CHAPTER 2

Sales Fluctuations

This workshop investigates the interaction between sales and capacity expansion policies in a growing market. The model is adapted from one in Richmond, Peterson, and Charyk (1994, Chapter 7). Background is presented in the next section, and then a simulation model for this situation is investigated.

2.1 Market Growth and Capacity Expansion

New products or services can experience periods of rapid sales growth alternating with periods of level or declining sales. From a system dynamics perspective, this pattern of behavior indicates that there is a positive feedback loop (which leads to exponential growth), and also a negative feedback loop with a delay (which leads to oscillating behavior). The superposition of the oscillating pattern on the exponential growth results in a pattern of overall growth, but with periods of level or even declining sales.

In this chapter, we investigate a possible explanation for this behavior in a market where delivery delays for the product or service have an important impact on sales. Such a situation can exist in a number of different types of markets. For example, if competitive pressures result in virtually identical prices and if in addition quality differences are small, then customers are likely to make decisions based on delivery time. Such a situation might exist for such services as retail banking or fast food. It might also exist for such consumer products as televisions, audio equipment or cameras.

A similar situation regarding the impact of delivery delays might exist in markets where a product is sold to original equipment manufacturers (OEMs). If the product is a relatively small part of the cost for the OEM s product, and if the market for the OEM s product is rapidly growing, then delivery time might play an important role in determining sales. An example of this is sales by a component manufacturer to personal computer manufacturers.

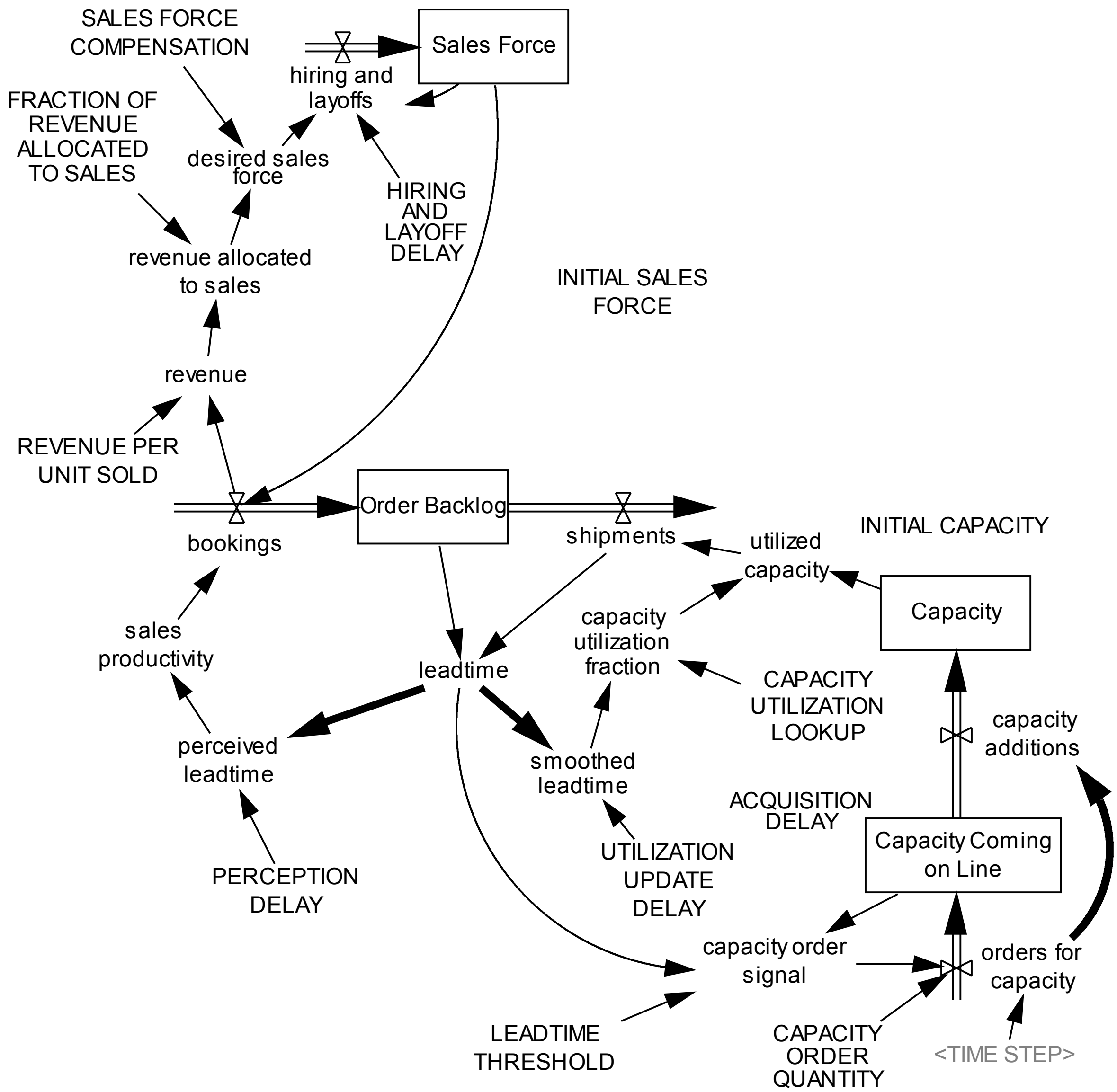

Figure 2.1 *Market growth and capacity expansion*

2.2 Simulation Model

The stock and flow diagram for a simulation model that is consistent with the situation described above is shown in Figure 2.1, and the Vensim equations for the model are given following this paragraph. In these equations, time is in units of months.

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(01) ACQUISITION DELAY = 6
(02) bookings = Sales Force * sales productivity
(03) Capacity = INTEG(capacity additions, INITIAL CAPACITY)
(04) capacity additions
          = DELAY FIXED(orders for capacity, ACQUISITION DELAY, 0)
(05) Capacity Coming on Line
          = INTEG(+orders for capacity - capacity additions, 0)
(06) CAPACITY ORDER QUANTITY = 20
(07) capacity order signal
          =  IF THEN ELSE(leadtime > LEADTIME THRESHOLD
                          :AND: Capacity Coming on Line = 0, 1, 0)
(08) capacity utilization fraction
          = CAPACITY UTILIZATION LOOKUP(smoothed leadtime)
(09) CAPACITY UTILIZATION LOOKUP  ([(0,0)-(10,10)],(0,0),(1,0.63),
          (2,0.75),(3,0.83),(4,0.9),(5,0.945),(6,0.99),(7,0.99),
          (8,0.99),(9,0.99),(10,0.99) )
(10) desired sales force
          = revenue allocated to sales / SALES FORCE COMPENSATION
(11) FINAL TIME  = 72
(12) FRACTION OF REVENUE ALLOCATED TO SALES = 0.4
(13) HIRING AND LAYOFF DELAY = 3
(14) hiring and layoffs
          = (desired sales force - Sales Force) / HIRING AND LAYOFF DELAY
(15) INITIAL CAPACITY = 20
(16) INITIAL SALES FORCE = 4
(17) INITIAL TIME  = 0
(18) leadtime = Order Backlog / shipments
(19) LEADTIME THRESHOLD = 5.5
(20) Order Backlog
          = INTEG(bookings - shipments, 5 * INITIAL SALES FORCE)
(21) orders for capacity
          = capacity order signal * CAPACITY ORDER QUANTITY / TIME STEP
(22) perceived leadtime = SMOOTH(leadtime, PERCEPTION DELAY)
(23) PERCEPTION DELAY = 2
(24) revenue = bookings * REVENUE PER UNIT SOLD
(25) revenue allocated to sales
          = revenue * FRACTION OF REVENUE ALLOCATED TO SALES
(26) REVENUE PER UNIT SOLD = 15
(27) Sales Force = INTEG(hiring and layoffs, INITIAL SALES FORCE)
(28) SALES FORCE COMPENSATION = 25
(29) sales productivity = 5 - 0.25 * (perceived leadtime - 2)
(30) SAVEPER  = TIME STEP
(31) shipments = utilized capacity
(32) smoothed leadtime
          = SMOOTHI(leadtime, UTILIZATION UPDATE DELAY, 1.4)
(33) TIME STEP  = 0.25
(34) UTILIZATION UPDATE DELAY = 1
(35) utilized capacity = Capacity  * capacity utilization fraction
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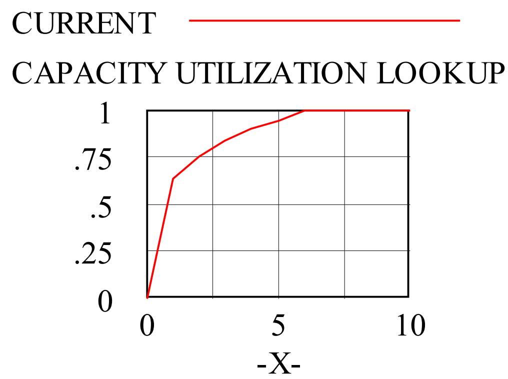


Figure 2.2 *Capacity utilization fraction as a function of smoothed leadtime*

2.3 Discussion of Model

The model shown in Figure 2.1 includes three sectors. Toward the top-left of the diagram is the sales sector. This shows that the Sales Force level is adjusted based on revenue, with a fixed FRACTION OF REVENUE ALLOCATED TO SALES used to set the desired sale force. The sales sector ties to the production sector, which is shown in the center-left of Figure 2.1, through bookings. The bookings flow is impacted by the level of Sales Force, and bookings in turn impacts revenue, which impacts the level of Sales Force as shown in the diagram.

The flow of bookings is impacted by both the level of Sales Force and the perceived leadtime for the customers. Equations 2 and 29 of the model show how the perceived leadtime impacts bookings. As these equations show, for higher levels of perceived leadtime, the sales productivity for the Sales Force decreases, and hence the bookings for a particular level of Sales Force also decreases.

Utilization of available capacity is also governed by leadtime, with greater leadtimes resulting in a higher fraction of the capacity being utilized. The specific relationship is governed by the capacity utilization fraction, which is shown in equations 8, 9, and 32. As shown by equation 32, there is a delay in responding to changes in leadtime. Equation 9 shows the relationship between the delayed (smoothed) leadtime and the capacity utilization fraction, and this relationship is graphed in Figure 2.2.

The third sector of the model, capacity acquisition, is shown in the lower right corner of Figure 2.1. A lengthening leadtime triggers a capacity order signal, as shown in equation 7. When capacity order signal is equal to one (1), an order is placed for new capacity. When it is equal to zero (0), no order is placed.

In this model, capacity is added in increments of CAPACITY ORDER QUANTITY, and it takes a time ACQUISITION DELAY to actually add the new capacity. (In some situations, the new capacity might be a manufacturing plant that needs to be constructed, while in others it might be acquired by purchase or by hiring new personnel.)

The method for including the addition of capacity in discrete increments within the simulation model is shown in equation 21. Understanding this equation requires that you understand how the Euler integration procedure works. With this procedure, new values are calculated for each variable in a simulation model at intervals of TIME STEP, and it is assumed that each variable retains the same value throughout a particular time interval of length TIME STEP.

With this assumption, the integration that must be carried out to calculate the change to a stock variable from inflows and outflows is done by multiplying the net value of the flows into and out of the stock by TIME STEP, and adding the result to the current value of the stock variable. That is, the flows are assumed to be constant over the interval of length TIME STEP so that the integration reduces to finding the area of a rectangle. Of course, this area is simply the height (which is the net value of the flow variables into the stock) multiplied by the width (which is TIME STEP).

Using this integration procedure, it is possible to add a pulse of flow to a stock all at once by taking the desired quantity to be added and dividing it by TIME STEP. When the result is subjected to the approximate integration procedure discussed in the preceding paragraph, the result will be to make an abrupt change in the level of the stock within a single time interval.

This procedure is used in equation 21 to set orders for capacity based on the capacity order signal. **Important:** Note that this procedure only works if the Euler integration procedure is used. It will lead to an error message in Vensim if a Runge-Kutta integration procedure is used, and the results that are calculated will be incorrect.

Note from equation 7 that once there is a positive level for Capacity Coming on Line no more capacity is ordered until the ordered capacity is actually acquired.

Vensim is able to determine the initial values for most of the variables in the model once the initial values are set for the stock variables. However, it is not possible to determine the initial values for the following variables: shipments, leadtime, smoothed leadtime, capacity utilization fraction, and utilized capacity. This is because these variables form a closed loop that does not include any explicit stocks, and hence Vensim would have to solve a set of simultaneous equations to determine their initial values. Vensim (along with other system dynamics simulation packages) does not include the capability to do this.

The solution to this problem is to use the SMOOTHI function, as shown in equation 32 for smoothed leadtime. With this function, you can specify an initial numerical value for the output of a SMOOTH function. In equation 32, an initial value of 1.4 is specified for smoothed leadtime. To set this initial value, different initial values were tried until the curves for the variables in the closed loop including shipments, leadtime, smoothed leadtime, capacity utilization fraction, and utilized capacity did not show any sudden jumps immediately after the start of the simulation run. This indicates that the initial value of 1.4 for smoothed leadtime leads to a self-consistent set of initial values for all of the variables in the closed loop. (If these initial values were not self-consistent, then they would immediately shift after the beginning of the simulation run to move toward self-consistency.)

2.4 Simulation Output

This section discusses the simulation model output from the perspective of different parts of the organization. Figure 2.3 shows how things appear from the perspective of sales/marketing. Figure 2.3a shows that revenue and bookings display the growth with oscillations behavior discussed above. While this behavior is evident from the graphs, it may not be so easy to see what is going on out there in the trenches. The graphs cover a time period of 72 months, or six years. Both the growth and downturn phases cover periods of several months. The fact that there is a long term pattern may not be evident to the sales personnel. How many of the personnel who see the start of the second downturn were even selling this product or service during the last downturn 18 months earlier? Furthermore, in the real world there will be random fluctuations in sales and it may take a while to detect that a downturn has actually started.

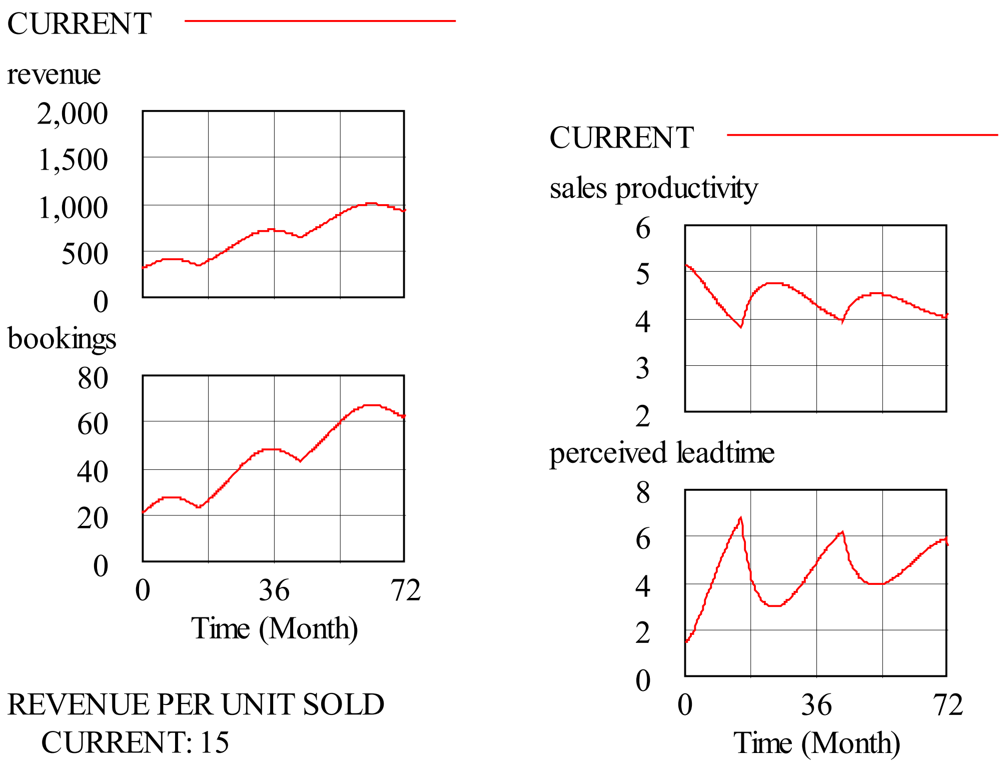
It is natural to seek explanations once it becomes evident that a downturn has occurred, and Figure 2.3b shows an immediate suspect sales productivity has declined. From this simulation model, we can see that sales productivity tracks inversely with perceived leadtime, and thus it makes sense to examine the role of leadtime in influencing sales. However, out in a realistic sales setting it may not even be clear that leadtime has increased. This product or service may only be one of many that sales personnel are attempting to move, and the sales personnel may not have all that good of an understanding of what influences sales for this particular product or service. Even if the field sales representatives understand the impact of leadtime, their managers may not. After all, those managers may have been in the field selling this product during the growth phase (before they were promoted to desk jobs). Thus, they may find it difficult to understand why the current field representatives can t sell the product or service.

An obvious solution is to fire the current sales representatives and get people who *can* sell the product. And, in fact, given the time delays in making such decisions, there is a good chance that the new representatives will be hired at just about the time that things bottom out and start up again. Thus, the facts will confirm to the sales managers that they were right in their decision to change personnel. However, we can see from other simulation output that they have not interpreted the situation correctly.

Production and Capacity Addition

Figure 2.4 shows the situation from the perspective of production and capacity acquisition. Figure 2.4a shows the oscillating behavior in leadtime and Order Backlog that you probably expect to see since you already know from Figure 2.3 that perceived leadtime is oscillating. Figure 2.4b provides an immediate explanation for the behavior. This shows that when new capacity comes on line, shipments immediately jump, and hence leadtime and Order Backlog both drop.

We know from the discussion above that the fluctuation in leadtime is the immediate cause of the revenue fluctuations, but it may not be apparent to the production managers that this fluctuation is even a problem. They know that



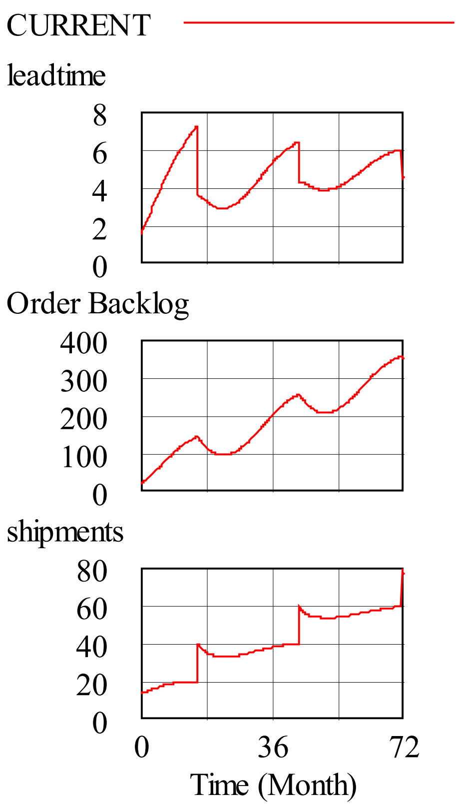
a. Revenue and its cause

b. Sales productivity and its cause

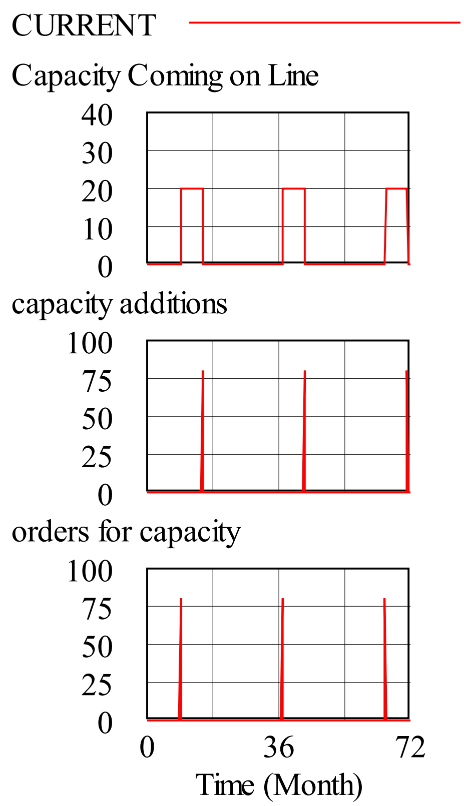
Figure 2.3 *Sales/marketing model output*

capacity comes on line in discrete chunks, and therefore they expect leadtime to fluctuate. This is the normal course of events, and thus nothing to worry about. It may be true that the sales force is always complaining about leadtime, but they just don t understand the realities of production!

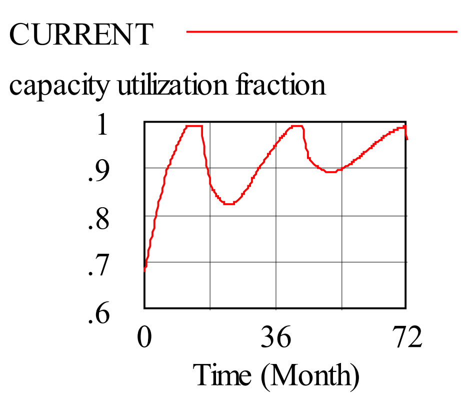
From the perspective of the financial staff who may have to approve additions to capacity, the situation may also not look like a capacity problem. Figure 2.4c shows the capacity utilization fraction. While it is true that this occasionally rises to near full utilization, this only happens every 18 months or so, and it only happens for a relatively short period of time. There are much longer periods of time when capacity utilization is substantially lower. The revenue fluctuations are a problem, but it may be hard to see that they are impacted by Capacity. In contrast, the cost of adding capacity (which is not considered in this model) is immediate and probably substantial. Thus, it is difficult to justify adding capacity any faster than it is currently done.



a. Leadtime and its causes



b. Capacity coming on line and its causes



c. Capacity utilization fraction

Figure 2.4 *Production and capacity addition model output*

2.5 Improving Performance: Taking a Systems View

This simulation model shows the critical role that interactions among different parts of a business can play in its success. The specific issue investigated here the impact of capacity acquisition policies on sales success is important in its own right, and it is also important as an illustration of the difficulties in achieving a systems view of performance problems. As discussed above, it is easy in this situation for corporate management to blame the sales staff for the declines in bookings, and it is easy for sales management to blame incompetent personnel or external events.

However, the model presented above shows that the observed pattern of bookings can be explained by the internal policies of the organization, and that this explanation does not require consideration of either external events or incompetent sales personnel. How do we know this is true? It is because the model does not include any change in effectiveness of the Sales Force over the time period considered or any external events, and yet it still displays the observed pattern of behavior. This indicates that the pattern of behavior results from internal operating policies, and hence could be improved by making changes in these policies.

1) Draw a causal loop diagram for the simulation model. This causal loop diagram should include all the variables (not constants!) shown in Figure 2.1.

We will now examine several different approaches to addressing the undesirable revenue and bookings patterns. We already know from the earlier discussion that the approach of firing the current sales staff and replacing them with people who have the right stuff will not work because in this model the current sales staff does not lose their innate sales ability. Instead, perhaps it makes sense to increase the Sales Force.

2) Conduct a sensitivity analysis on the base case (that is, the equations presented in Section 2.2) where the FRACTION OF REVENUE ALLOCATED TO SALES is increased by 25 percent from 0.4 to 0.5. Present and discuss how graphs of revenue, leadtime and capacity utilization fraction differ for the base case and the case where FRACTION OF REVENUE ALLOCATED TO SALES is at 0.5.

This modification leads to an improvement in the pattern of revenue and bookings. Both grow substantially faster than the base case, and neither now shows any substantial periods of decline. However, things are not so positive for leadtime and capacity utilization fraction. The leadtime is longer and production spends most of its time running flat out (that is, with a capacity utilization fraction of 0.99).

Essentially, sales are being generated by brute force throw a lot of sales people at the problem to overcome the poor service that is being provided to customers. The stress between sales and production is likely to be very severe with such an operating policy. Furthermore, this is being done by diverting a substantially larger portion of revenue to sales than in the base case. This may not be feasible for very long in an actual operations situation. Even if it is, it generates a situation where competitors are likely to enter the market because of the poor service that is being provided.

Now we switch from considering policies for the sales sector to considering approaches that impact capacity acquisition.

3) In the base case simulation results shown in Figure 2.4a, shipments jump each time that additional capacity is added, but then shipments immediately start to decline for a period of time before recovering. Explain why this decline happens in terms of the model equations.

The base case shows dramatic changes in shipments when a new chunk of capacity comes on line. This suggests that the situation might be improved by obtaining smaller chunks of new capacity more rapidly. This might smooth out the shipment pattern, and hence decrease the variations in leadtime.

4) Conduct a sensitivity analysis on the base case where both of the following are changed at once: CAPACITY ORDER QUANTITY is halved from 20 to 10 and ACQUISITION DELAY is also halved from 6 months to 3 months. Present graphs and discuss how the results change from the base case for revenue, leadtime, and capacity utilization fraction.

This proposed policy change seems reasonable because it seems that purchasing less capacity and bringing it on line more rapidly would allow you to respond more rapidly to the increase in leadtime and less severely impact shipments each time that new capacity is brought on line. Unfortunately, the results of the model run show that what you mainly do is decrease your revenue. It is true that there is less variation in leadtime, but the overall average isn t impacted much. In retrospect, that makes sense; the variation in leadtime is decreased but the average remains about the same because you are bringing capacity on line at the same average rate but just in smaller chunks.

5) Explain why this policy leads to lower revenue in terms of the model equations.

The explanation appears to be that you do not have the periods of low leadtime in which your sales increase substantially.

There is another possible disadvantage of this policy which is not considered in the model. Often larger production facilities are more efficient than smaller ones (provided that you can use the additional capacity). Therefore, the cost of production using smaller capacity units may be higher than the cost for larger capacity units.

There are a variety of other changes that might be investigated to improve the situation. We will turn to the use of system archetypes to attempt to find a desirable policy change.

6) Compare the causal loop diagram for this model with the growth and underinvestment system archetype. Identify the elements within the model which correspond to the various variables within that system archetype. Based on this system archetype, propose a policy change which might improve the pattern of revenue.

The growth and underinvestment archetype proposes that you should build capacity ahead of demand. Within our model, this corresponds to setting a lower LEADTIME THRESHOLD. That is, add capacity *before* leadtime deteriorates, rather than waiting until things are already bad.

7) Conduct a sensitivity analysis on the base case in which the LEADTIME THRESHOLD is reduced by 20 percent from 5.5 months to 4.4 months. Repeat this, but with LEADTIME THRESHOLD reduced by 30 percent from 5.5 months to 3.85 months. Do this once again with the LEADTIME THRESHOLD reduced by 50 percent from 5.5 months to 2.25 months. Present graphs and discuss how the results change from the base case for revenue, leadtime, and capacity utilization fraction. (Hint: Use Vensim s sensitivity analysis capabilities to present the graphs for the base case and all three sensitivity analysis cases of a variable in the same figure.)

Based on the results of this analysis, the pattern of behavior seems to steadily improve as the LEADTIME THRESHOLD is decreased. Thus, the conclusion seems to be that you should make the LEADTIME THRESHOLD as small as feasible. However, this is not the whole story. If you examine the amount of Capacity for each of the cases considered in the preceding question, you will see that as LEADTIME THRESHOLD decreases, more capacity is added. Of course, this capacity costs money. Perhaps the additional sales are not worth the additional cost of the capacity.

8) A crude measure of the effectiveness of a unit of Capacity is given by taking the ratio of revenue to Capacity. Compute this ratio at the send of the simulation run (at a time of 72 months) for the base case and the three other sensitivity analysis cases considered in the preceding question. That is, compute this ratio for LEADTIME THRESHOLD equal to 5.5, 4.4, 3.85, and 2.25 months. Discuss the implications of your results. (Hint: Use the Causes Table tool to determine the numbers required for these calculations.)

This ratio improves with decreasing values of LEADTIME THRESHOLD from 5.5 to 4.4 to 3.85 months, but it deteriorates when LEADTIME THRESHOLD decreases to 2.25 months. Thus, the results indicate that there is point beyond which adding capacity is not productive. However, it appears that a substantially lower LEADTIME THRESHOLD than is currently used might be appropriate.

2.6 Concluding Comments

Companies can lose market share or even go out of business because they did not add capacity at a high enough rate. This applies to situations where there is high growth and where there are competitors from whom your potential customers can obtain an equivalent product or service to the one you provide.

However, in other situations adding capacity ahead of demand can be a significant mistake. The model presented above does not include any external limits to the growth of sales, but in most situations there is an ultimate limit to the potential market and adding too much capacity can lead to longterm negative financial implications due to excess capacity. One of the challenges of managing in a high growth environment is accurately estimating the limits to that growth.

2.7 Reference

B. Richmond, S. Peterson, C. Charyk, *Introduction to Systems Thinking and ithink*, High Performance Systems, Inc., Hanover, NH, 1994.