The Marketing/Manufacturing Interface: Strategic Issues

Uday S. Karmarkar

Center for Manufacturing and Operations Management
William E. Simon Graduate School of Business Administration
University of Rochester
Rochester, New York 14627

Milind M. Lele

SLC Consultants
33 N. Dearborn, Suite 2201
Chicago, IL 60602

Abstract

Most firms separate the marketing and manufacturing functions into distinct organizational groups without fully considering the interactions and conflicts between the two functions. These interactions can have very significant costs for the firm, if they are not recognized. We discuss situations in which strategy and policy in the two areas are not synchronized. They include issues such as capacity decisions, shift policy, and location in manufacturing; price-promotion policy, forecasting and market intelligence in marketing. These topics are discussed in the context of case examples which illustrate problems that can arise when interactions are not recognized.

Introduction

In most manufacturing firms, the marketing (advertising, pricing, sales and distribution) and manufacturing functions are organizationally separate. There are several underlying reasons for this separation. One has to do with the desire to achieve economies of scale with centralized manufacturing in a few locations, while marketing and sales by their very nature, are likely to be more concerned with the geographical distribution of customers. Another reason might be that manufacturing is typically associated with cost minimization, while marketing is concerned with revenue maximization. Certainly, it is true that rather different skills and different knowledge bases are required in the two areas, and the organizational forms, incentives and procedures are likely to be very different. At any rate, the end result is a functional separation, which despite the reasons adduced, may lead to certain systematic problems.

A typical approach to separation of the functions is to designate the manufacturing function as a cost center, required to produce the required output at minimum cost. Marketing, on the other hand, might be required to maximize revenue net of marketing and sales expenses. Marketing thus sets prices and advertising policy, the market determines the quantities demanded, and manufacturing produces the quantities demanded at minimum unit cost. On the face of it, this appears to be a reasonable decomposition of the goal of profit maximization. However, there are interactions between manufacturing and marketing that are not taken into account in such a decomposition, which result in conflicts between the functions due to inconsistent objectives or externalities imposed by one function on the other.

In the following, we focus on examples of such interactions. These examples are drawn from experience with several case studies including

- a manufacturer of laboratory and medical products, sold worldwide through distributors,
- a fire chemicals manufacturer with direct and catalog sales,
- a manufacturer of electronic equipment sold internationally, directly and through distributors,
- a consumer products company with dedicated wholesalers.

We first discuss the effect of annual promotional cycles on the demand that is placed on manufacturing. We then describe the effect of capacity and location decisions in manufacturing on responsiveness to marketing situations. Finally some aspects of forecasting and market intelligence on inventory costs are discussed.

The Promotional Roller-coaster

In many companies, price promotions are instituted on a cyclical basis every year. For example, promotional drives may be instituted on a quarterly basis, that have the result of driving up sales at the end of each quarter. In many cases, it appears that these promotions primarily have the effect of shifting demand from one week to another, to create seasonalities that are artificial. The effect on manufacturing is to create a seasonal demand pattern which leads to a varying load on capacity. One result is to create a need to hold seasonal inventory accumulations, which are built up in periods of low demand, and then drawn down in periods of high demand, while leaving production levels fairly constant. If the seasonal variations become large enough, there may even be reason to add capacity, which starts to be driven to some extent by the seasonal peaks. Alternatively, instead of adding hard (i.e. equipment) capacity, there may be a need to add labor capacity at peak demand levels, or at least to incur overtime.

The reasons for these promotions are varied. A simple one is that sales quotas are reviewed on a quarterly basis, and that as the end of the quarter is reached, any shortfall starts to become visible, leading to a push to make the sales. On occasion, the push may arise because of quarterly internal reporting requirements. One company division which manufactures testing equipment sold through distributors, is required to make quarterly reports to corporate headquarters. Due to the way in which profits for the division are computed, the cost-of-goods-sold (COGS) calculation looks more favorable if inventories are high and worse if they reduce. This tends to lead to an end of quarter push either to make sales targets or at least to build to inventory, so that the reports look good. Another firm which sells industrial products through distributors, has argued that promotions help the firm to capture distributor's dollars and shelf space by periodic (quarterly) promotions. This is certainly a plausible idea, but

the costs imposed by the policy on manufacturing and on inventory levels, may not always be apparent to the group setting promotion and price policy.

Figure 1 shows the actual demand pattern observed for one particular product line of the manufacturer of industrial equipment. There is a pronounced quarterly pattern of demand, with peaks occurring every three months starting in December, and culminating with September. The pattern is apparently largely due to promotional activity. One way to determine this is to look at the end demand at the distribution level for the products under consideration. In this case (and with the testing equipment manufacturer as well), the products had no intrinsic seasonality in their end demand patterns. Furthermore, the peaks in demand as seen by manufacturing, were highly correlated to the timing of promotions and price discounts. Figure 2 shows the production pattern for the product line, and the seasonal inventory accumulation, as determined by a fairly standard LP seasonal planning model. The production plan is actually nearly level, once allowance is made for the varying number of days per month. The only variation is due to shut-down and vacation periods for the plant in August, December and January. Note the quarterly inventory accumulation pattern which is just about counter cyclical to the demand pattern. We conducted an analysis of what would happen to inventory accumulations if demand was level. The resulting inventory pattern is shown in Figure 3, in which the inventories are only held to cover the shut down and vacation periods. The difference in inventories and holding costs from the previous case, is obviously substantial.

In this particular case, it was a strongly held view that the promotional policy was an important tool in the competition for distribution assets. However, note that it is enough to obtain a commitment by the distributor to purchase a large enough quantity, so as to capture market share. It is not really necessary to deliver the purchased material immediately; in fact it only occupies the distributor's space, and requires more storage capacity. One possibility is to get a commitment from the distributor to purchase, and then to commit to delivery of the material only as it is needed (JIT!). Seasonality of demand at the plant level is thus effectively removed. This will also reduce the distributor's inventories and space requirements, and decrease the need for advance forecasting of demand on the distributor's part. The match between production and demand can be closer,

Figure 1: Seasonal demand pattern for an industrial product with quarterly peaks induced by promotion activity.

Figure 2: Aggregate production plan and seasonal inventory accumulation
to meet the seasonal demand pattern with limited production capacity.

Figure 3: Production plan and inventory accumulation under deseasonalized (level) demand conditions.

with less need for safety stocks. At the same time the purpose of the promotional activity will be served.

In the case of the testing equipment manufacturing division with quarterly reporting requirements, it should be noted that the COGS calculation requires continually increasing inventory levels to be manipulated. Obviously, with level demand, this cannot be kept up indefinitely. In particular, turn measures start to deteriorate, even though quarterly "profitability" may look good due to a poor measurement scheme. If it is recognized that increased inventory level is not an asset, and if the COGS calculation is changed (or the effect on the cost of inventory holding assessed correctly) the incentive for the sales push would largely go away.

Manufacturing Capacity and Demand Surges

The cost minimization role given to manufacturing leads to capacity decisions aimed at maximum utilization of capacity. Unit costs are typically calculated as total volume of production divided by the total costs of equipment (amortization) and operation. Naturally, the higher the capacity utilization, the lower the unit cost of production. Consequently, there is a tendency to have very little excess capacity at any time. On the one hand this implies level production, so that seasonal inventory accumulation is required if demand is seasonal. In addition, if an unpredictable demand surge occurs, the time taken to produce the necessary material can be very long, because there is no volume flexibility left in the system.

The industrial products company mentioned earlier, experienced significant demand surges due to large military and government contracts that it would sometimes win, often from countries in Europe or South Asia. When such a contract was won, the resulting surge would clean out inventories of certain products. There appear to be only two ways of handling these surges. One is to hold buffer inventories, and the other is to hold excess capacity. Holding inventories is not a viable policy, because the inventories have to be built up before the surge occurs. If the contract is not won, the inventories are in excess and production is left "holding the bag". Furthermore, the exact composition of the inventory required is not always easy to predict. As a result, the protective

inventory held as a substitute for capacity will have to be larger than the capacity cushion that is required. In particular, the tighter the capacity constraint, the longer the lead time to build up inventories, and the larger the safety stock component due to uncertainty in demand. In many cases, the lead time available for building safety buffers is limited by bidding and contracting cycle. Finally, an effective inventory policy often requires more cooperation between marketing and production than is usually forthcoming. Furthermore, such surge inventories should logically be under the ownership of marketing and sales, since they are caused by bid activity. However, manufacturing is often asked to hold the inventories.

One way to show the time taken to work off the effects of a demand surge is to consider how long it would take to produce the order, if advance notice of the surge was available. Figure 4 shows the effect of a demand surge equal to about 10% of annual demand, in the month of June. It has been assumed that demand does not have promotional seasonality but that shut-down and vacations periods are in effect. An LP model is used to determine the production plan. It can be seen that it takes about six months to prepare for the surge. This is a conservative analysis; in the presence of seasonality and if the surge occurred with little warning, the situation would be worse. Incidentally, we found managers to be surprised that the surge took more than a month's time to compensate for by preparation or reaction. There appeared to be the fallacious impression that a 10% surge should take 10% of the year to fix. However, the real issue is the surge volume relative to excess capacity, and not to total demand. Furthermore, if the surge coincides with the approach of a seasonal peak, capacity may be even tighter than on average.

The development of a suitable capacity and inventory plan to handle surges is quite complex. It depends upon many factors including the timing of the bid cycle, the information available about the contract requirements, the frequency of occurrence of such opportunities, the probability of winning the contract, and the delivery requirements of the contract. Such uncertainties are likely to exist with any situation where demand surges occur. However, the LP model can be used as a tool to analyze the effect of a surge. In particular, the time taken to work off a surge can be used to make a rough estimate of the inventory level needed to buffer against the surge (it is actually very conservative). The costs of such

Figure 4: Inventory accumulation pattern for level demand with a 10% demand surge in June.

inventory buffers can be compared with the cost of having excess capacity available. A complication here is that the excess capacity can also be used to reduce seasonal stocks at times when there are no surges, and the two issues have to be considered together. Our experience is that there is often a very strong argument to be made to deliberately hold excess capacity as a strategic buffer for markets with uncertain, seasonal and surge demands.

Manufacturing Capacity and Lead Times

A direct effect of high capacity utilization for regular operations, is that lead times in manufacturing increase. These increased lead times mean that larger safety stocks are required in finished inventory to protect against the longer replenishment times. This effect is quite distinct from the seasonal inventory and surge response issues dealt with above, although there is an underlying similarity.

The mechanism behind the increased manufacturing lead times is as follows: as capacity utilization is increased, there is less time available for setups and changeovers from product to product. As a result, run lengths (batch sizes) have to be larger. Consequently, the production cycle is increased; i.e. the time between successive runs of a product increases. This cycle time is, roughly speaking, proportional to the lead time for a product, since it determines the waiting time for an order to be filled by the next run of the product. As this lead time increases, so does the safety stock that has to be held, since that depends on the standard deviation of product demand over the lead time. An early discussion of this problem can be found in Magee (1956).

Figure 5 shows cycle time in days for a particular synchronous production facility, as a function of the fraction of excess capacity. In other words, 0.1 on the x-axis, indicates 10% excess production capacity in terms of time availability. Note that the cycle time rises sharply as utilization is driven to 100% and excess capacity to zero. The model used to determine the cycle time is described in the appendix. This is actually a very good situation in terms of the lead time implications; the situation is much worse for asynchronous facilities such as dynamic batch shops, where there are severe congestion and queueing problems. It can be shown that in the latter case, the effect of high capacity utilization can be

Figure 5: Cycle time (in days) as a function of excess capacity $(1-u)$.

worse by an order of magnitude (for example, see Karmarkar, Kekre, Kekre and Freeman, 1985; Karmarkar, 1987).

The effect of capacity utilization on safety stocks, cycle stocks and on setup costs (if present) is shown in Figure 6 for a particular case. Note that the safety stocks dominate cycle stocks, which in our experience is often if not always the case. In fact this calculation assumes that there is just one finished goods stocking location; the situation would be worse for stock levels in an extended multiechelon distribution system. Furthermore, the safety stock costs are larger as service levels are increased. Figure 7 shows the relationship between safety stock costs and service levels for different capacity utilization levels.

In many cases the inventory implications of capacity utilization are so significant, that they can justify the deliberate addition of excess capacity. Note that the excess capacity has to be considered in terms of its impact on lead times. In the case under consideration, excess capacity already existed in terms of actual equipment. The capacity addition considered was in terms of overtime and additional shifts on certain facilities. Figure 8 shows the effect of adding overtime and shift capacity on inventory and setup costs. The stepped curve reflects that overtime can only be tolerated upto a certain average per period, beyond which an extra shift has to be added. For the particular numbers that are being considered the total cost curve reaches its minimum at the point where two shifts are added and overtime is used to the maximum allowable level on available equipment. At this point, there is about 13% excess capacity deliberately being created, to permit shorter production cycles.

Manufacturing Presence

The economics of manufacturing, considered in isolation, often favor large centralized plants exploiting economies of scale. Again, this is a direct consequence of performance measures based on minimizing unit cost. It has begun to be recognized that that are diseconomies of scale, even at the plant level itself, that are often overlooked. Even more significant are some of the diseconomies of centralization that arise from the interactions with distribution, marketing and sales. One of these has to do with manufacturing "presence".

Figure 6: Inventory holding costs (safety and cycle stocks) and setup costs as a function of excess capacity $(1-u)$.

Figure 7: Safety stock costs as a function of service level
for different levels of capacity utilization.

Figure 8: Inventory costs (cycle and safety stock holding) and capacity costs (overtime and added shifts) relative to excess capacity $(1-u)$.

Plant location is often the result of historical accident; at least, it is the outcome of decisions made under circumstances that no longer exist. Even when the decision is current, market factors are only weakly reflected in the tradeoffs made. Typically, transportation costs are the only factor considered, and given economies of scale arguments, they can only cause small shifts in location of the one or two plants.

There is a set of issues that becomes particularly important in the context of global markets. In these markets, it is often the case that service tradeoffs and product design requirements are quite different from the "home" market in which the plant is situated. For example, in the case of a Far East division of the industrial equipment company, the service requirements for fill rate from inventory were simply stated to us as being "100%". The concept of a tradeoff between inventory level and service level was not seen as being acceptable, and the inventory to provide 100% service was not perceived as being infinite or even too costly. As one of the managers commented "If a distributor does not fill an order to a major customer, he would have to go with his senior managers as a group to the customer, and standing in a row before his counterpart, apologize profusely for the missed order". This might be hyperbole; but there is no doubt that the service requirements were much more stringent than the home market. In the least, missing on a shipment was likely to mean a customer permanently lost. Unfortunately, this issue was simply not perceived with enough seriousness at the central manufacturing plant, which then appeared to be indifferent to the division's concerns. In many cases, if there was a shortage of available production, the tendency was for it to be allocated to orders from the home market rather than to divisions abroad. This was a natural consequence of the home marketing divisions having more "clout" with the plant, partly due to their geographical (and cultural) proximity. The idea of establishing a "Far East Desk" at the plant was seriously considered as a way to circumvent the communication gap.

Similar issues arose with respect to product design. In Europe, minor product improvements made by local competitors were not being matched, since to the the plant they simply meant added manufacturing costs, with no visible benefits. Products designed to U. S. or Western ergonomic standards, did not work well in Eastern markets. For example, certain kinds of equipment proved to be

difficult to operate with a smaller sized hand. Again the response from manufacturing was listless.

These problems are directly traceable first to communication and transactions costs. The second factor is that the objectives for manufacturing, do not include any incentives for responding to foreign marketing and sales groups. The organizational route to exerting pressure on manufacturing runs from the foreign marketing division up to the division leadership, across to the corresponding level of the home division, and down to the manufacturing function. This is not a smooth communication channel, and is unlikely to be used to expedite a given shipment or to reallocate inventories. Since organizational form is so heavily driven by geography, there is no obvious reporting or incentive mechanism for inducing a high level of responsibility towards the off-shore marketing groups. Although these concerns are intangible and hard to quantify, they provide real reasons for considering a more decentralized manufacturing strategy. In many cases, it is not necessary to have every product manufactured in every market area. Just the presence of some manufacturing capabilities and a local branch of the manufacturing function improves communication and provides more organizational leverage. It is in fact useful to route communication from manufacturing function to manufacturing function across geographic divisions.

An intangible benefit to locating manufacturing closer to customers is that the firm has more credibility. This is likely to be much more important in the case of sales to OEM's and in situations where the design of the product is of concern to the user. However, it may also be true of consumer goods. A rather subtle effect of manufacturing "presence" is that the firm is taken more seriously because the investment in facilities implies commitment to the market. In a sense, the commitment to facilities is viewed as a bonding mechanism. Incidentally, this is true not only for customers, but also for the firm itself; it acts as an internal signal that the firm is serious about competing in the market.

While many of these effects are hard to quantify, they can have substantial implications for marketing success. When the tangible tradeoffs are close, or are a small proportion of the total costs, these intangible issues can become the decisive ones.

Beach-head Inventories and Normal Inventories

When a new product is introduced, or new markets penetrated, normal inventory control methods are inappropriate. First, the usual forecasting methods used for stable conditions, are inapplicable. Second, the tradeoff between service and inventory costs must be slanted heavily in favor of service, since the opportunity costs of not meeting demand in a new market are likely to be very high. Notice that both these issues are such that manufacturing can have no control over them; indeed, it is unrealistic to require manufacturing to make the necessary assessments. Yet it is very common to find that in practice, the responsibility for setting and maintaining finished product inventory levels falls on manufacturing practically by default.

In addition, the demand pattern with new products or new geographic markets, is likely to be much more variable even past the early startup stage. This demand pattern, or more accurately its forecast, cannot be controlled or improved by manufacturing. Furthermore, the variability inherent in the demand is likely to create uncertainties in production quantities.

With such new products and markets, inventories play a strategic role in the process of establishing a beach-head. The information necessary to set these inventories is with the marketing and sales function, and the benefits also flow in large part to that function. The responsibility for determining these levels, and the ownership of the material should both be placed with the marketing/sales function. The role of manufacturing is to provide the rapid response necessary to support the mission. However, the performance that is expected has to be based on what is possible. For example, excess capacity may be the best way to provide good response to new market needs. If so, manufacturing cannot be penalized because their unit production cost measure of performance is then calculated to include the cost of strategic capacity. Alternatively, if inventories are to be accumulated, then advance planning is required to build these up. As the surge example earlier showed, the time to build up adequate inventories with highly utilized facilities, can be very long.

Even under normal circumstances, the amount of finished goods inventory held depends partly on the lead time in manufacturing and partly on forecast accuracy. Specifically, service inventories are proportional to the standard deviation of demand forecast over lead time, as was discussed earlier in the section on capacity and lead times. One scheme that assigns responsibilities for these interactions in a reasonable way, is to have the marketing/sales function responsible for inventories, while manufacturing is responsible for lead times. Groenevelt and Karmarkar (1987) discuss the application of such a scheme in a pull system.

Forecasts, Plans and Market Intelligence

For any product line that experiences seasonal demands, stochastic demand variations, mix changes and volume changes due to competitive action, forecasting is a critical input for production and sales activity management. It is typically the case that the primary responsibility for forecasting demands falls on the sales and marketing function. This is as it should be, since it represents the location of the best information about the marketplace. Furthermore, sales and promotion activity can directly affect demand. It is very difficult for manufacturing to develop any real sense of the marketplace since the function is typically buffered from the market, and has no direct contact with customers. Marketing and sales therefore, typically provide forecasts for long term planning as well as short term inventory and production management.

A very common problem with this arrangement arises first from a confusion between forecasts and plans, and secondly from the very different incentives associated with forecasts in different functions. The former issue is relatively straightforward in the manufacturing function: care should be taken to distinguish between the best expectation or forecast of demand and the level of production that is planned to meet this demand. The issue is less clear in sales and marketing. The point is that the actual demand that is seen is very heavily dependent on pricing, promotions, and sales call activity. It is very difficult to distinguish an underlying market demand from the demand that will be seen as a result of planned sales activity. The earlier discussion on artificial demand seasonality engendered by promotion policies, emphasizes this point.

The second issue of incentives is related to the confusion between plans and forecasts in sales and marketing. Sales managers asked to make "forecasts" of sales in their regions, have an incentive to present an aggressive and optimistic sales plan. Furthermore, the most important numbers in this plan are aggregate sales dollar figures, and there is less emphasis on the specific mix that will be seen. Ex post too, if the observed mix does not match "forecasts" there are no significant repercussions in sales, as long as overall revenue and contribution expectations are realized. Obviously, the situation is very different in production and inventory management. Here, inventories are held at the item or SKU level; if the actual mix seen varies from the forecast mix, the result is simultaneously high inventory levels and poor service. Similarly in production scheduling and purchasing, capacity choices, production schedules and purchasing activity are very dependent on the actual mix to be produced.

As a result of these differences, it is not atypical to have the production function second-guess forecasts obtained from marketing. Unfortunately, this does not always work well simply because of the lack of market intelligence in the production function. If a product or item has relatively stable demand patterns, then using conventional forecasting techniques based on booked orders can work. However, if demand is significantly dependent on competitive action or is influenced strongly by sales and marketing activity, then automated forecasting at the inventory and production level can be a futile and misleading exercise.

The issue of forecasts is closely related to that of inventory ownership, discussed at the end of the preceding section. In the case of forecasts, the quality of forecasts affects inventory levels directly. One way to give the sales function incentives to make accurate forecasts is to let them decide on the level of finished inventories to be maintained — accumulations as well as buffers — and to then give them ownership of the inventories. The responsibility of production then, is to keep inventories at the desired level. In some firms the desired inventory levels are set by agreement in the course of an annual planning exercise. Such a planning discussion also allows commitments to aggregate capacity to be made by production on the basis of aggregate sales forecasts. This scheme is used by a large manufacturer of electronic equipment. Implementation of the planning agreements is done through a two-tier production control system in which a

"push" scheme controls the planned inventories, while a "pull" scheme allows rapid reaction to short term changes in volume (limited), and mix.

Summary

The conventional separation between marketing/sales and manufacturing functions has been to regard manufacturing as a supplier to sales. Manufacturing responsibility is seen as supplying products so as to minimize costs, while marketing/sales functions carry the responsibility for revenue generation, including pricing and promotion decisions. This conventional approach can be inadequate when rapidly changing market conditions or increased competition require a finer degree of coordination across the interface between the functions. In this paper we have described some strategic issues related to this interface. In many of these cases, the specific problems raised can be solved on a case basis. However, a basic and interesting question remains unanswered: is there a general scheme for co-ordinating these functions that will remove these issues? It may be that the only answer is more direct co-ordination and communication across the interface despite the increased costs.

Appendix A: Planning and Surge Evaluation Model

The planning model used to evaluate the effect of promotion policy and surges is formulated as a linear program (e.g. Hanssman and Hess, 1960. See Hax, 1978 or Saad, 1982 for reviews of such models). For illustration purposes, all products are aggregated into a single product. This is possible since the products are all similar, and have similar demand patterns and costs. Time periods are indexed by t , and the model minimizes variable production costs and inventory holding costs. Define:

X_t : Production in period t (units)

I_t : Inventory at end of period t

c_t : Variable cost of production (\$/unit)

h_t : Cost of holding inventory for one period (\$/unit)

P_t : Production capacity in period t (units)

D_t : Demand in period t (units)

The model is written as

$$\text{Min } \sum_t c_t X_t + \sum_t h_t I_t$$

$$\text{s.t. } I_{(t-1)} + X_t - I_t = D_t, \text{ each } t = 1, \dots, T$$

$$X_t \leq P_t, \text{ each } t = 1, \dots, T$$

$$X_t, I_t \geq 0, \text{ each } t = 1, \dots, T$$

In addition, the starting and ending inventory levels may either be given, or be set equal to simulate a repeating cycle. The production level in each period may not be equal due to differences in the number of days in each period, and due to holidays and plant close-downs. Similarly, the demand, though level, may also vary due to these reasons. It is straightforward to include extensions such as multiple products, lost sales or backorders, overtime and extra shifts.

In order to evaluate the effect of promotion policy, the model is run with the demand based on actual historical pattern, or the forecast demand pattern using a seasonal forecasting model. This is then compared with the level demand case. The surge evaluation is done using level demand, with the extra demand added in the appropriate period.

Appendix B: Excess Capacity, Lead time and Inventory Model

The relation between capacity and lead time is modelled using a conventional "rotation cycle" model for batching. This model is appropriate when the products (or families) produced in the facility, are all produced in each cycle because of similar demand levels and similar costs. More generally, products may be produced with different frequencies (e.g. see Elmaghraby, 1988, or Dobson, 1989). Let i index products, and define

T : Length of a production cycle (time)

s_i : Setup time for the i 'th product (time)

D_i : Demand rate for the i 'th product (units/time)

P_i : Production rate for the i 'th product (units/time)

As capacity is increased by adding machines, overtime or shifts, the production rate in terms of units produced per week, month or year, increases. It is well known that the cycle time T must satisfy

$$T \geq \sum_i s_i / (1 - \sum_i (D_i / P_i))$$

If there are substantial setup costs, then the cycle time may be larger than the right hand side of this inequality, and this also implies that there will be idle time during the cycle. In the latter case, if possible, capacity may be decreased to eliminate the idle time. In actual practice, with synchronous production, no idle time is seen, and the relation holds as an equality. Note that the denominator on the right hand side is precisely excess capacity.

The cycle time T may at a first approximation be taken as manufacturing lead time. When a production batch of a particular item is completed, there is an interval of approximately T , till production is undertaken again. Hence, the safety stock maintained in the system has to cover some fractile of demand over the cycle time T . Of course, this model can be refined, but for illustrative purposes, the simple approximation suffices. The cycle stock resulting from this model is simply $D_i T / 2$ for the i 'th product. The safety stock may be approximated by $k T^\beta \sigma_i$, where k depends on the service level to be maintained, β is a factor between $1/2$ and 1 depending on the degree of correlation in the demand, and σ_i is the standard deviation of demand per period for the i 'th product.

REFERENCES

- Dobson, G. (1987). "The Economic Lot-Scheduling Problem: Achieving Feasibility Using Time-Varying Lot Sizes". *Operations Research* **35**, 764-771.
- Elmaghraby, S. E. (1978). "The Economic Lot Scheduling Problem (ELSP): Review and Extensions". *Management Science* **24**, 587-598.
- Groenevelt, H. and U. S. Karmarkar (1988). "A Dynamic Kanban System Case Study". *Production and Inventory Management Journal* **29**, 46-50.
- Hanssman, F. and F. W. Hess (1960). "A LP Approach to Production and Employment Scheduling". *Management Technology* **1**, 46-51.
- Hax, A. C. (1978). "Aggregate Production Planning". Chapter 5, Vol. 2. *Handbook of Operation Research* (ed. J. Moder and S. E. Elmaghraby), Van Nostrand, Reinhold.
- Karmarkar, U. S. (1987). "Lot Sizes, Lead Times and In-Process Inventories". *Management Science* **33**, 409-418.
- Karmarkar, U. S., S. Kekre, S. Kekre and S. Freeman (1985). "Lotsizing and Lead Time Performance in a Manufacturing Cell". *Interfaces* **15**, 1-9.
- Magee, J. F. (1956). "Guides to Inventory Policy. Part II". *Harvard Business Review* **34**, 103-116.
- Saad, G. H. (1982). "An Overview of Production Planning Models: Structural Classification and Empirical Assessment". *Int. J. of Prod. Res.* **20**:1, 105-114.