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DIAGNOSTIC ANALYSIS OF A PRODUCTION AND DISTRIBUTION SYSTEM.(U)
OCT 78. A C HAX, N S MAJLUF, M PENDROCK

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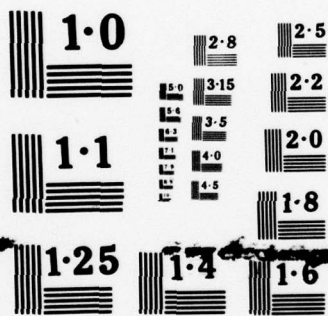
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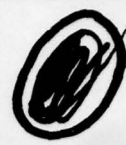
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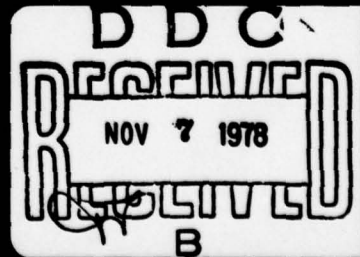
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DIAGNOSTIC ANALYSIS OF A
PRODUCTION AND DISTRIBUTION SYSTEM

by

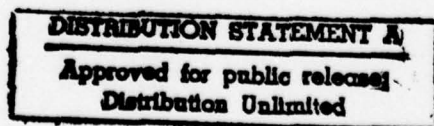
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Technical Report No. 157

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FOREWORD

The Operations Research Center at the Massachusetts Institute of Technology is an interdepartmental activity devoted to graduate education and research in the field of operations research. The work of the Center is supported, in part, by government contracts and grants. The work reported herein was supported by the Office of Naval Research under Contract N00014-75-C-0556.

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Jeremy F. Shapiro

Co-Directors

ABSTRACT

↙ This paper describes a diagnostic study of an existing centrally controlled production and distribution system for a large packaging company. The first part of the paper focuses on the data collection effort and the development of diagnostic measures to evaluate the performance of the existing systems. The second part presents a proposal for the design of a new system which follows a hierarchical approach. The managerial implications of the existing centralized system and the proposed hierarchical system are carefully analyzed. ↗

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1. Introduction

This paper reports on a study completed for a large firm in the consumer goods sector. At the time of the study, the firm was manufacturing and distributing more than one billion pounds of their final products. According to the managerial team, their logistic system was performing satisfactorily, except for minor problems that had started to emerge. In general, they considered the development of all production and distribution activities to be very much under control. This was viewed as a substantial achievement considering the size of the operation.

The main reason for starting this study on logistics was a "feeling of discomfort" expressed by the managerial team. They explained to us that the firm had been using the same system for so many years that they were unable to see problems or inefficiencies that the system may have had. Thus, the managers of the firm decided to have an external look at their operation. We obtained a mandate to perform a diagnostic study of the production and distribution system in the firm, a sort of very liberal "hunting license" for "shooting at any problem" we could find.

The broad description of the areas of concern in a diagnostic study presents some special characteristics which we are unable to find in most of the work published on logistic systems. A review of the Operations Research

literature reveals models for optimal configuration or control of a logistic system, but there is little guidance for performing a Phase I diagnostic study. Models available in the literature include mainly simulation models for testing inventory allocation policies (Bowersox, et.al. [3], Connors, et.al. [5], and Porter [13]); and mathematical programming optimization models for physical configuration design (most notably the Benders decomposition approach of Geoffrion, et.al. [7],[8]).

Unfortunately, these very large models are not appropriate for a diagnostic study, where the analyst needs to rely on simpler descriptive statements of the logistic system, more in line with the reduced time and budget allocations usually enforced. In a diagnostic study, the set of models used must be varied in nature, smaller, more aggregate in detail, and less data hungry than the design and control support tools. The main purposes in an exploratory study are to uncover potential areas for improvement and to determine if the realization of a deeper analysis with more formal large scale optimization and simulation models is a worthwhile undertaking.

It is hard for us to understand the reasons for the continuous neglect of diagnostic studies in the literature. Are they so trivial that their reporting seems unnecessary, or so complex that they have escaped genuine efforts for structuralization? Certainly, we do not think that diagnostic studies are simple, but we think that they have not been given the attention they ought to receive.

The tendency to overstudy techniques for solving problems, while the process of defining those problems is given little attention, is a bias that seems to pervade most of the research work in Management Science and Operations Research. Almost ten years ago, Pounds [14] conducted a study on "The Process of Problem Finding" and he suggested that we should concen-

trate our effort in the construction of models to define the relevant problems. This message seems to have gone unnoticed, but is the essence of a diagnostic study. There are many areas of attention, and we should define models to establish sound benchmarks against which actual performance can be measured. A problem is considered to exist whenever a change in actual practices can lead to a substantially improved state of affairs. Most of the time, this improvement can be measured in total dollars saved or earned, and the firm should be able to define, for each situation, a threshold over which a potential improvement will be considered attractive.

The diagnostic study reported in this paper adheres to the approach described above. A first step in this process is the selection of broad areas of attention, and a second step is the construction of models to judge actual performance. Issues of interest for managers emerge in a very natural way from this analysis.

Section 2 of this paper presents a framework for describing the logistic system, and analyzing its operation. Then, in section 3, the most important characteristics of the logistic system are discussed. Next, section 4, gives a definition of the areas of concern and describes the construction of several small scale models used in the exploration. Finally, the conclusions derived from this study are summarized.

2. Framework

We think it is useful to define at the very beginning of a study the conceptual framework used in its development. This framework provides a helpful guide in the initial stages of data collection, interviews with personnel in the firm, and in the later analytical treatment of this infor-

mation. Moreover, making a framework explicit exposes the conscious (and unconscious) biases chosen by the study group.

A first step in the modeling effort is the characterization of the production and distribution facilities. The essential elements of a logistics system are widely described in many different studies, and no effort is made in this paper to present an annotation of them. We limit ourselves to give in Table 1 some selected components which are of importance in conducting a logistics study. The interested reader is referred to Wagner [16], Hax [9], and Bowersox [2].

Our framework for the analysis of the planning and control system requires more extensive comment. In this case the attention is no longer focused on facilities and physical characteristics, but on the way the system operates. The framework we used for this analysis is the hierarchical planning approach developed by Hax, et.al. in several publications [1],[9],[10],[11].

The essential element in the hierarchical approach is the recognition of different hierarchical levels, with completely different responsibilities, information needs, and time frame. It is well known that the decision process in organizations follows a hierarchical structure in which the higher levels have responsibility for formulating basic policies that usually have long term consequences. At lower levels in the hierarchical structure, the problems are better defined and more time constrained. At the level of routine operation, the concern is with satisfactory completion of day to day activities.

The formalization of the hierarchical approach for decision making rests on two fundamental properties. One is identifying the proper degree of aggregation that each managerial level must use to perform satisfactorily its role in the decision making process. Too much detailed information

TABLE 1: ESSENTIAL COMPONENTS OF THE PRODUCTION-DISTRIBUTION PLANNING
PROBLEM. SELECTED ILLUSTRATIONS.

Elements -	Multiple Plants
	Multiple Warehouses
	Multiple Products and Raw Materials
	Inventory Accumulation
	Transportation System
	Communication and Data Processing System
Constraints -	Manufacturing and Distribution Characteristics
	Productivity
	Equipment Capacity
	Labor Availability
	Technological Constraints
	Lead Times (Manufacturing, Distribution)
	Demand Uncertainties and Seasonalities
	Service Requirements
Costs -	Others (Institutional, Financial, Marketing, etc.)
	Production and Purchasing Costs
	Set-up or Changeover
	Transportation and Handling
	Hiring and Firing
	Inventory Related
	Overtime
	Subcontracting
	Renting, Leasing
	Taxes
	Overhead
	Capital Investments, Depreciation

is an unnecessary distraction, and a waste of time, energy, and money. It may bog down the mind of the decision-maker and induce him to error. Too little information is an impediment to accomplish the desired end.

The other requirement that a formal hierarchical approach must satisfy is the coordination among all managerial levels. This is expressed in terms of an increasing number of constraints that narrows down the sphere of activity at lower levels in the organization. In the end, these lower levels are forced to fulfill the requirements imposed by the higher levels, but this final situation is only achieved after a fair amount of feedback guarantees that the plan is acceptable to all participants.

To summarize, the hierarchical approach implies that it is not adequate to have a unique monolithic system to satisfy the needs for support at different levels in the organization. A much more natural approach is the construction of a battery of models that work at different levels of aggregation, with different time frameworks, and such that the solutions provided by lower level modules are assured to be consistent with the outcome of higher level modules.

3. Characterization of the Existing System

3.1 Physical Characteristics

This initial phase of the study is aimed at developing a quantitative description of the physical system and also an understanding of the managerial decision-making process. In brief, the firm is a consumer goods manufacturer operating in a highly competitive market where sales promotions are prominent. Yearly sales are in the high nine-digit range. Facilities are located throughout the United States. The firm owns plants, distribution centers, sales branches, and the truck fleet used for delivery to retail stores; common

carriers are used for transportation between distribution centers and sales branches. There are relays between the distribution centers, but no transshipment activity between sales branches.

One important aggregation in a logistic system is the ABC analysis, which presents the level of contribution to sales. This was determined for both products and for sales branches (Figures 1 and 2). There are 200 distinguishable products and 200 sales branches. Not surprisingly, the ABC analysis for products shows a high contribution by a minority of the products, while the sales branches are fairly homogeneous, with little variation in size except for a few large and a few small branches. In future analyses we will emphasize the need to provide a different treatment to A and non-A items. We will also make use of the homogeneity of sales branches to simplify the analytical work dealing with sales branch consolidation.

Another aggregation criterion for products is the number of producing points. There are 10 plants (uniquely identified with 10 distribution centers) and each plant produces 40 products on average. Generally, the A level products are produced at more than one location. Table 2 shows the number of products for each number of producing plants. At this point, an important observation is the relative inflexibility of the origin of production decision: 76% of the products are produced at only one point, and 87% at one or two points. The origin decision is only concerned with 13% of the products, since in the remaining 87% this decision is trivial.

One further characterization of the products is with respect to promotional activity. End of year promotions are the major complicating factor for inventory management in this firm. Table 3 shows the severity of the situation. Roughly 50% of the products are promoted, with some products as often as 6 periods per year. It should be added that not only A-level

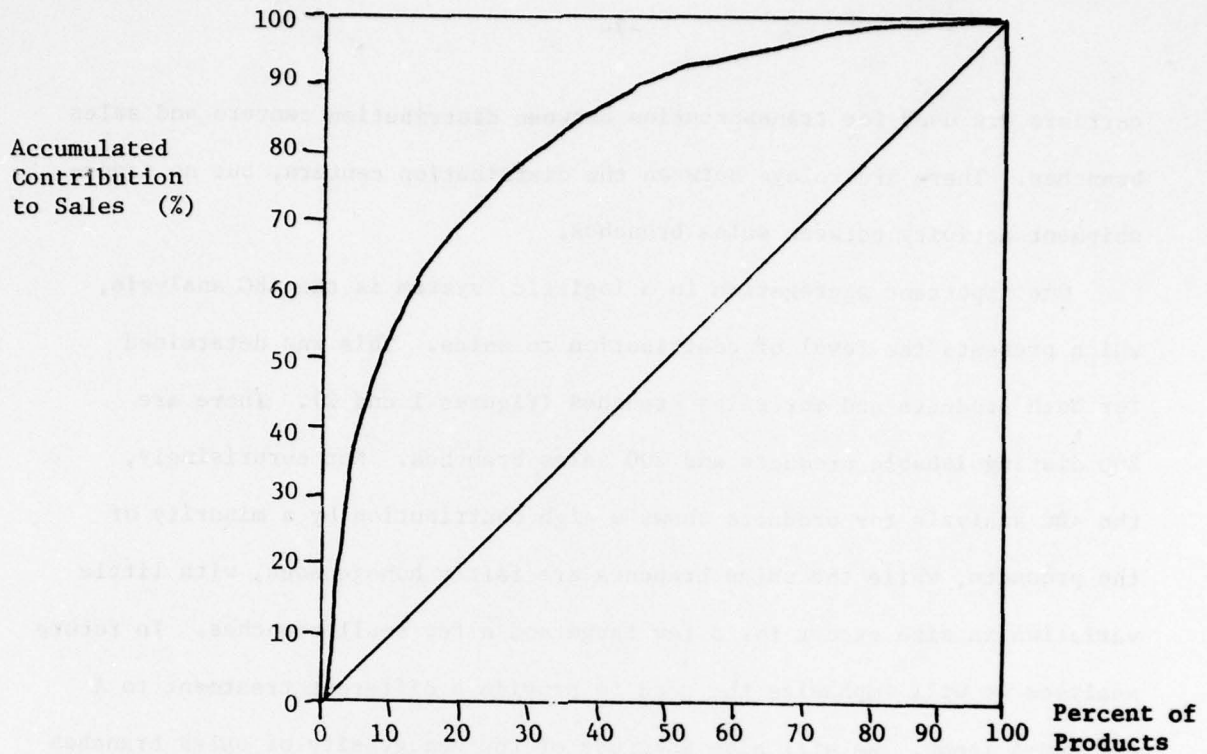


FIGURE 1: ABC-ANALYSIS FOR PRODUCTS

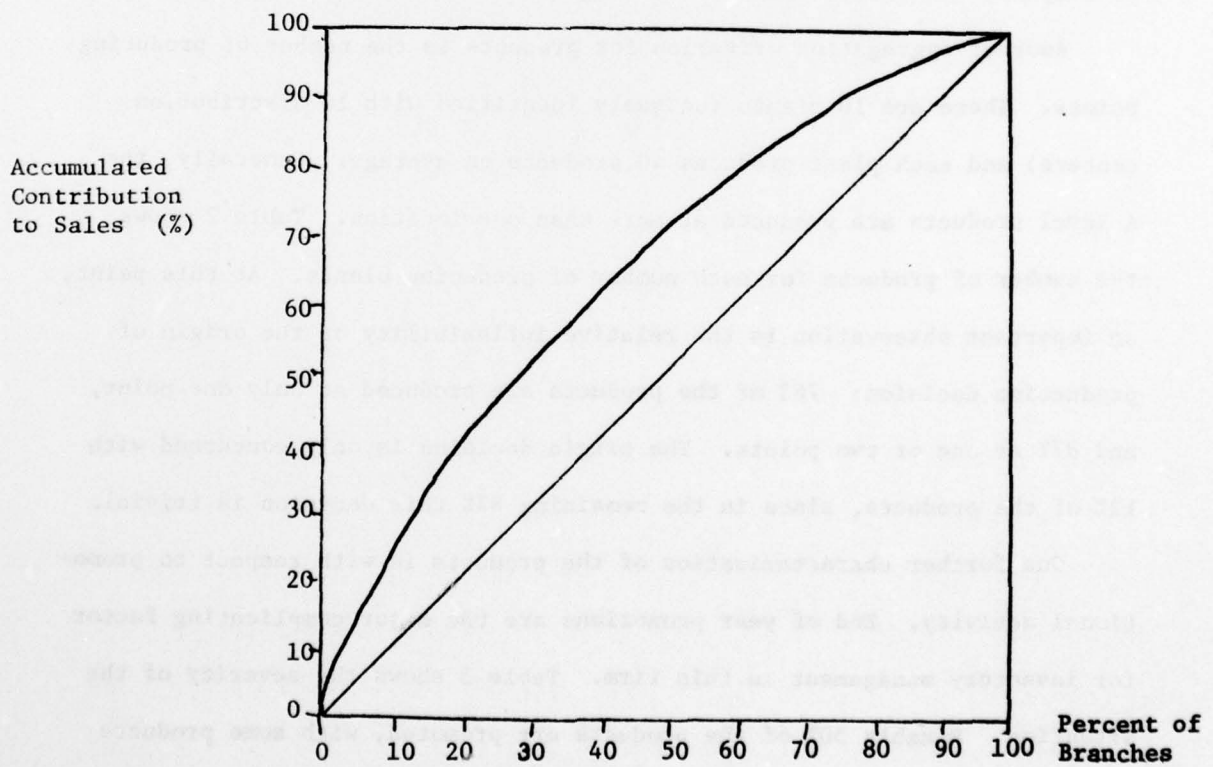


FIGURE 2: ABC-ANALYSIS FOR SALES BRANCHES

TABLE 2: ORIGINS OF PRODUCTION

<u>Number of Production Points</u>	<u>Total Number of Products</u>	<u>%</u>	<u>Cumulative %</u>
1	152	76.0	76.0
2	22	11.0	87.0
3	11	5.5	92.5
4	9	4.5	97.0
5	3	1.5	98.5
6	2	1.0	99.5
7	<u>1</u>	<u>0.5</u>	110.0
Total	200	100.0	

Dollar Contribution of Each Category:

<u>Number of Production Points</u>	<u>% of Sales</u>	<u>Cumulative %</u>
1	37.0	37.0
2	23.3	60.3
3	1.1	61.4
4	16.0	77.4
5	12.2	89.6
6	5.3	94.9
7	<u>5.1</u>	100.0
	100.0	

TABLE 3: SUMMARY OF PROMOTIONAL ACTIVITIES

Number of Products Promoted: 83 out of 200
Average number of Periods Promoted: 2.8

<u>Number of Periods Promoted</u>	<u>Number of Products</u>	<u>%</u>
1	27	32.5
2	18	21.7
3	11	13.3
4	8	9.6
5	13	15.7
6	<u>6</u>	<u>7.2</u>
	83	100.0

but also B- and C-level items are being promoted. There are severe demand peaks during the year for low volume items, which should normally receive less managerial attention than the higher volume items.

One final quantitative characterization which will be of interest is the loading profile for plants. This measures the fluctuation in capacity utilization at plants in the most aggregate terms, in this case number of production shifts per working day per month. (There are multiple production lines in each plant, and three shifts per day per line are possible. In total, there can be 240 production shifts per day for the company.) Table 4 shows the production loading, normalized to a base of percent of yearly average, e.g. in January there were 3% more production shifts per day than the yearly average. (Note that loadings reflected the end of year and January promotions.) While the promotional sales peaks were quite high, the production loadings were not overly dramatic, ranging from 94% to 111% of average. This indicates that the firm relies more heavily on advanced production than on overtime or seasonal workers. Advanced production places a strong emphasis on forecasting for detailed item demands.

TABLE 4: PRODUCTION LOADING

(Index: % of yearly average - Shifts per line per day)

<u>Month</u>	<u>System Total</u>
January	103
February	95
March	94
April	97
May	98
June	94
July	95
August	102
September	108
October	111
November	103
<u>December</u>	<u>101</u>
AVERAGE	100

It should be emphasized, though, that the fluctuation of production levels for individual plants is higher than the observed averages; and that there are four plants whose production levels exceeded or fell short of the average for the year by more than 20%. Therefore, the conclusions derived for the overall set of plants have to be carefully analyzed when studying the performance of individual plants.

3.2 Production and Distribution Planning and Scheduling System

The company has developed through a period of about 20 years a vast computer based system intended to support planning and scheduling decisions in the areas of production and distribution. This system is a centrally controlled function, consisting of a set of computer tools, the heart of which is a large scale mathematical programming model. A schematic overview of the system is presented in Figure 3, and a brief description follows.

Production and distribution decisions are reviewed weekly on the basis of sales branches forecasts covering four 4-week periods (16 weeks is the total horizon). Planning is made for the week after the next; that is to say, week 1 is frozen.

The 16-week sales estimates generated by sales branches, the actual production and distribution levels for week 0, and the corresponding commitments for week 1, are fed in as information to the large scale mathematical programming system. The outcomes of this system are a suggested distribution plan for week 2, and a suggested production plan for two 4-week periods (weeks 2 through 5, and 6 through 9), that are supposed to minimize the total production and distribution costs. The large scale model consists of a continuous linear program of about 84,000 constraints and one million variables.

The production plan suggests the total production, for each individual

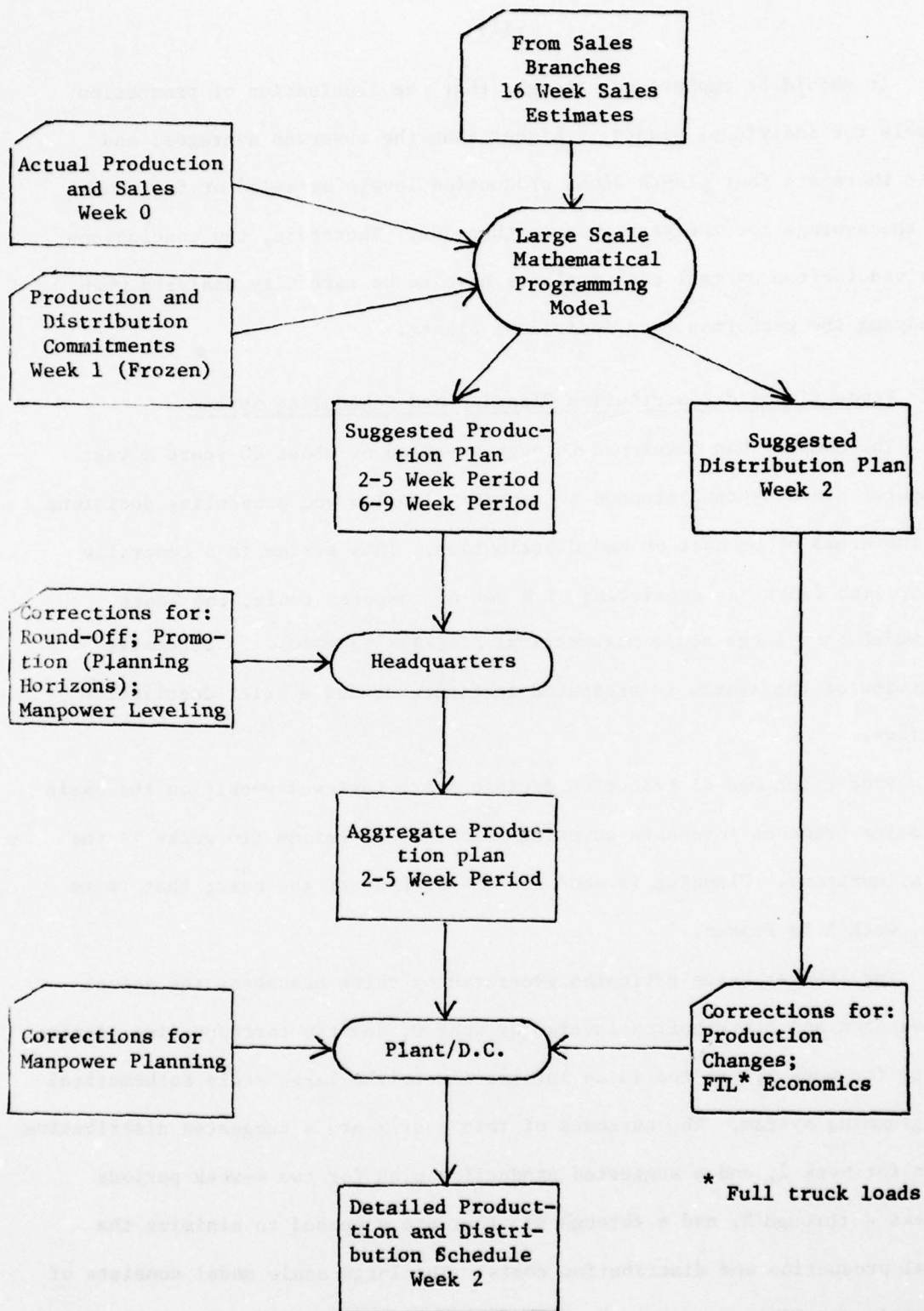


FIGURE 3: CURRENT PLANNING AND SCHEDULING PRODUCTION AND DISTRIBUTION SYSTEM

item in each plant, aggregated in two 4-week periods. A group at headquarters has assumed the responsibility of adapting the plan in two major ways: the time frame is halved and is decomposed in four individual weeks, and the individual items are aggregated into families of similar items, which can be processed in the same work station at a given plant.

The group at headquarters makes three additional modifications to the suggested plan. First, they round-off the fractional allocation of shifts proposed by the mathematical programming model for every working station. Second, corrections are introduced in order to smooth the total manpower requirements through time. And third, the production quantities are occasionally modified to take into account significant increases in sales requirements resulting from promotions and seasonalities occurring beyond the 16-week planning horizon considered by the model.

The corrected production plan for week 2 (which has been aggregated for products in the same family), and the suggested distribution plan for the same week, are finally received by plant and distribution center managers. They disaggregate the production plan into individual items, and introduce additional corrections due to manpower leveling, full truck load economies, and a host of factors affecting daily operations. Finally, they come out with a detailed production and distribution schedule for week 2.

4. Diagnostic Analyses

After completion of the field work and preliminary analyses necessary for the description of the system presented in section 3, several areas were identified for further diagnostic analyses. These areas were chosen in conjunction with the firm's managers, as being critical to the overall performance of the distribution operations, and also as areas which could

be adequately investigated within the scope of this study.

The primary issues included in our diagnostic analyses are to be discussed under the following section headings:

- 1) Production and Distribution Planning and Scheduling System. This section contains a critique of the existing planning and scheduling system as well as a proposed framework for improvements to the system.
- 2) Quality of Forecasting. An analysis of variance is performed which identifies the sources of bias in the sales branch forecasting as well as the overall quality of the forecasting data. The forecasts analyzed are for each sales branch, for each product, and for each four-week period.
- 3) Inventory Management. This section examines the aggregate inventory situation for the firm, and analyzes the specific components of the inventory carried in the sales branches. A model is developed to understand the magnitude of the sales branches' inventory, and this model is used to estimate potential changes in inventory with improvements in forecasting, lead times, and inventory service levels.
- 4) Consolidation of Sales Branches. A model is developed for an understanding of the nature of the costs for operation of sales branches. The model is used to estimate the magnitude of cost savings from consolidation of sales branches. The analysis considers several scenarios of sales growth and change in the product line which has different weight and volume characteristics.

4.1 Production and Distribution Planning and Scheduling System

This section discusses the major problems that we encountered with the design of this system, which is the basic support managers have to decide on production and distribution issues. An alternative design concept based

on the hierarchical approach is also presented.

4.1.1 Critique of the Existing System: Myopic Planning Horizon and External Corrections to the Model.

The first observation that one could make regarding the operation of the existing system is the inadequacy of its planning horizon. Due to the fluctuating nature of the demand pattern for most products, which results from both intense promotional activities and strong seasonalities, a sixteen week planning horizon is not sufficient to decide effectively on the allocation of production and manpower resources. This is confirmed by frequent corrections that are made to the production plans suggested by the model, both by managers at headquarters as well as by plant and distribution center managers. These corrections are designed to obtain smoother levels of manpower and to take into account the effect of promotions and other peaks in demand not covered in the sixteen week forecasts.

Moreover, it is important to notice that the corrections are introduced after the model is processed, thus disrupting the optimality criterion the model uses to allocate production capacity. The major reason why the existing model cannot work with a longer planning horizon is the enormous dimensionality of the large scale model that seeks to optimize, at a great level of detail, the production allocation process. This optimization effort, however, is destroyed by the mandatory external corrections that have to be introduced to the model's suggested plans due to the myopic planning horizon.

Another important correction that has to be inputted externally by headquarters' managers is the round-off of the fractional solution yielded by the system. After all these corrections are introduced, the original optimal solution sought by the model has been substantially modified, and its "optimal" character has been largely lost.

4.1.2 Critique of the Existing System: Excessive Level of Detail for Planning Decisions and Inadequate Support for Scheduling Decisions.

The existing system attempts to provide support to decisions that involve the appropriate planning of production and distribution resources, as well as the detailed utilization of those resources. Although these two types of decisions - planning and scheduling - have very different characteristics, they are handled in a single monolithical model. It is our opinion that this is an inappropriate design concept, which will produce unsatisfactory support for both types of decisions.

Let us be more specific. There are planning decisions that pertain to the overall corporation, which need a corporate scope to be resolved properly, as well as planning decisions that can be addressed at each plant independently. Among the most important corporate decisions we can cite are the allocation of products to plants and branches; that is to say, what products will be produced in which plants to serve which specific sales branches. These decisions have important consequences for the deployment of physical facilities and manpower resources, and frequently involve trade-offs in labor costs, transportation costs, in-transit inventories, and capital investments. Such decisions neither need to be revised every week nor should they be based on very detailed information (as currently done), but they need to be examined with long planning horizons from a corporate perspective.

After products have been assigned to plants and sales territories, an additional set of planning decisions have to be resolved within each plant. These decisions pertain to the levels of production, work force and inventories to satisfy the fluctuating requirements for each product group in an effective manner. Again a long planning horizon, covering at least a full seasonal cycle, is required to determine the values of those quantities.

Also in this case, too much detail becomes counterproductive to understand the implications of one's actions.

Once appropriate plans have been generated, we are left with the operational decisions that require the detailed scheduling of production at each plant and the detailed shipment of trucks from distribution center to sales branches. The production scheduling decisions need to take into account set up costs for each batch, interactions among successive batches, and costs related to changes in production levels (such as overtime, idle time, and changes in number of shifts). The shipment decisions should consider full truck load economies and balanced allocation of inventories among the sales branches. These decisions are not properly handled by the existing system, which again forces external corrections to the model to be made without adequate support.

After these comments, it should be clear the major paradox of the actual system is that it contains far too much detail for planning purposes, and not enough for scheduling reasons. Planning should be based on fairly aggregate information covering long time horizons. This will decrease the large amount of data manipulation currently needed, will increase the accuracy of the forecasting inputs (since it is easier to forecast aggregate rather than detailed quantities), and will improve the quality of planning decisions. On the other hand, scheduling should be based on short term detailed information, which is not currently available in the computerized data bank.

4.1.3 An Alternative Production and Distribution Planning and Scheduling System

The problems described so far tend to be generated by the monolithic character of the current computer support system, which attempts to describe, by means of a single model, a process which is hierarchical in nature. Clearly, there is not a single set of production and distribution decisions. Rather,

there is a hierarchy of decisions, involving different echelons of the organizational structure. This hierarchy of decisions involves a wide range of managers, from top executives at the corporate level to plant, distribution center, and sales branch managers; and it covers a range of issues that goes from the corporate allocation of resources, to the detailed scheduling of trucks. One of the major fallacies of the current system is to try to capture all these issues with a single mathematical model. We have already analyzed the problems that this approach creates due to the different planning horizons, and the distinct levels of aggregation of the information required to support the various types of decisions involved. But there is an additional problem which is even more critical.

A model is just a simplified representation of a problem that generates suggestions for managerial actions. These suggestions should be assessed and evaluated by the managers the model intends to support. Making these interactions viable is a major element in every model design. As we have already indicated, the production and distribution decisions of the firm involve several managerial levels; therefore, a system that deals with those decisions should recognize all of these hierarchical levels and provide the means to allow for effective managerial interactions from one decision level to the next. It is interesting to note that the actual implementation of the large scale approach has been modified over the year until it conforms more closely with the standards of the hierarchical approach.

These considerations have led us to propose an alternative production and distribution planning and scheduling system. The essence of the proposed system is described in Figure 4. Essentially, it consists of a hierarchy of small models, each one of them intending to capture one critical aspect of the planning and scheduling process. The outputs of these models would

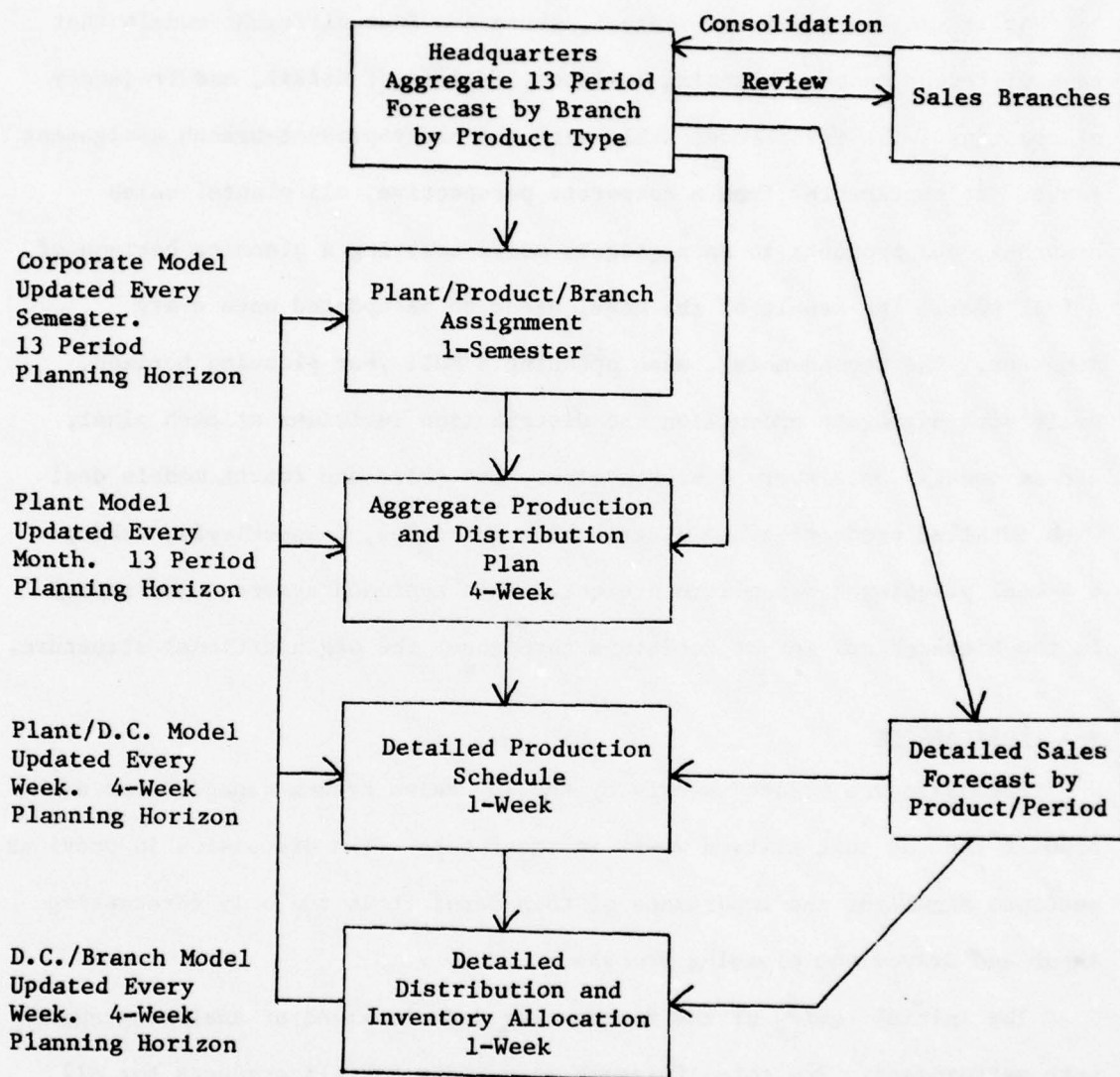


FIGURE 4: PROPOSED PRODUCTION AND DISTRIBUTION PLANNING AND SCHEDULING SYSTEM

be subject to the review of the managers in charge of the corresponding decision, prior to transferring that decision to the lower hierarchical level.

As it can be seen from Figure 4, there are four different models that have different scopes, planning horizons, degrees of detail, and frequency of updating. The first model deals with the plant-product-branch assignment issue. It represents, from a corporate perspective, all plants, sales branches, and products in an aggregate model covering a planning horizon of a full year. The result of the model needs to be updated once every semester. The second model, also spanning a full year planning horizon, deals with aggregate production and distribution decisions at each plant, and is updated once every 4-week period. The third and fourth models deal with detailed production and distribution schedules, respectively, taking a 4-week planning horizon into account. This approach assures consistency in the hierarchical set of decisions throughout the organizational structure.

4.2 Forecasting

Forecasts are updated weekly by the 200 sales branch managers for each product for the next sixteen weeks in the future. The discussion in previous sections highlight the importance of this data; it is the only forecasting input and drives the planning process.

The initial review of the forecasting data is aimed at analyzing aggregate performance. The total forecast in dollars for all products for all branches for each period is compared to the actual sales recorded for the period. In each of the 13 periods for the base year of analysis, the forecast exceeds actual sales. Table 5 shows the bias for each period. The bias is easily explained by the responsibility assigned to the sales branch manager who makes the forecast. The sales branch manager is only responsible for sales and revenue performance and is not accountable for inventory costs,

TABLE 5: AGGREGATE FORECASTING PERFORMANCE

<u>Period</u>	<u>Forecast Bias</u>
1	28.8%
2	10.8
3	8.2
4	12.4
5	21.5
6	18.4
7	14.6
8	15.3
9	18.1
10	14.4
11	21.6
12	26.3
13	18.2
Average	17.5%

Forecast Bias = $\left(\frac{\text{Forecast}}{\text{Actual Sales}} - 1 \right) * 100$

hence, the tendency to over-forecast and accumulate surplus inventory.

The upward bias alone is not a severe problem since its cause is explainable and its magnitude can probably be estimated. However, the bias complicates the evaluation of the forecast errors which is essential to inventory management. An Analysis of Variance (ANOVA) model is used to separate the bias from the forecast errors.

The hypothesis of the model is that distinguishable biases can be attributed to: an overall factor for all forecasts, and individual factors for each product, for each sales branch, and for each time period. Further, the size of the forecast errors should be proportional to the size of the forecast. The following multiplicative model was tested:

$$(1) \quad D_{pbt} = F_{pbt} \times M \times P_p \times B_b \times T_t \times e_{pbt}$$

s.t.

$$(2) \quad \pi_{p,p} = 1$$

$$(3) \quad \pi_{b,b} = 1$$

$$(4) \quad \pi_{t,t} = 1$$

where:

D_{pbt} = actual sales demand for product p, in sales branch b, in time period t

F_{pbt} = the associated forecast

M = the overall bias factor

P_p, B_b, T_t = The bias terms for each product, branch, time period

e_{pbt} = error term for the model - the error for the unbiased forecast $F_{pbt} \times M \times P_p \times B_b \times T_t$.

The model was calibrated with 234,000 data points representing 200 sales branches, each carrying about 90 products, for 13 time periods. The calibration was performed by a least squares linear regression on the log term of equations (1) - (4).

After the first calibration 200 P_p terms, 200 B_b terms, and 13 T_t terms were found. The outliers in the P_p data set were identified through exploratory data analysis techniques.* These all corresponded to D-level products, new products, or perfect substitutes for other products. These products were believed to be sufficiently removed from the general problem to be eliminated from the ANOVA. The model was re-calibrated with about 220,000 data points.

The results of the ANOVA are represented in the distribution of the bias terms, and in the quality of the forecasts. The overall bias term, M, is 0.17 or 17% of actual, confirming the data in Table 5. The product and

* Stem-and-Leaf and Schematic Plots; see Tukey [15].

branch bias terms are represented in Figures 5-7. The product biases exhibit a much larger spread than the branch biases, indicating that variations in forecasting accuracy are due more to differentiation between products than to differentiation in the skills or circumstances of the sales branch managers.

The crucial parameter used to measure the quality of the forecasts is the standard deviation of the forecast errors. This is equal to 0.5, representing an error equivalent to 1/2 of actual sales.

Assuming that the forecast errors follow a log-normal distribution, it may be concluded that it is not uncommon to find actual demand exceeding an unbiased forecast by 100%, or being only 50% or less of this forecast. (The chance for any one of these two events happening is approximately 10%.)

This conclusion is extremely important, because this range corresponds to the best approximation that may be achieved with this forecasting procedure after removing all identifiable biases. The high forecasting error increases the safety stock required to maintain a given service level. The actual impact of this volatility over inventories is later discussed in greater detail. What is important to consider now is that there seems to be plenty of room for some sort of modeling support for the eye-balling forecasting procedures used by sales branch managers.

4.3 Inventory Management

4.3.1 Basic Characteristics

The majority of the finished goods inventory is stored in the sales branches, with additional supplies in the distribution centers and in-transit between the distribution centers and sales branches. Accordingly, the analysis in this section is focused on the sales branch inventory.

The inventory in sales branches was examined initially in an aggregate manner. Table 6 shows the inventory in sales branches, and in-transit to

1.4* 0 1
 1.3* 0 6
 1.2* 0 1 2 2 3 4 4 5 5 6 6 7 7 8
 1.19 9
 1.18
 1.17 0
 1.16
 1.15 1 1 8
 1.14 1 2
 1.13 6 7 8 9
 1.12 5
 1.11 0 2 4 9
 1.10
 1.09 0 0 5
 1.08 0 1 4 5 5 9 9 9
 1.07 1 3 9
 1.06 3 4 5 6 6 7
 1.05 2 8 8 9
 1.04 1 6 6
 1.03 2 3 4 6 7
 1.02 0 3 5 8 9 9
 1.01 0 3 6 7 7 8 9
 1.00 1 3 6 6
 0.99 2 2 3 4 6 7 8 8
 0.98 4 7 8
 0.97 2 2 2 5 6 8
 0.96 1 1 6 6 7 8 9
 0.95 1 1 3 4
 0.94 1 2 2 3 4
 0.93 1 3 9
 0.92 0 1 2 4 5 5 5 5 6 6 7 7 8 8 9 9 9
 0.91 1 1 4 8
 0.90 1 1 1 1 2 7 8
 0.89
 0.88 4 4 6 6 7 8
 0.87 1 6 7
 0.86 3 8
 0.85 3 3 6 8
 0.84 0 2 2 2 4 7
 0.83 4 5
 0.82 5 6
 0.81 7
 0.80 1 2
 0.79 0
 0.75 8
 0.73 8

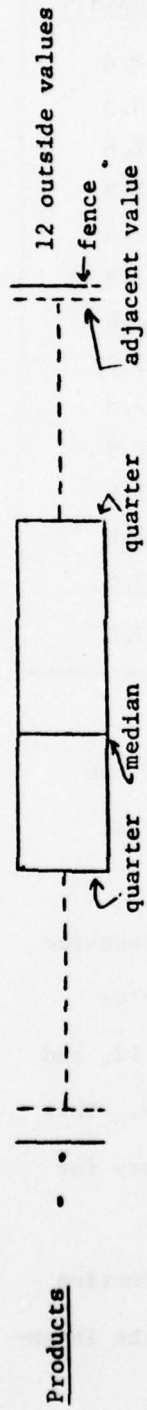
FIGURE 5: STEAM-AND-LEAF FOR PRODUCT BIAS*

*_P term in ANOVA

1.23 1
 1.16 1 3
 1.15
 1.14 2
 1.13 3 3
 1.12 1 3 6 1
 1.11 5 7
 1.10 7
 1.09 0 2
 1.08 2 3 7
 1.07 1 2 2 3 5 5 8 9
 1.06 2 2 2 2 4 4 5 7
 1.05 0 1 2 2 6 6
 1.04 2 4 5 6 7 8 9
 1.03 2 3 3 6 8 8
 1.02 0 0 3 3 7 8
 1.01 0 1 1 1 1 2 2 2 3 4 5 6 6 6 7 7 8 8 9
 1.00 1 3 4 6 8 8 9
 0.99 0 0 3 4 5 5 5 5 6 6 9
 0.98 0 1 1 4 4 6 6 6 7 7 7 8 8 8 9
 0.97 0 1 1 2 2 3 3 5 6 7 7
 0.96 0 0 1 1 2 2 3 6 6 8 8 9
 0.95 1 2 3 4 4 5 7 7 7 8 9 9
 0.94 0 1 7 7 7 7 9 9 9
 0.93 0 1 2 4 6 9
 0.92 1 3 3 8 8
 0.91 6 7
 0.90 4 4 4 5 6 6
 0.89 3
 0.88 1 3 4 7 7
 0.87
 0.86
 0.85 0

FIGURE 6: STEM-AND-LEAF FOR BRANCH BIAS*

*_{B_b} term in ANOVA



fence = 1 set outside quarters

step = 1.5 x Q-spread

Q-spread = difference of quarters

adjacent value = first value inside fence

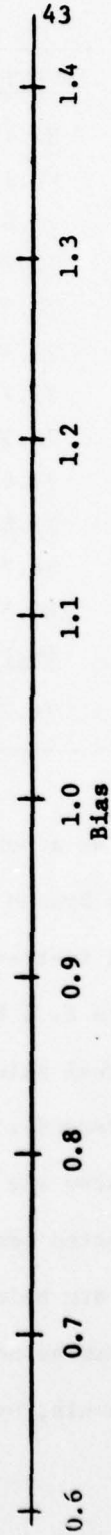
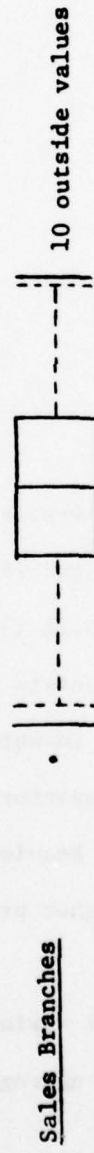


FIGURE 7: SCHEMATIC PLOT OF PRODUCT AND SALES BRANCH BIASES

TABLE 6: SALES BRANCH INVENTORY AND FORECAST DEMAND

PERIOD	% OF 4 WEEK FORECAST		DAYS OF FORECAST DEMAND	
	INVENTORY	IN-TRANSIT	INVENTORY	IN-TRANSIT
1 1976	85.49	12.80	17.1	2.6
2	69.22	16.56	13.8	3.3
3	75.61	13.82	15.1	2.8
4	72.70	13.84	14.5	2.8
5	70.38	13.10	14.1	2.6
6	74.40	14.62	14.9	2.9
7	77.74	14.09	15.6	2.8
8	70.31	14.93	14.1	3.0
9	71.60	13.93	14.3	2.8
10	71.60	14.25	14.3	2.9
11	76.75	18.01	15.4	3.6
12	85.58	18.89	17.1	3.8
13	<u>86.19</u>	<u>17.89</u>	<u>17.2</u>	<u>3.6</u>
TOTAL	76.20	15.20	15.2	3.0

sales branches as a percentage of the 4-week sales forecasts. Over the year, the sales branch inventory averages 76.2% of the 4-week forecast (15.2 days) and in-transit averages 15.2% (3.0 days).

Since there is a bias in the forecasts when the inventory is measured against the actual sales, the average inventory is 89% of actual sales (17.9 days of demand). The highest inventory occurs in periods 1, 12, and 13, which are also the periods of the heaviest promotional activity. This pattern is expected because of the higher priority given to inventory for products which are being promoted.

We will examine now the potential savings resulting from a reduction of inventory levels, by making a very aggregate representation of the inven-

tory problem. This is to be accomplished by building a single model that can be validated against the existing situation, and then determining the inventory improvements resulting from changes in the current operational policies.

Probabilistic models in the literature, usually relate inventory levels with stockout or backorder policies (see for example Brown [4] or Magee [12]). This same approach is used here with one basic difference, while most of models treat products individually, we examine aggregate levels of inventories. The firm under study did not have sufficient data (in machine readable form) to facilitate the development of probabilistic models at the disaggregate level, and resources were not available for a data collection effort.

4.3.2 Components of Inventory at Sales Branches

There are several reasons why a company needs to carry inventory. It is important to identify each of these reasons for the firm and try to estimate the magnitude of the inventory which is required. The components of inventory which are identified are summarized in Table 7.

There are three major components of inventory at the sales branches: Cycle Stock, Promotional Stock, Safety Stock.

Cycle Stock: Cycle stocks arise when shipments occur in lots rather than in a continuous supply. On average, cycle stock should be equal to one-half of the replenishment quantity. Sales branches are generally served weekly from each supply distribution center. This would lead to a cycle stock of 2.5 days of demand. Since a few branches receive some products less frequently than weekly, the cycle stock is estimated at 3.0 days.

Promotional Accumulation Stock: These stocks arise as a method of smoothing production levels in the face of systematic variations in demand. The average contribution to inventory was estimated at 1 day of sales.

TABLE 7: COMPONENTS OF INVENTORY AT SALES BRANCHES

<u>Sales Branch Inventory Components</u>	<u>Average No. of Days of Inventory</u>	<u>Assumptions</u>
Cycle	3	1 week replenishment time
Promotion	1	Average for the year
<u>Safety Stock</u>		
Variability in production time	2.5	Production available at end of week
Variability in distribution time	3.0	Distribution available in sales branch at beginning of week
Cushion stock	4.0	Given by firm
Forecast Bias	2.7	Difference between using forecast as a base & sales as a base
Other	<u>1.7</u>	
Total Safety Stock	<u>13.9</u>	
Total	17.9	

Safety Stock: This stock protects against uncertainty in demand over the lead time. There are several facets to this uncertainty which include variations in demand and variations in the actual replenishment time for sales branches. Table 7 shows the components of the safety stock and the assumptions used in their evaluation. The total safety stock results in 13.9 days of demand. The safety stock could be calculated theoretically from a study of the forecast errors, the lead time for production orders, and an inventory service level.

Based on the ANOVA model of the forecasting data, it was hypothesized that demand over the lead time assumes a log-normal distribution, whose density function is:

$$f(d;\mu,\sigma) = \frac{1}{\sqrt{2\pi} \sigma d} e^{-\frac{1}{2}\left(\frac{\ln d - \mu}{\sigma}\right)^2}$$

where:

$\tilde{d}$ = Demand over the lead time (Random Variable)

μ = Expected value of $\ln \tilde{d}$

σ = Standard deviation of $\ln \tilde{d}$.

The parameters μ and σ may be determined from the expected value and standard deviation of the demand over the lead time, which are designated by $\bar{d}$ and σ_d , respectively. The relations that link these four parameters are:

$$\mu = \ln \frac{\bar{d}}{\sqrt{1 + \left(\frac{\sigma_d}{\bar{d}}\right)^2}}$$

$$\sigma^2 = \ln \left[1 + \left(\frac{\sigma_d}{\bar{d}}\right)^2 \right]$$

To compute the inventory required to guarantee a service level, a standard table of the normal distribution is necessary. Suppose that the service level (defined as one minus the probability of stockout) is designated by p , and that the corresponding normal deviate obtained from the table is k_p . In this case, the resulting inventory (S) may be computed from:

$$\Pr(\tilde{d} \leq S) = p$$

or

$$\frac{\ln S - \mu}{\sigma} = k_p$$

or

$$S = \frac{\bar{d}}{\sqrt{1 + \left(\frac{\sigma_d}{\bar{d}}\right)^2}} e^{k_p \sqrt{\ln \left[1 + \left(\frac{\sigma_d}{\bar{d}}\right)^2 \right]}}$$

This expression allows us to represent inventory levels as a function of service level (p), expected demand over lead time ($\bar{d}$), and the coefficient of variation ($\sigma_d/\bar{d}$). To validate this model, we gave to these parameters

the values that characterize the existing situation, and observe the resulting inventory. Current service levels were set up at 90% implying a value of $k_p = 1.282$. The coefficient of variation, which is a measure of the forecasting quality, was obtained from the ANOVA model to be 0.5. With these substitutions, the above expression is reduced to:

$$S = 1.64 \times \bar{d}$$

To obtain a measure of the safety stock, one should subtract from the inventory level S , the average demand over the lead time. Therefore,

$$SS = 0.64 \times \bar{d}$$

$\bar{d}$ is expressed in terms of days of demand, currently equal to 22, the average lead time in days. Consequently, the model would predict for the existing conditions the presence of a safety stock of 14 days (0.64×22). This is perfectly consistent with the actual safety stock of 13.9 days presented in Table 7.

4.3.3 Potential Improvements in Sales Branch Inventory

The largest component of inventory is the safety stock. This component can be reduced through improvements in the accuracy of the forecasting data or in reduction of the lead time for meeting sales branch orders. Improvements in forecasting are represented by reductions in the standard deviation of forecast errors over the lead time. An improvement representing a 40% reduction in the standard deviation was taken as a scenario. Lead time reduction from 22 days to 15 days was taken as a scenario of lead time reduction. The two effects are not additive because with shorter lead times, the impact of improved forecasting is diminished. The model was then used to calculate safety stock levels for improved forecasting accuracy and reduced

lead times. The results are shown in Table 8.

TABLE 8: POTENTIAL IMPROVEMENTS IN SALES BRANCH INVENTORY (Days Inventory)

<u>Probability of Stockout</u>	<u>Lead Time</u>	<u>Forecasting Accuracy</u>	
		<u>Existing</u>	<u>40% Improvement</u>
10%	4.4 weeks	0*	-5.4 days
10%	3.0 weeks	-4.1 days	-7.8 days
5%	4.4 weeks	+6.2 days	-2.1 days
5%	3.0 weeks	+0.3 days	-5.6 days

* The actual level of inventory is 18 days of demand.

To really appreciate the extent of the potential improvements in inventory, the numbers in Table 8 should be compared with the actual level of 18 days of inventory. Each day of inventory corresponds approximately to a cash retention of \$5 million and an extra cost of \$1 million per year. Under any standard of comparison, the potential reductions are very attractive. What is interesting in this result is that the two variables controlling this conclusion are forecasting accuracy and lead time, and that both of them seem to exhibit a wide latitude for managerial intervention.

4.4 Consolidation of Sales Branches

There are several optimization models for strategic planning of warehouse and sales branch configuration. Notably the recent work by Geoffrion and Graves [7] offers an attractive large scale mathematical programming approach to this problem. However, given that the existing system has 200 sales branches and 10 plants, any macro-model would involve prohibitive data collection and computing costs for a Phase I diagnostic study. Moreover, management is merely attempting to assess the magnitude of the potential cost savings to determine whether further study is worthwhile. An alternative

approach would be the development of a simple, aggregate model for a broad understanding of the potential cost savings resulting from consolidation of sales branches. Geoffrion [6] has also advocated the use of mini-models as a way to gain insight in facilities location problems.

Several components of sales branch costs which would vary with the number of branches, and hence with the volume of activity at each branch, were identified, as well as the basic causal cost factors. Table 9 lists these components and factors. For each cost component, we fitted a model using data from a representative sample of five of the sales branches. The total cost was the sum of these cost factors over all sales branches.

TABLE 9: CONSOLIDATION OF SALES BRANCHES. COMPONENTS OF OPERATING COSTS AND CAUSAL FACTORS

1. Labor Costs
Office Labor
Warehouse Labor
Truck Labor
Selling Salaries
Managerial Salaries
Employee Benefits
2. Expenses
Miscellaneous Controllable Expenses
Truck Expenses
Selling Expenses
3. Rent, Depreciation, and Taxes
4. Other Expenses
Advertising Costs
General Administrative Costs
Cash and Trade Discounts
5. Total Cost = Sum of Items 1 Through 4.
Changes in inventory costs are excluded from this analysis, but their inclusion would tend to favor consolidation.

The functional forms of the relations used are summarized in Table 10. To maintain the confidentiality of the study we are not providing the resulting values of the coefficients. These relations should be considered

TABLE 10: FUNCTIONAL FORMS OF THE COST COMPONENTS AT SALES BRANCHES

1. Labor Costs

$$\text{Office Labor: } L_O = a_0 + a_1 N_b + a_2 N_b^2 + a_3 U_b$$

$$\text{Warehouse Labor: } L_W = b_0 + b_1 A_b + b_2 A_b^2 + b_3 U_b$$

$$\text{Truck Labor: } L_T = c_0 + c_1 T_b$$

$$\text{Selling Salaries: } L_S = d_0 + d_1 S_b$$

$$\text{Management Salaries \& Employment Benefits: } L_{MB} = e_0 (L_O + L_W + L_T + L_S)$$

2. Expenses

$$\text{Miscellaneous controllable expenses: } E_M = f_0 + f_1 A_b + f_2 A_b^2$$

$$\text{Truck Expenses (poor relation): } E_T = (\$/\text{stop}) N_b;$$

$$(\$/\text{stop}) = g_0 + g_1 / d_b + g_2 d_b$$

$$\text{Selling Expenses: } E_S = h_0 + h_1 D_b$$

3. Rent, Depreciation, and Taxes: Typical values are \$1/sq. ft. for old branches and \$2/sq. ft. for new branches, the average being \$1.72/sq. ft. Therefore, the estimation of this item is made as: $R = 1.72 \times A$

4. Other Expenses: Total advertising costs, general administration costs, and cash and trade discount costs for one year were taken at fixed costs, determined by the actual expenditures in those items for all sales branches. Therefore:

$$\text{Advertising Costs: } O_A = i_0 \text{ (total for all sales branches)}$$

$$\text{General Administration Cost: } O_C = j_0 \text{ (total for all sales branches)}$$

$$\text{Cash and Trade Discounts: } O_D = k_0 S_0$$

5. Total Cost Adding labor costs, all expenses, and rent, depreciation, and taxes, the following relation is obtained for total cost:

$$\begin{aligned} TC = & \ell_0 + \ell_1 B + \ell_2 \sum_b A_b + \ell_3 \sum_b A_b^2 + \ell_4 \sum_b D_b \\ & + \ell_5 \sum_b N_b + \ell_6 \sum_b N_b^2 + \ell_7 \sum_b S_b + \ell_8 \sum_b T_b \\ & + \ell_9 \sum_b U_b + \ell_{10} \sum_b \frac{1000 U_b}{N_b} + \ell_{11} \sum_b \frac{N_b^2}{D_b} \end{aligned}$$

TABLE 10: continued

Nomenclature:

L_O	= Office labor cost (000 \$/year)	O_D	= Cash and trade discounts (000 \$/year)
L_W	= Warehouse labor cost (000 \$/year)	b	= Index to identify a sales branch
L_T	= Truck labor cost (000 \$/year)	B	= Number of sales branches
L_S	= Selling salaries (000 \$/year)	A_b	= Area of sales branch b (000 sq. ft.)
L_{MB}	= Management salaries & employee benefits (000 \$/year)	D_b	= Distance covered by sales branch b in delivery trips (000 miles/year)
E_M	= Miscellaneous controllable expenses	N_b	= Number of stops made by sales branch b in delivery trips (000/year)
E_T	= Truck expenses	S_b	= Sales in branch b (000 \$/year)
E_S	= Selling expenses	T_b	= Number of trucks in branch b
R	= Rent, Depreciation, and Taxes	U_b	= Units delivered in branch b (000,000/year)
O_A	= Advertising costs (000 \$/year for all sales branches)	d_b	= $D_b N_b$ = miles per stop in branch b
O_C	= General administrative cost (000 \$/year for all sales branches)	u_b	= $1000 U_b / N_b$ = units delivered per stop in branch b

only tentative representations of cost-items, because they have been built on a thin data base. Nonetheless, they represent a good summary of the qualitative and quantitative information we obtained, and we believe they serve the purpose of assessing the order of magnitude of savings that may be expected by pursuing a consolidation strategy.

4.4.1 Total Cost in Terms of Number of Sales Branches Only

The specific question asked with regard to sales branches is if there is some room for consolidation. This issue must be pursued under different scenarios for business growth and product mix, which were signaled by managers of the firm as sensitive parameters in this problem.

A truly detailed analysis of branch consolidation is outside the scope of this study. The approach used instead, is to isolate in the total cost the impact that may be traced back exclusively to the number of sales branches. In this way, the cost function is expressed only in terms

of one decision variable (number of sales branches), and two scenario variables (business growth, and product mix).

The specific variables chosen in the formulation of the total cost are the following:

Decision variable:

B = Number of sales branches

Scenario variables:

g = Business growth factor (the base value is 1.0)

δ = Product mix factor (base value is 1.0).

The average volume per pound goes up with the value of δ .)

For the cost function to be derived, it is necessary to introduce certain simplifying assumptions, the most important ones being:

- Sales branches are assumed to be homogenous
- Total distance traveled and total number of trucks required in retail distribution go down when number of sales branches is increased
- Total warehouse space goes up proportionally with g and δ
- Total distance traveled goes up proportionally with g and δ
- Total number of stops does not change. (Number of clients and frequency of service remains approximately the same.)
- Dollar sales go up proportionally to the growth factor (in constant dollars)
- Total number of trucks goes up proportionally to g and δ
- Total number of units delivered goes up proportionally to g . (Pounds per unit remain the same.)
- Number of units delivered per stop goes up proportionally to g
- Service constraints are not considered.

The resulting functional form for the total cost expression in terms of B , g , and δ is as follows:

$$TC = \alpha_0 + \alpha_1 g + \alpha_2 \delta g + \alpha_3 B + \alpha_4 gB + \alpha_5 B^{-1} + \alpha_6 \frac{B^{1/2}}{\delta g} + \alpha_7 \delta^2 g^2 B + \alpha_8 \frac{\delta^2 g^2}{B} + \alpha_9 \frac{\delta g}{B^{1/2}} + \alpha_{10} B^{5/2}$$

By computing the total cost for different values of the number of sales branches, and under different combinations of growth and product mix, it may be concluded that the optimum number of sales branches is somewhere between 150 and 175 but that the savings generated by this transformation are not very impressive (see Table 11).

TABLE 11: ANNUAL COST OF OPERATION OF THE SALES BRANCH NETWORK
(100 represents actual cost for the base case with the existing number of sales branches)

Number of Sales Branches	TOTAL COST (000\$)			
	Base Case (g=1.0, δ=1.0)	Most likely Production for 1986 (g=1.2, δ=1.05)	1986 without increase in low density line (g=1.2, δ=1.0)	Extreme case for a 1986 situation (g=1.3, δ=1.1)
135	98.8	121.1	118.9	134.1
140	98.7	120.9	118.7	133.8
145	98.7	120.7	118.6	133.5
150	98.6*	120.6	118.5	133.3
155	98.7	120.5	118.4	133.1
160	98.7	120.4	118.3*	133.0
165	98.8	120.3*	118.4	132.9
170	98.9	120.4	118.5	132.8
175	99.0	120.5	118.6	132.7*
180	99.2	120.6	118.7	132.8
185	99.4	120.7	118.3	132.9
190	99.6	120.8	119.0	133.0
195	99.8	120.9	119.1	133.1
200	100.0	121.1	119.2	133.2

* Minimum total cost

4.4.2 Consolidation of a Subset of Sales Branches

The results in the previous section indicate that, in general, branch consolidation has some attraction, and that the firm should try to go toward a smaller number of sales branches. This section explores the benefits to be derived from some specific consolidations, in order to suggest the patterns that may be more profitable. It should be emphasized that each particular case must be analyzed independently because the patterns to be presented are derived from relations which are valid as an average, but which may not be good approximations in particular cases.

Table 12 presents the consolidation of three small branches of 10,000 sq. ft. each into one of 30,000 sq. ft. The result obtained is that this particular case generates \$142,000 savings per year, which represents 1.6¢ per dollar of sales. (The actual savings are dependent on the area for sales branches, as well as the values given to the other parameters such as number of stops, number of units delivered, total distance traveled, sales, number of trucks, and rent cost.)

Table 13 presents the consolidation of two 20,000 sq. ft. branches into one 40,000 sq. ft. branch. In this case, the savings in labor costs are almost totally wiped out by the increased expenses and rent.

The conclusion that this exercise seems to suggest is that in the consolidation of small branches there is room for savings generated in the large reduction in labor costs; but when branches become too large, the increase in other costs dominate this reduction, making the consolidation unattractive.

TABLE 12: THE CASE OF THREE SMALL BRANCHES CONSOLIDATED IN A LARGE ONE

<u>Annual Cost Estimates</u> (000\$)	<u>For the three small branches</u>	<u>For the consolidated branch</u>	<u>Savings from consolidation</u>
Labor costs	1103	927	176
Expenses	312	316	- 4
Rent, Depreciation & Taxes	30	60	- 30
Total	1445	1303	142
Cost per dollar of sales	16.0¢	14.4¢	1.6¢

<u>Data</u>	<u>Small branches</u>	<u>Consolidated branch</u>
Area (000 sq. ft.)	10	30
Number of stops (000)	15	45
No. of units delivered (000,000)	.5	1.5
Total distance traveled (000 miles)	100	300+25% penalty = 375
Sales (000\$)	3000	9000
Number of trucks	5	15
Rent cost (\$/sq. ft.)	1	2

(Advertising, General Expenses, and cash and trade discounts are assumed the same for both situations. They are not included in the cost estimates.)
Rental Costs are assumed to double for a new facility.

TABLE 13: THE CASE OF TWO AVERAGE BRANCHES CONSOLIDATED IN A LARGE ONE

<u>Annual Cost Estimates</u> (000\$)	<u>For 2 average branches</u>	<u>For the consolidated branch</u>	<u>Savings from consolidation</u>
Labor costs	1219	1116	103
Expenses	308	364	- 56
Rent, Depreciation, & Taxes	40	80	- 40
Total	1567	1560	+ 7
Cost per dollar of sales	15.7¢	15.6¢	+ 0.1¢

<u>Data</u>	<u>Average branches</u>	<u>Consolidated branch</u>
Area	20	40
Number of stops (000)	18	36
No. of units delivered (000,000)	1	2
Total distanced traveled (000 miles)	150	300+25% penalty = 375
Sales (000\$)	5,000	10,000
Number of trucks	10	20
Rent Cost (\$/sq. ft.)	1	2

(Advertising, General Expenses, and cash and trade discounts are assumed the same for both situations. They are not included in the cost estimates.)
Rental Costs are assumed to double for a new facility.

5. Conclusions

In this paper, we intended to present puzzling questions we faced when developing a diagnostic study of a logistics system. Our initial search in the literature did not produce a wealth of publications on which we could confidently base our study, so we had to explore some new avenues in the attack of the problem. In this section we want to summarize the main conclusions we derived from this professional experience in the general approach to a diagnostic problem, and the managerial recommendations stemming from this particular study.

5.1 Diagnostic Study of an On-going Logistics System

To draw general conclusions from a unique experience may be somewhat risky. Nevertheless, we feel that there are two important suggestions that seem to have a more permanent value, though we cannot offer sufficient empirical evidence to sustain this claim at this point.

In the first place, a diagnostic study is more properly completed by developing many small models rather than a big one. Our observation in this particular case is that managers of the firm were fully aware of the problems that the small models conceptualized, so there was no instance in which an aversion to the idea of modelling was expressed. On the contrary, these models, in many cases, were valuable in supporting some intuitive notions that managers had on specific problems.

The second fundamental recommendation is the use of the hierarchical approach to decision making as a framework for the study. This case happens to provide a very interesting validation of the basic ideas in that framework, because the planning and control system as was operated in practice at the time of the study exhibited a substantial deviation from its formal centralized and monolithic design. Some necessary interventions to the large scale approach were required to make it more responsive to the

immediate needs of managers at different levels in the hierarchical chain. It is interesting to realize that many of the problems that we uncovered in this particular application were born in the tension between the need for managers to conduct their tasks in the terms which are more natural and familiar to them, and the constraints that a large scale centralized system necessarily imposes upon them.

5.2 Managerial Recommendations

A great deal of attention was given to the formulation of suggestions for managerial action, including the definition of priorities and timetables. Due to space constraints, we will limit ourselves to list the most important of those suggestions for each one of the issues presented in section 4.

5.2.1 Production and Distribution Planning and Scheduling

- 1) Recognize the implications of the hierarchical nature of the managerial process.
- 2) Consider the establishment of profit centers at the sales branch level.

5.2.2 Forecasting

- 1) Assign responsibilities for aggregate forecasting to a head-quarters group.
- 2) Improve procedures for sales branch forecasting.

5.2.3 Inventory management

- 1) Attempt to reduce lead time and improve forecasting accuracy.
- 2) Make sales branch managers accountable for inventory performance.

5.2.4 Consolidation of Sales Branches

- 1) Continue the reduction in the number of sales branches.
- 2) Concentrate attention where the consolidated sales branch would be large enough to overcome the increased rental cost of a new facility.

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