PHYSICAL DISTRIBUTION ANALYSIS FOR THE TRAFFIC MANAGER

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ACCEPTANCE

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ABSTRACT

The physical distribution concept recognizes the interrelationships between transportation, materials handling, warehousing and the other processes that are involved in the physical flow of traffic from the source of raw materials, through production and distribution facilities, to the firm's customers. The essence of the concept is that it is the total cost of the several processes, rather than the cost of individual processes, that must be taken into account in decisions in which there are alternatives for the physical movement of materials and products. Physical distribution analysis involves the formulation and comparison of the alternatives for traffic flow.

This thesis is concerned primarily with the development of a procedure for physical distribution analysis that may be useful in the formulation of decisions that are within the Traffic Manager's sphere of responsibility. In order to identify the nature of these decisions and in order to develop a suitable framework for the Traffic Manager's analyses, the second chapter describes the major decisions in which physical distribution principles should be applied; relates these applications to successive

planning intervals; and considers the scope of these decisions in terms of the authority that is necessary for their implementation.

The author suggests that the major applications of the physical distribution concept include long-term decisions related to the spatial allocation of production capacities, intermediate-term decisions involving changes in the fixed facilities for physical distribution, and short-term decisions concerning the utilization of existing production and physical distribution facilities. Of these applications, it is only the short-term decisions that are likely to be made by the Traffic Manager. Chapters three to five, therefore, are concerned with the procedures for formulating and comparing short-term alternatives.

To facilitate presentation, the author deals specifically with the development of a procedure for analysis for two of the short-term physical distribution problems -- the day-to-day problem of meeting customer orders out of inventories that are on hand at distribution warehouses; and the problem of allocating short-term output among the firm's plants.

The author recommends the linear programming technique as the method for selecting the optimum alternative for each of these problems. The application of this technique is described in detail in Chapter V. The major determinants of physical distribution alternatives, the identification of feasible alternatives, and the development of unit variable costs required by the linear programming models are dealt with in Chapters III and IV.

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

In the not too distant past, the business firm was required to adapt its distribution facilities and operations to the railway monopoly on inland transportation. The railways opened new markets by providing relatively rapid and inexpensive transportation for materials and products. Business firms expanded their production operations to accommodate these markets and established warehouses and other distribution facilities that were complimentary to the railway method of transportation.

The basic function of the traffic manager in this environment was to negotiate with the railways for suitable freight rates and services. The right to route traffic -- that is to select the carrier -- was an effective bargaining tool in territories that were served by two or more railways. Negotiation with transportation agencies is still a basic function of the traffic department and the effectiveness of this activity has been considerably enhanced in recent years as alternative transportation agencies strive to improve their individual competitive position.

The alternative methods of transportation that are available in today's environment, however, provide opportunities that are far greater in scope than a mere reduction in freight rates. New markets and new sources of raw materials have become available that could not previously be reached through railway facilities; spatial allocations for production capacities and distribution facilities are now free of the constraining influence of railway availability, rates and service; inventory levels at plants and at distribution points have become more flexible with the range of delivery service that is offered through alternative carriers; and packaging demands as well as the equipment for loading and unloading materials and products are no longer dictated by the requirements of a single carrier. These and other opportunities that have emerged with competition in the transportation industry demand a new approach to the problems that are associated directly and indirectly with the physical movement of materials and products. The new approach must recognize the interrelationship between transportation and the other processes that are involved in the flow of traffic to plants and through distribution points to customers. Dr. Plowman, vice-president, traffic, of the United States Steel Corporation of Delaware has said:

> Traffic management ... has become a complex problem, a transport control problem, of selection of the best combination. In this selection process, which involves not only the best form of transportation but also the most desirable among the numerous competing carriers, there is need for careful and accurate calculation of transportation cost and of its relation or balance with other factors such as inventory and warehousing costs and customer service requirements.[1]

Physical distribution is the nomenclature that is most frequently used in referring to this complex of interrelated variables.

I. THE PROBLEM

Statement of the Problem. The purpose of this study is to indicate the essential considerations in an analysis of the physical distribution function; and to develop a model that may be used by a business firm to establish its optimum method of physical distribution. More specifically, the objectives are to:

1) Determine the considerations necessary in the

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[1] Edward W. Smykay (ed.) Essays on Physical Distribution Management (New York: The Traffic Services Corporation, 1961), p. 59.

development of a plan for physical distribution analysis,

2) Determine, examine and relate the cost components of the physical distribution function, and

3) Incorporate these components into a mathematical model capable of indicating the optimum method of physical distribution.

It is the hope of the writer that this study will strengthen the trend toward physical distribution analysis and assist management in the evaluation of its physical distribution operations.

<u>Importance of the Study.</u> The lack of attention in the area of physical distribution is apparent when one considers that few business firms are able to isolate the cost of moving their materials and products to the factory and from the factory to consumer. Dr. Smykay states:

> In those companies that are not presently applying the principles of physical-distribution analysis and planning, a cost reduction of at least 10 per cent can generally be attained quite easily.[2]

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[2] Edward W. Smykay, "Physical-Distribution Management: Concepts, Methods, and Organizational Approaches", <u>New Concepts in Manufacturing Management</u>, AMA Management Report Number 60, Manufacturing Division, American Management Association Inc., New York: 1960, p. 43.

This reduction must be realized if the business firm is to maintain its competitive position, and if the economic resources that are available to the enterprise are to be allocated efficiently. Management must become aware of the potential in this area and must be given the tools with which distribution alternatives can be measured.

Recent managerial literature has indicated an interest in the physical distribution function. The majority of writings have successfully identified the cost components and have stressed the need to consider the interrelationships between these factors.

It appears, however, that the types of problems to which the physical distribution concept should be applied have not been clearly defined; and that the procedures or techniques that will be useful in an analysis of physical distribution alternatives have not received adequate attention. An attempt is made in this thesis to isolate the major applications of the physical distribution concept; and one of the objectives of this study is to outline a technique that may be of use to a business firm in selecting its optimum method of physical distribution.

Limitations of the Study. A substantial volume of literature that describes the physical characteristics of the various transportation, materials handling, warehousing, and communications facilities are available in writings specifically related to these areas. For this reason, a review of these considerations will not be included in this study.

Procedures for forecasting sales have been excluded for the same reason, although a well developed sales forecast is essential to physical distribution analysis.

The procedures that are suggested for comparing physical distribution alternatives include the technique commonly referred to as linear programming. This thesis does not include the mathematical theory upon which this technique is based.

II. DEFINITIONS OF TERMS USED

System of Physical Distribution. A system of physical distribution may be defined for purposes of this thesis as the fixed facilities that are associated with a specific alternative for materials and product movement, eg., warehouses, materials handling equipment, order-processing and communications facilities, etc.

Method of Physical Distribution. A method of physical distribution may be defined as one of the ways in which the facilities that comprise a system of physical distribution may be utilized. Several methods of physical distribution will generally be available with each system of facilities.

III. ORGANIZATION OF THE REMAINDER OF THIS THESIS

This thesis is divided into six chapters. Chapters two to four deal progressively with the problem of establishing a framework for analysis, and the problem of identifying physical distribution alternatives and quantifying these into a form that is suitable for use in the linear programming application described in chapter five.

Chapter two examines the nature of the major opportunities that are available to the business firm through application of the physical distribution concept and considers the objectives and framework for an analysis of each of these opportunities. This chapter emphasizes the importance of relating distribution opportunities to successive intervals of the firm's future time period in order to develop an appropriate framework for each analysis. The role of the traffic manager in physical distribution analysis and the criteria to be used in a comparison of alternative courses of action are also discussed in this chapter.

Chapters three to five are concerned specifically with the short-term application of the physical distribution concept since it is in this area that decisions fall within the scope of the traffic manager's authority and responsibility. The major determinants of short-term physical distribution alternatives are identified in chapter three. Chapter four deals with the problems of collecting, preparing and relating cost data for alternative methods of materials and products movement and chapter five outlines the linear programming technique in selecting the optimum of these alternatives. A summary of the findings of this study is included in chapter six.

CHAPTER II

THE FRAMEWORK AND OBJECTIVES FOR PHYSICAL DISTRIBUTION ANALYSIS

"The objective of physical distribution is to have the right quantity of goods in the right place at the right time."[1] To ensure that this objective is achieved, it is necessary to define the physical distribution requirements of the firm; to formulate the alternatives for physical distribution that will meet these requirements; and to compare the alternatives with a view to selecting the optimum according to the criteria of efficiency that is acceptable to the firm.

The first step in physical distribution analysis is to establish objectives and a framework for the study that will serve as a basis for the formulation and comparison of alternatives. This task is complicated by the need to develop a framework that will permit evaluation of physical distribution opportunities that are significantly different in scope and that emerge at

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[1] Edward W. Smykay, Donald J. Bowersox, Frank H. Mossman, Physical Distribution Management (New York: The MacMillan Company, 1961), p. 267.

successive intervals in the firm's future. The nature of the several opportunities that are associated with the physical distribution concept, and the types of objectives and framework that are necessary to an evaluation of each of these opportunities are discussed in the first section of this chapter. The role of the Traffic Manager in physical distribution analysis is discussed in the second section, and the criteria for the comparison of alternatives is included in the last part of the chapter.

Establishing the Framework and Objectives for Physical Distribution Analysis.

The alternatives for physical distribution are adequate or inadequate depending upon the volumes of traffic, the locations of materials, plants and markets, and the standards of delivery service. These specifications are the basic framework for physical distribution analyses and must be defined in specific terms before alternatives can be isolated and compared.

An initial problem in establishing this framework is that the volume, place and service possibilities change over time with the implementation of production and marketing plans and with market growth or deterioration, shifts in the location of materials or markets, changes in the competitive environment, technological innovation and other environmental changes. It is necessary, therefore, to define the time period for analysis in order to isolate the physical distribution possibilities that are available in that particular period.

It is possible to select any time period for analysis purposes; to isolate the volume place and service requirements, or the alternatives of these specifications over this period; to develop the alternatives for physical distribution for each of the relevant set of specifications; and to select the optimum course of action according to the criteria of efficiency that is acceptable to the firm. This procedure, however, will not ensure physical distribution efficiency. If the period is too long, the alternatives will be required to embrace too broad a range of specifications. As a result, the firm may overlook opportunities to improve physical distribution efficiency through changes in methods or systems that are adequate for shorter periods of time. In other words, the alternative that is selected on this basis will be optimum when compared with other alternatives covering the same period, but not necessarily optimum over the whole time period. Conversely, if the selected period is too short, the analysis may overlook alternatives that would prove more efficient over a longer time period than the series of adjustments indicated on the basis of successive short-term analyses.

The appropriate time periods for physical distribution analyses are those that reflect differences in the nature of the opportunities that are available to the firm. In general, there are three distinct opportunities for physical distribution and these are related to separate and successive intervals in the firm's time period. These opportunities are:

1. A more efficient utilization of existing physical distribution facilities.
2. A more efficient system of physical distribution.
3. A more efficient spatial arrangement of production facilities.

These three opportunities are related in the sense that the existing system of production and physical distribution facilities is one of the alternatives to be taken into account in a comparison of systems of physical distribution, and in a comparison of the alternative spatial allocations for production capacities. It is only the optimum utilization of the existing system, however, that is relevant in a study of alternative physical distribution systems. Similarly, it is only the optimum system of physical distribution with existing plant locations that is relevant in a study of alternative spatial arrangements for production capacities. It follows, therefore, that a study of the physical distribution function may be divided into three parts. A first analysis to establish the optimum utilization of existing facilities; a second to determine the system of physical distribution that is optimum with given plant locations; and a third to establish the optimum spatial allocation for production capacities.

There are two steps that may be followed in defining the time period for the three analyses. The first step is to define the period during which the existing facilities can efficiently handle the anticipated range of volume, markets and delivery service and the period during which changes in these requirements are sufficient to justify changes in the system of physical distribution, but not significant enough to warrant a spatial rearrangement of production facilities. This step requires a preliminary survey of the existing system of physical distribution and alternative systems at successive intervals in the future until the point is reached where the present system is inadequate or inefficient. Similarly, the point in time is reached where an alternative spatial arrangement of production facilities becomes superior to the changes that can be made in the system of physical distribution alone.

This step identifies the points in time at which it becomes desirable to adopt a new system of physical distribution or to change the spatial allocation of production facilities. This step alone is deficient, however, in that there may be significant differences between what is desirable and what is feasible for the firm. It is conceivable, for example, that the changes in physical distribution requirements within the next few years will suggest a spatial relocation of production facilities. This information is of little practical value to the firm, however, if the capital and flexibility that is necessary for such a change is not available.

In considering the problem of defining time periods for operations analyses, Baumol points out that decision flexibility within the firm is circumscribed by present policy, contracts and other commitments, and that flexibility increases with the time period as these commitments expire.[2] This fact suggests that the second step in defining the time periods for physical distribution analysis is to relate these to decision flexibility within the firm. The goal is to determine the time in the future at which it becomes practical for the firm to adopt an alternative system of physical distribution; and the point in the distant future at which the firm is free to consider the alternative spatial allocation of production facilities.

The first interval of time for analysis can be defined as the short-term period during which alternatives are limited to the flexibility of the existing physical distribution facilities. While it is possible that short-run volume market and service requirements can be accommodated more efficiently through an alternative combination of handling, transportation, inventory, order-processing and communication facilities, a change in system in the short-term is impractical. The time that is required to establish one or more of the facilities that are a part of an alternative system; the inflexibility of short-term policy, contracts and other commitments; and

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[2] William J. Baumol, <u>Economic Theory and Operations Analysis</u> (Englewood Cliffs, N.J.: Prentice Hall Inc., 1961), p. 187.

the rigidity of established routine with suppliers and consumers and in the methods of physical distribution do not permit a rapid change from one system to another.

The flexibility that is required to introduce a change in the system of physical distribution will, of course, vary with the nature of the alternatives. There is a specific interval of time, however, before it becomes practical to introduce any of the alternatives to the present system. To define this interval of time it is necessary to review the potential systems of physical distribution in the light of the capital and flexibility that would be required with their adoption. A survey of capital availability within the firm, and other short-term constraints mentioned above, will then indicate the point in time at which a change in system becomes feasible.

Opportunities up to this point include alternative allocations of output among productive units; adjustments in inventory levels; changes in transportation rates and service; greater efficiency in the handling and warehousing of goods and in the utilization of order-processing and communications facilities; and other alternatives that do not involve changes in system facilities, ie., warehouses, handling and transporting equipment, order-processing and communications facilities, etc.

The point in time at which capital and flexibility is sufficient to permit the adoption of alternative physical distribution facilities, should such action prove desirable, marks the end of the short-term period and the beginning of the second period for physical distribution analysis. At this point in time, the opportunity shifts from methods to systems of physical distribution. The short-term analysis seeks to establish the optimum method of physical distribution with given facilities and specifications, while analysis in the second period is concerned with the formulation and comparison of the optimum methods of system alternatives. In other words it is only the most efficient utilization of the present system and each of the alternative systems of physical distribution that are relevant in the intermediate period analysis.

It is important to recognize that alternative systems of physical distribution emerge at successive points in the intermediate period as more and more of the shorter term constraints expire and as changes in physical distribution requirements become more significant.

If all of the costs associated with a system of physical distribution were variable, the successive alternatives would be independent and it would be possible to limit the intermediate-term analysis to a comparison of alternatives as they emerge over time. A system of physical distribution, however, consists of a specific set of fixed facilities for the handling, transporting or storing of materials and products and for order-processing and communications services. It is a change in one or more of these facilities that constitute a change in the system of physical distribution. Hence, alternative systems involve capital investment in one or more of the fixed facilities and these costs, as well as the variable operating costs, must be taken into account in the intermediate-term analysis.

The problem in comparing individual systems of physical distribution is that the economic life of the incremental investment costs may or may not correspond with the life of the alternative system with which they are initially associated. An initial alternative, for example, may include an investment in warehouses that are also a part of the facility requirements of a later alternative. If the economic life of these warehouses is assumed to be equal to the life of the initial alternative, this system will be less attractive from a cost standpoint than other alternatives with a lower investment content. The later alternative will be more or less attractive depending upon whether or not the initial alternative, which included the warehouse investment, was adopted by the firm. It is impractical to assume that the useful life of physical distribution facilities will or will not extend beyond the system with which they are associated until the requirements of future systems have been ascertained. The incremental investment cost of a future alternative on the other hand, is dependent upon the nature of fixed facilities that are available from the preceding system. Hence, it is incorrect to evaluate two or more successive alternatives independently when these are related through common physical distribution facilities.

The approach to intermediate-term analysis must be to formulate and compare alternative plans that include one or more successive systems of physical distribution. In other words, each of the alternative plans will include an alternative system that is available at the beginning of the intermediate period and may also include one or more changes in system over the period as flexibility permits and as physical distribution requirements demand.

In practice, many of the plans will consist of successive modifications of the initial system, eg., additional warehouses or the consolidation of distribution outlets; new facilities for handling or transporting materials and products; new order-processing or communications facilities, etc.

The second period for analysis terminates when there is sufficient capital and flexibility to permit changes in the spatial allocation of production facilities, should such action prove desirable. Until this time, the systems of physical distribution that are available to the firm are limited to those that can accommodate the volume, market and service requirements of the firm from existing production locations. The framework for the second period analysis is the total range of volume, markets and service possibilities between the time at which a change in system becomes feasible to the time at which the opportunity includes a change in the spatial arrangement of production facilities. The objective of analysis is to determine the optimum physical distribution plan for the period. Alternative plans may include a single system that is capable of meeting total requirements over the period; a series of physical distribution systems; or a series of system modifications.

The third time period for analysis occurs when there is maximum decision flexibility. This point in time is usually referred to as the firm's long-term or very long-run.

> The very-long run is a period over which the firm's present contracts will have run out, its present plant and equipment will have been worn out or rendered obsolete and will therefore need replacement, etc. In other words, the long-run is a period of sufficient duration for the company to become completely free in its decisions from its present policies, possessions and commitments. Thus the long-run is a sufficiently distant period in which the firm is free to reconsider all of its policies. For example, if the company finds that the demand for its product has increased substantially, it may be ten years before it can afford to redesign its plant and equipment completely in accord with the requirements of this development.[3]

The major difference between intermediate and long-term flexibility is that the firm is free in the long-term to consider alternative locations for production facilities. The geographical limits of the firm's operations in the intermediate-term are those markets that can be accommodated by the physical distribution function from fixed plant locations. In the long-term, markets are similarly limited for each specific combination of plant locations and systems of physical distribution, but are

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[3] William J. Baumol, op. cit., p. 187.

variable in that the firm is free to select alternative locations for production.

The overall task in the long-term is to formulate and compare the alternative combinations of markets, plant locations and systems of physical distribution. The objective is to select the optimum combination of these three interrelated variables.

The volume, market and service possibilities for physical distribution in the long-term are undefined until the spatial allocation of production facilities has been decided. This decision, however, can be made only if the capacity and efficiency of alternative systems of physical distribution are taken into account. Hence, the selection of the long-term system will be simultaneous with the selection of long-term markets and the spatial allocation of production facilities.

Physical distribution analysis in the long-term context is only a part of the overall analysis. The task is to provide information related to the capacity and efficiency of systems of physical distribution for each of the potential combinations of plant locations. The objective is to ensure that all of the alternatives for physical distribution in the long-term are identified and made available for inclusion in the formulation and comparison of alternative combinations of markets and plant locations.

In summary, the total benefits that are available to the firm through the physical distribution concept will be realized if there is an efficient utilization of physical distribution facilities over the short-run period of time during which changes in system are impractical; if changes in the system of physical distribution are optimized for the period prior to a spatial relocation of production facilities; and if the principles of physical distribution are taken into account in plans for the future spatial allocation of production capacities.

Decision flexibility determines the points in time at which it is practical for the firm to adopt changes in the system of physical distribution, or to introduce changes in the spatial allocation of plants. If these points in time are identified it is possible to define the range of volume, market and service requirements, or the alternatives of these specifications, for each of the short-term, intermediate-term and long-term planning periods.

The Role of the Traffic Manager in Physical Distribution Analysis

Physical distribution analysis is a part of the planning process and as such should be undertaken at the proper administrative level of the organization. In the typical organization structure the various activities of the business are divided among functional departments, eg., sales, production, traffic, etc., with provision for co-ordination at headquarters level. Planning by individual department heads is then limited to activities that are within their specialized sphere of operations, while plans that are beyond the scope of a single department are developed at a higher level. Granger lists three levels in the organizational structure at which planning takes place:

> (1) Planning by the heads of existing operating units for future earnings in their own area. (2) Headquarters level planning for generating future sources of earnings from areas beyond the normal scope of the existing units (including profit improvement by possible withdrawal from some of the present operations); and (3) Planning by heads of headquarters staff units, such as financial planning, marketing planning, research and development planning, etc. (to the extent that such activities exist at the headquarters-staff level).[4]

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[4] Charles H. Granger, "Best Laid Plans", _The Controller_ (August 1962), p. 44.

The Traffic Manager, as the head of an operating unit of the firm, plays a major role in all three physical distribution analyses because of his specialized knowledge of the alternatives for handling, moving and storing the firm's materials and products. His role is advisory, however, whenever the decisions in physical distribution are likely to affect operations in other functional departments. Of the three analyses suggested in the foregoing it is only the short-term analysis that the Traffic Manager is in a position to direct and co-ordinate. In the intermediate and long-term periods, production, marketing, financial and other factors that are beyond the scope of the traffic department's operations must be taken into account in the analysis.

In the intermediate-term, some of the system alternatives will enable the firm to serve additional markets or to increase the volume of sales in existing markets -- up to the limits of productive capacity. Moreover, differences in the cost of system alternatives affect the margin of profit on unit sales so that opportunities exist for improving the firm's overall financial results through adjustments in the total volume of operations. Hence, the intermediate-term alternatives affect operations in the marketing and production departments as well as in the traffic department. Physical distribution analysis for this period requires top-level direction and co-ordination with the participation of the marketing, production, traffic and other interested departments. A study of the long-term spatial allocation of facilities should also be undertaken at an upper-level in the organization since no one of the operating departments are in a position to identify the interrelationship between markets and production locations with each of the alternatives for physical distribution.

The short-term alternatives for physical distribution are limited to the flexibility of given facilities. Moreover, the volume, markets and delivery service specifications for physical distribution are inflexible during this period of time. Markets are limited to the geographical territory that can be served with existing facilities and are further limited to that portion of the territory in which the firm has established the necessary marketing channels, eg., dealers, distributors, agents, wholesalers, or other channels through which output is distributed. Short-term volume may be sensitive to the standard of delivery service that is offered. It will be explained in the following chapter, however, that the short-term delivery standard should be one that the firm will wish to maintain on a longer-term basis. In other words, while a change in volume may be possible through a temporary adjustment in delivery standard, the need to maintain a consistent and reliable standard of service to customers on a longer-term basis will generally preclude this type of interim action. Given the markets and the delivery standard to be offered in these markets, it is clear that the choice of short-term physical distribution alternative will not affect marketing plans or operations.

The efficiency with which marketing specifications can be satisfied in the short-term depends upon the location of output in relation to markets and the alternative methods for physical distribution. Once production is completed the locations of output are fixed and alternatives are limited to methods of physical distribution. The choice of method in this case does not affect production operations.

The objective in the short-term, however, is not only to optimize the physical distribution of available output, but also to optimize the location of output according to combined production and physical distribution efficiency. In other words, there is a second application of the physical distribution concept in the short-term period in that total operating efficiency can be improved through an integration of production and physical distribution planning. If cost is the criteria, for example, the objective is to allocate output among productive units in such a way as to achieve minimum total delivered product cost rather than minimum total production cost.

In the typical business organization, the Production Manager allocates output among productive units on the basis of total production cost -- subject to various short-term constraints including policy related to employment stabilization, equipment utilization, the use of overtime, employee and public relations, etc. The Traffic Manager's direct responsibility is generally considered to be the efficient movement of materials and products to plants and to markets. "The major functions or responsibilities of the traffic department are those concerned with freight movements".[5] The Traffic Manager,

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[5] Charles A. Taff, Traffic Management Principles and Practices (Homewood, Illinois: Richard D. Irwin, Inc., 1959), p. 11.

however, is familiar with the physical distribution alternatives that should be taken into account in determining the optimum allocation of output among plants.

The problem is in bringing together the specialized knowledge of the two departments in the output allocation decision. This can be done through co-ordination at an upper level or through co-operation at the departmental level. It is suggested that the latter is the most desirable since the integration that is required is continuous rather than periodic. Output plans must be geared to marketing expectations over the production cycle. Better estimates become available over the cycle, however, and it is desirable to adjust output at specific plants if flexibility permits. Hence, a continuous review of demand in relation to production flexibility is necessary to achieve the optimum locations for output.

In summary, the Traffic Manager may be called upon to provide information related to the cost and efficiency of alternative systems of physical distribution in the intermediate-term and long-term analysis. His role is advisory in both analyses since marketing, production, financial and other factors with which the traffic department is unfamiliar must be taken into account. Moreover, the effect of decisions that become necessary as a result of these analyses extend beyond the Traffic Managers sphere of responsibility and cannot, therefore, be considered a part of his authority.

Physical distribution analysis for the short-term period insofar as the movement of available output is concerned, is within the Traffic Manager's area of operations. The allocation of output among productive units is a co-operative function to be handled jointly by the traffic and production departments.

Since the Traffic Manager is directly responsible only for the short-term physical distribution analyses and decisions, the balance of this thesis will be related to the methods for formulating alternatives and selecting the optimum alternatives for this period.

The Criteria of Efficiency

The desirability of one alternative over another depends upon the purpose to be served by analysis. If profit maximization is the purpose of analysis, for example, profit is the criteria to be used in comparing alternatives. Alternatively, maximum customer service is the standard if this is the purpose for analysis. Bowersox suggests that maximum service, maximum profit and minimum cost are alternative standards for physical distribution analysis.[6]

A maximum service criteria implies the use of delivery service as a marketing strategy in that such an objective would be intended to increase sales volume, to maintain customer loyalty, to improve customer relations, etc. While these objectives may be valid, it is incorrect to assume that maximum delivery service is the most efficient strategy for their achievement. Advertising, increased sales effort, and other marketing alternatives may well accomplish the desired result at less economic cost. For this reason the estimated cost and result of alternative service standards should be compared with other strategy in the formulation of marketing plans. The Traffic Manager is in a position to advise the marketing department with respect to the range of available service standards and the incremental cost of adopting successively higher standards. Once the marketing department has determined the standard of

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[6] Smykay, Edward J. (Ed.), Essays on Physical Distribution Management (Washington: The Traffic Service Corporation, 1961), p. 23.

delivery service that is optimum in relation to other strategy, this standard becomes one of the specifications to be satisfied by physical distribution alternatives. In other words, delivery service is more appropriate as a guide in the formulation of physical distribution alternatives than as a criteria for selecting the optimum.

A minimum cost criteria would be applicable only in the special case where demand for the firm's products is insensitive to variations in delivery service. The minimum cost criteria is also applicable, however, when it is associated with fixed product prices and given volume, market and service specifications. In this case minimum cost physical distribution is equivalent to the maximum profit alternative -- which is the goal that most firms wish to achieve. "In contrast to much academic speculation, with very few exceptions, firms seek to maximize profits in distribution decision making".[7] The minimum cost standard within the framework of given prices and given volume, market and service requirements has at least two additional advantages:

1. Minimum cost is a generally understood and commonly used criteria of efficiency.

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[7] Ibid.

2. The need to define the marketing specifications of the firm -- including delivery service -- places the proper emphasis on service as a marketing strategy. If the marketing department is required to justify the defined standards of service, the cost and result of this alternative will be taken into account in the marketing plans of the firm.

CHAPTER III

THE MAJOR DETERMINANTS OF PHYSICAL DISTRIBUTION ALTERNATIVES

In relating the problems of production and inventory control, Magee states: "A realistic system must recognize limitations in flexibility but take advantage of elements of flexibility that do exist."[1] This statement is particularly relevant in the formulation of short-term physical distribution alternatives. Opportunities in this area emerge with elements of flexibility in the production, handling, transportation and warehousing of materials and products, but action is limited to the alternatives that will satisfy given marketing requirements and that are within the flexibility of given policy, commitments and physical facilities.

Flexibility is a meaningless term unless it is related to a specific point in time. In the day-to-day problem of moving materials and products to plants, stock

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[1] John F. Magee, Production Planning and Inventory Control (New York, N.Y.: McGraw Hill Book Company, 1958), p. 22.

points and customers, flexibility is limited to alternatives for shipping and transportation. If we are speaking of next month's operations, however, there may be sufficient time to adapt facilities to a broader range of transportation alternatives; to adjust the rate of output at some of the plants; to adjust the rate of handling and the level of inventories at certain warehouses; etc. It is important to identify the points in time at which the various elements of flexibility become available so that decisions that are related to these opportunities can be made in time for their implementation. Finally, the period of time can be taken far enough into the short-term future to permit a review of the allocation of anticipated demand among the firm's productive units -- subject to various policy and commitments, but free from the constraining influence of existing production schedules and the current level of activity at distribution points.

To recapitulate, the extremes of short-term physical distribution decisions deal with the day-to-day transportation problem and the future allocation of output among plants. During the interval between these extremes, elements of flexibility in the various processes that are involved in traffic flow permit decisions that are greater in scope than the daily decisions, but lesser in scope than the output allocation decision. This thesis will be limited to consideration of the two extremes since the methods of analysis for other short-term intervals will be a modification of those for day-to-day and for output allocation decisions.

In the day-to-day problem, given customer orders are to be filled from the given quantities of products that are available for distribution at final stock points. The determinants of physical distribution alternatives in this situation are simply the delivery service requirements of customer orders, and the availability of alternative methods of shipping and transportation.

The short-term planning problem is essentially to determine the optimum allocation of anticipated demand among the firm's plants according to the combined costs of production and physical distribution. The pattern of traffic flow that is implicit in the solution to this problem will indicate the mix and volume of traffic that each of the production and physical distribution facilities will be required to accommodate. The objective is not to provide a detailed plan of operations, but rather to indicate the optimum flow of traffic sufficiently in advance to permit production and physical distribution facilities to be geared to this requirement. Changes in plant and warehouse layout, production schedules, agreements with transportation agencies, employment adjustments and other detailed planning that may be required to adapt facilities to the optimum flow can be left to the individual plant managers, purchasing agents, warehouse managers and other personnel who are responsible for the various segments of operations that are involved in the processing and movement of materials and products. It is necessary only that the alternatives that are considered in analysis be feasible in terms of the required changes in operations. The optimum of these alternatives, broken down into its component parts will then provide the necessary direction and co-ordination for detailed operating plans.

Alternatives for short-term traffic flow are determined by:

1. Market, service and volume specifications.
2. Flexibility in the utilization of given production and physical distribution facilities.

Marketing specifications and the relative importance of individual customers in analysis is discussed in the first half of this chapter. The last half deals with the nature and flexibility of production and physical distribution facilities.

I. MARKETING SPECIFICATIONS

Delivery Service Requirements of Customers

The alternative methods of physical distribution are relevant only if they will satisfy the delivery service requirements of customers. The first step in defining the delivery standard is to identify the explicit or apparent policy of the firm toward customer service. Some of the more common policies include:

1. Service equivalent to that of competitors.
2. A similar standard for all of the firm's customers.
3. A similar standard for all customers within defined geographical areas.
4. Consumer oriented delivery service, ie., service as specified by some or all of the firm's customers.

In the absence of specifically defined delivery requirements, the traffic manager may use the present level of delivery service as a standard in formulating alternatives -- provided policy constraints are satisfied. It is possible, however, that present delivery standards reflect the method of transportation that has been used in the past rather than the minimum delivery service that is acceptable to the firm's customers. It is suggested, therefore, that the existing delivery service be used as a guide in the formulation of alternatives, but that judgement be employed in accepting or rejecting alternatives that fail to meet this assumed standard. Some of the factors that will be important in deciding whether the deviation from the present standard is significant include the sales volume of the affected customers, the nature of the product, the competitive environment, and customer reaction in the past to delivery delays.

If the optimum alternative is one in which service to certain customers or areas is substandard, its adoption should be subject to approval by the marketing department. This procedure is a necessary safeguard against improper evaluation of customer reaction by the traffic department.

In addition to the limit on substandard delivery service, it is also desirable to limit short-term improvements in the standard of service. Once the firm's customers have adjusted to a level of delivery service, it may be difficult to reduce the standard without serious consequences. For this reason, the short-term standard of service should not be significantly higher than can be economically maintained on a longer-term basis. Ideally, the longer-term plan will be developed prior to short-term analysis and the delivery standards from this plan can be used as the upper limit for short-term delivery service.

The delivery standards of the firm should be expressed in terms of delivery delay, eg., the number of days delay from receipt of orders to delivery at customer's establishments.

Market Dimensions

An initial problem in establishing the framework for short-term analysis is that of dividing the firm's total sales forecast into the market areas that will determine the pattern of traffic flow through plants and physical distribution facilities.

Many firms divide their total market into defined geographical regions and adopt the practice of serving the customers within each of these territories from specific distribution points. A four division system for national distribution in Canada, for example, may include defined Atlantic, Central, Prairie and Pacific regions with distribution warehouses located in Montreal, Toronto, Winnipeg and Edmonton. The forecasting task as well as the whole analysis is much simpler if pre-defined service areas for warehouses are used as the basis for short-term production and physical distribution planning. This procedure, however, may overlook significant savings if some of the firm's customers can be served from more than one of the distribution warehouses.

To avoid the exclusion of relevant alternatives, the firm that sells its products to a small number of large customers may be justified in treating each customer as a separate demand unit in analysis. The more common situation, however, is where the firm's products are sold to a large number of various size customers. In this case it is desirable to simplify forecasting and analysis procedures through a preliminary grouping of individual customers. A combination of short-term constraints -- including the delivery service requirements of customers, and the fixed location and capacity of distribution warehouses -- facilitate customer groupings that do not eliminate the relevant alternatives for traffic flow.

The first of these groupings can be achieved by identifying the customers or customer areas that are within the exclusive delivery range of each distribution warehouse. Given the delivery service specifications and the alternative transportation facilities and schedules between stock points and customers, it is possible to define the outer limits of the geographical area that can be served from each of the final distribution warehouses. To illustrate, assume that the firm's products are sold within the geographical area indicated in Figure 1.

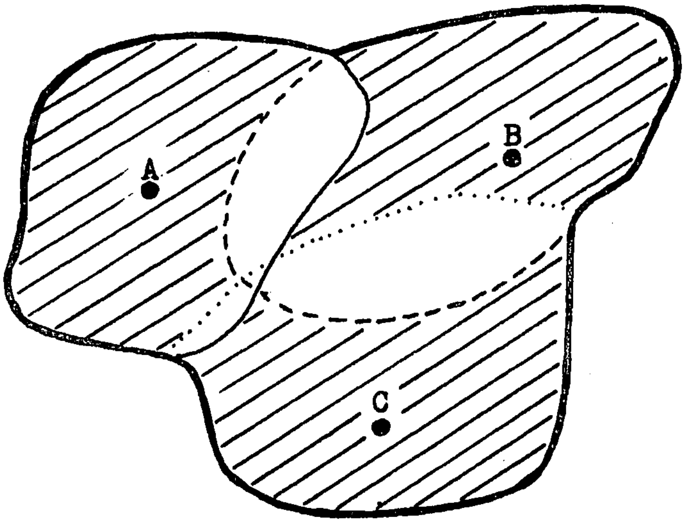

FIGURE 1

DELIVERY RANGE OF WAREHOUSES A, B, AND C

This total area is served by three warehouses A, B, and C, whose service areas, based on delivery standards, are within the boundaries indicated by the solid line, broken line and dotted line respectively. The cross-hatched sections represent the market areas that are exclusive to one or the other stock point. Since these areas can only be served from one or the other warehouse, the total customers within each can be grouped into single demand units for planning purposes.

If the total demand that is generated by customers within these exclusive territores represents the bulk of the firm's sales it is reasonable to assume that this demand will dictate the pattern of flow through plants and between plants and distribution points; and that the demand of other customers, ie., customers within delivery range of two or more distribution points, will merely increase the volume via alternative routes of this basic pattern. In other words, the pattern of traffic flow will be the same whether or not the non-exclusive delivery areas are included in analysis, provided demand within these areas is a sufficiently small proportion of the total.

To include the overlapping delivery areas in analysis, one cannot simply treat each of these as a single demand unit, unless the transportation rate is the same to all customers within the area. The alternative cost of serving one of these customers includes the delivered product cost at alternative distribution points plus the final transportation cost. Where the transportation rate differs among customers within the territory, it is possible that the total delivered product cost to some of these customers will favor delivery through one warehouse, while other customers will be optimally served through an alternative stock point. Since a great deal of additional work may be involved if each of the customers within overlaps are to be included in analysis, it is desirable to limit the analysis to the exclusive territories whenever demand within these areas is sufficient to dictate the pattern of traffic flow; and whenever the volumes through the channels of this pattern are a sufficient proportion of the total to provide a reasonable basis for short-term operating plans. These conditions will usually be satisfied if the exclusive delivery areas as defined above include all of the firm's major market areas.

If there are a few large customers outside of the exclusive areas, their inclusion in analysis as separate demand units may provide the desired level of confidence and precision. If not, it is desirable to achieve a further grouping rather than to treat a great number of small customers as separate demand units.

The limited capacity of stock points serves as a basis for a further grouping. Assuming that total capacity at final distribution points is sufficient, but not significantly in excess of total anticipated demand, a reduction in the delivery range of final distribution points to their handling capacity will result in an increase in the groups of customers that are to be accommodated exclusively through one or the other distribution warehouse. To illustrate, assume the service areas of warehouses A and B, based on delivery standards, are as shown in Figure 2.

The cross-hatched section represents the geographical area that can be served from either point insofar as meeting customer delivery requirements is concerned. We know, however, that neither warehouse A nor B can accommodate all of the customers within this territory in addition to the customers within their exclusive range,

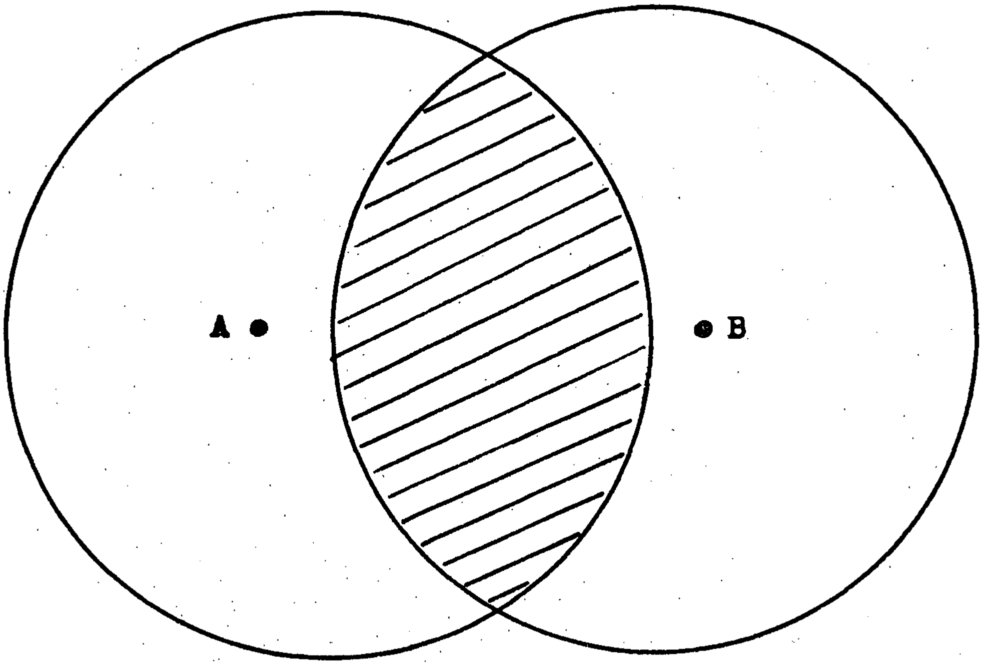

FIGURE 2

DELIVERY RANGE OF WAREHOUSES A AND B

ie., the clear area in Figure 2. The clear area in the centre of Figure 3 represents the remaining overlap in the service territory of warehouses A and B after a reduction in the delivery range of these two stock points to their handling capacity.

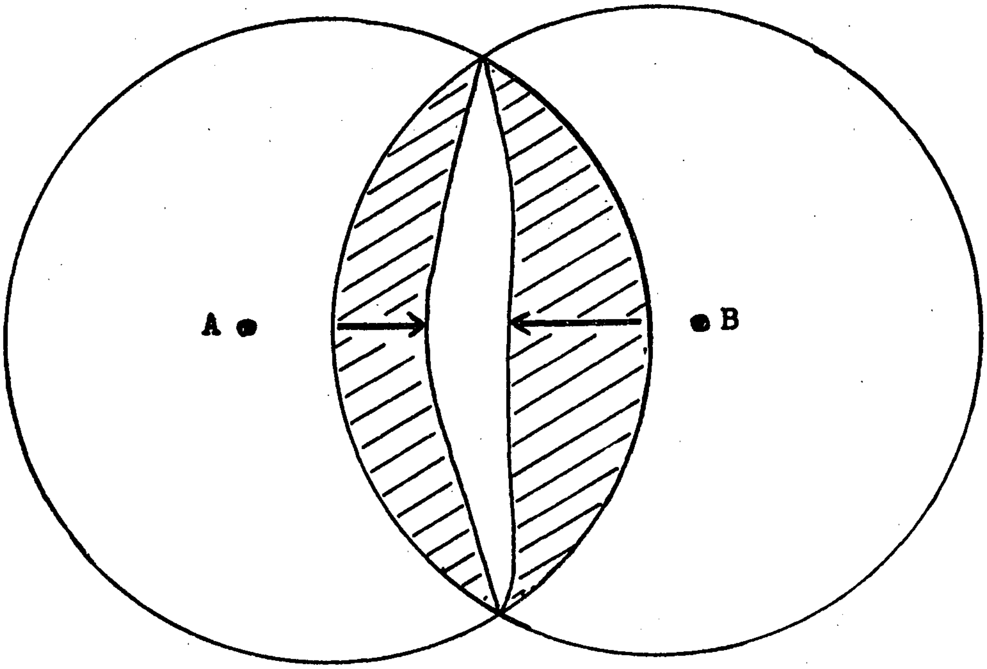

FIGURE 3

THE REDUCTION IN DELIVERY RANGE OF DISTRIBUTION POINTS A AND B TO THEIR HANDLING CAPACITY

The cross-hatched section on the right is now a part of the total market area to be served exclusively from warehouse B. The same section on the left is now a part of the total market area to be served exclusively from warehouse A.

The extent of the remaining overlap in service areas depends upon the anticipated volume of traffic in relation to distribution point capacities. In general, the total handling capacity of all of the final distribution points within a system will not be significantly greater than the total flow of traffic -- except where warehouse capacity has been established on the basis of overly optimistic forecasts. Hence, only a minor portion of the total volume of traffic is likely to be within range of alternative distribution points after the service areas of stock points have been reduced to their handling capacities. In this case it is reasonable to assume that the bulk of the firm's volume which has now been assigned to one or another distribution point will determine the optimum pattern of traffic flow. Once this pattern has been established, the marginal cost of increasing the flow through alternative production-distribution channels of the pattern can be used to determine which of the distribution points should serve customers within the remaining overlaps.

The problem at this stage is to develop a method that can be used to achieve this reduction in overlapping service areas. A forecast of the flow of traffic to the group of customers within the exclusive delivery range of a stock point subtracted from its handling capacity, indicates the surplus capacity that is available at that point for service to customers within delivery range of an alternative warehouse. More specifically then, the problem is to determine the particular customers or customer areas within an overlap that should absorb the surplus capacity of a distribution point, in the event the optimum plan calls for the utilization of its total handling capacity.

Taking the simple case of the overlapping delivery area for the two distribution points in Figure 2, we know that the volume of traffic that cannot be accommodated through warehouse A must be handled through warehouse B. If the capacity of warehouse A is fully utilized, the volume of traffic that will pass through B is also fixed. Hence, costs that are incurred in the flow of traffic prior to final distribution from warehouse to customer will be the same regardless of the combination of customers within the overlap that are serviced from the fully utilized warehouse. These costs may be ignored, therefore, in determining the capacity service area of distribution points.

Since shipping and transportation costs are the only additional costs between final stock points and customers, the total of these costs may be used as the basis for allocating the <u>surplus</u> capacity of a distribution warehouse among customers or customer areas within the overlapping territory. The objective is to minimize the total shipping and transportation cost to customers within the overlap -- given that the warehouse in question is to be fully utilized. Referring again to Figure 2, we would first establish the capacity service area of warehouse A by minimizing total shipping and transportation cost to all customers within the overlap-- given that the total capacity of A is to be utilized. The next step would be to determine the capacity service area of warehouse B in the same way and assuming that B, and not A, will be fully utilized.

Where a large number of customers are included in the overlap, it is desirable to avoid a forecast of traffic for each by dividing the territory into transportation rate areas. Each of these areas should include the group of customers with the same relative freight rate from the alternative distribution points. For example, if one hundred customers can be served from warehouse A at the same freight rate, but only fifty of these have the same rate from warehouse B, the rate area would consist of the fifty customers with the same relative rate from the two warehouses.

A forecast of demand within each of these rate territories can now be related to the capacity that is available to the overlap from the alternative distribution points.

In Figure 4, the overlapping delivery range of warehouses A and B has been divided into transportation rate areas. The forecast of sales to customers within each segment is shown as well as the capacity that is available to the total overlap from distribution points A and B.

The problem, then, is to determine which of these segments would be served from A if A is used to capacity in the optimum plan; and, similarly the segments that would be served from B, if B is used to capacity.

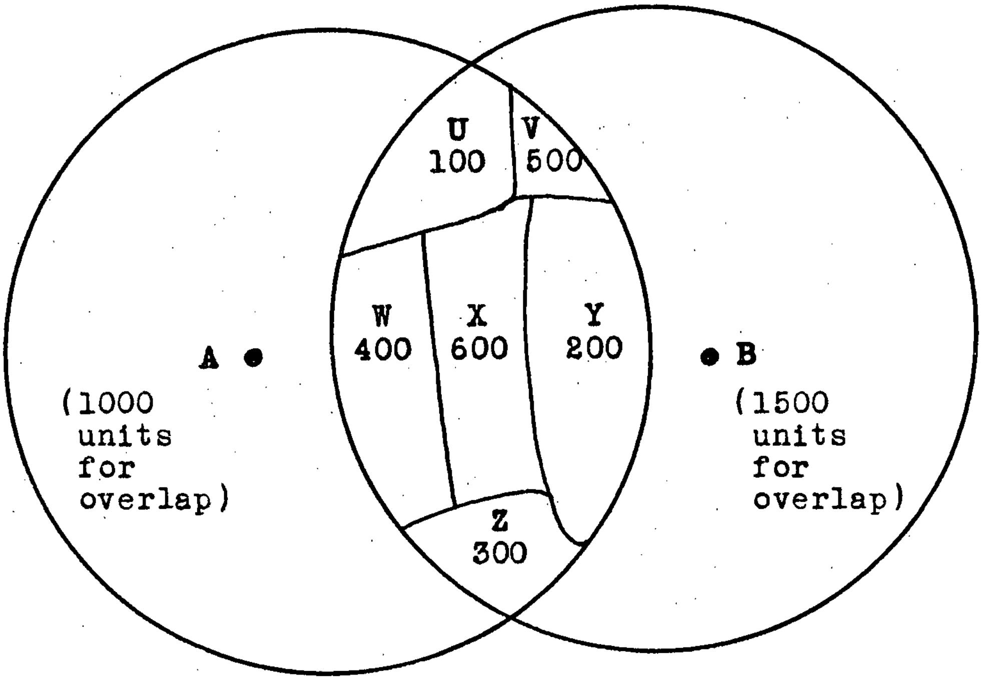

FIGURE 4

TRANSPORTATION RATE AREAS WITHIN
THE OVERLAPPING DELIVERY RANGE
OF WAREHOUSES A AND B

Assuming the sum of shipping and transportation costs between warehouses and customers are as shown in Figure 5, we can establish an order of service preference from each distribution point.

Market Areas	U	V	W	X	Y	Z
Warehouse A	1.00	1.70	1.70	1.80	2.20	1.90
Warehouse B	1.50	1.30	2.30	1.80	1.40	1.80
A - B	-.50	.40	-.60	0	.80	.10

FIGURE 5

SHIPPING AND TRANSPORTATION COST

PER UNIT (DOLLARS)

The relative cost of serving the various territories from warehouse A, indicates that the cost to territory W is seventy cents per unit higher than to territory U. We know, however, that if warehouse A has sufficient capacity to serve only one of these territories that the other must be served from the alternative distribution point. Hence, the relative cost of serving the two customers from warehouse B must also be taken into account. It is clear that the per unit saving from A to U (seventy cents) is offset by the higher cost of serving W from B (eighty cents). Territory W, therefore, must be served from point A in preference to territory U.

The simpler comparison is the relative cost of serving each territory from the two distribution points. The saving of sixty cents per unit by serving territory W from A instead of B is greater than the saving of fifty cents per unit in serving U from A. Both methods lead to the same net result. The order of preference, therefore, can be established for each distribution point on the basis of the difference in shipping and transportation cost to the same customers. The order of preference for warehouse A is territories W, U, X, Z, V and Y as indicated by the third row in Figure 5.

If the optimum pattern of traffic flow calls for the capacity utilization of distribution point A, the 1000 units of capacity available at A must be allocated as shown in Figure 6. No other allocation will result in a lower total cost.

We may conclude, therefore, that while territory V, X, Y and Z are within delivery range of distribution point A, the capacity of A will not permit delivery to V, Y or Z, and, if fully utilized will meet only five-sixths of the volume required in territory X. Hence, territories V, Y, Z and one-sixth of X may be excluded from the capacity service area of warehouse A without eliminating the relevant alternatives for product flow.

Market Areas	U	V	W	X	Y	Z
Warehouse A	100		400	500		
Warehouse B		500		100	200	300
Market Demand	100	500	400	600	200	300

FIGURE 6

OPTIMUM ALLOCATION OF DISTRIBUTION POINT A'S AVAILABLE CAPACITY

The order of preference for warehouse B is, of course, the opposite of A, and the same analysis will indicate that territories U, W, and one-sixth of X may be excluded from the capacity service area of warehouse B.

Territories excluded from the capacity service area of one warehouse automatically become part of the total market area to be served from the alternative stock point. The result in the above example is a reduction in the overlap of the service area of warehouses A and B to two-thirds of the anticipated volume within territory X.

The volumes of traffic to territories that are excluded from A's capacity area can be added to the total volume within B's exclusive delivery range. Similarly, volumes excluded from B's capacity area can be added to the total volume within A's exclusive delivery range. Analysis to determine the optimum flow of traffic through production and physical distribution facilities is thus simplified by reducing the number of demand units to the number of distribution points (assuming the volumes within the remaining overlaps are relatively insignificant and can be ignored in formulating traffic flow alternatives.) If a significant proportion of forecasted volume is to customers within the remaining overlaps, the number of demand units for analysis can be increased to include some or all of the transportation rate areas that are within these market segments.

It should be noted that the above procedure for identifying segments of the overlap with specific distribution points can be used only for the distribution of a single product. Transportation rates, however, tend to be geographically distributed and there will be a similar relationship, therefore, between the cost from two warehouses to the same customer areas for various commodities. Hence, the same transportation rate areas are likely to apply for several of the firm's products and sufficient of these can be included in analysis to provide the desired level of confidence and precision.

Sales Forecasts

According to a study sponsored by the Controllers Institute Research Foundation, almost all manufacturing firms use sales forecasts as a primary basis for short-term planning in the various functions of the business.[2] The short-term forecast generally originates in the marketing department. Following approval by upper management, it is passed on to operating divisions to guide and co-ordinate planning and budgeting. The anticipated volumes of sales are commonly expressed in dollar figures which are then converted by the various departments into units that are appropriate to planning in their respective areas.

It is desirable that the approved sales forecast be used as the basis for production and physical distribution

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[2] Burnard H. Sord, Glenn A. Welsch, Business Budgeting (New York: Controllers Institute Research Foundation, 1958), p. 133.

planning to ensure that the level of planned activity in this area is geared to marketing requirements. This forecast, however, will require refinement before it can be used for this purpose. In particular, the total volume of sales will have to be divided among the territories, and into the product groups that are relevant for physical distribution planning.

It is suggested that the traffic manager's role in forecasting should be limited to defining the market dimensions and the product groups that are relevant for his purposes. The marketing department should then assume the task of allocating the anticipated sales among the defined territories according to the various assumptions that underlie the approved forecast.

II. FLEXIBILITY IN PRODUCTION AND PHYSICAL DISTRIBUTION FACILITIES

Production Facilities

The alternatives for product flow are limited in the short-term by the fixed location of the firm's productive units and by the limited capacity of each of these units.

"Production is the result of the flow of work that goes from one to another of the fundamental structural elements, each of which includes man, machine, tools, material, and specifications."[3] The machines and tools at a plant with which materials can be transformed into products of the desired specifications are given in the short-term. The output at a plant, therefore, is limited first of all to the volume that can be achieved through the maximum utilization of its machines and tools. Expansion of output to this level, however, may be impossible in the short-term for several reasons. Additional manpower of the type that is required may not be readily available, or it may be impossible to adequately train the additional personnel in the time that is available. If increased output calls for the use of overtime, this may conflict with existing labor agreements or management policy. The period may be too short to organize and introduce the new operations and maintenance procedures that are required with a higher utilization. These and other constraints must be considered in determining the maximum level of output that is realistic for each plant in the short-term.

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[3] Raymond Villers, Dynamic Management in Industry (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960), p. 222.

Reinfeld and Vogel employ what is referred to as the bottleneck concept in determining alternative production mix for a plant.[4] This concept may also be used to simplify a study of output flexibility. The procedure is to identify the least flexible of the manufacturing processes within the plant. This may be a specific machine operation, a process requiring special labor skill, etc. A thorough study of this particular segment of the total manufacturing operation will reveal the maximum output that can be achieved, regardless of flexibility in other processes.

Elements of short-term inflexibility including technical problems, policy and commitments, may also limit the extent to which output at individual plants can be reduced. A decrease in the level of output at a plant will generally involve a reduction in the labor force and a redistribution of work among remaining employees and among machines. The technical implications of this action may include a change in plant layout; new operations and maintenance plans; and employee training where the redistribution of work requires the remaining employees

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[4] Nyles V. Reinfeld, William R. Vogel, Mathematical Programming (Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1958), p. 210.

to handle new or additional tasks. The solution to these problems may well require more time than is available in the short-term. Commitments that limit a reduction in plant output may include restrictive clauses in labor contracts, eg., guaranteed annual wage clauses, minimum work crews, etc. The firm may have entered into longer term purchase agreements with suppliers or transportation contracts for minimum quantities of materials to be shipped to specific plants. Policy will often govern the more intangible factors that are involved in reducing the level of plant operation. Employment stabilization policy, for example, may be explicit in order to avoid adverse public or employee reaction. Policy may also apply where output reductions are likely to affect the welfare of employees, dependent suppliers or the community in which the plant is located.

In summary, the relevant alternatives for product flow are those that call for a level of output at each plant that is within the feasible minimum and maximum range. This range should be defined by responsible production personnel who are familiar with the various constraints that limit flexibility in this function of the business.

Distribution Warehouses

The constraints that limit flexibility in the rate of flow through each of the firm's stock points are similar to those that limit the range of output at plants.

Limited storage capacity and given packing and materials handling facilities; inflexibility in the utilization of facilities due to labor agreements, policy, skills; and shortages of the types of labor that are required to increase handling, are some of the constraints that must be taken into account in determining the range of traffic volumes that can be accommodated through distribution points.

Concentration on the least flexible of the handling procedures at a warehouse will simplify the problem of establishing its feasible handling capacity. Materials handling equipment, for example, may limit the volume that can be accommodated regardless of flexibility in other warehousing operations.

Transportation and Handling

Although there may be a great number of available modes of transportation between stock points and customers, the alternatives that are acceptable in the short-term are limited to those that will meet the following conditions:

1. A minimum delivery service to customers. This may be the existing standard; an approved lower standard; or a level of service requested by the customer or the marketing department.
2. A maximum delivery standard. This constraint is necessary to prevent the adoption of a level of service that cannot be maintained on a longer term basis. The maximum should be the standard called for in the longer-term distribution plans.
3. Transportation methods that are suitable for the firm's products and that can be used in conjunction with loading and unloading facilities at plants and warehouses. It may be impossible in the short-term, for example, to adapt the physical layout of a plant to truck loading if the existing arrangement is intended for rail loading. Freight handling or packaging equipment at a plant or warehouse may be limited to use with a specific method of transportation.
4. Transportation methods that are acceptable to customers. If customers specify the method, all other forms of transportation are irrelevant in

analysis.

Transportation alternatives to plants and between plants and warehouses are limited to those that are suitable for the firm's materials and products; and to those that can be used in conjunction with existing loading and unloading facilities at plants and warehouses.

Order-Processing and Communications

In addition to satisfying physical movement requirements, alternatives in the short-term must be feasible in terms of the changes that are necessary in order-processing and communications procedures.

A flow of traffic is preceded by the flow of paper work associated with the preparation and dispatch of customer orders and supply requisitions. Flexibility in the utilization of clerical staffs and office equipment must be adequate for the patterns of distribution being considered in analysis. The constraints on short-term changes in staff that were discussed in the production and warehousing sections also apply in this area.

Communications facilities in the form of mail, telephone and telegraph are generally available for any of the changes that may be considered for traffic flow.

Some firms, however, employ electronic systems for processing and communicating orders from distribution points to plants and in some cases from customers to distribution points. If, in this case, the firm has abandoned the conventional staff, equipment and paper procedures that can be used as an alternative to the system, it may be impractical to consider alternatives for traffic flow that do not conform with established channels of the communications network.

CHAPTER IV

COLLECTION AND PREPARATION OF DATA

The method of analysis suggested in Chapter V to determine the optimum allocation of output among the firm's plants involves a comparison of the variable cost of the alternative routes that traffic may take through the production-physical distribution system. It is necessary, therefore, to determine the alternative traffic routes that are available to the firm in the short-term and to identify and relate the elements of variable cost that are associated with each of these routes.

Flow diagrams may be useful in identifying alternative routes and the major processes that are involved in traffic flow. The preparation of these diagrams is dealt with in the first section of this chapter. The variable costs of the various processes involved in traffic flow and the types of information that are required in order to relate adjacent processes are discussed in a later section.

I. FLOW DIAGRAMS

Magee states that "... an organization, whatever it may be can be viewed as consisting of a number of stock points and a number of operations, together with a control system. In principle a flow chart can be constructed showing the course of the flow from the sources of raw materials through the intermediate stock points to customers."[1] Transportation is the connecting link between adjacent stages in the flow of materials and products and its availability and suitability, therefore, will determine the potential routes that traffic may take to plants, between plants and warehouses and from final distribution warehouses to customers.

A chart of alternative traffic routes should begin by defining the locations of raw materials, plants and stock points. An evaluation of transportation facilities between adjacent stages will then indicate the feasibility of linking a given plant with a particular source of raw materials, a given warehouse with a particular plant, etc.

Delivery service is a prime consideration in determining the feasibility of linking a final distribution point and a customer through a particular mode of transportation. Delivery service, however, is undefined in the

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[1] John F. Magee, Production Planning and Inventory Control (New York, N.Y.: McGraw Hill Book Company, 1958), p. 16.

movement of traffic to plants and between plants and stock points -- except where product perishability or obsolescence is involved. If transportation facilities are available and are technically suitable for the movement of the firm's traffic through to a distribution warehouse, the route is feasible regardless of movement time. While successively longer delivery time increases the inventory carrying cost, this additional cost may well be offset by savings in one or more of purchasing, production, warehousing and transportation costs.

The technical suitability of a method of transportation must be evaluated in terms of the nature of materials or products as well as the handling requirements at plants and warehouses. The carrier, for example, must be capable of accommodating the dimensional size and weight of the firm's materials or products and must be able to provide refrigerated, heated or other specialized equipment where this is required. Loading and unloading facilities at plants and warehouses must be adaptable to the requirements of the carrier. A stock-pile of materials or products on a railway spur, for example, may be inaccessible to motor vehicles. Specialized loading equipment such as cranes and conveyors, and the physical location and layout of the firm's plants and warehouses may also limit its ability to adapt to a particular mode of available transportation. These and other considerations must be taken into account before the route is accepted as technically feasible.

Figure 7 is a flow diagram of a hypothetical three plant, five warehouse system. Raw materials are available from four locations. The lines linking raw materials supply points with plants, and plants with warehouses, indicate the feasible traffic routes insofar as transportation availability and suitability is concerned.

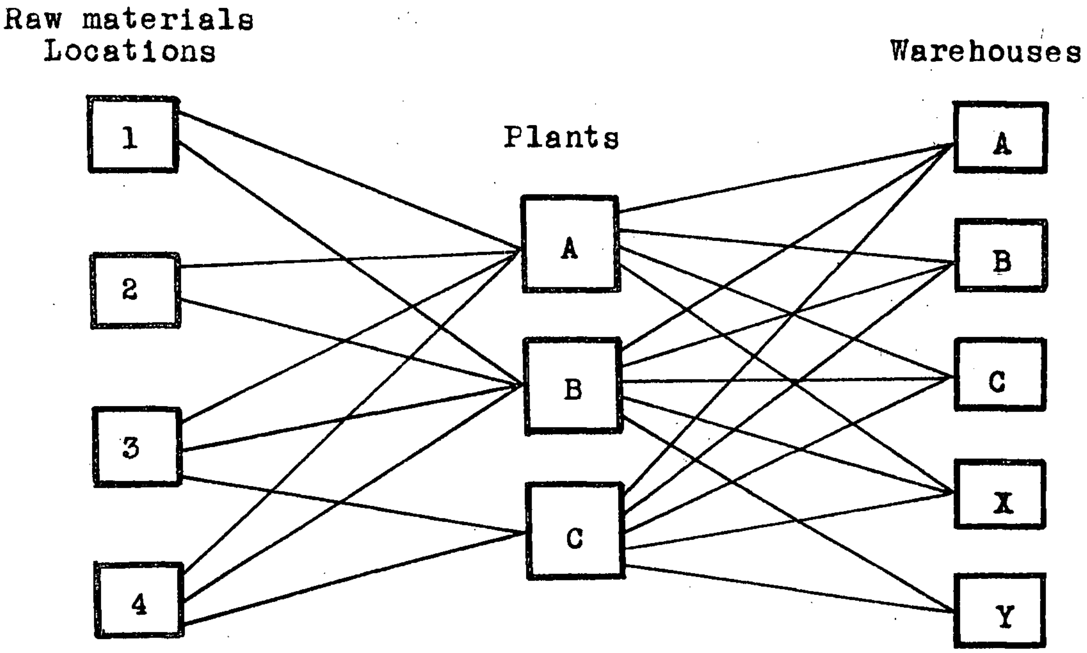

FIGURE 7

FLOW DIAGRAM

The diagram indicates that supplies for plants A and B can be shipped from all of the raw materials locations, while plant C must receive its supply from points 3 and 4. Warehouse Y cannot be served from plant A. Additional detail is included in Figure 8 to identify the cost elements that are involved in the physical flow.

COST ELEMENTS:

1) Purchase Price
2) Transportation
3) a) Warehousing
   b) Inventory
4) Production
5) a) Warehousing
   b) Inventory
6) Transportation
7) a) Warehousing
   b) Inventory
8) Transportation

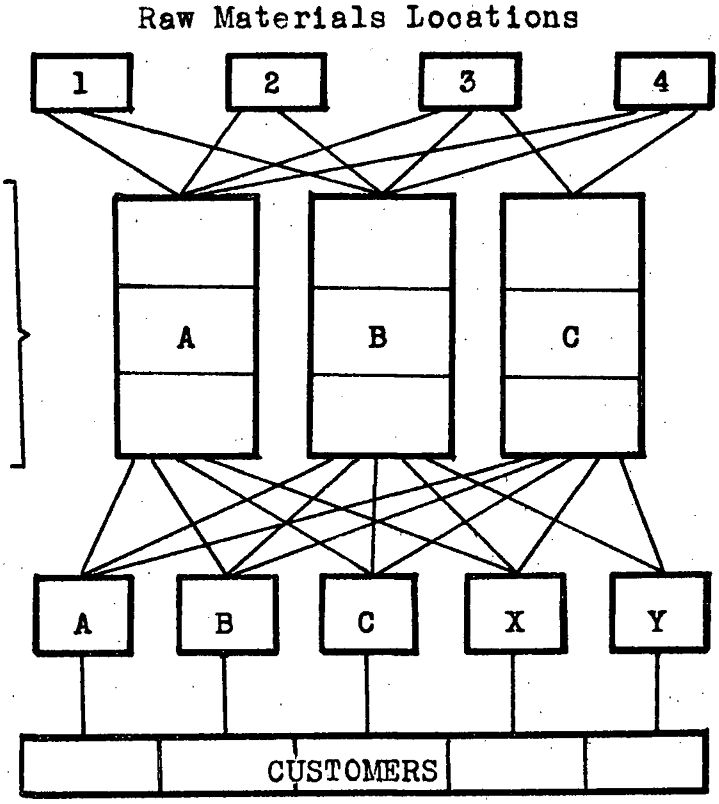

FIGURE 8

FLOW DIAGRAM

The diagram assumes that customers have been divided among the five warehouses according to the procedure described in the previous chapter.

The advantage of a flow diagram is that its preparation assists the analyst in his understanding of the existing system by requiring preliminary studies of the various processes and their technical relationships. This background information is useful in identifying the feasible traffic routes and the alternatives for moving traffic through each of these routes.

II. COST SCHEDULES AND OTHER DATA

The cost elements shown in Figure 8 are not independent. The delivered cost of raw materials at plants varies with the sources from which they are received and the method of transportation that is used for their delivery. Moreover, the volume of inventory that must be carried at stock points, as well as the volumes in transit, vary with differences in the delivery time of alternative carriers. Handling costs at warehouses may also differ with the alternative methods of receiving and forwarding materials and products.

Hence, in addition to estimates of cost for each segment of the alternative traffic routes, the data for analysis must include the key parameters that permit a linking of individual cost elements into total route costs. These costs and parameters are discussed in the following sections. The preparation of data into total route costs is dealt with in the last part of the chapter.

It is assumed for purposes of this thesis that all raw materials are purchased; that these are transported by public carrier to processing plants; that facilities at the plant include storage space for materials and finished products; and that products are transported by public carrier to company owned field warehouses for distribution to customers.

Raw Materials Data

The purchase price of raw materials should be listed for each point at which these are available to the firm. Alternative prices should be shown if the price varies with the size of the order.

A review of the locations and price of raw materials should be undertaken by the firm's Purchasing Agent. The results of this survey may be prepared in a form such as shown in Table 1.

The last column has been included to indicate shipment size. This may be important in relating raw materials price and transportation alternatives, eg., railway carload and truck-load rates both apply to a minimum shipment size.

TABLE I

RAW MATERIALS DATA

Description	Location	Order Quantity	Price Per Unit	Units Per 100 Lbs.
			$	
Part 101	Montreal	1000 or less	0.50	20
		1001 - 2000	0.45	
		2001 or more	0.40	
	Toronto	2000 or less	0.55	
		2001 or more	0.45	
Part 403	Hamilton	No Discount	5.00	½
	Toronto	No Discount	4.75	

Transportation Data

In addition to freight rates, transportation data should include the minimum weight and units of materials or products (if any) to which these rates apply as well as the delivery time for each of the available carriers. This information should be collected and assembled by the Traffic Manager in a form such as is indicated in Table II.

The delivery time includes time for filling the order at the supply point.

TABLE II

TRANSPORTATION DATA

Commodity: Raw Material - Part 101

Carrier	From	To	Rate Per 100 Lbs.	Minimum Weight	Minimum Units	Delivery Time
			$			
CNR	Mtl.	Wpg.	2.50	None	-	4 Days
CNR	Mtl.	Wpg.	1.70	20,000 lbs.	4000	6 Days
Midland	Mtl.	Wpg.	2.80	None	-	3 Days
Midland	Mtl.	Wpg.	2.00	10,000 lbs.	2000	3 Days

Delivery time has been included in Table II because of its direct relationship to transit and safety inventories. Minimum shipment volumes to which certain rates apply may also require larger than normal cycle inventories. The nature of these relationships will be discussed in detail in a later section of this chapter.

Production Data

The variable processing cost for each product that is manufactured at a plant should be estimated by the Production Manager. These estimates will consist largely of the wages of some or all of the plant employees and the cost of operating machines and equipment. The cost of raw materials will be handled separately and should not, therefore, be included, but information from the production department should include the types and quantities of raw materials that are required for each product.

Given the period of time to be covered in the analysis, the Production Manager will be in the position to ascertain the variability in cost of the various plant operations. The determination of costs may be relatively simple if the firm's cost accounting system provides a logical allocation of variable costs among products. Processing cost may be presented in the following form:

TABLE III

PROCESSING COST DATA

Location of Plant: Montreal

Product	Variable Cost Per Unit of Product Labor	Machines	Other	Total
	$	$	$	$
10D	0.50	0.33	0.08	0.91
6F	0.82	0.54	0.15	1.51

In addition to cost information, the Production Manager should determine the output capacity for each plant over the planning period.

Where only one product is manufactured, or when manufacturing processes for each product are independent, capacity can be expressed in "units of product". The more general problem, however, is where a plant manufactures several products, each of which pass through one or more of the same processes. In this case, the mix of output that will absorb plant capacity cannot be predetermined and it becomes necessary to define capacity in man-hours, machine-hours or other appropriate common measurement. The capacity measurement that should be used depends upon the nature of the manufacturing process that limits total output. Production at a furniture plant, for example, may be limited to the rate at which its carpenters can assemble the basic frames. In this case, available man-hours in the frame assembly division is an appropriate measurement of capacity. The output of a pipe mill, on the other hand, may be limited to the capacity of its welding equipment. In this event, available processing time on welding machines is the capacity measurement that should be used in analysis.

Defining maximum capacity in this way, ie., in terms of the bottleneck operation,[2] implies that the output of other manufacturing processes at the plant can be adjusted to whatever mix of production is called for in the optimum plan. This assumption may or may not be valid. A necessary concluding step in analysis, therefore, is to compare the proposed output of a product with the capacity of its exclusive manufacturing processes; and to compare combined product outputs against the capacity of the appropriate common manufacturing processes.

Information related to plant capacities should include a list of the manufacturing processes in the plant; the short-term capacity for each process in man-hours, machine-hours or other appropriate measurement; the products that pass through each of the processes; and the quantity of process capacity that is required for each unit of product. Table IV is an example of the form in which this information may be presented.

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[2] Nyles V. Reinfeld, William R. Vogel, Mathematical Programming (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1958), p. 210.

TABLE IV

PLANT CAPACITY DATA

LOCATION: Montreal

Process	Capacity	Products	Capacity Required Per Unit
Mat'l Handling	4480 Man Hrs.	10D	0.10 Hrs.
		6F	0.08 Hrs.
Lathes	9500 Machine Hrs.	10D	0.33 Hrs.
		6F	0.50 Hrs.
Drills	1900 Machine Hrs.	10D	0.20 Hrs.

Warehousing Data

The variable cost of handling materials or products at warehouses should be developed by the officer in charge of these operations. Warehouses for raw materials may be under the Production Manager's jurisdiction, while product warehouses may be the responsibility of the Sales Manager.

Variable costs in this area will consist largely of the wages of warehouse employees and the costs of operating materials handling equipment. Costs may differ, however, with the method that is used to transport goods to and from these points. The transportation schedule illustrated in a previous section of this chapter indicates the potential methods for the movement of raw materials and products to plant warehouses and to distribution warehouses. Using this schedule as a guide, the handling cost per unit of material or product should be developed for each of the potential modes of transportation. This information may be presented in a form such as is indicated in Table V.

TABLE V

WAREHOUSING DATA

LOCATION: <u>Winnipeg</u>

Product	Method of Transportation	Handling Cost Per Unit
		$
10D	Rail - CL	0.025
	Rail - LCL	0.015
	Truck	0.010
6F	Rail - CL	0.100
	Rail - LCL	0.125
	Truck	0.125

The capacity of distribution warehouses will have been taken into account in determining their geographical service areas.[3] Warehousing space for raw materials and

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[3] See Chapter III, pp. 41-57.

finished product inventories at plants will not be considered directly in the production allocation analysis. Provision should be made, however, to check the space capacity of those points at which the volume of inventories (as suggested in the allocation solution) is significantly greater than in the past.

Inventory Data

The cost of carrying inventory in the short-term includes the risk of obsolescence and deterioration, as well as the opportunity cost of having funds invested in inventories. A cost is involved in the use of storage space at warehouses only if the space has alternative productive use.

It is assumed for purposes of this thesis that the cost of carrying inventory is largely the opportunity cost involved in having funds tied up in materials and products. This cost should represent "...the return that would be obtained if the capital were invested otherwise. In making this estimate, account should be taken of the liquidity and risk involved."[4]

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[4] Charles C. Holt, Franco Modigliani, John F. Muth, Herbert A. Simon, Planning Production, Inventories and Work Force (Englewood Cliffs, N.J.: Prentice-Hall Inc., 1960), p. 71.

The quantity and value of inventory that will be required for each of the traffic routes is dealt with in the latter part of this chapter. At this stage it is sufficient to define the cost of carrying inventory in terms of the percentage return that is required on inventory investment.

Order-processing and Communication Data

The cost of placing an order includes the clerical time involved in preparing the requisition, the cost of stationary, and the variable cost of using office machines and equipment. Transmitting the order to the supply point includes the cost of postal, telephone, telegraph and other facilities that may be used for this purpose. The cost of processing an order received at a plant from a distribution point will include the variable clerical, stationary and machine costs of issuing shipment requisitions or other instructions to the shipping department.

The variable cost of order placement and transmission should be developed for each of the relevant combinations of raw materials supply points and plants. The variable cost of order placement, transmission and receipt should be developed for each of the plant to warehouse alternatives. This information may be prepared as shown in Table VI.

TABLE VI

ORDER PROCESSING AND COMMUNICATION COSTS

Variable Cost Per Order					
From	To	Placing Order	Receiving Order	Order Transmission	Total Cost
		$	$	$	$
Mtl.	Wpg.	10.00	10.00	5.00	25.00
Mtl.	Edmtn.	10.00	7.00	7.00	24.00

The fourth column will be left blank for orders placed by the plant since it is assumed that all raw materials are purchased from outside suppliers.

III. TOTAL ROUTE COST

The method of comparing alternatives suggested in Chapter V requires an estimate of the total unit variable cost incurred in the manufacture and physical distribution of each product to each distribution warehouse and through each of the routes that the product may take through the production-distribution system.

The first section of this chapter indicated that the potential traffic routes and their major component processes can be identified through the preparation of a flow diagram. Each of the alternative routes consist of a source of raw materials, a plant and a distribution warehouse linked together by one or more methods of transportation. The second section discussed the variable cost of the individual processes involved in the flow of traffic and the types of other information that may be required to link successive processes into route alternatives. At this stage it is necessary to examine some of the implications of adding together the related costs of adjacent processes.

The first part of this section deals with the problems of relating the variable costs of physical distribution between a plant and a final distribution warehouse. It is assumed for purposes of this discussion that the accumulated variable cost of the product up to the point at which it is available for distribution at the plant has been determined. The first half of the traffic route, ie., the purchase and distribution of raw materials and the manufacturing process, is discussed in the latter half of this section.

Estimating the Costs of Physical Distribution from Plant to Warehouse

The problem at this stage in analysis is to determine the minimum cost method of utilizing each of the feasible plant to warehouse routes. Taking one route at a time, we may proceed by relating each of the cost elements to each of the alternative methods of transportation for the route. A comparison of the total costs associated with each of the alternatives for transportation will then indicate the minimum cost method of physical distribution for the route.

To illustrate the procedure, we will assume that the planning period has been defined as "the year ending December 31, 1965", and that the following information relating to this period has been developed:

1. Product value at the Plant (PV) = $10.00 per unit.
2. Transportation alternatives between the plant and warehouse and their respective per unit costs:

Alternative	Transportation Cost Per Unit $	Minimum Shipping Quantity (Units)	Transit Time Plant to Warehouse (Days)
1) Rail-CL	0.10	1,200	7
2) Rail-LCL	0.17	-	5
3) Truck-TL	0.14	600	4
4) Truck-LTL	0.20	-	3

3. Handling costs per unit at the plant and warehouse, assuming a direct relationship to the method of transportation that is used.

Method of Transportation	Handling Cost Per Unit Plant $	Warehouse $	Total $
1) Rail-CL	0.015	0.025	0.040
2) Rail-LCL	0.015	0.015	0.030
3) Truck-TL	0.010	0.010	0.020
4) Truck-LTL	0.010	0.010	0.020

4. Order-processing and communication costs (S):

Cost of placing an order at the warehouse	$10.00
Cost of receiving and distributing the order at the plant	10.00
Cost of expediting the order	5.00
Total per order	$25.00

5. Cost of carrying inventory (I): 25 percent of the inventory value.

6. Estimated product demand at the warehouse for the period (Y): 40,000 units, or an average of 109.6 units per day.

Transportation and Handling Cost

Given the above data, the total of transportation and handling costs for the period can be established for each of the alternatives by multiplying forecasted demand by each of combinations of these costs, as follows:

Alternative 1: 40,000 (\$0.10 + \$0.04) = \$ 5,600

Alternative 2: 40,000 (\$0.17 + \$0.03) = \$ 8,000

Alternative 3: 40,000 (\$0.13 + \$0.02) = \$ 6,000

Alternative 4: 40,000 (\$0.20 + \$0.02) = \$ 8,800

Inventory Carrying Cost

The cost of carrying inventory can be estimated by applying the percentage rate given in the foregoing data to the dollar value of the average inventory for the planning period. The dollar value is the summation of the variable route costs up to the point in the flow at which inventory is carried. Hence, the value of inventory in transit will include accumulated product cost at the plant and the handling cost out of the plant. Inventory value at the warehouse will include accumulated product cost at the plant, handling cost out of the plant and into the warehouse and transportation cost. In our example, product value on a per unit basis at the three inventory locations is shown in Table VII.

TABLE VII

INVENTORY VALUE PER UNIT

	At the Plant	In Transit	At the Warehouse
	$	$	$
Alternative 1:	10.00	10.04	10.14
Alternative 2:	10.00	10.03	10.20
Alternative 3:	10.00	10.02	10.15
Alternative 4:	10.00	10.02	10.22

The next step is to estimate the volume of inventory that will be carried at each of the three locations so that the value of the average inventory can be established.

In estimating the volume and value of inventory it is convenient to divide the total inventory into its three component parts:

1. Transit inventories, ie., the average stocks enroute from plant to warehouse.
2. Cycle inventory, or the average stocks that are

carried at the plant and warehouse to meet normal demand.

3. Safety inventory, ie., stocks that are held at the warehouse to protect against unanticipated increases in demand between the time orders are placed and received.

These three inventories are shown graphically in Figure 9.

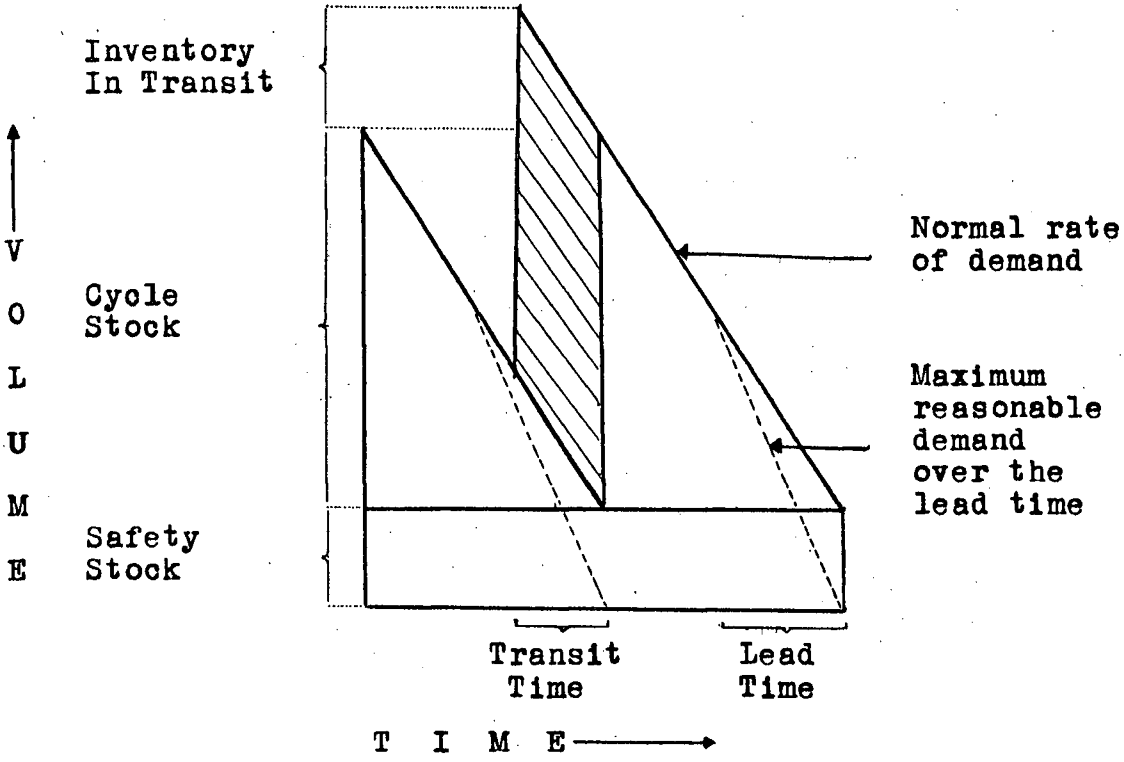

FIGURE 9

AVERAGE CYCLE, TRANSIT AND SAFETY INVENTORIES

The average volume of inventory in transit for the planning period is simply the normal rate of demand per day multiplied by the number of days it takes to transport the product from plant to warehouse.[5] The volume and value of transit inventory in our example, therefore, may be computed as follows:

TABLE VIII

VOLUME AND VALUE OF TRANSIT INVENTORY

	Normal Demand Per Day	Transit Time	Average Transit Inventory	Per Unit Value	Value of Avge. Inventory in Transit
	(Units)	(Days)	(Units)	$	$
Alternative 1:	109.6	7	767	10.04	7701
Alternative 2:	109.6	5	547	10.03	5496
Alternative 3:	109.6	4	436	10.02	4393
Alternative 4:	109.6	3	328	10.02	3295

In estimating the average volume of cycle stock that will be carried with each of the four alternatives, we may employ a modification of the equation that is used by

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[5] Magee, op. cit., p. 17. Note that the result of this calculation represents the average inventory in transit over the planning period rather than the average over the transit intervals of the period.

Whitin to determine the optimum purchase quantity.[6]

The equation, before modification, is as follows:

$Q = \sqrt{\frac{2\ YS}{IC}}$ where,

Y = expected yearly sales in units

Q = economic purchase quantity in units

C = unit cost

S = procurement expense in making one order (in dollars)

I = cost of carrying a dollars worth of inventory over the planning period.

This equation recognizes that the total variable cost associated with cycle stock includes the cost of procuring the inventory as well as the cost of carrying the inventory. Expressed in equation form, procurement cost for the period becomes $\frac{Y}{Q}\ S$ and carrying cost becomes $\frac{QC}{2}\ I$. The division by two in the latter equation suggests that, on the average, one-half of the order quantity will be on hand at the stock point. This assumption is reasonable when it is expected, as in our

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[6] Thomson M. Whitin, The Theory of Inventory Management (Princeton, New Jersey: Princeton University Press, 1957). p. 33.

example, that demand at the stock point will tend toward a uniform rate over the period.

Since procurement cost increases with the number of orders while the reverse relationship holds between inventory carrying cost and the number of orders, it follows that the minimum of these combined costs occurs where:

$$C(Q/2)\ I = S(Y/Q)$$

Solving for Q, the equation becomes:

$$Q = \sqrt{\frac{2YS}{IC}}$$

Two modifications of this equation are necessary before it can be used to determine the average volume of cycle stock that is optimum with each of the four alternatives for plant to warehouse distribution. Firstly, the equation as formulated above assumes that the product is purchased from an outside source and that inventory is carried only at the warehouse. In our problem, warehouse replenishment orders will be filled out of inventory that is on hand at the plant. Hence, cycle inventory will be carried at both the plant and the warehouse. Secondly, the equation for our problem should reflect the fact that per unit product cost at the warehouse is higher than at the plant by the per unit handling and transportation costs.[7]

Assuming for our purpose that the rate of production at the plant will be geared to the normal rate of demand at the warehouse, output at the plant will accumulate at the same rate as inventory at the warehouse is depleted. Total cycle stock, therefore, will be equal to the size of the warehouse replenishment order -- an average of one-half of this quantity being on hand at each of the plant and the distribution warehouse. If we let C_p denote the unit cost of the product at the plant and C_w the unit cost of the product at the warehouse, the cost of carrying cycle stock can be written as:

$$I(Q/2)\ C_p + I(Q/2)\ C_w\ ,\ \text{or}\ I(Q/2)\ (C_p + C_w)$$

Then the total of procurement costs (order-processing and communications) and inventory carrying costs is at a minimum where:

$$I(Q/2)\ (C_p + C_w) = S(Y/Q)$$

Solving for Q, this equation becomes;

$$Q = \sqrt{\frac{2YS}{I(C_p + C_w)}}$$

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[7] See Table VII, p. 87.

This equation may now be applied to determine the optimum volume of cycle stock for each of the four alternatives for physical distribution between the plant and warehouse. Using the sales volume (Y), the order-processing and communications cost (S), and the carrying cost per dollar of inventory (I) given in the data at the beginning of the section;[8] and the per unit product costs at the plant and the warehouse as shown in Table VII, the optimum cycle stocks (Q) for each of the alternatives are as follows:

$$\text{Alternative 1: } Q = \sqrt{\frac{2\ (\$25.00)\ (40{,}000)}{0.25\ (\$10.00 + \$10.14)}} = 630 \text{ units}$$

$$\text{Alternative 2: } Q = \sqrt{\frac{2\ (\$25.00)\ (40{,}000)}{0.25\ (\$10.00 + \$10.20)}} = 629 \text{ units}$$

$$\text{Alternative 3: } Q = \sqrt{\frac{2\ (\$25.00)\ (40{,}000)}{0.25\ (\$10.00 + \$10.15)}} = 630 \text{ units}$$

$$\text{Alternative 4: } Q = \sqrt{\frac{2\ (\$25.00)\ (40{,}000)}{0.25\ (\$10.00 + \$10.22)}} = 629 \text{ units}$$

Referring back to the data presented at the beginning of this chapter, however, we see that there is a minimum shipping quantity of 1,200 units associated with the carload transportation alternative. Hence, although the above formula suggests an order quantity of 630 units for alternative one, it is clear that the order quantity

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[8] See pp. 85-86.

will have to be 1,200 units for this alternative in order to obtain the carload freight rate.

Since, on the average, one-half of the order quantity will be on hand at each of the plant and warehouse, the dollar value of cycle stock may be expressed as follows:

$$Q/2\ (C_p) + Q/2\ (C_w)$$

The result of this calculation is shown in Table IX for each of the alternatives in our example.

TABLE IX

VOLUME AND VALUE OF CYCLE INVENTORY

	Volume (units)	Value $
Alternative 1:	1200	12,084
Alternative 2:	629	6,353
Alternative 3:	630	6,347
Alternative 4:	629	6,359

Safety inventory at a distribution warehouse is necessary to protect against unpredictable increases in demand over the lead time, ie., over the interval between the time a replenishment order is placed and received. But the cost of carrying additional inventory to protect against maximum possible demand over these intervals is usually prohibitive. It becomes necessary, therefore, to establish "...a reasonable balance between the amount of extra inventory (and its capital, storage and other costs) and the protection obtained against stock exhaustion."[9]

To estimate the volume of safety stock at which this balance is achieved, Magee states that two pieces of information are required:

1. A distribution of differences between forecast and actual demand over a lead time.
2. An agreement as to how often run-outs may be allowed to occur.[10]

The first part of this information indicates the frequency with which stock shortages are likely to occur at various levels of safety inventory. The permissable frequency of stock run-outs given in the second part then indicates the level of safety inventory that is necessary.

The distribution of differences between forecast and actual demand can be estimated from historical experience. Assume, for example, that the lead time is

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[9] Magee, _op. cit._, p. 69.

[10] _Ibid._, p. 72.

twelve days. Demand over twelve day intervals of the previous period or periods for the group of customers to be served by the warehouse can then be examined to establish:

1. The average demand from this group over twelve day intervals.
2. The percentage of twelve day intervals in which the level of demand was at specified higher or lower volumes than the average.

When average demand in the past does not correspond with forecasted average demand, it is desirable to convert the historical figures into percentages as shown in Figure 10. One hundred percent on the horizontal scale represents average demand.

The distribution of differences between <u>forecast</u> and actual demand can now be determined by applying the percentage figures to forecast volume. In our example, forecast average demand at the warehouse is 109.6 units per day, or 1,315 units over a twelve day lead time. Applying the percentages given in Figure 10, we can see that during ten percent of the twelve day lead times there is likely to be a demand of 1,900 units or more, ie., forecast average demand of 1,315 units multiplied by 145 percent; that during twenty percent of the twelve day lead times there is likely to be a demand of 1,575 units or more, ie., forecast average demand of 1,315 units multiplied by 120 percent; etc.

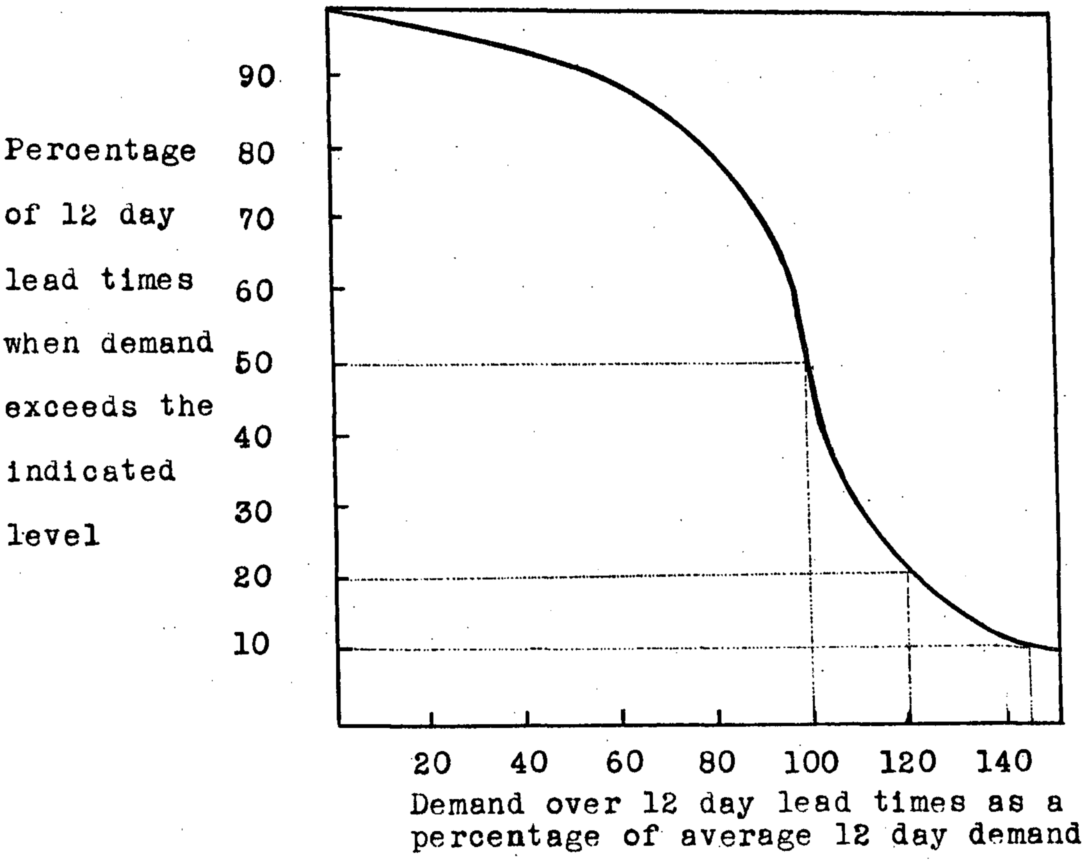

FIGURE 10

DISTRIBUTION OF DEMAND OVER TWELVE DAY INTERVALS

To continue with our example, we will assume that the lead times for the four alternatives are as shown in Table X.

TABLE X

LEAD TIME

Description of Delays	Alternative 1 Days	Alternative 2 Days	Alternative 3 Days	Alternative 4 Days
Placing the orders at the Warehouse	1	1	1	1
Transmitting the order to the plant	1	1	1	1
Receiving and processing the order at the plant	1	1	1	1
Filling the order	1	1	½	½
Transportation plant to warehouse	7	5	4	3
Unloading the order at the warehouse	1	1	½	½
Total lead time	12	10	8	7

We will assume further that the distribution of differences between forecast and actual demand has been estimated for each of the alternatives as indicated in Figure 11. The broken lines represent forecast average demand over each of the lead times. Since cycle inventory is intended to satisfy average demand, safety inventory will be the volume in excess of this quantity. Hence if the protection that is required against stock shortages is set at a level equivalent to ten percent of the lead times, it is apparent that a safety stock of 585 units will be necessary with a lead time of twelve days (1,900 units as shown in Figure 11 at the ten percent level less average demand over the lead time of 1,315 units).

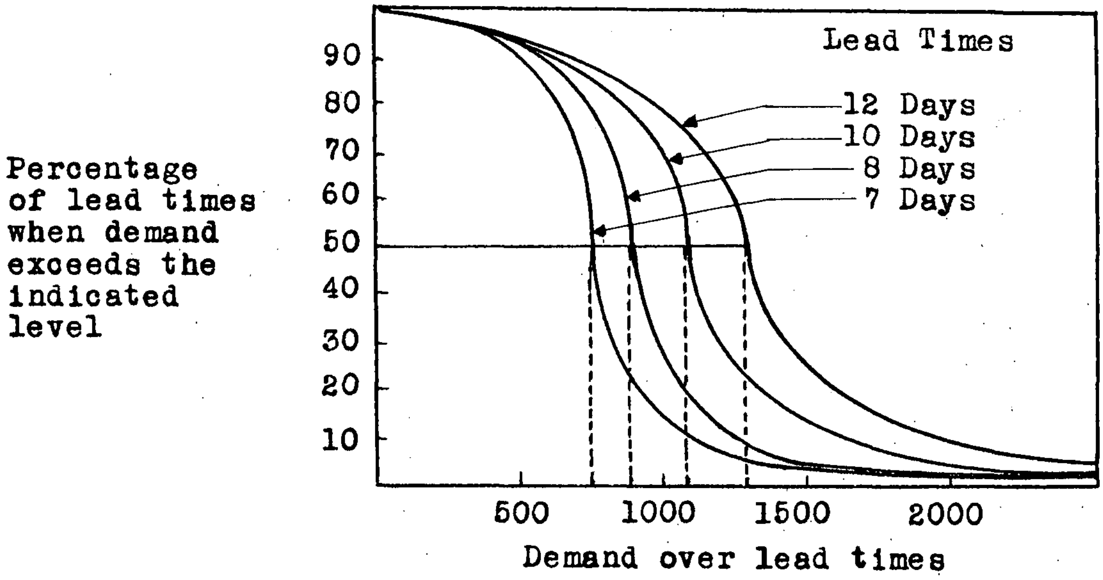

FIGURE 11

DISTRIBUTION OF DEMAND OVER INDICATED LEAD TIME

The next step in estimating the volume of safety inventory is to determine the level of protection that is required against stock shortage. This will depend in part upon the cost of carrying successively larger volumes of safety stock and in part upon opposing factors such as possible losses in sales due to stock shortages, deterioration in relations with customers as a result of delivery delays, etc.

The cost of carrying safety inventory for alternative levels of protection can be estimated by multiplying the appropriate volumes, as calculated from Figure 11, by the cost of carrying a unit of inventory over the defined planning period. The extent and cost of sales losses and deteriorated relations with customers as a result of stock shortages, however, is difficult to identify and to quantify. In the typical case, therefore, the judgement of experienced management personnel is likely to play an important role in estimating these costs, and in balancing the sum of these factors against the costs of carrying safety inventory to arrive at an agreement as to the permissible frequency of stock run-outs.

Continuing with our example, we will assume that an agreement has been reached to the effect that stock shortages should not occur more frequently than six times during the planning period. This is equivalent to saying that it is permissible to have a stock shortage at the warehouse during six of the total lead times, since it is only during a lead time that the risk of run-out occurs. There will be a total of thirty-three lead times over the period if alternative one is used (total demand of 40,000 units for the year divided by the order quantity of 1,200 units). Alternatives two, three and four each require a total of sixty-four lead times over the period. Hence, the level of protection expressed as a percentage-of-lead-time will be eighteen percent for alternative one and nine percent for each of alternatives two, three and four (permissible stock-outs divided by the total number of lead times). The volume of safety stock can now be determined from Figure 11 by taking the difference between the quantities indicated in this chart at the eighteen percent and fifty percent levels for alternative one and at the nine percent and fifty percent levels for alternatives two, three and four. Figure 11 has been used in estimating the volumes of safety stock shown in Table XI.

TABLE XI

VOLUME AND VALUE OF SAFETY STOCK

	ALTERNATIVE			
	1	2	3	4
Maximum demand over the lead time at the 18% level of protection (units)	1650			
Maximum demand over the lead time at the 9% level of protection (units)		1625	1200	1080
Average demand over the lead time (units)	1315	1096	877	767
Safety stock (units)	335	529	323	313
Unit product value at the warehouse	$10.14	$10.20	$10.16	$10.22
Dollar value of safety stock	$3397	$5396	$3282	$3199

Having estimated the value of transit, cycle and safety stocks, the cost of carrying inventory can now be estimated for each of the four alternatives by applying the carrying cost per dollar of inventory to the sum of these three inventory amounts. Inventory values given in Tables VIII, IX and XI have been totalled in Table XII and the percentage rate has been applied to produce an estimate of the cost of carrying inventory over the planning period.

TABLE XII

COST OF CARRYING INVENTORY

	Total Inventory Value	Carrying Cost as a % of Inventory Value	Inventory Carrying Cost.
	$	%	$
Alternative 1:	23,182	25	5796
Alternative 2:	17,245	25	4311
Alternative 3:	14,022	25	3506
Alternative 4:	12,853	25	3213

Order-Processing and Communications Cost

Order-processing and communications cost has been estimated at twenty-five dollars per order.[11] Dividing total demand for the period by the order quantity indicates that there will be thirty-three orders placed over the planning period with alternative one and sixty-four orders placed over the period with each of alternatives two, three and four. Order-processing cost for the period, therefore, will be $825 for alternative one and $1600 for alternatives two, three and four.

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[11] See p. 85.

Total Variable Cost

To complete the example that we are using for illustration purposes, it remains to total the individual cost elements developed in the preceding section. Table XIII is a summary of these costs and shows the total and the per unit cost of physical distribution from the plant to the distribution warehouse for each of the four alternatives.

TABLE XIII

TOTAL VARIABLE COST OF PHYSICAL DISTRIBUTION

PLANT TO WAREHOUSE

Cost Elements	ALTERNATIVE 1	2	3	4
Transportation and Handling	$ 5,600	$ 8,000	$ 6,000	$ 8,800
Inventory	5,796	4,311	3,506	3,213
Order-processing and Communication	825	1,600	1,600	1,600
Total Cost	12,221	13,911	11,106	13,613
Per Unit Cost	0.306	0.348	0.278	0.341

It is clear that the third alternative is the optimum method for physical distribution from the plant to the distribution warehouse used in this example.

To produce an estimate of the total variable cost for the whole route we must now add the $0.278 per unit for plant to warehouse distribution to the variable cost per unit for the first half of the route, ie., to the accumulated variable cost of the product up to the point at which it becomes available for distribution at the plant. In developing inventory carrying costs for the plant to warehouse portion of the route, we assumed that the accumulated variable cost for the first half of the route had already been estimated at $10.00 per unit. Total variable cost for the whole route, therefore, would be $10.28 per unit. This figure will be the one that is compared with similarly developed unit costs representing alternative routes to determine the optimum allocation of output among the firm's plants. This comparison will be dealt with in chapter V.

Returning now to the procedure for determining total variable cost for the first half of the route, the problem is to relate the processes that are involved in the physical distribution of raw materials and in their manufacture into the finished product. The objective is to determine the minimum per unit product cost at each of the plants for each of the points from which raw materials may be received.

Estimating the Cost for the First Half of a Traffic Route

Dealing with one plant at a time, the first problem is to specify the products that the plant is equipped to manufacture and the raw materials requirement for each of these products. At this point it should be decided if it will be worthwhile to investigate the physical distribution of all of the materials that are used in the manufacturing process. If the product consists of one or two basic materials and only minimal amounts of several other relatively low cost items, an investigation of the physical distribution of the latter group is not likely to bring about a significant change in product cost. The quantity, purchase price and transportation cost of each of the raw materials that are used for a product are the major factors that should be considered in deciding which of these should be included in the study of raw materials distribution.

It may be assumed, for purposes of estimating the per unit cost of the excluded group, that these materials will be received from the same source as in the past; that the transportation and handling cost will be the same and that the same level of inventory per unit of material will apply. In other words, an approximation based upon historical records should be adequate for an estimate of the per unit delivered cost for this group of materials.

The second step is to investigate the physical distribution of each of the raw materials that have been selected for further investigation. The objective is to determine the minimum cost method of physical distribution to the plant from each of the available sources of supply. The available sources are those from which there are suitable methods of transportation.

The costs that are involved in the physical distribution of raw materials include the purchase price, transportation, handling, order-processing and inventory carrying costs. The purchase price can be obtained from the purchasing department. The alternatives for transportation and handling and their respective costs will be available if the schedules discussed in the previous section of this chapter have been prepared.

Inventory and order-processing costs for this portion of the route cannot be established with the same degree of precision as for plant to warehouse distribution. It has been shown that the volume of inventory that is required is closely related to the rate of demand. The demand for a product at a specific plant, however, is clearly unknown at this stage since it is the objective of analysis to determine how total demand should be allocated among the firm's plants.

For purposes of a preliminary estimate of order-processing and inventory carrying costs, it may be assumed that demand for raw material at the plant over the planning period will be the same as in the past. The procedure as described above for plant to warehouse distribution may now be used to estimate the total inventory and order-processing cost for the period for each of the alternatives for transportation and handling between a source of raw materials and the plant. Since it is assumed that raw materials are purchased, there will be no stocks held at the source. Cycle inventory, therefore, will be equal to one-half of the order quantity, as compared with a cycle inventory equivalent to total order quantity for plant to warehouse distribution. It should be noted that the percentage of inventory value representing the cost of carrying inventory will, in this case, be applied to the sum of the purchase price and the cost of transporting and handling the material between its source and the plant.

The estimate of inventory and order-processing cost may now be added to the related purchase price, transportation and handling costs to determine the total variable cost of the raw material at the plant. A comparison of the total variable cost associated with each of the methods of transportation and handling will then indicate the alternative that offers minimum materials cost from a given source.

It is assumed in this thesis that there is no limit to the volume of a raw material that can be purchased from a single source. Hence, where there are two or more available sources of supply for a specific plant, the cost of material used in determining product cost will be the minimum of all of the alternatives. In other words, a final comparison of the minimum material cost at the plant from each of the sources of supply will have to be made to ensure that the material cost used in analysis is the minimum of the alternatives from all available sources of supply.

Given the minimum total variable cost of raw materials at the plant, it remains to add the cost of the quantities required by a product to the processing cost to determine the variable cost of the product at the plant. The types and quantities of raw material that are used in the manufacture of a product, as well as the processing cost per unit of product, will be available from the information provided by the production department.

The per unit product cost at the plants as determined through the above procedure may now be used as the basis for establishing delivered product cost at each of the firm's distribution points. The method for determining total cost for the plant to distribution warehouse portion of the route has been outlined in the first part of this section. Although plant to warehouse distribution was considered first in the foregoing discussion, it is necessary, of course, to develop estimates of product cost at the plants before the total cost of the product at final distribution warehouses can be ascertained.

In summarizing this chapter it is suggested that a preliminary study of transportation and handling alternatives will be useful in identifying available route alternatives between the source of raw materials and plants and between plants and distribution warehouses. Given this framework, effort can be concentrated in the development of costs for the various processes involved in the relevant alternatives for traffic flow. These processes and their respective costs were discussed in the second section of the chapter.

The objective of the latter section of the chapter was to outline a procedure for relating the elements of route cost in order to produce unit product costs at each distribution warehouse for each of the alternative routes that traffic may take to these points. The way in which these unit costs will be used to determine the optimum allocation of output among the firm's plants will be the subject of the following chapter.

CHAPTER V

DETERMINING THE OPTIMUM ALTERNATIVE

It was indicated in Chapter III that this thesis will deal with two of short-term physical distribution problems. These two problems were defined as:

1. The day-to-day alternatives for satisfying customer orders from output that is available at distribution warehouses, and
2. The alternatives for allocating short-term production among the firms plants.

Having discussed the determinants of the alternatives that are associated with each of these problems and the procedure that may be used to identify alternatives and their cost, it remains to outline the method for selecting the optimum in each case.

The number of alternatives that must be taken into account in the typical physical distribution problem precludes analysis through conventional methods. Henderson and Schlaifer make the following comment to illustrate the need for improved methods for day-to-day physical distribution decisions:

> When there are only a few possible courses of action -- for example, when a company with only two plants wants to supply three or four customers at the lowest possible freight cost -- any competent scheduler can quickly find the right answer. However, when the number of variables becomes larger -- when a company has a dozen factories and 200 or 300 customers scattered all over the country -- the man with the job of finding the best shipping pattern may well spend many days only to end up with a frustrated feeling; though he thinks he is close to the right answer, he is not at all sure that he has it. What is worse, he does not even know how far off he is, or whether it is worth spending still more time trying to improve his schedule.[1]

The solution to a physical distribution problem requires an allocation of limited resources among competing demands. In the case of the day-to-day problem, there is usually sufficient inventory to meet total customer orders, but there are competing orders for the limited quantity of products that are available at individual distribution warehouses. Similarly, there are competing ways in which the limited capacity of each production and physical distribution facility may be utilized in the short-term planning problem. The limited resources, competing demands characteristics place these problems within the realm of mathematical solution that

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[1] Alexander Henderson and Robert Schlaifer, "Mathematical Programming," Harvard Business Review, May - June, 1954, p. 118.

is generally referred to as linear programming.

The chief advantage of the linear programming technique is the ease with which it provides the right answer to a problem that may involve a multitude of interdependent alternatives.

> What "mathematical" programming does is to reduce the whole procedure to a simple, definite routine. There is a rule for finding a program to start with, there is a rule for finding the successive changes that will increase the profits or lower the costs, and there is a rule for following through all the repercussions of each change. What is more, it is absolutely certain that if these rules are followed, they will lead to the best possible program; and it will be perfectly clear when the best possible program has been found.[2]

The first section of this chapter will illustrate the use of the linear programming technique in selecting the optimum alternative for output allocation decisions. The latter part of the chapter will outline the application of the technique to the day-to-day physical distribution problem.

I. LINEAR PROGRAMMING MODEL FOR OUTPUT ALLOCATION DECISIONS

Several methods are available for solving linear programming problems. Most of these have been developed

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[2] *Ibid.*, p. 119.

as alternatives to the general procedure -- sometimes referred to as the Simplex.[3] The general procedure will solve any linear programming problem, but the work that is required in the application of this method is tedious. One of the alternative methods that can be used for certain types of problems and "...by far the most frequently useful of the shorter procedures is the one known as the Transportation Problem Procedure".[4]

Problems that can be solved through the Transportation Procedure must meet certain conditions -- one of which is that demands and constraints be expressed in the same units. The output allocation problem with which we are concerned in this section does not meet this condition and cannot, therefore, be formulated directly for solution through the Transportation Method. The problem must be formulated for the Simplex, but in certain circumstances it is possible to convert the Simplex tableau into a Transportation matrix so that the Transportation Method of solution can be used.

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[3] For a description of the general procedure see: A. Charnes, W.W. Cooper, and A. Henderson, An Introduction to Linear Programming. (New York, John Wiley and Sons, Inc., 1953.)

[4] Alexander Henderson and Robert Schlaifer, op. cit., p. 138.

The objective of this portion of the chapter is to develop the Simplex tableau for the output allocation problem; to demonstrate a conversion to a Transportation matrix and to indicate the circumstances under which such a transformation is acceptable; and to indicate the method of solution through the Transportation Procedure. The data that will be used for illustration purposes are summarized in the following section.

Demands, Constraints and Costs

The various types of information that are required for the output allocation analysis were discussed in Chapter IV. It is assumed that the preliminary studies to develop this data have been undertaken and that the results of these studies have been summarized as follows:

1. Warehouse demand:
    1) Product 10D
        Warehouse at Plant A (AW) = 40,000 units
        Warehouse at Plant B (BW) = 30,000 units
        Warehouse at Plant C (CW) = 35,000 units
        Warehouse X (XW) = 20,000 units
        Warehouse Y (YW) = 10,000 units
    2) Product 6F
        Warehouse at Plant A (AW) = 30,000 units

Warehouse at Plant B (BW) = 20,000 units

Warehouse at Plant C (CW) = 15,000 units

Warehouse X (XW) = 10,000 units

Warehouse Y (YW) = 8,000 units

2. Plant Capacities: 280,000 machine minutes for each of Plants A, B and C.

3. Minutes of time per unit of product on capacity limiting process:

	Product 10D (Minutes)	Product 6F (Minutes)
Plant A	2.00	5.50
Plant B	2.20	6.00
Plant C	2.45	6.40

4. Accumulated variable cost per unit of product at distribution warehouses.

1) Product 10D:

	To AW $	To BW $	To CW $	To XW $	To YW $
From Plant A:	3.40	4.20	5.10	3.90	-
From Plant B:	4.50	2.90	3.80	3.30	3.50
From Plant C:	5.30	5.20	4.00	4.50	4.30

2) Product 6F:

	To AW $	To BW $	To CW $	To XW $	To YW $
From Plant A:	8.10	10.50	11.20	9.20	-
From Plant B:	10.20	8.70	9.50	9.00	9.30
From Plant C:	12.20	11.80	8.90	9.60	9.20

The figures shown above represent the minimum cost methods of utilizing each of the potential traffic routes. A preliminary comparison of alternatives for distributing product 10D from Plant A to warehouse C, for example, has shown that the minimum delivered product cost via this route will be $5.10.

The Simplex Formulation

Given the data in the preceding section, the first step in setting up the Simplex is to express the demands and constraints algebraically. Standard mathematical notation may be used as follows:

1. Number the plants one through three.
2. Number the distribution warehouses one through

five for product 10D; and six through ten for product 6F. (Numbers one and six both refer to warehouse A, two and seven both refer to warehouse B, etc.)

3. Let X_{ij} equal the number of units of product supplied by plant i to warehouse j. Then the quantities of product required at warehouses can be stated as follows:

1) $X_{11} + X_{21} + X_{31} + U_4 = 40,000$
2) $X_{12} + X_{22} + X_{32} + U_5 = 30,000$
3) $X_{13} + X_{23} + X_{33} + U_6 = 35,000$
4) $X_{14} + X_{24} + X_{34} + U_7 = 20,000$
5) $X_{25} + X_{35} + U_8 = 10,000$
6) $X_{16} + X_{26} + X_{36} + U_9 = 30,000$
7) $X_{17} + X_{27} + X_{37} + U_{10} = 20,000$
8) $X_{18} + X_{28} + X_{38} + U_{11} = 15,000$
9) $X_{19} + X_{29} + X_{39} + U_{12} = 10,000$
10) $X_{2,10} + X_{3,10} + U_{13} = 8,000$

The U variable is added to each equation in order to eliminate the inequalities.

The capacity constraints at each plant are given by the following equations:

11. $2.00\ X_{11} + 2.00\ X_{12} + 2.00\ X_{13} + 2.00\ X_{14}$
$+ 5.50\ X_{16} + 5.50\ X_{17} + 5.50\ X_{18} + 5.50\ X_{19}$
$+ U_1 = 280{,}000$

12. $2.20\ X_{21} + 2.20\ X_{22} + 2.20\ X_{23} + 2.20\ X_{24}$
$+ 2.20\ X_{25} + 6.00\ X_{26} + 6.00\ X_{27} + 6.00\ X_{28}$
$+ 6.00\ X_{29} + 6.00\ X_{2,10} + U_2 = 280{,}000$

13. $2.45\ X_{31} + 2.45\ X_{32} + 2.45\ X_{33} + 2.45\ X_{34}$
$+ 2.45\ X_{35} + 6.40\ X_{36} + 6.40\ X_{37} + 6.40\ X_{38}$
$+ 6.40\ X_{39} + 6.40\ X_{3,10} + U_3 = 280{,}000$

These equations recognize that capacities are stated in terms of minutes of time that is available in the bottleneck process at each plant. Hence, 2.00 minutes of capacity at plant A is used for every unit of product 10D that is manufactured at that point; 5.50 minutes of capacity for every unit of product 6F, etc. The U variable eliminates the inequalities in the equations and represents unused capacity.

The objective of analysis is to minimize total production and physical distribution cost. Expressed algebraically, this objective becomes:

$$3.40\ X_{11} + 4.50\ X_{21} + 5.30\ X_{31} + 4.20\ X_{12}$$
$$+ 2.90\ X_{22} + 5.20\ X_{32} + 5.10\ X_{13} + 3.80\ X_{23}$$
$$+ 4.00\ X_{33} + 3.90\ X_{14} + 3.30\ X_{24} + 4.50\ X_{34}$$
$$+ 3.50\ X_{25} + 4.30\ X_{35} + 8.10\ X_{16} + 10.20\ X_{26}$$
$$+ 12.20\ X_{36} + 10.50\ X_{17} + 8.70\ X_{27} + 11.80\ X_{37}$$
$$+ 11.20\ X_{18} + 9.50\ X_{28} + 8.90\ X_{38} + 9.20\ X_{19}$$
$$+ 9.00\ X_{29} + 9.60\ X_{39} + 9.30\ X_{2,10} + 9.20\ X_{3,10}$$
$$+ U_1 + U_2 + U_3 + U_4 + U_5 + U_6 + U_7 + U_8 + U_9$$
$$+ U_{10} + U_{11} + U_{12} + U_{13} = \text{MINIMUM}$$

The next step in the formulation of the Simplex is to set up the variables and coefficients from the above equations in matrix form.[5] This has been done in Table XIV on page 122.

The coefficients of the objective equation have been placed in the second row from the top. The first fifteen spaces in this row indicate the unit variable cost of product 10D at each warehouse from each of the alternative plants. Spaces sixteen through thirty in this row

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[5] For a description of the Simplex matrix see Nyles V. Rienfeld, William R. Vogel, Mathematical Programming, (Englewood Cliffs, N.J., Prentice Hall, Inc., 1958), p. 81.

TABLE XIV

SIMPLEX MATRIX

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		COST $	3.40	4.50	5.30	4.20	2.90	5.20	5.10	3.80	4.00	2.90	3.30	4.50	M	3.50	4.30	8.10	10.20	12.20	10.50	8.70	11.60	11.20	9.50	8.90	9.20	9.00	9.60	M	9.20	9.20	0	0	0	0	0	0	0	0	0	0	0	0	0
			10D to AW			10D to BW			10D to CW			10D to XW			10D to YW			6F to AW			6F to BW			6F to CW			6F to XW			6F to YW															
Plant Capacities	1.	A 280,000	2.00			2.00			2.00			2.00			2.00			5.50			5.50			5.50			5.50			5.50			1												
	2.	B 280,000		2.20			2.20			2.20			2.20			2.20			6.00			6.00			6.00			6.00			6.00			1											
	3.	C 280,000			2.45			2.45			2.45			2.45			2.45			6.40			6.40			6.40			6.40			6.40			1										
Warehouse Requirements	4.	AW 40,000	1	1	1																															1									
	5.	BW 30,000				1	1	1																													1								
	6.	CW 35,000							1	1	1																											1							
	7.	XW 20,000										1	1	1																									1						
	8.	YW 10,000													1	1	1																							1					
	9.	AW 30,000																1	1	1																					1				
	10.	BW 20,000																			1	1	1																			1			
	11.	CW 15,000																						1	1	1																	1		
	12.	XW 10,000																									1	1	1															1	
	13.	YW 8,000																												1	1	1													1

show the same information for product 6F. Spaces thirty-one through forty-three indicate that there is no variable cost involved in unused plant capacity or unfilled demand. Note that the letter M has been entered in the thirteenth and twenty-eighth spaces. Since it is impossible to ship output from plant A to warehouse Y the M may be interpreted as a sufficiently high cost to preclude the inclusion of this route in the solution to the problem.

Plant capacities in minutes are shown in the second column at the left in rows numbered one through three. Warehouse demands for product 10D are shown in units of product in rows four through eight and warehouse demand for product 6F in rows nine through thirteen.

The body of the matrix (ie. column one through thirty) includes the coefficients of the plant capacity equations and the coefficients of the warehouse demand equations. The figure one in rows numbered four through thirteen signify that total production for each warehouse is not to exceed its demand, but that demand may be satisfied from any one or more of the plants.

The coefficients of the U variable from each of the aforementioned equations are shown in the identity portion of the matrix (ie., column thirty-one through forty-three).

These coefficients consist of the figure one in each case and it is a requirement of the Simplex matrix that these be diagonally arranged as shown in the table.

It is possible to find the minimum cost solution to this problem by applying Simplex rules to the matrix as formulated in Table XIV, page 122. It is generally impractical, however, to attempt a solution through hand calcualtion. It has been assumed for simplicity sake in our example that there are only three plants, five warehouses and two products. These assumptions have produced a matrix with 539 spaces. A more typical example would probably involve a considerably broader product line and perhaps additional plants and warehouses to produce a matrix of several thousand spaces. Rienfeld and Vogel suggest that it would perhaps take from two to three months to solve a Simplex matrix with from 800 to 1200 spaces.[6] Bearing in mind that the model is to be used for short-term planning purposes and that a great deal of time will have already been spent in developing the data to be included in the analysis, a rapid solution is desirable.

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[6] Ibid, p. 132.

Many of the larger computers have been programmed for the Simplex and this is the preferred method of solution for the size of matrix that will usually be involved in this type of problem.

In certain circumstances, however, the Simplex method of solution can be avoided by reducing the matrix to one that is suitable for solution through the Transportation Method. The procedure for reduction and the circumstances under which this simplification will produce an adequate solution are described in the following section and have been adapted from the writings of Rienfeld and Vogel.[7]

Conversion of the Simplex Matrix

A Simplex tableau can be reduced to a form suitable for conversion into a transportation model provided each of the figures contained in the body of this matrix can be transformed to the figure one. The body of the matrix in Table XIV consists of rows numbered one through thirteen, up to and including column number thirty. The following matrix algebra rules will be used for the required Simplex

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[7] *Ibid.*, p. 137 - 141.

transformation:

1. You can divide or multiply any row in the matrix by any number other than zero.
2. You can divide or multiply any column in the matrix by any number other than zero.

In either case, every number in the row (or column) must be multiplied (or divided) by the number.

The transformation with the use of these rules can be achieved in four steps, as follows:

1. Divide rows numbered one through three by 2.00, 2.20, and 2.45 respectively. All of the figures in the body up to and including column number fifteen become 1's. The tableau after completion of this step is shown in Table XV, page 127.
2. Divide column number sixteen and every third column thereafter up to and including column twenty-eight by 2.75.

   Divide column number seventeen and every third column thereafter up to and including column twenty-nine by 2.73.

   Divide column number eighteen and every third column thereafter up to and including column

TABLE XV

SIMPLEX TABLEAU AFTER STEP 1.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		COST $	3.40	4.50	5.30	4.20	2.90	5.20	5.10	3.80	4.00	3.90	3.30	4.50	M	3.50	4.30	8.10	10.20	12.20	10.50	5.70	11.80	11.20	9.50	8.90	9.20	9.00	9.60	M	9.30	9.20	0	0	0	0	0	0	0	0	0	0	0	0	0
			10D to AW			10D to BW			10D to CW			10D to XW			10D to YW			6F to AW			6F to BW			6F to CW			6F to XW			6F to YW															
Plant Capacities	1.	A 140,000	1			1			1			1			1			2.75			2.75			2.75			2.76			2.75			.500												
	2.	B 127,270		1			1			1			1			1			2.73			2.73			2.73			2.73			2.73			.455											
	3.	C 114,280			1			1			1			1			1			2.61			2.61			2.61			2.61			2.61			.408										
Warehouse Requirements	4.	AW 40,000	1	1	1																															1									
	5.	BW 30,000				1	1	1																														1								
	6.	CW 35,000							1	1	1																											1							
	7.	XW 20,000										1	1	1																									1						
	8.	YW 10,000													1	1	1																							1					
	9.	AW 30,000																1	1	1																					1				
	10.	BW 20,000																			1	1	1																			1			
	11.	CW 15,000																						1	1	1																	1		
	12.	XW 10,000																									1	1	1															1	
	13.	YW 8,000																												1	1	1													1

thirty by 2.61.

These divisions also apply to the figure in the cost row. Table XVI on page 129 shows the result of this transformation.

3. Divide rows nine through thirteen by 0.371, ie., by the average of the three figures in each of these rows. The result of this step is shown in Table XVII on page 130.

Note in Table XVII that the figures in the body of the matrix in each of rows nine through thirteen now approximate the figure one. Since this is the last of the steps that can be taken to transform the body of the matrix, it must be decided whether or not each of these figures are sufficiently close to the figure one to consider the matrix as transformed sufficiently to apply the Transportation Method of solution. In this particular example, the converted figures indicate that there will be a maximum error of 3.2 percent in the solution that is suggested for product 6F through the use of the Transportation Method. But there will be no error in the solution suggested for the production and physical distribution of

TABLE XVI

SIMPLEX TABLEAU AFTER STEP 2.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	19	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		COST $	3.40	4.50	5.30	4.20	2.90	5.20	5.10	3.80	4.00	3.90	3.30	4.50	M	3.50	4.30	2.95	3.74	4.67	3.80	3.19	4.52	4.07	3.45	3.41	3.35	3.30	3.68	M	3.41	3.53	0	0	0	0	0	0	0	0	0	0	0	0	0
			10D to AW			10D to BW			10D to CW			10D to XW			10D to YW			6F to AW			6F to BW			6F to CW			6F to XW			6F to YW															
Plant Capacities	1.	A 140,000	1			1			1			1			1			1			1			1			1			1			.500												
	2.	B 127,270		1			1			1			1			1			1			1			1			1			1			.455											
	3.	C 114,280			1			1			1			1			1			1			1			1			1			1			.408										
Warehouse Requirements	4.	AW 40,000	1	1	1																														1									
	5.	BW 30,000				1	1	1																												1								
	6.	CW 35,000							1	1	1																										1							
	7.	XW 20,000										1	1	1																								1						
	8.	YW 10,000													1	1	1																						1					
	9.	AW 30,000																.364	.366	.383																				1				
	10.	BW 20,000																			.364	.366	.383																		1			
	11.	CW 15,000																						.364	.366	.393																1		
	12.	XW 10,000																									.364	.366	.383														1	
	13.	YW 8,000																												.364	.366	.383												1

TABLE XVII

SIMPLEX TABLEAU AFTER STEP 3.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
		COST $	3.40	4.50	5.30	4.20	2.90	5.20	5.10	3.60	4.00	3.90	3.30	4.50	M	3.50	4.50	2.96	3.74	4.67	3.60	3.19	4.52	4.07	3.48	3.41	3.35	3.30	3.68	M	3.41	3.53	0	0	0	0	0	0	0	0	0	0	0	0	0
			10D to AW			10D to BW			10D to CW			10D to XW			10D to YW			6F to AW			6F to BW			6F to CW			6F to XW			6F to YW															
Plant Capacities	1.	A 140,000	1			1			1			1			1			1			1			1			1			1			.500												
	2.	B 127,270		1			1			1			1			1			1			1			1			1			1			.455											
	3.	C 114,280			1			1			1			1			1			1			1			1			1			1			.406										
Warehouse Requirements	4.	AW 40,000	1	1	1																																	1									
	5.	BW 30,000				1	1	1																															1								
	6.	CW 25,000							1	1	1																													1							
	7.	XW 20,000										1	1	1																											1						
	8.	YW 10,000													1	1	1																									1					
	9.	AW 80,860																.981	.987	1.032																							2.70				
	10.	BW 53,910																			.981	.987	1.032																					2.70			
	11.	CW 40,430																						.981	.987	1.032																			2.70		
	12.	XW 26,950																									.981	.987	1.032																	2.70	
	13.	YW 21,560																												.981	.987	1.032															2.70

product 10D since all of the figures in this portion of the matrix are exactly ones. Hence, the maximum total error resulting from the use of the Transportation Method is likely to produce an error of less than two percent, considering the relationships between converted costs and demands of the two products. A potential error of this size will usually be insignificant -- particularly since the estimates that are necessary in the formulation of forecasts and product costs are likely to contain errors of this size or larger. In any case, the size of error that is acceptable must be considered in the light of the saving in time and effort that is available through the use of the Transportation Method.

4. The final step is to convert the identity portion of the matrix. This can be accomplished by multiplying each of the figures contained therein by the appropriate integer to produce the figure one.

The Simplex matrix has now been converted into the form suitable for setting up the Transportation matrix.

The circumstances in which the reduction to the Transportation Method is desirable is, of course, related to the size of the error discussed under step three. The size of this error will increase with larger differences in the units of capacity utilized in the manufacture of products at alternative plants. It is clear, however, that a few calculations can be made to determine the desirability of the Transportation Method without performing the complete conversion as discussed above.

Solution Through the Transportation Procedure

To set up the Transportation matrix, the warehouse requirement figures shown in Table XVII are treated as product demands; the converted available minutes are taken as the plant capacities; and the converted cost figures are inserted in the small squares of the Transportation matrix (see Table XVIII). Plant capacity in this example exceeds demand for the period and a dummy warehouse has been added to the matrix to eliminate this inequality. There is no variable cost associated with unused capacity as indicated by the zeros in the small squares of the dummy warehouse column.

The first step in solution is to inspect the cost figures in this matrix and to take a guess at the best

TABLE XVIII

TRANSPORTATION MATRIX

		DISTRIBUTION WAREHOUSES											
		10D to AW	10D to BW	10D to CW	10D to XW	10D to YW	6F to AW	6F to BW	6F to CW	6F to XW	6F to YW	Dummy Ware-House	Plant Capacity
PLANTS	A	3.40	4.20	5.10	3.90	M	2.95	3.80	4.07	3.35	M	0	140,000
	B	4.50	2.90	3.80	3.30	3.50	3.94	3.19	3.48	3.30	3.41	0	127,270
	C	5.30	5.20	4.00	4.50	4.30	4.67	4.52	3.41	3.68	3.53	0	114,280
Product Demand		40,000	30,000	35,000	20,000	10,000	80,860	53,910	40,430	26,950	21,560	22,840	381,550

assignment of demands according to the capacities available at each plant. Starting with the first column, for example, it appears likely that the demand for product 10D at warehouse A should be met from plant A since this is the lowest cost frame in the column. Product demand of 40,000 units may be entered in this frame, therefore, and similarly for each succeeding guess until all demands have been satisfied. The circled figures in Table XIX represent a completed guess at the optimum solution. Note that the assignment must be made in such a way that the circled figures in each row add up to the figures shown in that row for plant capacity. Similarly, the circled figures in each column must add up to the corresponding product demand figure.

The problem at this stage is to determine whether or not this assignment is the minimum cost solution. The test of optimality requires an investigation of the change in total cost that would result if the assignment were to include any one of the excluded routes, ie., the frames in Table XIX in which there are no circled figures. These routes must be analyzed one at a time. It is sufficient to appraise the cost of moving one unit via an unused route to determine whether or not its utilization will improve the assignment.

TABLE XIX

TRANSPORTATION MATRIX - INITIAL ASSIGNMENT

		DISTRIBUTION WAREHOUSES											
		10D to AW	10D to BW	10D to CW	10D to XW	10D to YW	6F to AW	6F to BW	6F to CW	6F to XW	6F to YW	Dummy Ware-house	Plamt Capacity
PLANTS	A	3.40 40000	4.20 1.25	5.10 1.10	3.90 0.55	M M	2.95 80860	3.80 0.56	4.07 0.66	3.35 13590	M M	0 5550	140000
	B	4.50 1.15	2.90 30000	3.80 -0.15	3.30 20000	3.50 10000	3.94 1.04	3.19 53910	3.48 0.12	3.30 13360	3.41 -0.07	0 0.05	127270
	C	5.30 1.90	5.20 2.25	4.00 35000	4.50 1.15	4.30 0.75	4.67 1.72	4.52 1.28	3.41 40430	3.68 0.33	3.53 21560	0 17290	114280
Product Demand		40000	30000	35000	20000	10000	80860	53910	40430	26950	21560	22840	381550

Bearing in mind that the assignment must always satisfy demand and capacity constraints, it is clear that to place a unit in an empty frame requires at least three adjustments in the existing assignment. Assume, for example, that one unit is placed in the second frame of the first row of Table XIX. To reduce the total assignment in the second column to the required 30,000 units it is now necessary to subtract one unit from the second frame of the second row. But this will result in an unassigned unit of capacity for plant B, while at the same time the total assignment in row one now exceeds plant A's capacity by one unit as a result of the initial step. The next adjustment, therefore, must correct the assignments in rows one and two without violating demand requirements. This can only be done by subtracting one unit from the assignment in the ninth frame of the first row and adding this unit to the assignment in the ninth frame of the second row. These adjustments, expressed in terms of cost indicate that an additional $4.20 would be involved in assigning one unit to the second frame of the first row, a saving of $2.90 by reducing the assignment in the second frame of the second row by one unit; an additional $3.30 for increasing the assignment in the ninth frame of the second row; and a saving of $3.35 by reducing the assignment in the ninth frame of the first row. In total, the use of this route would involve an additional cost of $1.25 per unit ($4.20 - $2.90 + $3.30 - $3.35). This figure has been shown in the second frame of the first row in Table XIX. Since the total cost would be increased, it is clear that the utilization of this route will not improve the assignment.

A few simple rules can be used to quickly evaluate each of the empty frames. These rules are as follows:

1. Start from an empty frame and record its unit cost.
2. Proceed to a frame in the same row or column in which there is a circled number and record its unit cost as a minus figure.
3. Make a right angle turn and proceed to the second circled number. Record its unit cost. (The second move must, of course, be to a circled number from which the third move is possible).
4. Make another right angle turn and proceed to the third circled number. Record its cost as a minus figure. (The third move must be made

in such a way that the fourth move is possible). If this circled number is in the same column or row as the empty frame, the loop is complete. If not, continue the series of right angle moves to successive frames in which there are circled numbers (recording the unit cost alternatively as positive and negative) until the circled figure to which a move is made is in the same column or row as the starting point.

5. Total the unit costs and enter the figure in the empty frame.

Examples of the application of these rules are shown in Figures 12 and 13. Both figures are sections of the body of the matrix shown in Table XIX.

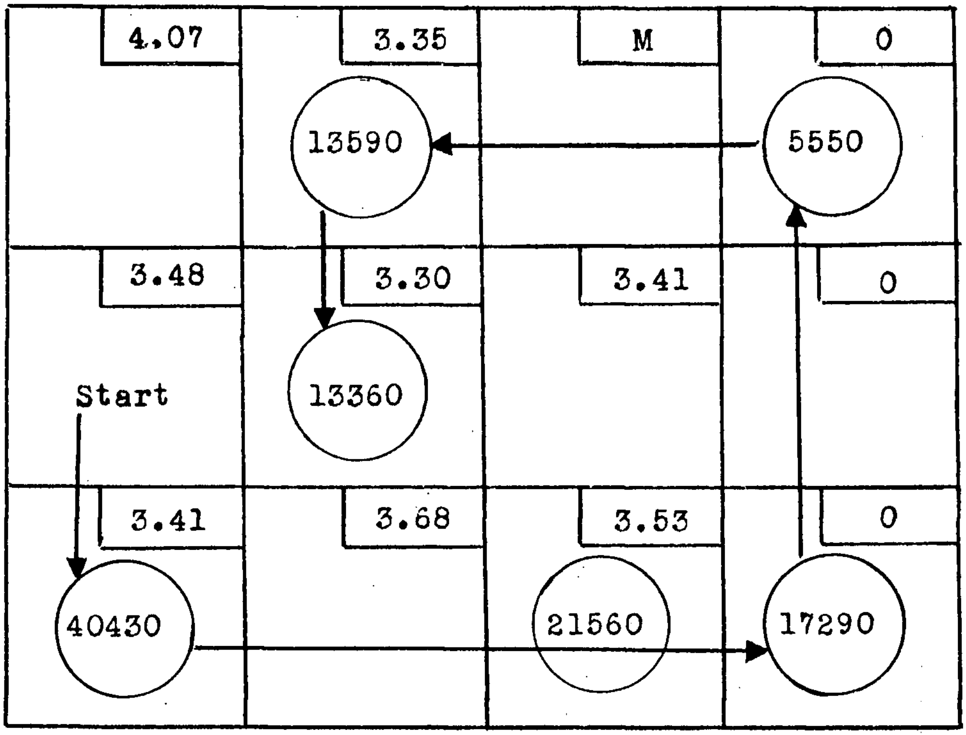

FIGURE 12

DETERMINING THE COST OF AN

UNUSED TRAFFIC ROUTE

Following the arrows; costs would be recorded as follows:

Start	$3.48	
Step 1		-$3.41
2	0	
3		- 0
4	3.35	
5		- 3.30
	6.83	- 6.71

The net change in total cost, if the first frame of the middle row in Figure 12 is included in the assignment, would be an additional $0.12 per unit.

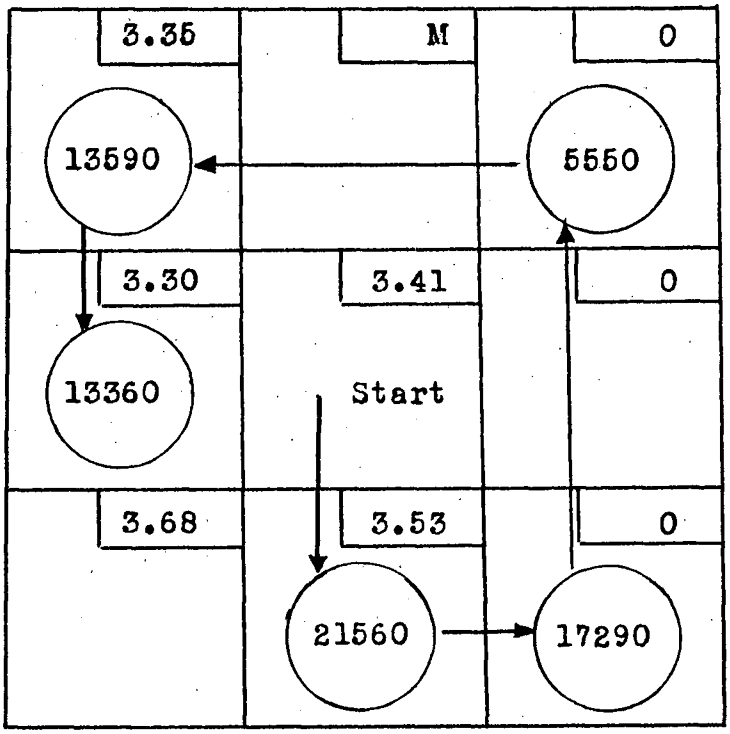

FIGURE 13

DETERMINING THE COST OF AN

UNUSED TRAFFIC ROUTE

In this example, changes in cost are as follows:

Start	$3.41	
Step 1		-3.53
2	0	
3		0
4	3.35	
5		-3.30
	6.76	-6.83

The net change in total cost, if the second frame in the middle row of Figure 13 is included in the assignment, would be a saving of $0.07 per unit.

The above procedure has been carried out in evaluating the per unit cost associated with the utilization of each of the routes that have been excluded from the assignment. The numbers in each of the unused frames in Table XIX are the result of these evaluations. The negative figures appearing in the third and tenth frames of the second row indicate that the assignment, as originally formulated, is not optimum. There is a potential reduction in total assignment cost of $0.15 per unit for every unit that can be placed in the third frame, and $0.07 for every unit that can be placed in the tenth frame. The next step, therefore, is to change the assignment to include these routes.

The procedure for this step is to follow the same path that was used to evaluate the frame in which the negative number appears. The path that was used to evaluate frame ten of the second row is shown in Figure 13 and will be used, therefore, to illustrate this step. Normally, however, the first change would be to include the frame in which the largest negative number appears.

Referring to Figure 13, the first step in adjusting the assignment is to determine the maximum number of units that can be placed in the starting frame. Following the arrows, we see that we will have to subtract the units that are placed in this frame from three of the circled numbers -- 21,560, 5,550 and 13,360. Since the distribution from plant to warehouse must be either zero or a positive quantity, it is clear that 5,550 is the maximum number of units that can be placed in the starting frame. The total adjustment through the inclusion of 5,550 units in the starting frame and successive subtractions and additions of the same amount to the circled numbers in Figure 13, is shown in Table XX.

The next step is to recompute the cost of utilizing each of the routes that have not been included in the new assignment. The result of this calculation is shown in each of the frames of Table XX in which circled numbers do not appear. The negative number in the third frame of the second row indicates that the solution is still not optimum. The same procedure as outlined above will indicate that the 5,550 units that has just been placed in the tenth frame of the second row, must now be placed in the third frame of that row, with a

TABLE XX

TRANSPORTATION MATRIX - FIRST ADJUSTMENT

		DISTRIBUTION WAREHOUSES											
		10D to AW	10D to BW	10D to CW	10D to XW	10D to YW	6F to AW	6F to BW	6F to CW	6F to XW	6F to YW	Dummy Ware-house	Plant Capacity
PLANTS	A	3.40 40000	4.20 1.25	5.10 1.17	3.90 0.55	M M	2.95 80860	3.80 0.56	4.07 0,73	3.35 19140	M M	0 0.07	140000
	B	4.50 1.15	2.90 30000	3.80 -0.08	3.30 20000	3.50 10000	3.94 1.04	3.19 53910	3.48 0.19	3.30 7810	3.41 5550	0 0.12	127270
	C	5.30 1.83	5.20 2.18	4.00 35000	4.50 1.08	4.30 0.68	4.67 1.65	4.52 1.21	3.41 40430	3.68 0.26	3.53 16010	0 22840	114280
Product Demand		40000	30000	35000	20000	10000	80860	53910	40430	26950	21560	22840	381550

corresponding subtraction and addition respectively in the third and tenth frames of the third row. The change in assignment as a result of this adjustment is shown in Table XXI.

The recomputed cost of utilizing each of the routes that have been excluded from the new assignment are also shown in Table XXI. Note that all of these figures are now positive. This means that it is impossible to rearrange the assignment to produce a lower total cost. The solution, therefore, is optimum.

As a point of interest, the total cost of the assignments in each of Tables XIX, XX and XXI has been established by summing the product of each of the circled figures and their appropriate unit cost (eg., 40,000 x $3.40 + 80,860 x $2.95 + , etc.). The result of these calculations are as follows:

Table XIX	$1,178,098	
Table XX	1,177,709	(Improvement $389.)
Table XXI	1,177,265	(Improvement $444.)

The saving through re-assignment in Table XX can be established by simply multiplying the saving per unit that was shown to be available in frame ten of the second row in Table XIX by the number of units assigned to that frame in Table XX, ie., $0.07 x 5,550 = $389. Similarly, the

TABLE XXI

TRANSPORTATION MATRIX - OPTIMUM SOLUTION

		DISTRIBUTION WAREHOUSES											
		10D to AW	10D to BW	10D to CW	10D to XW	10D to YW	6F to AW	6F to BW	6F to CW	6F to XW	6F to YW	Dummy Ware-house	Plant Capacity
PLANTS	A	3.40 40000	4.20 1.25	5.10 1.25	3.90 0.55	M M	2.95 80860	3.80 0.56	4.07 0.81	3.35 19140	M M	0 0.15	140000
	B	4.50 1.15	2.90 30000	3.80 5550	3.30 20000	3.50 10000	3.94 1.04	3.19 53910	3.48 0.27	3.30 7810	3.41 0.08	0 0.20	127270
	C	5.30 1.75	5.20 2.10	4.00 29450	4.50 1.00	4.30 0.60	4.67 1.57	4.52 1.13	3.41 40430	3.68 0.18	3.53 21560	0 22840	114280
Product Demand		40000	30000	35000	20000	10000	80860	53910	40430	26950	21560	22840	381550

saving through re-assignment in Table XXI can be computed by multiplying the saving per unit shown in the third frame of the second row of Table XX by the number of units assigned to that frame in Table XXI, ie., \$0.08 x 5,550 = \$444. These savings are relatively small in comparison to the total cost. It should be remembered, however, that we have limited the number of plants, warehouses and products in these illustrations in order to simplify the discussion. As a result, we were able to come closer to the optimum solution on the first try than would usually be possible in the practical situation where the analyst would be working with a matrix that is made up of a substantially larger product line and perhaps additional plants and warehouses. It is clear, however, that the organization of data into a Transportation matrix in itself provides the basis for a more intelligent guess at the optimum solution.

Interpretation of the Optimum

The reduction of the Simplex to a form suitable for the formulation of the Transportation matrix resulted in a transformation of some of the original data. The solution that has been provided through the Transportation Method is, of course, in terms of this transformation and must now be converted back to the original data.

Product costs, demand forecasts and plant capacities are given in the original data and there is no need, therefore, to convert these figures. Furthermore, the warehouse requirements of product 10D were not changed in the transformation process and are stated, therefore, in actual physical quantities in the Transportation solution. The only conversion that is necessary is that required to establish the physical quantity of product 6F that has been assigned to each plant in the optimum solution.

In transforming the Simplex, the warehouse requirements of product 6F were divided by the number 0.371 (see step 3 of the conversion process on page 128). These converted or normalized figures were then transferred to the Transportation matrix. The physical quantities of product 6F, therefore, will be 37.1 percent of the figures shown in the Transportation solution.

Taking 37.1 percent of the sum of the circled figures for product 6F in each row of Table XXI, we see that the output of this product that will be required at each plant is as follows:

Plant A = 37,100 units (37.1% of 80,860 + 19,140)
Plant B = 22,900 units (37.1% of 53,910 + 7,810)
Plant C = 23,000 units (37.1% of 40,430 + 21,560)

The output of product 10D that will be required at each plant -- taken directly from Table XXI -- is as follows:

Plant A = 40,000 units
Plant B = 65,550 units
Plant C = 29,450 units

The total capacity that will be absorbed by the above combination of output at each plant is shown in Table XXII.

TABLE XXII

PLANT CAPACITY ABSORBED IN THE TRANSPORTATION SOLUTION

Plant	Product	Units	Production Time Per Unit	Total Production Time
A	10D	40,000	2.00	80,000
	6F	37,100	5.50	204,000
	Absorbed Capacity at A			284,000
B	10D	65,550	2.20	144,200
	6F	22,900	6.00	137,400
	Absorbed Capacity at B			281,600
C	10D	29,450	2.45	72,200
	6F	23,000	6.40	147,200
	Absorbed Capacity at C			219,400

We have stated in the original data that there will be 280,000 minutes of capacity time available at each plant. Absorbed time at plant C is, of course, below this constraint because the solution has provided that the firm's excess productive capacity be concentrated at this point. Absorbed time at plants A and B is slightly above the capacity constraint. This has occurred as a result of the assumption that each of the converted figures in the Simplex matrix were sufficiently close to the figure one to permit the formulation of a Transportation model.[8] It was recognized, however, that there would be a potential error of less than two percent in the Transportation solution as a result of this assumption. It is not surprising, therefore, that the solution suggests a combination of output that exceeds the capacity constraint at plant A by 1.4 percent and at plant B by 0.6 percent. An adjustment in the assignment to conform with appropriate reductions in the capacity constraints of both plants A and B will, of course, be necessary if it is impossible to accommodate the increase in output that would be required with the solution as given in Table XXI. In general, however, there will be some flexibility in the capacity estimates that are used in analysis. It will be advisable, therefore, to re-evaluate these estimates in the light of the solution that has been provided. The solution should be rejected only when this re-evaluation has shown that one or more plants will be

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[8] See pp. 128 and 131.

unable to adapt to the suggested level of output.

Demand constraints for product 10D have, of course, been met by the solution since there was no conversion in transferring these figures to the Transportation matrix. To show that these constraints have also been satisfied for product 6F, the circled figures in the appropriate columns of Table XXI should be multiplied by 37.1 percent, as follows:

Warehouse A = 80,860 x 37.1% = 30,000 units
Warehouse B = 53,910 x 37.1% = 20,000 units
Warehouse C = 40,430 x 37.1% = 15,000 units
Warehouse X = 26,950 x 37.1% = 10,000 units
Warehouse Y = 21,560 x 37.1% = 8,000 units

The results of these calculations correspond with demand figures shown in the original data.

Solution Implications

The method that has been described in the foregoing was based upon bottleneck capacity at each plant, and a predetermined product cost at distribution warehouses via alternative traffic routes. The validity of the assumptions that underlie these two parameters must now be evaluated in the light of the traffic flow that is implicit in the output allocation solution.

Plant capacity. It was indicated in Chapter IV that plant capacity defined in terms of the bottleneck operation implies that the output of other manufacturing processes at the plant can be adjusted to whatever mix of production is called for in the optimum plan. In other words, while the output allocation solution will be within the capacity limits of the assumed bottleneck operation, it is possible that the particular mix of output that would be required by this solution will cause an unforeseen bottleneck in other plant operations.

It is necessary, therefore, to check the capacity of each of the manufacturing processes in the plant in the light of the mix of output that is called for in the solution. The solution will be an adequate basis for short-term planning only if the mix is within the capacity limits of all of the production processes in each plant.

Product Cost Estimates. In estimating product costs at distribution warehouses, it was necessary to assume a certain flow of traffic through a route in order to approximate certain of the cost elements.

The method and cost of transportation, for example, assumed that total demand at a warehouse would be met through one or another traffic routes. If we look at the optimum solution as shown in Table XXI, we see that the demand for product 6F at warehouse X is to be satisfied through two routes. The question then arises as to whether or not the split in demand among the two routes will affect the method of transportation that will be used. If the rail carload rate was used in costing the plant B to warehouse X movement, for example, will the much lower volume through this route preclude a rail carload movement? If so, is the change in transportation rate significant?

Inventory carrying costs and order processing costs at distribution warehouses were based in part upon the assumed method of transportation. It is possible, therefore, that these costs will change if the transportation method differs from that assumed in the cost estimates. The transportation and inventory cost estimates for raw materials also assumed a certain minimum flow. The validity of this assumption may also be questionable in the light of the mix of output that is suggested in the optimum solution.

It is desirable, therefore, to ensure that the pattern of traffic flow that is implicit in the output allocation solution will not result in significantly different unit costs from those that were used in the analysis. This may be done by re-computing the unit costs for each of the traffic routes that are included in the solution -- using the traffic flow from this solution as the basis for the new estimates. If it is found that there is a difference between the original and the new estimate for a particular route, put the new estimate through the Simplex conversion and transfer the result to the appropriate frame in the Transportation matrix. It will then be apparent whether or not the difference is significant enough to require an adjustment in the output allocation solution.

II. LINEAR PROGRAMMING MODEL FOR DAY-TO-DAY PHYSICAL DISTRIBUTION DECISIONS

It was suggested in Chapter III that shipping and transportation from distribution warehouses to customers is the only additional cost in the physical distribution process, once the firm's output becomes available at its final stock points. One of the traffic manager's tasks, therefore, is to minimize the shipping and transportation cost in filling customers orders out of the given quantities of products that are available for distribution at final warehouses. It is assumed that customer orders are received at a central location and that the traffic manager allocates these among distribution warehouses on a daily basis.

The quantity of products that are available for distribution on any particular day requires some clarification. If it is assumed that all of the inventory that is on hand at a stock point may be used for immediate customer orders, there is a danger of sub-optimization. To illustrate, consider the simple case of two warehouses, A and B, and two customers, Y and Z. There are only 500 units of product on hand at warehouse A. Shipping and transportation cost per unit to Y and Z are as follows:

A to Y $1.00 and A to Z $3.00

B to Y $4.00 and B to Z $5.00

On the first day an order is received from Z for 500 units. Since the shipping and transportation cost from A is less than from B, the order is filled from A at a cost of $1500. On the following day, and before inventory at A can be replenished, an order is received from Y for 500 units. This order must be filled from warehouse B at a cost of $2000. Total cost for the two orders is $3500. Had both orders been received on the same day, or in reverse order, Y would have been supplied from A and Z from B at a total cost for the two orders of only $3000.

To avoid this kind of sub-optimization it is desirable to limit the day-to-day distribution from each warehouse to what may be termed <u>surplus inventory</u>. A portion of the total inventory at each warehouse is intended to protect against a maximum demand from a specific group of customers over a lead time, ie., between the time a replenishment order is placed and received. If day-to-day distribution is limited to the inventory in excess of this portion, sub-optimization is not likely to occur. This limit may change from one day to the next -- depending upon whether or not a replenishment order has been placed and, if so, the time that will elapse before receipt of the order. To illustrate, consider a situation in which the level of inventory at a warehouse is based upon a group of customers with a maximum demand of ten units per day. If it takes ten days to receive a replenishment order from the plant, distribution from the warehouse on any day before an order is placed should be limited to the quantity on hand in excess of one hundred units. If a replenishment order has been placed, however, any quantity in excess of ten units multiplied by the remaining days of lead time should be considered as available for distribution.

A perpetual record of inventory availability and distribution at each warehouse will simplify the formulation of a day-to-day physical distribution model. Table XXIII is an example of the way in which this information may be recorded.

TABLE XXIII

INVENTORY AVAILABILITY AND DISTRIBUTION RECORD

PRODUCT: 10D DATE: June 1

Warehouse	On Hand	To be Retained	Available	Shipped	Balance On Hand
A	1,000	400	600	100	900
B	200	100	100	70	130
C	400	200	200	120	280
X	1,000	400	600	80	920
Y	800	300	500	80	720

The balance on hand after shipments have been made on June first are shown in the last column. The figures from this column may now be transferred to a second copy of the form to record inventory transactions for the following day. This has been done in Table XXIV.

Note that the quantity to be retained at warehouse B has been reduced to 50 units in Table XXIV. This reduction shows that a replenishment order has been placed and that the order will be received at B on June 3. (Units to be retained at B on June 2 divided by a maximum demand per day of fifty units). It is also apparent from Table XXIV that a replenishment order has been placed for warehouse C.

TABLE XXIV

INVENTORY AVAILABILITY AND DISTRIBUTION RECORD

PRODUCT: 10D DATE: June 2

Warehouse	On Hand	To be Retained	Available	Shipped	Balance On Hand
A	900	400	500		
B	130	50	80		
C	280	150	130		
X	920	400	520		
Y	720	300	420		

The figures in the available column of Table XXIV may now be used as the capacity constraints in a linear programming model to determine the minimum cost method of meeting customer orders on June 2.

In addition to product availability, the model for day-to-day physical distribution decisions must include customer demands and the shipping and transportation cost to each customer from alternative warehouses.

It is assumed for illustration purposes that customer orders for June 2 are as shown in Table XXV.

TABLE XXV

CUSTOMER ORDERS

Customer		Location	Order Quantity	To be Delivered by	
1.	Adams	Ottawa	30	Wednesday	A.M.
2.	Wilson	Montreal	50	Wednesday	A.M.
3.	Brown	Toronto	140	Wednesday	A.M.
4.	White	Hamilton	100	Thursday	A.M.
5.	Smith	Winnipeg	60	Friday	A.M.
6.	Jones	Edmonton	20	Friday	A.M.

Shipping and transportation cost per unit of product between each warehouse and customer is shown in Table XXVI. It is assumed that a comparison of the alternative methods of transportation to each customer from each warehouse has been made and that the costs shown represent the minimum cost alternative for each warehouse-customer combination -- given the size of the orders and the delivery requirements. The letter M indicates an impossible shipping route.

TABLE XXVI

SHIPPING AND TRANSPORTATION COST

(IN DOLLARS PER UNIT OF PRODUCT)

To From	CUSTOMERS 1	 2	 3	 4	 5	 6
A	.32	.20	.50	.52	.65	M
B	.45	.15	.12	.30	.60	.76
C	.40	.30	.22	.25	M	M
X	.38	.58	.53	.59	.16	.35
Y	M	M	.59	.61	.20	.12

The data as outlined above may now be transferred directly to a Transportation matrix. This has been done in Table XXVII. The procedure for solving the Transportation matrix has already been described in the preceding section of this chapter. Using this same method, it is found that the minimum cost shipping pattern for June 2 is as indicated by the circled numbers in Table XXVII.

TABLE XXVII

TRANSPORTATION MATRIX

To From		CUSTOMERS							Avail-able Quantity
		1	2	3	4	5	6	Dummy	
WAREHOUSES	A	32 30	20 50	50	52 30	65	M	0 390	500
	B	45	15	12 80	30	60	76	0	80
	C	40	30	22 60	25 70	M	M	0	130
	X	38	58	53	59	16 60	35	0 460	520
	Y	M	M	59	61	20	12 20	0 400	420
Customer Demand		30	50	140	100	60	20	1250	1650

Once again, the minimum cost solution is rather obvious in this case through an inspection of the Transportation matrix. In the practical situation, however, the selection of the optimum will usually be complicated by a far greater number of customer orders than has been used in this illustration. But even then, the Transportation Method will provide the optimum solution in a few simple steps.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

The physical distribution concept is concerned with the group of interrelated processes that are involved in the physical flow of traffic from the source of raw materials to production and from production through distribution facilities to customers. These processes include transportation, materials handling, warehousing, order-processing and communications.

There is an increasing volume of literature emphasizing the fact that it is the total cost of the physical distribution processes rather than cost of individual processes that must be taken into account in problems related directly or indirectly to the physical movement of materials and products. This literature, however, tends to concentrate on one or the other of the several problems to which the physical distribution concept may be applied. There also tends to be a lack of attention in the area of procedures that can be followed by the firm in the formulation and comparison of physical distribution alternatives.

Chapter two of this thesis attempted to identify the major applications of the physical distribution concept and to isolate those applications that are within the scope of the traffic manager's sphere of responsibility. Chapters three to five developed the step-by-step procedures that may be useful to the traffic manager in applying the physical distribution concept to decisions that fall within his jurisdictional area.

Major Applications of the Physical Distribution Concept

The scope of the problem to which the physical distribution concept should be applied tends to increase with the time period. In day-to-day operations, demand must be met out of inventories that are on hand at distribution points. The application in this case is limited to the determination of which customer orders should be filled from which distribution point, and the methods of transportation that should be used between stock points and customers. Considering the problem over successively longer planning intervals, however, it becomes clear that alternatives of progressively greater scope emerge with the expiration of present constraints in the form of capital shortage, contracts and other current commitments. Typically, the alternatives for physical distribution will increase in scope in the following order as the planning period is extended further into the future:

1. Alternative utilization of existing physical distribution facilities.
2. Alternative systems of physical distribution facilities with present production locations and capacities.
3. Alternative systems of physical distribution in combination with alternative spatial allocations for production capacities.

A study of the physical distribution function should provide for an evaluation of each of these groups of alternatives if the total benefit that is envisaged in the concept is to be realized.

Since the three groups of alternatives listed above emerge at successive intervals in the future, the study can be divided into three separate analysis. Care must be exercised, however, in defining the time period for each analysis in order to avoid sub-optimization in physical distribution planning. Sub-optimization will occur, for example, if plans for the utilization of present facilities are developed for a period during which it is feasible to introduce a more efficient system of physical distribution facilities. Similarly, planned changes in system facilities will be sub-optimum if the time interval that has been used in the development of this plan extends beyond the point in time at which a change in the spatial allocation of plants should be introduced.

Increasing flexibility over time in the form of capital availability and freedom from present policy, contracts and other commitments will determine, successively, the points in time at which it becomes <u>practical</u> to consider changes in system facilities and changes in plant locations. An analysis of long-term alternatives will then determine the point at which it becomes <u>desirable</u> to adopt a change in plant locations. This point in time marks the end of the period during which alternatives are limited by existing plant locations and, hence, defines the shorter-term interval of time over which analysis should be concerned with potential changes in the system of physical distribution facilities. Similarly, an analysis of changes in physical distribution facilities (assuming present plant locations) will identify the point in time at which the first change in system becomes desirable. The period prior to this date is the appropriate interval for an analysis of the alternatives for utilizing the present system of physical distribution facilities.

In addition to the need to avoid sub-optimization, properly defined time periods are necessary to the formulation of relevant physical distribution alternatives. Physical distribution alternatives are adequate or inadequate depending upon the volumes of traffic, the location of raw materials, plants and markets and the standards of delivery service, or the alternatives of these specifications. Alternatives are feasible only if they are within the confines of operating constraints, including capital shortages, unexpired contracts and other commitments, and the capacity and other operating limitations of fixed facilities (if any). Physical distribution requirements and operating constraints are both subject to change over time and it is only when the time period is clearly defined that these elements of the framework can be identified.

It is apparent, therefore, that a study of the physical distribution function should progress from a long-term analysis to an investigation of the alternatives for successively shorter-term intervals of the future time period. This procedure will avoid sub-optimization in physical distribution planning and will facilitate the development of an appropriate framework for each of the three applications of the physical distribution concept.

The Traffic Manager's Role

The traffic manager plays an important role in each of the three applications of the physical distribution concept. His role is usually advisory, however, in decisions related to a change in plant location or a change in physical distribution facilities. These decisions generally affect operations in several functional departments, eg., marketing, production and finance, and cannot, therefore, be properly evaluated by any one of the functional department heads. Decisions of this nature require top level direction and co-ordination with the participation of the traffic, marketing, production and other interested departments.

Shorter-term applications are defined in this thesis as those in which alternatives are limited to the utilization of existing facilities. These applications range from the day-to-day problem of distribution to customers from available inventories, to the problem of planning the short-term allocation of output among the firm's plants. The day-to-day decision is entirely within the traffic manager's sphere of responsibility since alternatives in this case are limited to the methods for shipping and transportation -- operations that are traditional traffic department responsibilities.

The output allocation decision has been traditionally associated with the production manager's responsibility. It is clear, however, that physical distribution principles should be used in making this decision to ensure that the product is delivered to the market at minimum total cost. This decision, therefore, should be a joint undertaking by the traffic and the production managers who are familiar respectively with physical movement and production alternatives. (It should be pointed out that marketing specifications in the short-term are usually fixed by longer-term plans and policy. Short-term physical distribution alternatives must meet these requirements and there is no danger, therefore, that marketing activity will be adversely affected by the short-term production allocation decision).

Since it is only the short-term applications of the physical distribution concept in which physical distribution decisions will be made by the traffic manager, this thesis has been limited to the development of a method of analysis for two of the physical distribution applications for this period -- the day-to-day problem and the output allocation problem.

The solution to both of these problems requires an allocation of limited resources among competing demands. In the day-to-day problem, there are competing customer orders for the limited quantity of inventory that is available at individual distribution warehouses. In the output allocation problem, there are competing ways in which the limited capacity of each production and physical distribution facility can be utilized. The limited resources, competing demands characteristics place the solution to these problems within the scope of the linear programming technique. This thesis attempts to set down the step-by-step procedures that can be followed in developing the physical distribution alternatives into a form suitable for solution through this technique.

The Day-to-day Problem

In the day-to-day problem, customer orders must be satisfied out of inventories that are on hand at final distribution warehouses. The objective of analysis is to determine which customer orders should be filled from which warehouse in order to minimize the total cost of filling the day's orders. Shipping and transportation is the only additional physical distribution cost, once the product becomes available for distribution at the final distribution points. The optimum solution to the day-to-day problem, therefore, will be the one that minimizes the total of these costs for the day's orders.

The linear programming model in this case requires a list of the customers from whom orders have been received and the size of their respective orders; a list of the distribution warehouses and the units of product that are available for distribution at each of these points; and the minimum shipping and transportation cost per unit of product to each customer from alternative distribution points.

The list of customers and their order quantities can be taken directly from the day's sales orders, or from shipping requisitions received from the sales department. The units of product that are available for distribution at each warehouse can be calculated from warehouse inventory records -- the available inventory at a warehouse being the difference between the quantity on hand and the quantity that is expected to be required over the period prior to receipt of a replenishment order to satisfy a predetermined maximum reasonable demand from customers that are normally served from that point.

The minimum shipping and transportation costs per unit of product will have to be established through a comparison of the alternatives of these processes for each of the feasible warehouse-customer combinations. A warehouse-customer combination is feasible if there is a suitable method or suitable methods of transportation that will satisfy delivery service specifications. The required delivery service for each order may be specified in the shipping requisition, or by the marketing department. In other instances, the analyst may assume that the level of service that has been provided in the past is adequate.

Having established the minimum per unit cost for shipping and transportation between each of the feasible warehouse-customer combinations, this information together with individual customer orders and the quantity of inventory that is available for distribution at each warehouse, can be inserted in a linear programming matrix. The optimum method of physical distribution can now be established from this matrix by applying the linear programming method of solution commonly referred to as the Transportation Method. This method is described in detail in Chapter V.

The Output Allocation Problem

In the output allocation problem, the objective of analysis is to determine the optimum allocation of forecast short-term demand among the firm's plants. The optimum is the alternative that will minimize the total of short-term production and physical distribution costs.

The linear programming model for this problem requires a forecast of product demand at each of the distribution warehouses; a definition of the production capacity of each plant; and an estimate of the total unit variable cost that would be incurred in the manufacture and physical distribution of each product to each distribution warehouse and through each of the routes that traffic may take through the production-distribution system.

In forecasting the units of product that will pass through each warehouse during the period, the first step is to define the market areas that will be served from each point. This can be accomplished in two steps. The first step is to identify the geographical segments of the total market that can be served from each distribution warehouse. The procedure is to relate delivery service requirements in the various customer areas with transportation availability to determine whether or not it is feasible to serve a specific customer location from a given warehouse. The second step is to reduce the size of the market area that can be served from a warehouse to its handling capacity by eliminating the demand of those customers that can be served from an alternative warehouse at a lower shipping and transportation cost.

Sales forecasts and defined delivery standards are necessary in the above procedures. Since the marketing department is likely to be familiar with the territorial breakdown of the total sales forecast, this department should be called upon to allocate forecast demand in units of product among geographical areas as defined by the traffic manager. Delivery service specifications for the various customer areas may be defined explicitly by the marketing department, or may have to be developed by the traffic manager through a review of policy, longer-term plans or historical service records. The delivery standards used in analysis should not be higher than those that will be provided in the longer-term and should not be lower than in the past, unless approval has been obtained from the marketing department.

Having established the forecast of demand at each distribution warehouse, the next step in analysis is to define the output capacity of each of the firm's plants over the short-term period. The output of a plant during this period is limited by technical considerations in the utilization of facilities, policy, organizational problems and other constraints that contribute toward production inflexibility. The production manager should examine these constraints with a view to defining the minimum and maximum output that is feasible for each plant over the defined interval. The maximum output figures will be used in the linear programming model. Minimum output figures will not be used directly in the model but rather as a check on the solution to ensure that the output that is called for at each plant is not below the feasible minimum.

When two or more of the products that are manufactured at a plant pass through one or more of the same processes, the mix of output that will absorb capacity cannot be predetermined and it becomes necessary to express capacity in terms of man-hours, machine-hours or other common measurement. In this case, the various manufacturing operations in the plant should be examined to determine the common process that limits total output. If this bottleneck process is a manual operation, plant capacity should be defined in terms of available man-hours in this process for the period. Similarly, if the bottleneck process is a machine operation, total available hours in this process for the period would be the appropriate capacity measurement. The production manager should also define the portion of bottleneck capacity that will be absorbed in the manufacture of a unit of each of the firm's products so that the combinations of product volumes that will absorb total capacity at the plant can be identified.

Given the demand forecast for each warehouse, and the output capacity of each plant, it remains to complete the data for the linear programming model by estimating the total per unit variable cost of each product at each of the distribution warehouses and through each of the routes that traffic may take through the production-physical distribution system.

A traffic route consists of a source or sources of raw materials for the product, a plant at which the product can be manufactured and a distribution warehouse, linked together by one or more methods of transportation. The first step is to define the feasible traffic routes by determining whether or not there is a suitable and available method of transportation between each source of raw materials and each plant, and between each plant and each distribution warehouse. The result of this investigation can be shown in a flow diagram.

The second step is to identify the variable cost of each of the production and physical distribution processes and the key parameters that will permit a linking of the individual process costs into total route cost. The unit variable cost for a route will include the purchase price of raw materials used in the product, the cost of shipping and transportation between the source of raw materials and the plant, the cost of manufacturing, the cost of shipping and transportation between the plant and distribution warehouse, the cost of carrying raw materials and finished product inventories at the plant, the cost of carrying product inventory at the warehouse and the cost of order-processing and communication procedures.

Schedules for each of these costs and the procedures to be followed in estimating and relating individual process costs into total route costs are described in detail in Chapter IV.

When there are alternatives for transportation between the source of raw materials and the plant or between the plant and warehouse portions of a route, the total variable cost that would be incurred with each method of transportation must be developed. A comparison of the total variable costs associated with alternative methods of transportation must then be made in order to identify the alternative that offers minimum per unit product cost for the route. This cost figure will be the one that is used in the linear programming model.

Having established the minimum variable cost per unit for each product and for each of the feasible traffic routes, this information, together with the demand at each distribution warehouse; the capacity of each plant and the capacity that will be absorbed at each plant by a unit of each product, should be inserted in a linear programming matrix of the type that is commonly referred to as the Simplex Matrix. The minimum cost solution to the production allocation problem can be determined by applying prescribed Simplex rules to this matrix. It is generally impractical, however, to attempt a solution through hand calculation because of the volume of work that is involved in applying these rules. Many of the larger computors have been programmed for the Simplex and this is the preferred method of solution when this equipment is available.

In certain circumstances, however, the Simplex matrix can be transformed into a matrix that is suitable for solution through the relatively simple Transportation Method. The particular circumstances in which this transformation is acceptable and the step-by-step procedure to be followed in converting from a Simplex to a Transportation Matrix is described in detail in Chapter V of this thesis.

II. CONCLUSIONS

The physical distribution concept emphasizes the interrelationship between transportation, handling, order-processing, warehousing and the other processes that are involved in the physical flow of traffic from the source of raw materials to plants and from plants through distribution facilities to customers. The essence of the concept is that it is the total cost of the several processes rather than the cost of individual processes that should be taken into account in decisions that are related directly or indirectly to the physical movement of materials and products.

The business decisions in which physical distribution cost is an important element include the long-term spatial allocation of production facilities; the intermediate-term changes in the system of physical distribution facilities; the short-term utilization of existing production and physical distribution facilities;

and the day-to-day distribution of available output.

In making these decisions, it is important to recognize that physical distribution alternatives (except day-to-day alternatives) are usually interrelated with alternatives in one or more of the purchasing, production and marketing functions of the enterprise. This interrelationship is not surprising since physical distribution is the connecting link between purchasing and production and between production and marketing operations. The cost of raw materials input at a plant, for example, includes the price of raw materials as well as the cost of physical distribution from their source to the plant. Hence, when there are alternative sources of raw materials, the purchase decision and the physical distribution decision cannot be made independently. Similarly, the cost of the product at a distribution point includes the cost of the manufactured product at a plant as well as the cost of physical distribution from plant to warehouse. Hence, when distribution warehouses can receive the product from alternative plants and when future demand is not expected to absorb total production capacity, there must be an integration of the decisions that will govern the rate of output at each of the firm's plants and the methods of physical distribution between plants and distribution warehouses.

Considered in the longer-term, there will be sufficient capital and operating flexibility to introduce changes in the system of physical distribution facilities, some of which will either extend the geographical territory that the firm will be able to accommodate, increase the efficiency in terms of cost or delivery service with which the existing markets can be served or change the relative efficiency with which the product can be delivered to specific segments of the present market. In other words, marketing implications are associated with physical distribution alternatives and decisions in the two areas are therefore interdependent. In the very long-term, flexibility will be sufficient to permit the firm to consider a relocation of production capacities together with a change in the system of physical distribution. It is imperative, of course, that each of the alternative combinations of markets that are available to the firm in the very long-term be evaluated in the light of total delivered product cost through alternative spatial allocations of production capacities and alternative systems of physical distribution facilities.

In view of these interrelationships, it is clear that physical distribution analysis, ie., the formulation and comparison of physical distribution alternatives, is usually only a part of the overall analysis in which physical distribution alternatives are integrated with alternatives in other areas of operations to determine the optimum course of action for the firm. An exception is the day-to-day problem of satisfying customer orders from output that is available at final distribution points. Physical distribution alternatives in this case must satisfy inflexible marketing requirements (given customer orders and delivery service). Purchasing and production operations are unaffected by the day-to-day warehouse to customer physical movement decisions.

Day-to-day decisions in physical distribution appear to fall within the sphere of responsibility that is usually assigned to the traffic manager. It is clear, however, that longer-term decisions in which it is necessary to integrate alternatives for physical distribution with alternatives in other areas of operations, are beyond the scope of the decisions that can be made by the traffic manager of the typical organization structure. A few firm's have appointed physical distribution managers.

This title, however, appears to be functionally oriented if it is intended that these officers are to integrate marketing, production and physical distribution alternatives.

In the author's opinion, physical distribution decisions for the longer-term, ie., changes in the system of physical distribution facilities and in the spatial allocation of production capacities, is an integral part of the development of overall corporate plans. The corporate planning function is usually undertaken by a planning unit that reports directly to the chief executive, or by a research and development department. It would seem that this is where the interrelationship between the longer-term physical distribution alternatives and other operations can be properly evaluated. The role of the traffic department and other operating departments should be to contribute to the overall planning process by providing cost and other information related to alternatives within their respective fields.

While the traffic manager's role is advisory in planning for the longer-term, it would seem that this officer is in a position to direct and co-ordinate the analysis that is necessary for short-term operating plans in which materials and product distribution is involved. Marketing requirements during this period are usually fixed since the firm will have committed itself, through longer-term plans and policy, to certain markets and to a certain standard of service within each of these markets. Production and distribution facilities are also fixed during this period, but there will usually be some flexibility in the mix and the rate of output that can be achieved at each plant, and in the methods of physical distribution that can be employed with given facilities.

Marketing requirements, the location and price of raw materials, and the cost and flexibility of production at each plant can be defined for analysis purposes by the marketing, purchasing and production departments. This framework will permit the traffic manager to develop the alternatives for short-term traffic flow through the production-distribution system; to determine the total cost of production and physical distribution for each of the flow alternatives; and to select the alternative that offers minimum total delivered product cost for the period. The pattern of traffic flow that is implicit in the solution to this problem will indicate the locations from which materials are to be purchased and the mix and volume of traffic that each of the production and physical distribution facilities will be required to accommodate. The solution, then, will provide the basis for detailed operating plans within each of the purchasing, production and physical distribution areas of business operations.

Mathematical programming in general and linear programming in particular appear to have promise as the methods in which the complex interrelationships that are usually associated with physical distribution applications can be resolved. The problems for which mathematical programming is ideally suited are those in which there are several possible courses of action; certain conditions that must be met (demands); and certain limitations that must not be exceeded (constraints). Physical distribution applications fall within this group of problems. In the short-term planning problem, for example, there are several ways in which future demand may be allocated among the firm's plants, but alternative allocations must satisfy warehouse demands and must not exceed the capacity of production and physical distribution facilities. The advantages of the mathematical programming technique are that it requires a mathematical formulation of the problem and, hence, requires an organized procedure for the formulation of alternatives; it permits all of the quantifiable demands and constraints that are relevant to the problem to be taken into account; and it provides the best solution out of the several possible solutions through a simple and a definite routine.

In view of these imposing advantages and the fact that the characteristics of physical distribution applications place these problems within the realm of this technique, it is surprising that few of the proponents of the physical distribution concept have emphasized the potential of mathematical programming in physical distribution analyses. There is a need for further research into the development of linear programming, non-linear programming and other mathematical models as the tools for physical distribution analysis.

This thesis has not dealt in detail with some of the obvious problems that are likely to arise in the development of data for the planning model. The per unit handling costs and order-processing and communications costs per order, for example, are not likely to be readily available from accounting and other records that are maintained by the firm -- particularly for the alternatives to present methods. It may be necessary, therefore, to employ work study procedures, regression analysis, engineering studies or other methods to develop suitable estimates of individual process costs. A second shortcoming of this thesis is that the assumed relationships between physical distribution processes that have been used in the illustrated example may be overly simplified. Handling costs, for example, may vary with the degree of congestion at the stock point as well as with the method of transportation that is used. Order-processing and communication costs, which include the cost of expediting an order through the system, may vary with the point from which materials are received or with the method of transportation that is used. It is essential, of course, that all of the relationships between physical distribution processes be identified in order to produce reliable estimates of route costs.

In practice, the planning problem may be complicated by several factors that have not been taken into account in the hypothetical problem that has been described in this thesis. The purchase price of raw materials, for example, may vary with order size; it may be possible to combine various materials or products for shipping purposes; it may be possible to achieve higher output at plants through the use of overtime; etc.

A procedure for the formulation and comparison of alternative systems of physical distribution facilities and alternative spatial allocations for plant capacities was beyond the scope of this thesis. These applications of the physical distribution concept have been discussed in some of the published literature, most of which has dwelt upon the development of alternatives within the framework of given marketing specifications. It should be emphasized however, that the markets that can be served and the standards of service that can be offered may vary with alternative systems of physical distribution facilities and with alternative spatial allocations for production capacities. If marketing specifications are predefined, it is possible that an opportunity to serve a more profitable combination of markets, or an opportunity to improve the net contribution from existing markets, will be overlooked.

A review of the literature dealing with the physical distribution concept suggests the need for additional case histories of successful applications. These case studies should be sufficiently detailed to permit the readers to evaluate:

1. The factors that have been taken into account

in establishing the objectives and the framework for analyses.

2. The procedures that have been used in the development of physical distribution alternatives.
3. The procedures that have been employed in establishing the interrelationship between the cost of individual physical distribution processes.
4. The provision that has been made for relating physical distribution alternatives with alternatives in other areas of operations.
5. The method that has been used in selecting the optimum alternative.

In conclusion, it appears that there is a need at this time for a bridge between physical distribution theory and physical distribution practice. More empirical studies are necessary before management will be able to grasp the essentials of physical distribution analysis and the procedures for analysis that will satisfy their individual requirements.

BIBLIOGRAPHY

1. BOOKS

Ammer, Dean S. Materials Management. Homewood, Illinois: Richard D. Irwin Inc., 1962.

Baumol, William J. Economic Theory and Operations Analysis. Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1961.

Bock, Robert H., and William K. Holstein. Production Planning and Control: Text and Readings. Columbus, Ohio: Charles E. Merrill Books Inc., 1963.

Bowman, Edward H., and Robert B. Fetter. Analysis for Production Management. Homewood, Illinois: Richard D. Irwin Inc., 1957.

Brown, R.G. Statistical Forecasting for Inventory Control. New York: McGraw-Hill Book Company Inc., 1959.

Charnes, A., W.W. Cooper, and A. Henderson. An Introduction to Linear Programming. New York: John Wiley and Sons Inc., 1953.

Churchman, C. West, Russell L. Ackoff, and Leonard E. Arnoff. Introduction to Operations Research. New York: John Wiley and Sons Inc., 1957.

Dorfman, R., P.A. Samuelson, and R.M. Solow. Linear Programming and Economic Analysis. New York: McGraw-Hill Book Company Inc., 1958.

Frederick, John F. Using Public Warehouses. Philadelphia: Chilton Company Inc., 1957.

Greenhut, Melvin L. Plant Location in Theory and in Practice. Chapel Hill, North Carolina: The University of North Carolina Press, 1956.

Holt, Charles C., et al. Planning Production, Inventories, and Work Force. Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1960.

Isard, Walter. Location and Space-Economy. New York: John Wiley and Sons Inc., 1956.

Lewis, Howard T., and James W. Culliton. The Role of Air Freight in Physical Distribution. Boston: The Alpine Press Inc., 1956.

Magee, John F. Production Planning and Inventory Control. New York: McGraw-Hill Book Company Inc., 1958.

Reinfeld, V., and William R. Vogel. Mathematical Programming. Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1958.

Sasieni, Maurice, Arthur Yaspan, and Lawrence Friedman. Operations Research-Methods and Problems. New York: John Wiley and Sons Inc., 1959.

Smykay, Edward W., Donald J. Bowersox, and Frank H. Mossman. Physical Distribution Management. New York: The MacMillan Company, 1961.

Sord, Burnard H., and Glenn A. Welsch. Business Budgeting. New York: Controllers Institute Research Foundation, 1958.

Taff, Charles A., Traffic Management Principles and Practices. Homewood, Illinois: Richard D. Irwin Inc., 1959.

Vazsonyi, Andrew. Scientific Programming in Business and Industry. New York: John Wiley and Sons Inc., 1958.

Villers, Raymond. Dynamic Management in Industry. Englewood Cliffs, New Jersey: Prentice-Hall Inc., 1960.

Welch, W. Evert. Tested Scientific Inventory Control. Greenwich, Connecticut: Management Publishing Corporation, 1956.

Whitin, Thomson M. The Theory of Inventory Management. Princeton, New Jersey: Princeton University Press, 1957.

2. PERIODICALS

Baer, John W. "Pinpointing Transport's Hidden Costs," Distribution Age, LIX, No. 7 (July, 1960), pp. 36, 37 and 70.

Baumol, William J., and Philip Wolfe. "A Warehouse Location Problem," Operations Research, VI, 1958, pp. 252-63.

Dillon, John D. "Geographical Distribution of Production in Multiple Plant Operations," Management Science, II, No. 1 (October, 1955), pp. 353-65.

Eneborg, C.G. "How to Plot the Ideal Location for a Warehouse," Management Methods, XIII (January, 1958), pp. 52-55.

Forrester, Jay W. "Industrial Dynamics: A Major Breakthrough for Decision Makers," Harvard Business Review, XXXVI, No. 4 (July-August, 1958), pp. 37-66.

Granger, Charles H. "Best Laid Plans," The Controller, (August, 1962), pp. 42-45.

Greene, A.W. "The DM, New Man On Industry's Top Team," Distribution Age, LIX, No. 3 (March, 1960), pp. 37-38.

Henderson, Alexander, and Robert Schlaifer. "Mathematical Programming, Better Information for Better Decision Making," Harvard Business Review, XXXII, No. 3 (May-June, 1954), pp. 117-44.

Heskett, J.L. "Ferment in Marketing's Oldest Area," Journal of Marketing, XXVI, No. 4 (October, 1962), pp. 40-45.

Holt, C.C., F. Modigliani, and H.A. Simon. "A Linear Decision Rule for Production and Employment Scheduling," Management Science, II, No. 1 (October, 1955), pp. 1-30.

"Keys to Warehouse Selection," *Distribution Age*, LX, No. 2 (February, 1961), pp. 30-31.

Landis, Eugene. "Distribution Management. How to Set Up Your Department," *Distribution Age*, LX, No. 11 (November, 1961), pp. 34-36.

Lazer, William. "Distribution and Marketing Mix," *Transportation and Distribution Management*, II, No. 12 (December, 1962), pp. 12-17.

Magee, John F. "Guides to Inventory Policy," *Harvard Business Review*, XXXIV, No. 1 (January-February, 1956), pp. 49-60; XXXIV, No. 2 (March-April, 1956), pp. 103-16.

________. "The Logistics of Distribution," *Harvard Business Review*, XXXVIII, No. 4 (July-August, 1960), pp. 89-101.

"Mathematics in Management," *Plant Administration and Engineering*, XXII, No. 11 (November, 1962), pp. 53-72.

Modigliani, F., and F.E. Hohn. "Planning over Time, with Some Conclusions About the Nature of the Expectation and Planning Horizon," *Econometrica*, XXIII (January, 1955), pp. 46-66.

"Pitt Seminar Analyses Total Costs in Distribution Management," *Railway Age*, CL, No. 9 (February 27, 1961), pp. 40-41.

Rapoport, Leo A., and William P. Drews. "Mathematical Approach to Long-Range Planning," *Harvard Business Review*, XL, No. 3 (May-June, 1962), pp. 75-87.

Schorr, Jerry. "Product Glut and Start-Up Inventory," *Transportation and Distribution Management*, III, No. 4 (April, 1963), pp. 24-26.

Shycon, Harvey N., and Richard B. Maffie. "Simulation: Tool for Better Distribution," *Harvard Business Review*, XXXVIII, No. 6 (November-December, 1960), pp. 65-75.

Smykay, Edward W. "Physical Distribution Management," *Traffic World*, CVII, No. 7 (February 18, 1961), pp. 75-81; CVII, No. 15 (April 15, 1961), pp. 64-69.

Snyder, Richard E. "Physical Distribution Costs," *Distribution Age*, LXI, No. 1 (January, 1962), pp. 44-51.

_______. "Putting the Physical Distribution Cost Survey Findings to Work," *Distribution Age*, LXI, No. 3 (March, 1962), p. 35; LXI, No. 4 (April, 1962), p. 37.

Sweeney, Richard J. "How to Determine the Number and Location of Warehouses," *Modern Materials Handling*, XVII, No. 1 (January, 1962), pp. 76-79.

"Warehouse X - Its Profitable Shipping Area," *Distribution Age*, LX, No. 2 (February, 1961), pp. 32-33.

3. PUBLICATIONS OF THE GOVERNMENT AND OTHER ORGANIZATIONS

Beckmann, M., and T. Marschak. "An Activity Analysis Approach to Location Theory," *Proceedings of the Second Symposium in Linear Programming*, pp. 331-79. Washington: National Bureau of Standards, U.S. Department of Commerce, 1955.

Flaks, Marvin. *Total Cost Approach to Physical Distribution*. BMC Report Number 3. Greenwich, Connecticut: Business Management Council Inc., 1963.

Physical Distribution Management. AMA Management Report No. 49. New York: American Management Association Inc., 1960.

Smykay, Edward W. (Ed). *Essays on Physical Distribution Management*. Washington: The Traffic Service Corporation, 1961.

4. UNPUBLISHED MATERIALS

Roberts, Merrill J. "Transport Dynamics and Distribution Management." Paper read at the Physical Distribution Management Seminar, University of Pittsburgh, February 3, 1961.

Thompson, John T. "Unimarket, An Integrated Distribution System." Paper read at the Distribution Management Conference sponsored by the American Management Association Inc., San Francisco, California, April 13, 1960.