorter term productions plans. Production quantity decision is complex since it comprises demand forecasts, actual demands, judgments of people from marketing, production and other departments. Capacity of the plant regarding work staff level, machine level, etc. is also a constraint for production quantity decisions. Material requirement planning (MRP) is used to decide on the production levels of end items and sub-assemblies. If the demand is known (or forecasted) and variable in each period, MRP may be employed as a top-down approach. Production planning under probabilistic stationary demand is discussed in Sect. 2.2. MRP works as a push system since it relies on forecast of the end items and production quantities push the production of sub-assemblies. MRP structure and its relation to manufacturing planning is shown in Fig. 2.1. MRP has bill of materials and master production schedule components. If capacity constraints are considered then it becomes a more global planning tool called manufacturing resource planning (MRP II) that is included in enterprise resource planning (ERP).

For example, a toy laptop consists of an assembly of a screen and lower part assembly. Lower-part assembly consists of a board on which chips are installed and a keyboard. A tree that shows the dependency between these parts is called bill of materials (BOM). BOM may be represented as a list or tree as shown in Fig. 2.2.

Lead times (LT) are given in weeks. Based on the lead times, a toy laptop is produced in 4 weeks. Table 2.1 shows the weekly demands for the next 6 weeks starting from the fifth.

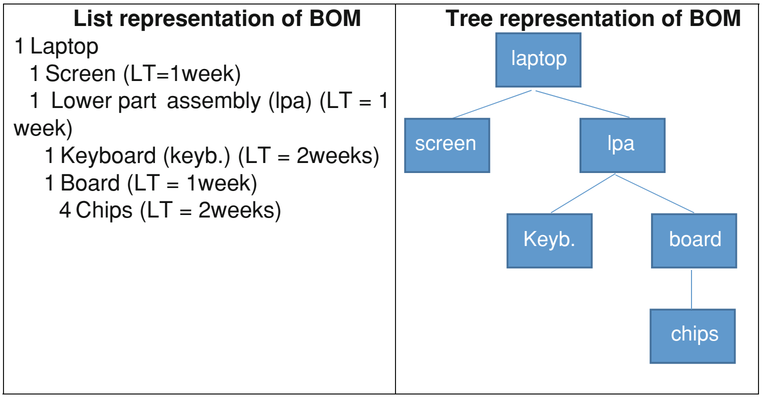

Fig. 2.2 Bill of materials

Table 2.1 Weekly demands for toy laptop

Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
50	60	45	70	78	40

Table 2.2 Scheduled toy laptop returns

Week 5	Week 8	Week 9	Week 10
5	10	13	6

Table 2.3 Master production schedule for toy laptop

Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
45	60	45	60	65	44

The company might receive returns throughout 6 weeks. Let's assume scheduled receipts as given in Table 2.2.

The company updates the inventory according to scheduled receipts and it is fair to assume that at the end of the last week the company policy requires an inventory level of 10 laptops. Master production schedule is prepared netting the demand by inventory information as shown in Table 2.3.

Now these plans are pushed to next levels down the bill of materials tree. The MPS will be translated as gross requirement for lower part assembly, and screen. There is no multiplicative factor since one laptop requires one from each sub-part (screen, lower part assembly). Also, assuming that there will be no scheduled receipt and on hand inventory for the sub-parts, we can MRP calculations for both screen and lower part assembly as seen in Table 2.4.

Table 2.4 MRP calculation for screen and lower part assembly

Week	4	5	6	7	8	9	10
Gross requirements		45	60	45	60	65	44
Net requirements		45	60	45	60	65	44
Shifted requirements	45	60	45	60	65	44	
Orders	45	60	45	60	65	44	

Table 2.5 MRP calculations for board

Week	2	3	4	5	6	7	8	9	10
Gross requirements			45	60	45	60	65	44	
Net requirements			45	60	45	60	65	44	
Shifted requirements	45	60	45	60	65	44			
Orders	45	60	45	60	65	44			

Table 2.6 MRP calculations for keyboard

Week	2	3	4	5	6	7	8	9	10
Gross requirements			45	60	45	60	65	44	
Net requirements			45	60	45	60	65	44	
Shifted requirements		45	60	45	60	65	44		
Orders		45	60	45	60	65	44		

Here orders quantities are the same with the lead time shifted requirements. That is known as lot-for-lot ordering policy. Amount of order may differ based on different ordering policies. Some of them are reviewed in Sect. 2.2.

Similar calculations are made for board and keyboard. MRP calculations are shown in Tables 2.5 and 2.6.

Assuming that chips are similar to each other, one board requires four chips. So ordering boards starting from third week pushes chip orders 2 weeks before with the quantity of four times the amount of boards. Table 2.7 shows the MRP calculations.

Here, demands are assumed to be deterministic. In reality, manufacturers resort to safety stocks because of the uncertainty in demands. If we approximate the cumulative distribution value for meeting the demand, i.e. normally distributed, we can add safety stock to our demands to be used as new gross requirements. For example, if we want to meet the demand (normally distributed) for toy laptop each week with a probability of 95 %. Then average demand + standard deviation times 1.65 (standard normal variate value) will give the new gross requirements.

Lead times might not be deterministic as well. They also can be adjusted, for example by a multiplicative factor to include variability.

Capacity of the plant may be a constraint to produce the orders from MRP. Capacity planning shifts MRP to MRP II (manufacturing resource planning)

Table 2.7 MRP calculations for chip

Week	1	2	3	4	5	6	7	8	9	10
Gross requirements			180	240	180	240	260	176		
Net requirements			180	240	180	240	260	176		
Shifted requirements	180	240	180	240	260	176				
Orders	180	240	180	240	260	176				

paradigm that incorporates different departments of the company for production planning. Capacity planning problem will be reviewed in Sect. 2.3.

MRP serves as a tool to make production quantity decision. However, MRP assumes deterministic demands subject to changes in different periods. MRP is a push system. The example above assumes a static MRP that has a fixed planning horizon, 6 weeks. In reality an MRP needs to be run each period to manipulate productions decisions. *Rolling horizon* approach implements only the first-period decision of N-period problem [3]. When using rolling horizon approach, number of periods should be long enough to make the first-period decision constant.

2.2 Ordering Policies

In this chapter, MRP calculations resulted in number of orders and we determined the number based on a lot-for-lot policy. Order lot size is equal to the lead time shifted requirements. However, this lot sizing policy is not necessarily optimal. There are other order size policies and also there is an optimal policy.

The simplest model to start is for the uncapacitated single item lot sizing problem (USILSP). A natural mixed integer formulation of the problem is given as follows [1]:

$$\min \sum_{t=1}^{T} (s_t Y_t + c_t X_t + h_t I_t)$$

subject to

$$I_{t-1} + X_t - D_t = I_t; \forall t$$

$$X_t \le Y_t D_{tT}; \forall t$$

$$Y_t \in \{0, 1\}; \forall t$$

$$X_t, I_t \ge 0; \forall t$$

s_t is the set-up cost in period t ($t = 1,\ldots,T$). c_t is unit production cost in period t. h_t is inventory holding cost in period t. X_t is the production quantity in period t. I_t is the inventory at the end of period t. $D_{tT} = D_t + D_{t+1} + \cdots + D_T$. Here, beginning and ending inventory levels are zero.

The objective function of the model minimizes the total cost that includes set-up cost at each production run, production cost, and inventory cost over T periods. First set of constraints imply that the inventory level at the end of period t is equal to the sum of inventory level of the previous period and production amount in period t minus the demand in the same period.

The model can be extended to include multiple facilities introducing W_{jkt} transfer variables defined as quantity transferred from facility j to facility k in period t. The new objective function includes transfer cost and inventory constraints include transferred products:

$$\min \sum_{j}^{F} \sum_{t=1}^{T} \left(s_{jt} Y_{jt} + c_{jt} X_{jt} + h_{jt} I_{jt} + \left(\sum_{k \neq j} r_{jkt} W_{jkt} \right) \right)$$

$$\textit{subject to}$$

$$I_{jt-1} + X_{jt} + \sum_{l \neq j} W_{ljt} - D_{jt} = I_{jt} + \sum_{k \neq j} W_{jkt}; \forall j, t$$

$$X_{jt} \leq Y_{jt} \sum_{j=1}^{F} \sum_{i=t}^{T} D_{ji}; \forall j, t$$

$$Y_{jt} \in \{0, 1\}; \forall j, t$$

$$X_{jt}, I_{jt}, W_{jkt} \geq 0; \forall j, \quad k \neq j, t$$

Capacity constraints can be added to both of the models introduced above.

Since integer programming models are hard to solve, it might be efficient to use heuristics to find a reasonable—not optimal solution to a lot sizing problem. Here are some of the widely used ones:

1. Silver-Meal heuristic
2. Least unit cost heuristic
3. Part period heuristic

Silver-Meal is a myopic heuristic that works based on average cost per period. The cost function of the heuristic spans future periods as long as the value of it increases. $C(t, t + n)$ is the cost in period t to cover periods from t to $t + n, n + 1$ periods. D_t is the demand in period t, then the cost spanning $n + 1$ periods is found by:

$$C(t, t+n) = S + h \sum_{i=0}^{n} i D_{t+i}$$

The first period cost C(1, 1) is only the set-up (or order) cost S. The average cost spanning two periods is:

$$\frac{C(1,2)}{2} = \frac{S + h\sum_{i=0}^{1} iD_{t+i}}{2} = \frac{S + hD_2}{2}.$$

The average cost spanning three periods is:

$$\frac{C(1,3)}{3} = \frac{S + hD_2 + 2hD_3}{3}.$$

As we generalize it:

$$\frac{C(1,n+1)}{n+1} = \frac{S + hD_2 + 2hD_3 + \cdots + nhD_{n+1}}{n+1}.$$

The stopping criteria for the heuristic is

$$\frac{C(t,t+n)}{n+1} > \frac{C(t,t+n-1)}{n}.$$

Once the heuristic stops, the lot size for period t is set as $D_t + D_{t+1} + \cdots + D_{t+n-1}$ and the heuristic starts over at period $n + 1$.

If we return to our toy laptop example in this chapter, shifted requirements for laptop screen were 45, 60, 45, 60, 65 and 44. Let's assume an \$400 order cost for screens and holding cost of \$5. Then we can work out Silver-Meal heuristic.

$$C(1,1) = 400, \frac{C(1,2)}{2} = \frac{400 + 5 \times 60}{2} = 350,$$
$$\frac{C(1,3)}{3} = \frac{400 + 5 \times 60 + 2 \times 5 \times 45}{3} = 383.33$$

We set the lot size for period one as 45 + 60 = 105 and start over from third period.

$$C(3,3) = 400, \frac{C(3,4)}{2} = \frac{400 + 5 \times 60}{2} = 350,$$
$$\frac{C(3,5)}{3} = \frac{400 + 5 \times 60 + 2 \times 5 \times 65}{3} = 450$$

We set the lot size for period three as 45 + 60 = 105 and start over from fifth period.

$$C(5,5) = 400, \frac{C(5,6)}{2} = \frac{400 + 5 \times 44}{2} = 310$$

Since all periods are over we set the lot size for period five as 65 + 44 = 109.

We can make cost comparison between lot-for-lot policy and Silver-Meal policy. Lot-for-lot policy will have only order costs of 6 × 400 = \$2,400. Silver-Meal will have order costs of $3 \times 400 = \$1{,}200$ and holding costs of $300 + 300 + 220 = \$820$. Total cost is \$2,020. So, Silver-Meal saves around 16 % here.

Least unit cost heuristic can be viewed as a modified version of Silver-Meal heuristic. Modification is made on the cost function. The cost function is divided by the total demand, instead of number of periods.

We can write unit cost expressions for the first period spanning one period as:

$$\frac{C(1,1)}{D_1} = \frac{S}{D_1}.$$

The unit cost expression spanning two periods starting from the first one is

$$\frac{C(1,2)}{D_1 + D_2} = \frac{S + hD_2}{D_1 + D_2}.$$

The unit cost expression spanning three periods starting from the first one is

$$\frac{C(1,3)}{D_1 + D_2 + D_3} = \frac{S + hD_2 + 2hD_3}{D_1 + D_2 + D_3}.$$

General unit cost expression spanning $n + 1$ periods starting from the first one is

$$\frac{C(1,n+1)}{D_1 + \cdots + D_{n+1}} = \frac{S + hD_2 + 2hD_3 + \cdots + nhD_{n+1}}{D_1 + \cdots + D_{n+1}}.$$

Stopping criteria for the heuristic is:

$$\frac{C(t,t+n)}{D_t + \cdots + D_{n+1}} > \frac{C(t,t+n-1)}{D_t + \cdots + D_n}.$$

The lot size for period t is set as $D_t + D_{t+1} + \cdots + D_{t+n-1}$ and the heuristic starts over at period $n + 1$.

We can apply the unit cost heuristic to the same example:

$$\frac{C(1,1)}{D_1} = \frac{400}{45} = 8.88, \frac{C(1,2)}{D_1 + D_2} = \frac{400 + 5 \times 60}{105} = 6.66,$$
$$\frac{C(1,3)}{D_1 + D_2 + D_3} = \frac{400 + 5 \times 60 + 2 \times 5 \times 45}{150} = 7.66.$$

Stopping criteria is met. Lot size for the first period to span two periods is $45 + 60 = 105$. We start over from the third period:

$$\frac{C(3,3)}{D_3} = \frac{400}{45} = 8.88, \frac{C(3,4)}{D_3 + D_4} = \frac{400 + 5 \times 60}{105} = 6.66,$$
$$\frac{C(3,5)}{D_3 + D_4 + D_5} = \frac{400 + 5 \times 60 + 2 \times 5 \times 65}{170} = 7.94.$$

The lot size for the third period to span two periods is 45 + 60 = 105. Starting over from fifth period:

$$\frac{C(5,5)}{D_5} = \frac{400}{65} = 6.15, \frac{C(5,6)}{D_5 + D_6} = \frac{400 + 5 \times 44}{109} = 5.69.$$

The unit cost heuristic stops since the number of periods is reached. The lot size for the fifth period to span two periods is 65 + 44 = 109. The lot sizes are the same with Silver-Meal results. However, it is most likely that two heuristics will result in different lot sizes solving bigger real world problems. Heuristics are not guaranteed to find optimal solutions. Also, it is hard to judge which heuristic is better for all scenarios.

Part period heuristic aims to balance set-up cost and inventory holding cost. Assuming the inventory holding cost $I(t, t + n)$ associated with carrying inventory for n periods. If the inventory holding cost is greater than the set-up cost, then it is reasonable to place a new order at the period $t + n$.

Using the data for the toy laptop example, the first period will not have any inventory holding cost, $I(1,1) = 0$. The holding cost for carrying from first to second period $I(1,2)$ will be $5 \times 60 = 300$ that is less than the set-up cost. The holding cost carrying till third period $I(1, 3)$ will be $5 \times 60 + 2 \times 5 \times 45 = 750$ that is more than the set-up cost, 400. So, we set the lot size for the first period 45 + 60 = 105, and place a new order for the third period. Holding cost for the third period $I(3, 3)$ will be zero. $I(3, 4) = 5 \times 60 = 300$ that is less than the set-up cost. $I(3, 5) = 5 \times 60 + 2 \times 5 \times 65 = 950$ that is more than the set-up cost. The lot size for the third period to cover two periods is 45 + 60 = 105. We place a new order for the fifth period and the lot size is calculates as follows: $I(5, 5) = 0$, $I(5, 6) = 5 \times 44 = 220$ that is less than the set-up cost. The heuristic stops since the number of periods is reached. The lot size for the fifth period is 65 + 44 = 109.

For this problem three of the heuristics gave the same result associated with a total cost value of $2,020.

Besides IP models and heuristic methods, dynamic programming approaches are used for lot sizing as well. Dynamic programming breaks the problem into overlapping sub-problems, solves each sub-problem optimally and uses these solutions for finding the optimal solution to the original problem. Here, finding the optimal lot sizes can be represented as a directed acyclic network. Then, the shortest path on the acyclic network gives the optimal solution, lot sizing policy. Dynamic programming can be employed to find the shortest path on the directed acyclic network. Nodes of the network represent the periods. An extra node is added to represent the end of periods. Arc (i, j) represents that ordering happens at period i and the lot size is $D_i + D_{i+1} + \cdots + D_{j-1}$ and next ordering happens at period j. The network for the toy laptop example is shown in Fig. 2.3.

For example, if the optimal lot sizing policy required ordering in the first, third, and the fifth period that would mean path 1–3–5–7 (for toy laptop example, we need seven nodes). Arc weights (c_{ij}) are the costs that include set-up and/or inventory holding cost. C_{ij} is defined as the cost of ordering in period i to cover

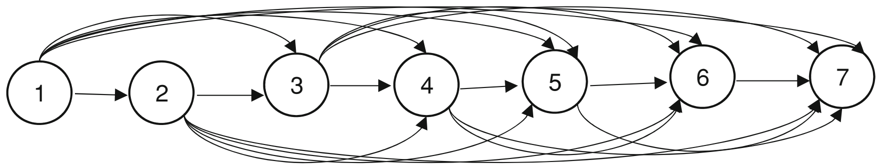

Fig. 2.3 Directed acyclic network for the toy laptop example

demand through period $j - 1$. Let f_i be the minimum cost starting at node i with the order placed in period i. Then we define a recursion:

$$f_i = \min(c_{ij} + f_j), \quad i<j, \quad i = 1, \ldots, n$$

The minimum cost for the ending node is zero, $f_{n+1} = 0$.

Our example has six period, seven nodes, $f_7 = 0$.

$f_6 = \min(c_{6j} + f_j) = 400$. Here j can only take the value seven.

$$f_5 = \min(c_{5j} + f_j) = \min\begin{Bmatrix} c_{56} + f_6 \\ c_{57} + f_7 \end{Bmatrix} = \min\begin{Bmatrix} 400 + 400 \\ 620 + 0 \end{Bmatrix} = 620, \quad j = 7$$

$$f_4 = \min(c_{4j} + f_j) = \min\begin{Bmatrix} c_{45} + f_5 \\ c_{46} + f_6 \\ c_{47} + f_7 \end{Bmatrix} = \min\begin{Bmatrix} 400 + 620 \\ 725 + 400 \\ 1{,}165 + 0 \end{Bmatrix} = 1{,}020, \quad j = 5$$

$$f_3 = \min(c_{3j} + f_j) = \min\begin{Bmatrix} c_{34} + f_4 \\ c_{35} + f_5 \\ c_{36} + f_6 \\ c_{37} + f_7 \end{Bmatrix} = \min\begin{Bmatrix} 400 + 1{,}020 \\ 700 + 620 \\ 1{,}350 + 400 \\ 2{,}010 + 0 \end{Bmatrix} = 1{,}320, \quad j = 5$$

$$f_2 = \min(c_{2j} + f_j) = \min\begin{Bmatrix} c_{23} + f_3 \\ c_{24} + f_4 \\ c_{25} + f_5 \\ c_{26} + f_6 \\ c_{27} + f_7 \end{Bmatrix} = \min\begin{Bmatrix} 400 + 1{,}320 \\ 625 + 1{,}020 \\ 1{,}090 + 620 \\ 2{,}065 + 400 \\ 2{,}945 + 0 \end{Bmatrix} = 1{,}635, \quad j = 4$$

$$f_1 = \min(c_{1j} + f_j) = \min\begin{Bmatrix} c_{12} + f_2 \\ c_{13} + f_3 \\ c_{14} + f_4 \\ c_{15} + f_5 \\ c_{16} + f_6 \\ c_{17} + f_7 \end{Bmatrix} = \min\begin{Bmatrix} 400 + 1{,}635 \\ 700 + 1{,}320 \\ 1{,}150 + 1{,}020 \\ 2{,}050 + 620 \\ 3{,}350 + 400 \\ 4{,}450 + 0 \end{Bmatrix} = 2{,}020,$$

$$j = 3$$

To obtain lot sizes, we backtrack the solution. Last solution informs that j = 2, lot size is equal to the first period's demand, 45. Next order is in period two, where j value is four. So, the lot size will cover demands for periods two and three that is 105. Next order is in period four, where j value is five. The lot size is equal to the demand in period four, 60. The next order is in period five, where j value is seven. The lot size will cover demands for periods five and six that is 109.

So the optimal solution is the path 1–3–5–7. Lot sizing policy is ordering 105 in the first period, 105 in the third period and 109 in the fifth period. As seen in the results before, heuristics also found the optimal solution for this example.

Till here, we assumed deterministic demands. However in real world scenarios, it is highly likely that demand changes fitting a statistical distribution. Newsboy model is a widely used approach. We can assume the demand D as a random variable. A boy purchases Q newspapers to sell and based on the demand, he has an underage cost c_u (when demand is more than the number of newspapers, Q) or overage cost c_o (when Q is greater than the demand). Then the optimal number of newspapers to purchase is found by:

$$F(Q) = \frac{c_u}{c_u + c_o}$$

Here, $F(Q)$ is the cumulative distribution function of demand at Q. That's the probability that the demand is less than Q.

Lot size re-order systems reviews the system continuously. The system has two variables R and Q. When inventory level hits R, Q units are ordered. As we assume a lead time L, demand during the lead time becomes the source of uncertainty. S is the set-up cost, p is the penalty cost per unit for unsatisfied demand. Then the following equations are solved back and forth iteratively [3]:

$$\mathrm{Q} = \sqrt{\frac{2\mathrm{D}[\mathrm{S} + \mathrm{pn}(\mathrm{R})]}{\mathrm{h}}},$$

$$1 - \mathrm{F}(\mathrm{R}) = \frac{\mathrm{Qh}}{\mathrm{ph}}.$$

F(R) is the cumulative distribution function of D. One approximation is setting Q value to EOQ value and solving it for R. n(R) is the expected number of shortages in a cycle:

$$E(\max(D - R, 0)) = \int_{R}^{\infty} (x - R) f(x) dx$$

(Q, R) values are found through continuous review policy. In periodic review systems (s, S) policy is used. When the inventory on hand is less than or equal to s, quantity up to S is ordered.

2.3 Capacity Planning

Demands may not be able to be satisfied each period because of some capacity restrictions. Even, lot size decisions may not be feasible because of the capacity constraints. Considering toy laptop example, D (here, net requirements) = (45, 60, 45, 60, 65, 44) we can assume that production capacities for each period Cap = (50, 50, 50, 50, 50, 50). The following constraints must be satisfied to maintain feasibility.

$$\sum_{i=1}^{j} Cap_i \geq \sum_{i=1}^{j} D_i; \quad j = 1, \ldots, 6$$

We can check if the problem is feasible.

First period constraint: $50 \geq 45$ is satisfied.

Second period constraint: $100 \leq 105$ is not satisfied. We don't need to check remaining constraints since the problem became infeasible. We cannot satisfy the demands of the first two periods with our available resources for the first two periods. However, all of the constraints were satisfied, then the next step would be to find an initial feasible solution. For example, as we increase the capacities for each period to 60, the problem becomes feasible. We can shift back demands to find initial solution. Fifth period net requirements is more than our capacity, so five units are shifted to third period. Then our new production/ordering schedule becomes D′ = (45, 60, 50, 60, 60, 44). Now we can improve the initial solution. There may be different approaches to improve the solution, we adopt one mentioned by Nahmias [3]. The idea is to shift production orders back as long as the holding costs is less than the set-up costs starting from the last period. In our example, we don't have enough capacity in previous periods to shift 44 back.

Production decisions may change based on the structure of the demand (deterministic vs. stochastic, stationary). Inventory review policies (periodic review vs. continuous review) may affect the production decisions as well.

Inventory policy decisions is based on the costs associated with holding inventory and set-up costs. Economic order quantity (EOQ) model is a simple approximation for a quantity decision based on total production cost. The simplest EOQ model assumes that demand rate is constant. Once the order of Q is given (when the inventory level hits zero), the inventory level is updated to Q immediately. In other words, the model assumes lead time zero. Shortage is not allowed. Each order has a fixed set-up cost of S, variable cost of c per unit, and a holding cost h per unit per inventory holding time is charged. Usually holding cost is expressed as a percentage of c. The objective is finding the Q level that will minimize the average production cost per period (usually a year). Each ordering cycle will have a cost of $S + cQ$. Assuming that cycle length is L, dividing the cost expression by L will give the cost per unit time. Q units are used by demand rate D. Hence, $L = Q/D$. The average inventory level per cycle is $Q/2$ since Q decreases linearly. Then, we compute average annual (periodical in general) cost (AAC) as:

$$\mathrm{AAC(Q)} = \frac{S + cQ}{L} + \frac{hQ}{2} = \frac{S + cQ}{Q/D} + \frac{hQ}{2} = \frac{SD}{Q} + Dc + \frac{hQ}{2}$$

Last three terms include average periodical set-up cost, purchase cost, and inventory cost. The cost function is convex function. Hence, the Q value based on the first derivative of the expression will be the global optimum. In other words, Q value that satisfies $\mathrm{AAC(Q)}' = 0$ is the optimal value denoted as Q^* known as EOQ. The EOQ formulation is:

$$Q^* = \sqrt{\frac{2SD}{h}}$$

For example, if the weekly demand for laptop toy is 500 units and set-up cost to initiate the order is $200, and a laptop has a variable cost of $5 per unit, assuming a holding cost of 10 % of variable cost per period, we can find the optimal order quantity:

$$Q^* = \sqrt{\frac{2 * 200 * 500}{0.5}} \cong 633$$

Here, set-up cost is relatively high compared to holding cost. It is reasonable to order in high quantities once every 9 days (663/500 translated to days, assuming 7 days a week). Since set-up cost are usually high in batch or mass production, this example also shows that to achieve just in time (JIT) production or eliminate inventory set-up time reductions (assuming set-up costs are proportional to set-up time) is a critical point. As JIT requires frequent orders of small batch sizes.

After decision of order or production quantities, transportation decisions should be made. The company may have a contract with third party carriers or may use its own trucks and transportation facilities to deliver products to customers. Especially, international firms need to consider modes of transportation, inbound and outbound logistics costs. Road, railway, waterway, air, and pipelines are common modes of transportation. Intermodal transportations are possible as well.

Road transportation is preferred inside a country. The main rule is to be able to carry as long and as much as possible to minimize the transportation cost. Monitoring this mode of transportation is easy. Perishable and non-perishable items may be carried. Some disadvantages are: there may be delays due to traffic, some regulations may be a restriction on driving routes, might be affected by weather conditions and subject to accidents that will lead to severe damages on products.

Railway transportation has a capacity and cost advantage compared to road transportation. Even, it is safer and more reliable. A disadvantage is that railways are limited worldwide and rail freight destinations may be far away from customer. Hence, delivery to customer needs to be handled after railway transportation.

Waterway is used to carry heavy and huge items. This mode of transportation is slow and may be cheap compared to road and railway. Disadvantages are long lead times, subject to bad weather influence, inter-country restrictions are available.

Table 2.8 Comparison of transportation modes

Mode	Intercity tonnage	Intercity ton-miles	Freight expense	Revenue
Road	3,745	1,051	402	9.1TL, 26.1LTL
Railway	1,972	1,421	35	2.4
Waterway	1,005	473	25	0.7
Air	16	14	23	56.3
Pipeline	1,142	628 (oil)	9	1.4

Air transportation is the fastest and the most expensive mode of transportation. Air transportation is due to flight schedule cancellations or changes and may have restriction on items to deliver.

Pipeline transportation is used for transferring gas, petroleum products, and sewage. The flow is slow, and investment cost is high. However, this mode is not affected by weather conditions and flow goes on continuously. Pneumatic tubes are used for example in hospitals to deliver documents, blood samples etc.

Chopra [2] gives the intercity weight (in millions of tons) and distance (in billions of ton-miles) capacities, freight expenses (in billions of dollars) and revenue (cents per ton-mile) in US shown in Table 2.8.

Of course transportation costs may affect facility location decisions. Review of some optimization problems regarding transportation is in Sect. 4.1.

Remarks

- Key supply chain management decisions include selection of new facility locations, manufacturing quantities, transportation, and information system related decisions.
- MRP is a push system that deals which resource planning in a hierarchical manner. Running MRP system relies of bill of materials and master production schedule. Demands are viewed as deterministic, varying by period.
- Different lot sizing policies exist. Integer programming formulation for the uncapacitated single item lot sizing problem gives the optimal solution.
- Heuristic approaches include Silver-Meal, unit cost, and part period heuristics.
- Lot sizing can be represented as a directed acyclic network. Dynamic programming may be employed to find the shortest path of the network that is the optimal lot sizing policy.
- Newsboy model is used in periodic review problems. It ignores set-up cost.
- (Q, R) policy requires continuous review. Once the inventory level hits R, Q quantity is ordered. In periodic review (s, S) policy $S–I$ is ordered if the inventory on hand (I) is less than or equal to s.
- Economic order quantity (EOQ) model assumes a constant demand rate. Shortage in fulfilling orders is not allowed.
- Different modes of transportation have benefits and disadvantages and they have an effect on supply chain success.

References

1. Brahimi N et al (2006) Single item lot sizing problems. Eur J Oper Res 168:1–16
2. Chopra S, Meindl P (2004) Supply chain management, 2nd edn. Pearson, Upper Saddle River
3. Nahmias S (2009) Production and operations analysis, 6th edn. McGraw Hill, New York

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