CAPACITY ADJUSTMENTS IN A TEXTILE DIVISION
Management Response To A System Dynamics Study

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ABSTRACT

A division of a large textile company was chosen as the focus of a system dynamics study to determine how management would respond to any capacity adjustment problem. The company produces fabrics for household as well as industrial uses and the annual sales of the company are several billion dollars.

The division under study produces yarn and piece dyed draperies, mattress tickings, and upholstery fabrics. The four major manufacturing processes in the division are spinning, yarn preparation, fabric formation and fabric dyeing and finishing.

Although not aimed at any particular perceived problems, the study was undertaken with two purposes, firstly to develop a system dynamics model that would describe the performance of the division and secondly to use the model to investigate the effects of demand changes on various capacity adjustment policies practised in the division.

The study includes interactions among a large number of factors in forecasting and inventory control, raw material supplies, employment, and production capacity. These factors related to some ten plants and four processes of the division.

Data and other information have been collected by questionnaires and interviews with management. The model has been tested for its validity in representing the actual operations. The model is now being used in testing some of the policies in response to changes in customer order rate.

INTRODUCTION

The decorative fabrics division of a large textile company was the focus for this system dynamics study. The junior author was acquainted with the division through three months of work experience, and management was receptive to the proposed study. Company approval for the study was granted in September, 1983, and work was begun at that time.

Products of the division include fabrics for drapery, upholstery, and mattress ticking. Ten plants comprise the division, and four production processes are conducted in manufacturing the fabrics.

The first process, spinning, is responsible for transforming raw fibers into yarn. The basic steps of this process begin with blending the correct mixture of fibers together. Next the fibers are carded, drawn, and spun.

The second process is yarn dyeing and preparation. At this point, some yarn is dyed. Some yarn has various chemical mixtures applied to it for the enhancement of properties such as strength.

Fabric formation is the third process. The warp yarn is wound onto beams in preparation for weaving. At this stage, some beams are treated with more chemicals and/or dyed before weaving takes place.

The final process is called dyeing and finishing. Some cloth requires dyeing after being woven. Finishing involves the application of chemicals imparting various physical properties to the cloth, such as soil resistance and strength. The finished fabrics leave the division through shipment to other company divisions and outside customers.

In general, growth of the textile industry is closely linked to U.S. economic conditions. When recovery from the last recession began, textiles were among the first industries to benefit. However, growth came unexpectedly strongly and quickly. As a result, this decorative fabrics division, in particular, was challenged to find ways to manage the new growth as best it could. Capacity adjustment in response to a sudden growth in demand is of critical importance. This system dynamics study was initiated as a means for management to understand the interacting factors involved in capacity adjustment.

PURPOSE AND PROCEDURE

System dynamics modeling is applicable to many industrial problems which involve complex systems made up of the interactions between flows of information, materials, manpower, money, and capital equipment. The dynamic behavior of such systems is largely due to delays in decisions and actions, policy structure, and the structure of interacting organizational functions. Such systems usually involve feedback loops. Feedback loops occur when the environment causes a decision which in turn affects the environment (cause and effect circles). This feedback process is a continuous one.

> The study of feedback systems deals with the way information is used for the purpose of control. It helps us to understand how the amount of corrective action and the time delays in interconnected systems can lead to unstable fluctuation. (Roberts, 1978)

Three benefits of using a system dynamics approach with DYNAMO are:

1. Construction of the model allows the company to take into account a greater number of factors than can be considered with intuition alone.
2. The model provides a means of explicitly calculating the effect of different goals and policies on corporate behavior.
3. The model is a vehicle for testing the response of company policies to different economic, competitive, and evnironmental scenarios. (Lyneis, 1982)

The present study was undertaken with two purposes. The primary purpose was to provide an educational experience with regard to system dynamics. The second purpose was to examine the capacity adjustment policies of a large textile company division, and to provide management with recommendations for improved policies.

Initial contact was made with a "pilot plant" in the division. Knowledge of the division's four production processes was gained through work experience with the pilot plant (part of process 1) and tours of several plants performing processes 2 through 4.

The general procedure of the present study was conducted as follows. First, a single production process model (Lyneis, 1982) was modified to fit the pilot plant. The single process model could be run using DYNAMO II. Second, a comprehensive model, including all four production processes as well as the pilot plant, was developed. This development involved the use of arrays and DYNAMO III. Third, data were collected from the division's ten plants to be used as parameters. Fourth, validity data were gathered for a single plant (validity data were not gathered from the other nine plants due to the project's time constraint). Fifth, validity of the system dynamics approach was researched. Sixth, parameters of the composite model were varied in order to discover policy improvements. Seventh, policy recommendations were developed. Finally, conclusions regarding the entire course of the project were developed.

THE MODEL

A single process model was developed, based on Lyneis' (1982) production model. Included were equations regarding interactions of inventory systems, forecasting, company suppliers, labor, and capital equipment.

Lyneis's description of the model is such that each successive sector expounds upon particular equations of the preceding sector. In order to integrate the five different sectors into a single model, those equations which included the effects of all possible variables had to be identified and included. Preliminary equations which were limited in scope had to be identified and excluded from the model.

Due to constraints in the collection of data and of time, some sectors of Lyneis' model were omitted entirely. These sectors include the dynamics of interactions between customers and competitors, financial variables, and professional resource variables. Although the inclusion of these sectors would upgrade the model, they were omitted in the process of defining the scope of this project. Their exclusion should not lessen model validity as long as the assumption that they do not directly affect capacity adjustment policies is noted when using model results.

A second model was developed which assigned each parameter a 1 x 5 array of values. Each of the first four elements of the array represents one of the four production processes under study. The last array element represents the pilot plant for which validity data were gathered. The parts arrival rate equation was modified to act as a connector of the four processes. The parts arrival rate of the second process is equal to a delayed shipment rate of the first process, and so forth.

Data Collection

A questionnaire was designed as the primary means of gathering data from each of the ten plants. Managers of the pilot plant were interviewed via the preliminary questionnaire structure, which was subsequently modified to be more easily understood.

The modified questionnaire was then sent to three divisional managers representing the three main production processes. Each of these managers completed a separate questionnaire for each plant performing the production process they represent. A conference call between the divisional managers and the investigators was used as a means of clarification.

Once the data had been gathered, it became clear that a breakdown of four production processes would produce a more accurate representation of the division. Data from each plant in a process were averaged with a weighting corresponding to each plant's constant customer order rate. Table 1 contains the weighted averages of plant data for each production process. Definitions of the symbols in Table 1 are given in the Appendix.

The pilot plant data were checked for validity. The past six months' data regarding finished inventory, parts inventory, production rate, labor, labor firing rate, labor hiring rate, labor attrition rate, and capital equipment orders were compared with computer simulation results. Examination of these validity

Table 1 Weighted Averages of Plant Data

Variable	Process 1	Process 2	Process 3	Process 4
TCWIP	4	5	15.9	13.1
PSDT	9.8	5	.9	28.7
TOCORG	3.1	91	51.2	6.8
TACOR	3.1	91	51.2	6.8
TCFI	27.3	5	63.2	15.8
TOPRGR	3.1	91	51.2	6.8
DDFI	16.5	8	5.9	35
TAPRPO	12.1	5	54.2	9
TCPI	15.3	5	54.6	20
DDPI	42	5	7.7	4.6
CCOR	69.3	69.3	69.3	69.3
LPROD	.51	.09	.31	.55
LRD	44.7	52	123	57.6
ALE	4884	2920	2077	3552
TAL	22.1	10	58	10.9
TALAR	133.3	65	169.6	131.3
DDSPIH	42	5	7.7	4.6
TACORE	90	91	65.1	30
TOCORE	69.4	91	56.7	28
TSCE	4276	4380	4522.4	5241.3
TAQCE	196.2	112	119.3	122
TACE	83.7	91	72.8	45.8
TACES	1709.5	91	930.8	5475
TACORC	180.8	91	284.8	232.3
TOORGC	240	240	240	240

data should indicate to management the level of confidence they will want to place in the model. Although the simulated data did not exactly fit actual validity data, the model still may be considered "valid" in the sense that general patterns of behavior are simulated well.

It is assumed that data from each of the other nine plants are of equal validity, since the same means of data collection was used.

Data from each process and the pilot plant were tested to make sure the model produces stable behavior when not disturbed by changes in the customer order rate. Minor adjustments in the preliminary model were made in order to assure that each process started out in equilibrium.

Problems were encountered in effectively communicating the nature of data needs to management. Particular difficulties arose when management was asked to estimate such parameters as the time to observe production rate growth rate, used in forecasting future production rate. Responses varied widely from plant to plant within each process for more quantifiable variables, as well. For example, the constant customer order rate differed between each process, thereby causing the model to be in disequilibrium at the start. An adjustment was made so that all four processes experience the same constant customer order rate.

Although data inconsistencies are not desirable, they do not necessarily detract one from the usefulness of the model. As long as data are within reasonable ranges the model can be used with the aim of providing understanding of various system interactions. Patterns of behavior of particular variables are of interest in designing effective policies. Specific output data are not needed for this purpose, and should not be interpreted literally.

MODEL CREDIBILITY

The use of quantitative techniques in operational problem areas has been accepted as credible because face validity tests (determination of the degree to which models reflect the real situation being represented) clearly distinguish valid techniques from invalid techniques. As these methodologies (including the system dynamics approach) began to be applied to policy analysis, the issue of model credibility (specifically, validity) has become more critical. Many of the more well-defined validation techniques are difficult to apply to policy analysis models because these models represent more "squishy" problem areas. "There is an inverse relationship between a model's credibility and the squishiness of the problem" (Gass, 1983, p. 605).

The fact that many policy analysis models defy standard validity testing does not mean that such models are not useful. On the contrary,

> The completeness and effectiveness of the model depends on the planned use of the model results, the available resources and time, and the inclinations and experiences of project sponsors, analysts, and programmers. (Gass, 1983, pp. 606-607)

In other words, if the model achieves its purposes (subject to such constraints as time, personnel, etc.) it should be perceived as credible.

The demonstration of model credibility involves verification, validation, and assessment/evalution. Each of these elements of credibility will be discussed below in terms of the present study.

Verification involves the assurance that the computer model works as the designer intended it to. One test of verification is to check the logic of the program. Prior to the present study, the Lyneis model was studied in depth. As a general representation of a typical production process, the model is logically constructed.

A second test for verification involves determining the accuracy of the model's numerical results. In the present study, calculations of the critical variables in the single process model were performed manually as a check for accuracy. Also, these variables were plotted for each process, and checks were made to be sure that the results were logical. For example, variables such as labor and production rate should not attain

negative values. The range of values for each variable was checked for reasonableness.

Validation involves the determination of the extent to which model behavior represents behavior of the real system being modeled. As is the case with the present study.

> For first-time or futuristic models validity is superseded by the concept of model credibility, as defined by the decision maker ... Knowing the limits of the model's predictive capabilities will enable you to express proper confidence in the results obtained from it. (Gass, 1983, p. 610)

According to Schellenberger (1974), model validity can be classified into several types which include technical, operational, and dynamic validity. Technical validity is composed of model, data, logical/mathematical, and predictive validity. The former three types of technical validity are examined as part of the model description and data gathering section (in terms of the study's assumptions). Predictive validity refers to the ability of the model to predict outcomes of the real system. The time constraint of the present study prevented testing for predictive validity.

Tests for operational validity check to see that results of a policy analysis are reasonable in light of the model assumptions. Although difficult to establish, attempts toward operational validity can be accomplished through the use of sensitivity analysis. Sensitivity analysis involves the identification of parameters whose values are critical to subsequent decision making. As parameters are varied one at a time, the magnitude of variability in resulting policy recommendations is examined. When it is noted that policy decisions resulting from the model are particularly sensitive to certain parameters, the values chosen for those parameters should be justified and documented. In the present study, sensitivity analyses were performed as part of the development of policy recommendations. Of the testing performed, few of the policies proved to be highly sensitive to parameter changes.

Another aspect of operational validity is implementation validity, which involves determining the degree to which modeled behaviors are similar to actual behaviors when certain policy recommendations have been implemented. In the absence of actual implementation, the establishment of this type of validity reduces to the provision of a statement that recommendations resulting from a modeling study are feasible in the real system. For the present study, the investigator is not qualified to make such a judgment. Therefore, implementation validity will have to be established by the decision makers actually using the model at a later date.

Dynamic validity involves the establishment of procedures by which the model systematically will be updated and reviewed. If a commitment is made to actually use the model, a committee should be organized to monitor the dynamic validity. Such a committee should include "decision makers, solution implementers, and model developers in sessions that cover divergences between the predicted solution and actual outcomes, proposed model changes, and a new evaluation of the model's validity" (Gass, 1983, p. 615).

Gass states that:

> The main function of assessment is ... a process by which interested parties (who were not involved in a model's origins, development, and implementation) can determine, with some level of confidence, whether or not the model's results can be used in decision-making. (Gass, 1977a, cited in Gass, 1982, p. 617)

Based on this definition, it can be concluded that management should arrange for model assessment before the model is used.

Assessment procedures vary (see Gass, 1982, for reports of Gass, 1977b, Kresge, 1979, Wood, 1980, Holloway, 1980a,b, Weisbin et al., 1981, Alsmiller, 1980, and U.S. Gao, 1979). The process of evaluation should be structured to serve the model scope and objectives. Model developers have the responsibility to provide upon request all information deemed necessary for evaluation of the model. Included is information regarding:

Computer program documentation
Model documentation
Computer program consistency and accuracy
Overall computer program verification
Mathematical and logical description
Technical validity
Operational validity
Dynamic validity

Training
Dissemination
Usability
Program efficiency
Overall model validation (Gass, 1982, p. 618)

An effort has been made to provide enough of the information specified above. Throughout this study, assumptions and model documentation have been provided. It is hoped that management will follow up on this study with an assessment process, and subsequently will utilize the model according to their level of confidence in it.

POLICY RECOMMENDATIONS

One of the purposes of the present study was to develop a set of recommendations for improved capacity adjustment policies. The approach taken was to change variables which are under the control of the company management. Eighteen such "controllable" variables exist in the model (Table 2). The definitions of the symbols in Table 2 appear in the Appendix.

With four production processes, a multitude of policy variables and functions, and several possible customer order rate change patterns, the combinations of policy variations were far too numerous to attempt testing them all. The scope of policy testing had to be limited because of time constraints.

It was decided to use the fourth production process output in determining the effects of policy parameter changes on the division. Since finished product from the fourth process is the only material actually being sold to outside customers, it is assumed that performance of this dividion sector is more critical than that of the first three process sectors. However, the performance of all four sectors should be evaluated before any policy change is actually implemented.

Table 2 Variables Under Management Control

Inventory, Forecasting, Parts Supplier Sector	Labor Sector	Capital Equipment Sector
TOCORG	TAL	TACE
TACOR	TALAR	TACES
TCFI	DLS	TACORC
DDFI	DDSPIH	TOORGC
TAPRPO	TACORE	
TOPRGR	TOCORE	
TCPI		
DDPI		

Most of the table functions do not vary from Lyneis' specifications. Although management certainly could vary some of these functions, time did not permit this investigator to do so.

Some of the 18 policy parameters were changed in various combinations. Several of the possible combinations were studied. The policy variations were evaluated with respect to a 30 percent step increase in customer order rate. Although many other customer order rate change patterns are possible (such as steady growth, cyclical changes, and random changes), they were not investigated in the present study. However, these other change patterns should be used to test any policy changes which are candidates for implementation.

Lyneis' policy design guidelines were used as a framework for testing various combinations of policy parameters.

A 30 percent step increase in customer order rate on day 60 of the simulation was used to study the stability and response time of the model with varied sets of policy parameters. Each policy change was evaluated with respect to the model behavior with the "actual" policy sets, as reported by company management. Figure 1 is a graph of the behavior of several system variables in response to a 30 percent step increase of customer order rate at day 60. The policies reflected in this graph are those observed in the company at present.

Figure 1 illustrates several features of an inventory system's response to a sudden increase in demand. First, production rate rises in response to the increased demand. Simultaneously, parts inventory decreases because of the increased production rate. Parts order rate increases in response to the increased production rate.

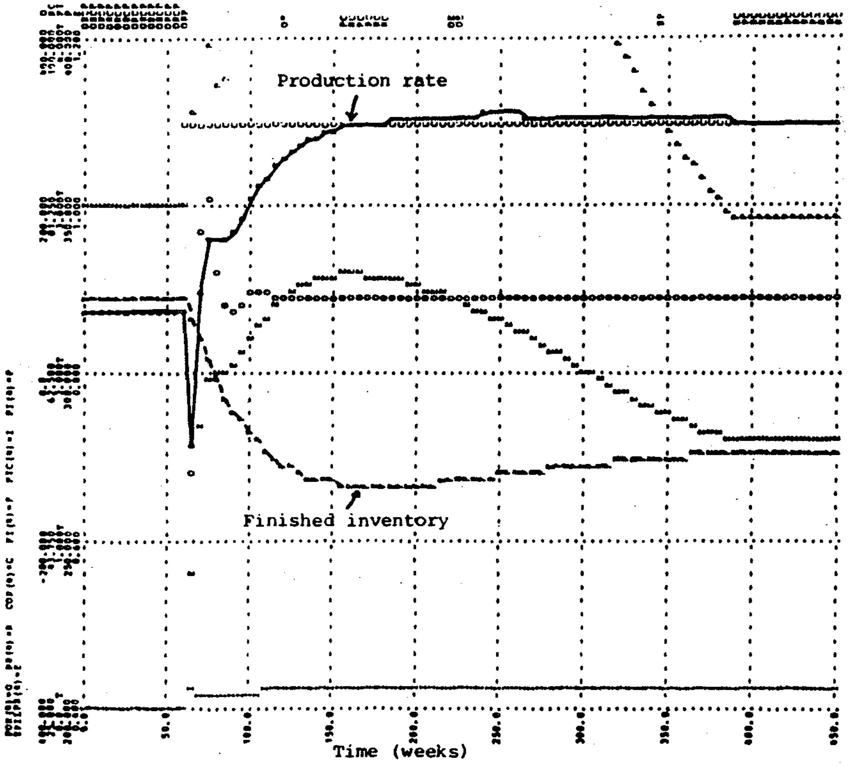

Figure 1. Inventory system response to a 30 percent step increase in COR at day 60.

The production rate increase is amplified above the 30 percent increase in customer order rate. The reason is that the forecasted base customer order rate, to which production rate responds, is delayed in recognizing that growth in customer order rate is temporary. Since customer order rate growth does not continue at 30 percent, production overshoots this rate. When the system recognizes that customer order rate is once again constant, production rate falls until it equals customer order rate.

Finished inventory declines because of the delay in correcting finished inventory. Also, the shortage of parts inventory constrains the production rate to a reasonable rate. Therefore, more units are shipped from finished inventory than are built up in finished inventory from production completions. Another factor contributing to the drop in finished inventory is the physical delay, time to complete work in process, between production rate and production completions.

Parts order rate does not amplify the 30 percent increase in customer order rate as production rate does. Since parts order rate is part of the second stage of the inventory system, it responds to the amplification in production rate rather than just the increased customer order rate. Therefore, parts order rate is amplified more than production rate. The reason is that parts inventory goals have been based on the amplified production rate. When production rate decreases again, parts order rate responds and drops below production rate temporarily.

Parts inventory lags finished inventory, just as parts order rate lags production rate, because the parts stage follows the production stage. Stage one includes production rate, finished inventory, and all interactions. Stage two includes parts order rate, parts inventory, and all interactions.

Two aspects of Figure 1 were used in evaluating the performance of various policy sets. First, the degree of amplification of production rate is important. A highly amplified production rate usually indicates the tendency toward system instability. Companies normally try to avoid the costs associated with such fluctuating conditions. To evaluate various policy sets, production rate amplification was calculated as the percentage of increase (above the 30 percent customer order rate increase) that production rate shows before falling again. This amplification was then normalized by the production rate amplification which occurs with the actual observed policy sets. The resulting performance indices were then used to compare the results of policy tests. Lower performance indices indicate better policy sets with respect to production rate amplification.

Second, the percentage of loss of finished inventory was calculated for each policy set. This percentage of loss was divided by that for the presently observed policy sets. The resulting perofrmance index was used to compare various policy sets. Companies whose finished inventory drops below customer order rate bear opportunity costs of lost sales. Therefore, lower performance indices indicate better policies with respect to finished inventory loss.

A composite performance index can be computed by calculating a weighted average of the production rate amplification and finished inventory loss performance indices. The weights should be based on the relative costs to the company of instability and inventory loss. When enough testing has been conducted for a particular policy set, the results (as shown in Table 3) can be graphed as in Figure 2. Those policy sets with lower composite performance indices are the more desirable ones.

Recommendations Based on Policy Tests

Recommendations based on test results are as follows:

1. Use a capital equipment buffer against inaccurate forecasts.
2. Continue the use of overtime, provided that the costs of such a policy are less than those incurred from increased instability and inventory losses when overtime is not used.
3. Increase time to average customer order rate and time to correct finished inventory by 30 percent.
4. Maintain the present times to observe customer order rate growth rate and production rate growth rate.

Table 3 Test Performance Indices

Variation of TACOR/TCFI	PR AMP[a]	PR PI[b]	FI LOSS[c]	FI PI[d]	AVG PI[e]
-30%	2.78%	1.54	52.27%	1.15	1.35
-20	2.43	1.22	49.40	1.09	1.16
-10	2.18	1.09	47.14	1.04	1.07
0	1.99	1.00	45.41	1.00	1.00
+10	1.85	.93	44.05	.97	.95
+20	1.72	.86	42.95	.95	.91
+30	1.63	.82	42.09	.93	.88

[a] PR AMP = production rate amplification.
[b] PR PI = production rate performance index.
[c] FI LOSS = finished inventory loss.
[d] FI PI = finished inventory performance index.
[e] AVG PI = average performance index.

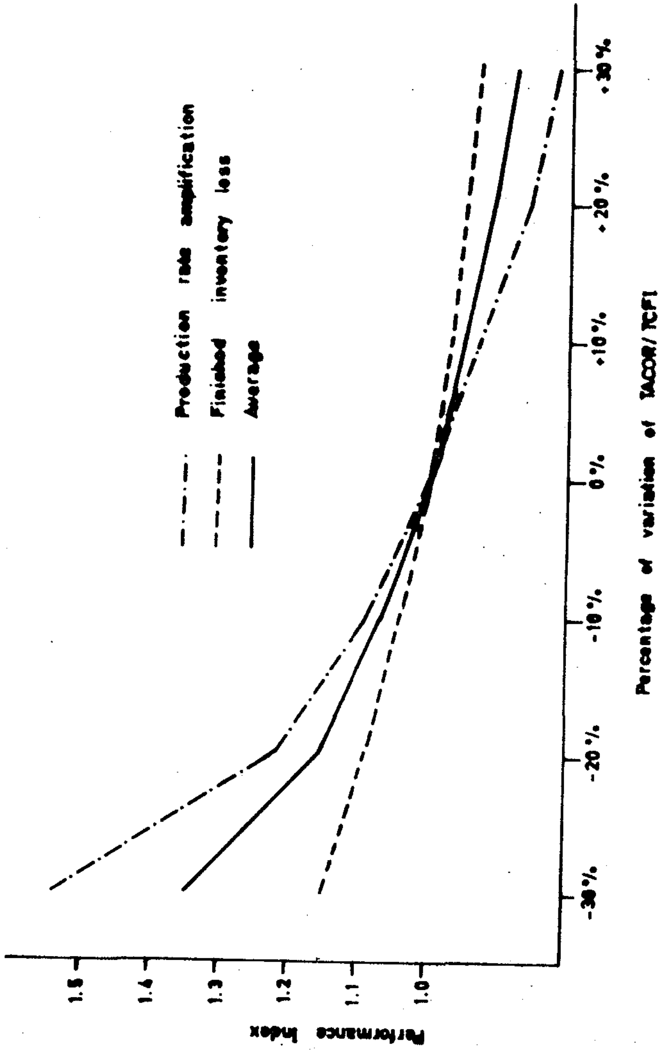

Figure 2. Graph of test performance indices for TACOR and TCFI

5. Maintain the present desired days of parts inventory.
6. Increase desired days of finished inventory by 30 percent.
7. Further investigate the model validity, data validity, and results of more extensive policy testing before implementing any of the above recommendations.

CONCLUSIONS

The purposes of this project have been achieved. First, the investigators learned more about the system dynamics approach in general, and about the situations encountered while conducting an actual study. Second, several capacity adjustment policies were examined, and recommendations for their improvement were developed.

It is hoped that the textile company management will study the project report carefully to determine the level of confidence that they can place in it. Since the model construction is of adequate validity and the system dynamics approach is useful for this type of application, management will profit from working with it further. The data used in the model should be updated continuously, as should the model structure. Finally, further policy testing will generate a deeper understanding of the various interactions which affect capacity adjustment.

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APPENDIX: DEFINITIONS OF SYMBOLS

ALE	Average length of employment (days)
CCOR	Average customer order rate (million pounds/day)
DDFI	Desired finished inventory (days of supply)
DDPI	Desired raw material inventory (days of requirement)
DDSPIH	Desired days supply parts inventory for hiring (days)
DLS	Desired labor switch
LPROD	Labor productivity (million pounds/day/person)
LRD	Labor recruitment delay (days)
PSDT	Raw material delivery delay (days)
TACE	Time to adjust capital equipment (days)
TACES	Time to average equipment scrappage rate (days)
TACOR	Time to average customer order rate for production rate (days)
TACORC	Time to average customer order rate for capacity (days)
TACORE	Time to average customer order rate for employment (days)
TAL	Time to adjust labor level (days)
TALAR	Time to average labor attrition rate (days)
TAPRPO	Time to average production rate for raw material order rate (days)
TAQCE	Delay in capital acquisition (days)
TCFI	Finished inventory correction time (days)
TCPI	Raw material inventory correction time (days)
TCWIP	Time to complete work in process (days)
TOCORE	Time to average customer order rate for hiring rate (days)
TOCORG	Time to observe customer order rate growth (days)
TOORGC	Time to observe order rate growth for capacity (days)
TOPRGR	Time to observe production rate growth (days)
TSCE	Average life of capital equipment (days)