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CONCEPT DESIGN AND ANALYSIS OF INTERMODAL FREIGHT SYSTEMS

VOLUME I: EXECUTIVE SUMMARY

P. J. WONG, A. R. GRANT, M. SAKASITA, A. E. MOON

SRI International
Menlo Park, California 94025

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16. Abstract

This report documents the concept design and analysis of intermodal freight systems. The primary objective of this project was to quantify the various tradeoffs and relationships between fundamental system design parameters and operating strategies, as they impact costs and performance. The report is in two volumes:

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PREFACE

This report documents the concept design and analysis of intermodal freight systems. The work was performed for the Office of Systems Engineering, U.S. Department of Transportation (DOT) under contract DOT-OST-77-031. The project technical monitor was Dr. S. C. Chu of DOT. This report consists of the following two volumes:

- Volume I: Executive Summary
- Volume II: Methodology and Results

The study was conducted by the Transportation and Industrial Systems Center at SRI International. Dr. P. J. Wong was the project leader and directed a team consisting of:

- R. M. Corbett--developed cost models.
- A. R. Grant--responsible for simulation modeling and analysis.
- M. A. Hackworth--performed analysis of simulation data.
- A. E. Moon--responsible for costing methodology.
- M. Sakasita--responsible for hand-analytical investigations.

The author would like to acknowledge the active technical participation of Dr. S. C. Chu, the DOT project technical monitor who contributed substantially to the technical direction and content of this project. Also, appreciation is expressed to the following for their comments and technical advice during the research effort: J. Ward of the Office of Science and Technology, and R. Favout and G. Watros both of the Transportation Systems Center.

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BACKGROUND AND OBJECTIVES

The three major components of an intermodal freight system are the local service component, which picks up and delivers commodities within a local terminal area; the linehaul component, which transports the commodities between terminals; and the terminal component, which aggregates and transfers commodities between the first two components. An effective and economically successful intermodal freight system is possible only if the local service, linehaul, and terminal components are harmonized and fully integrated. Harmonizing all the freight shipment components requires an understanding of trade-offs between fundamental system design parameters.

Currently, the set of knowledge concerning fundamental design and system integration questions is sadly lacking. This lack of understanding manifests itself when attempts are made to optimize each component of the system in order to optimize the entire system. Unfortunately, this approach rarely leads to an optimized total system. The development of a fundamental understanding of the quantitative interrelationship between major elements of a freight system would:

- Enhance the design of freight systems under existing technology.
- Guide future technology innovations where they will contribute the most system impact.
- Provide a systematic basis for transportation planning/policy decisions.

The primary objective of this project was to quantify the various trade-offs and relationships between fundamental system design parameters and operating strategies, as they impact costs and performance. The purpose was to determine the directions in which the greatest payoff may lie and, therefore, the type of research and development (R&D) that needs to be further pursued. Thus, the outputs of this study, layed a firm foundation and understanding for the concept design of a new innovative intermodal freight system. So as not to restrict unduly the range of what is feasible and potentially desirable, the study was conducted without the constraints of today's existing plants, current technology limitations, and institutional restrictions.

The emphasis in the study was not to evaluate or analyze specific realizations or implementations of advanced intermodal concepts, because to do so would provide a narrow knowledge base. Rather the emphasis was on the study of a generic intermodal system that is independent of a specific implementation concept. In this manner, understanding was developed along a continuous spectrum of freight system characterizations, and therefore was not restricted to an evaluation of specific design alternatives. This allowed the development of a methodology and data base to evaluate and analyze all system design alternatives. Indeed, the methodology developed is an important output of the study, for it can be used to analyze other types of questions such as operational strategies and policy analyses. The degree of detail and specificity can be increased by changing the cost function module in the overall methodology to be appropriate for the type of questions raised.

Because of the generic nature of the study, the important tradeoff questions were among fundamental design parameters or policy variables at an aggregate level, rather than on a detailed "micro" design level. Examples of the tradeoff questions and interdependencies of interest include the following concepts:

- There is a broad spectrum of available operating strategies ranging from nonstop, origin-to-destination train movements to trains with several intermediate stops. For each intermediate stop, time is spent for container transfer and for container accumulation; this, in turn, affects equipment utilization. The economies that can be achieved by aggregating containers at intermediate nodes and by decreasing utilization of equipment due to the time spent waiting at these nodes are areas to be analyzed.

- Vehicle and crew productivity increases with increasing speed; on the other hand, so do the costs of maintenance, energy and investments. Thus, each system design will have an optimal operating speed range for the given demand that the system has to serve. The relationship of "optimal" design speed to the number and size of trains needs to be analyzed.
- A container can spend a substantial amount of time in the linehaul portion of the system and in the terminal portion. The optimum match between terminal processing capability and linehaul speed requires investigation.

The framework of the study assumes an intermodal system consisting of a basic grade-separated, dedicated right-of-way network for linehaul vehicles. Intraregional collection and distribution would be performed by pickup/delivery vehicles on highways. For such a system it can be assumed that the freight is containerized and that transfer between pickup/delivery vehicles and linehaul vehicles occurs at terminals.

ANALYSIS OF A LINEAR CORRIDOR SYSTEM

In view of the fact that a complete intermodal system characterization is complex and has many variables and degrees of interaction, and that very little research exists in the systematic understanding of freight system tradeoffs, it was decided to focus initial attention on the simple linehaul system represented by the five-node linear network shown in Figure 1. Such a simple linear system has real world analogs in the numerous heavy volume freight "corridors" that exist in the U.S.

Although the linear network is simple, it provides an abundance and richness of insights that are necessary before one can systematically cope with a more complex two-dimensional system. It is anticipated that the study of a more complex two-dimensional network can be conceptually broken down into the study of a sequence of linear segments with container transfers between linear segments.

For this simple linear system, the demand is characterized by the number of containers going from each origin to each destination. A number of trains move over the linehaul segments carrying containers between terminals; a train moves at a constant speed over the linehaul segments and has a fixed maximum capacity (or size) for carrying containers. All terminals are identical and are characterized by a single processing time that is the combined time needed to both load and unload containers from a train; the number of terminal platforms (or berths) determines the number of trains that can be simultaneously processed. Thus the five main engineering system design parameters whose interrelationships and tradeoffs were studied are displayed in Table 1.

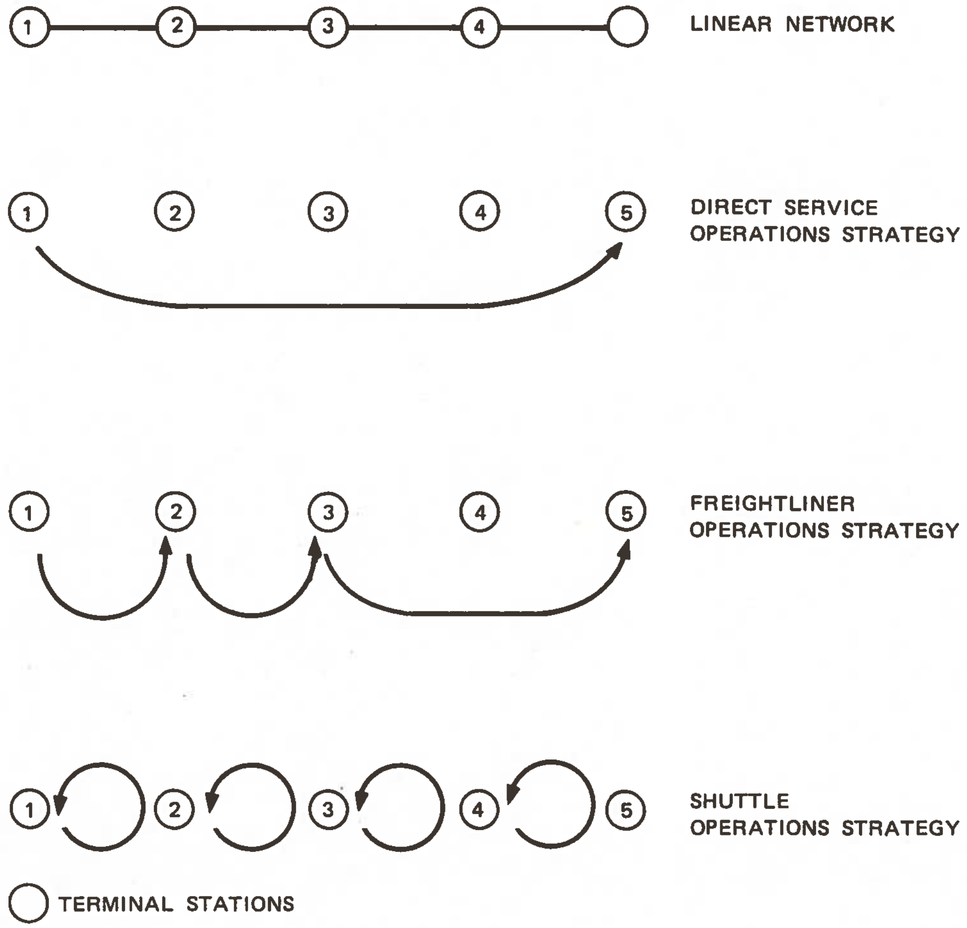

FIGURE 1 LINEAR NETWORK AND TRAIN OPERATIONS STRATEGY

Table 1

ENGINEERING SYSTEM DESIGN PARAMETERS

- Number of trains (fleet size), N.
- Train speed (mph) V (the term train speed or velocity are used interchangeably in this report).
- Train capacity (capacity in containers), C.
- Terminal processing time (loading/unloading a train), P.
- Number of terminal platforms (train berths for loading/unloading).*

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*In this analysis, the number of terminal platforms refers to the number of platforms in a terminal for one direction only; we assume that terminals are symmetric.

The specification of the simple linear system is incomplete until the train's operating strategies on this linear network are specified. It was decided that the most insight can be gained by restricting the study of train operations to a small set of simple "cannonical" strategies. Cannonical strategies represent fundamental strategies; all other train strategies can be considered as hybrid combinations of these cannonical strategies. The three strategies presented in Figure 1 are:

(1) Direct Service--A train carries containers directly from origin to destination without intermediate stops.

(2) Freightliner--A train leaves the initial terminal carrying all containers going in the same direction; a train will stop at an intermediate terminal only if it has containers to set out. Once stopped, the train will pick up additional containers going in the same direction. (This is essentially a local train operation which can skip stops.)

(3) Shuttle--Trains shuttle back and forth between adjacent terminals; containers desiring to go further than the next stop are required to transfer between shuttle trains.

Two complimentary approaches were developed to study the problem. The first approach is based on a detailed computer simulation; the computer simulation is called LINET. The second approach is based strictly on the development of closed-form analytical equations; the approach is referred to as "hand analysis." Because the problem is multidimensional, with many parameters and variables, there is a problem in selecting which relationships should be studied and how they should be displayed. Thus not only the methods used to study the problem are important, but also how the problem was broken down into manageable pieces and displayed is important. The key results are presented in the following pages.

MAJOR FINDINGS AND IMPLICATIONS FOR RESEARCH AND DEVELOPMENT

Several performance measures were analyzed in this study along with their cross impacts on each other. The conclusions were based on the results of these analyses. One of the more telling measures is the following composite ratio, which can be interpreted as a measure of system productivity (or effectiveness):

$$\text{Productivity Ratio} = \frac{\text{average effective container velocity}}{\text{total daily system cost}}.$$

The effective container velocity is calculated by dividing the total distance of container travel by the total time spent in terminals and in linehaul segments. The total daily cost includes terms for guideway costs, terminal costs, crew costs, fuel costs, equipment capital costs, and equipment maintenance costs. The units of this composite measure are miles per hour per dollar, and can be interpreted as a normalized (by the number of containers per day) measure of system productivity.

The costs are based on an extrapolation of current railroad experience and technology (i.e., steel on rail). We assume that the system under study bears the entire cost of the guideway, and that the guideway costs increase with the square of the design train speed. The design speed parameter V was varied over a wide range in order to illuminate the tradeoff between equipment and crew productivity and the costs associated with higher speeds. In all cases, guideway cost was a dominant component of system costs and, thus, mediated against very high design speeds.

In an analogous fashion, terminal processing technology, as embodied in a processing time parameter P, was also varied over a very wide spectrum. The cost component dealing with terminal processing was assumed to increase with the reciprocal of the terminal processing time (i.e., it increases inversely with terminal processing time). The results of the variation indicated high payoff for reducing terminal processing time well below even the best current technologies.

Figure 2 shows an overlay of three curves representing cost, effective velocity, and productivity ratio. The cost curve increases with V^2. The effective velocity rises rapidly with V and then levels off; this reflects the fact that increasing V increases the velocity over the linehaul segments but not through the terminal. Thus we see that the curve of the productivity ratio has a maximum value. The curve shown in Figure 2 is a function of one parameter, namely train speed; a family of such curves and an associated set of optimum train speeds exist for various values of the other engineering parameters, e.g., number of trains, train capacity, and terminal processing time. In particular, Figure 3 shows contours of equal productivity in the two-dimensional parameter space of terminal processing time P and the average linehaul transit time between terminals D/V, where D is the average distance between terminals. We see that the contours are closed and that there is a distinct optimum marked by an "X".

If one varies train capacity as the independent variable, and keeps the system capacity the same, then Table 2 shows the optimum value of the other engineering parameters. We see that the optimum system configurations from a productivity standpoint are those associated with small train sizes; note the productivity ratio is nearly identical for the 10 and 25 capacity trains. Thus the optimum system configurations have a large number of trains (i.e., 30 to 60 trains) of relatively small size (i.e., 10 to 25 container-carrying capacity), which travel at moderate speeds (i.e., 45 to 60 mph). The associated optimum terminal processing time is in the range of 6 to 12 minutes to both load and unload a train.

The assumed cost relationships play a critical role in determining the most cost-effective system design. However, for the cost relationships and cost-effectiveness ratio criteria assumed here, the conclusion can be stated as follows:

- The most cost-effective systems engineering design for a freight system calls for a large number of small trains going at moderate speeds; the associated terminal processing times are on the order of fractions of an hour.

This conclusion remains valid even if the following three modifications to the assumed cost formulation are made: (1) total guideway cost

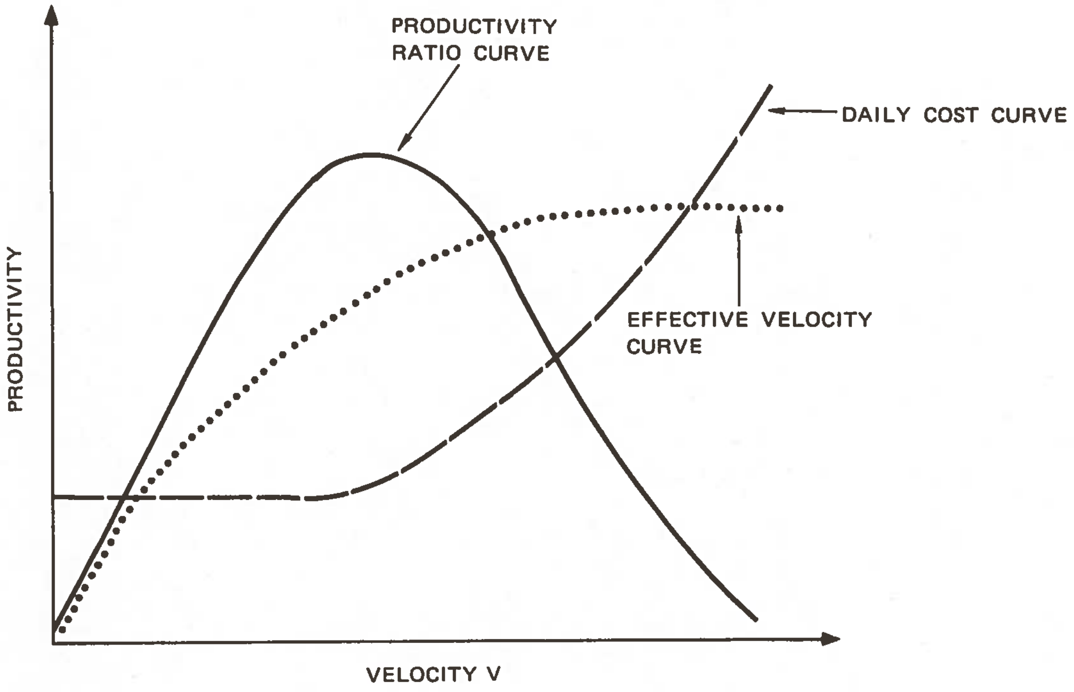
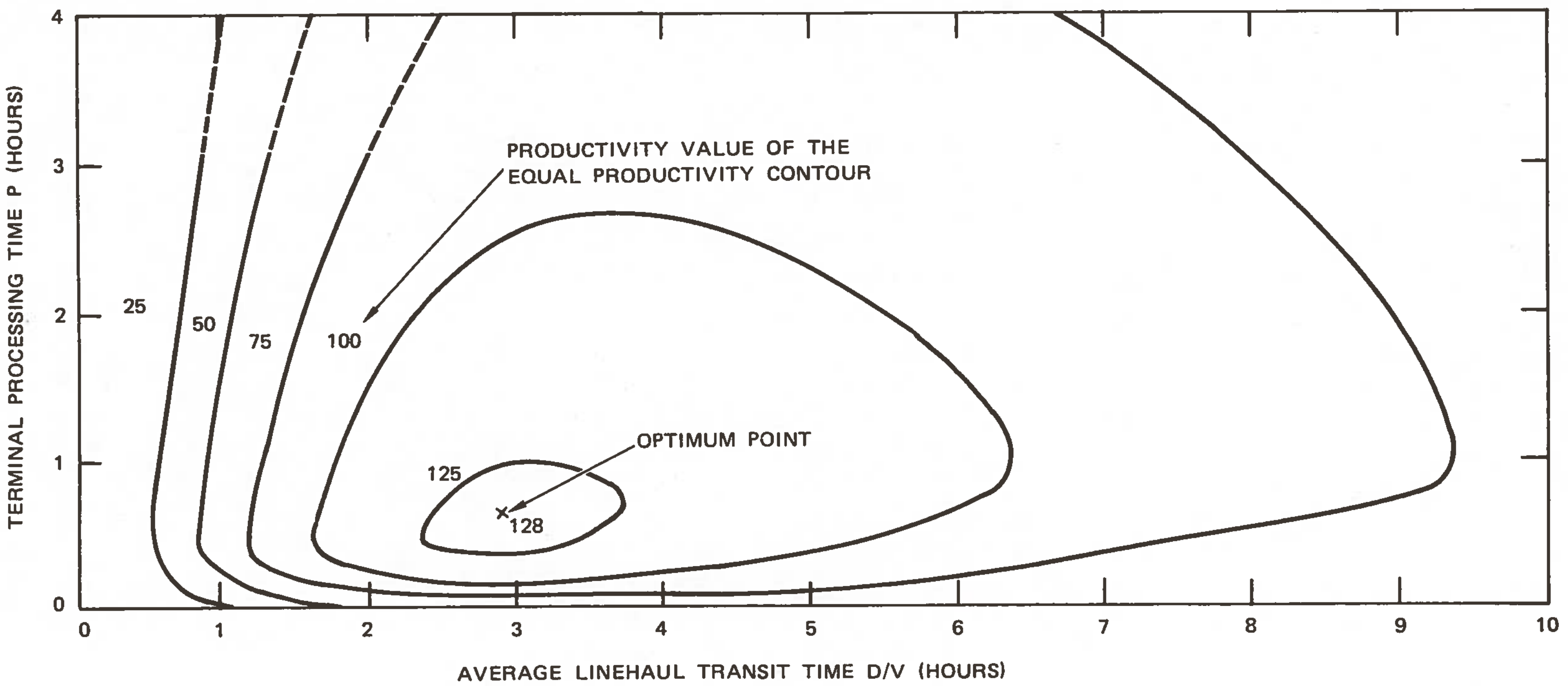


FIGURE 2 THE PRODUCTIVITY RATIO CURVE



FOR PARAMETER VALUES:

C = 100 Containers
D = 108 Miles/Station
Demand = 2300 Containers/Day
I = Terminal Platform

FIGURE 3 CONTOUR CURVES OF EQUAL PRODUCTIVITY

Table 2

OPTIMUM SETS OF ENGINEERING SYSTEM PARAMETERS

	Train Capacity (Containers)				
	10	25	50	100	150
Cost effectiveness	175	171	153	128	119
Number of trains	59	31	19	11	7
Linehaul speed (mph)	60	47	40	37	36
Terminal processing time (hours)	.1	.2	.36	.6	.85
Effective container speed (mph)	48	34	25	21	22
Daily cost ($ millions)	.27	.20	.17	.16	.18

(fixed plus velocity dependent terms) is reduced by a factor of one-tenth, (2) only the velocity-dependent term of the guideway cost is reduced by a factor of one-tenth, and (3) a new guideway cost is formulated to be equal to a $2 surcharge on every dollar spent for fuel.

The rationalization or interpretation of these results is outlined in the following explanation:

- One can achieve a specified level of system capacity through a small number of high-speed trains or a larger number of smaller-sized, moderate-speed trains. The effective container velocity can be increased in one of two ways: (1) by increasing the speed over the linehaul segment by maintaining higher train speeds, or (2) by increasing the speed through the terminals by maintaining faster terminal processing times and more frequent train departures (i.e., more trains) to reduce the container wait time for a train connection. Because the cost functions assumed in this study increase rapidly with the square of train speed (Figure 2), and because the additional cost of adding more trains is a less expensive alternative to higher train speeds, then the optimum cost-effective strategy is to have more smaller trains going at moderate speeds rather than fewer high-speed trains. As one increases the number of trains, the arrival frequency at the terminal increases; to avoid queuing delays for service at the terminal, it is necessary that the terminal processing time for a train be rapid.

The implications for R&D and the interrelationship with alternate cost and financing schemes for advanced freight systems are fundamental and are listed below.

(1) Terminal and Container Transfer Technologies--Assuming that the cost functions are correct, rather than concentrating capabilities on the design, technology, and operations of very high-speed trains, more R&D emphasis should be directed at developing innovative design, technology, and operational strategies to achieve terminal processing times that are significantly faster than those currently available. This rapid terminal processing must be achieved by focusing on the terminal, the container, the pickup and delivery vehicle, and the linehaul container-carrying vehicle as integral parts of the total transfer process.

(2) Guideway Technology and Costs--The results are based on costs obtained by extrapolating current railroad technology and experience. More research is needed to develop accurate cost relationships based on future advanced technology (especially guideway costs) because the optimum train speeds are critically dependent on the nature of the cost functions. Another aspect of guideway costs is that of right-of-way financing. It is assumed that the system under study bears the entire burden of financing the guideway costs. A few different financing schemes, such as user charges, were tested. While the overall conclusions would not have been altered, there were differences in performance results. At this time we do not know the full implications of this but we are certain this is an area where more research will provide substantial new knowledge.

COST-EFFECTIVE SYSTEM DESIGN WITH COST CONSTRAINTS

One of the important questions faced by a system designer is how to develop the most cost-effective design for a specified budgeted cost. Furthermore, to enhance our fundamental understanding of the interrelationships and tradeoffs in the system design parameters displayed in Table 1, it would be desirable to see how this design changes as the cost of the system varies. Figure 4 (a-e) shows the most cost-effective values of the system design parameters plus the associated average transit-time for various specified system costs. For example, for a specified level of cost, one simply "picks off" the most cost-effective set of system engineering parameters from the various curves.

The results, trends, and interpretation of these sets of design curves are as follows:

- As one spends more money on the system, the trend is toward
    - higher speed trains
    - fewer trains
    - smaller trains
    - faster terminal processing times.
- There is a "knee" in the transit-time curve. Up to the point of the knee it is cost effective to spend more money on the system; but after the knee, the marginal gain in cost effectiveness for every dollar spent is less. The optimum cost-effective point is in the region of this knee.
- In the region of the knee of the transit-time curve, the train speeds are moderate; there are a large number of small trains, and the terminal processing is rapid. This indicates that in the region of the knee it is more cost effective to spend money on more trains and faster terminal processing times than on very high-speed train operations.

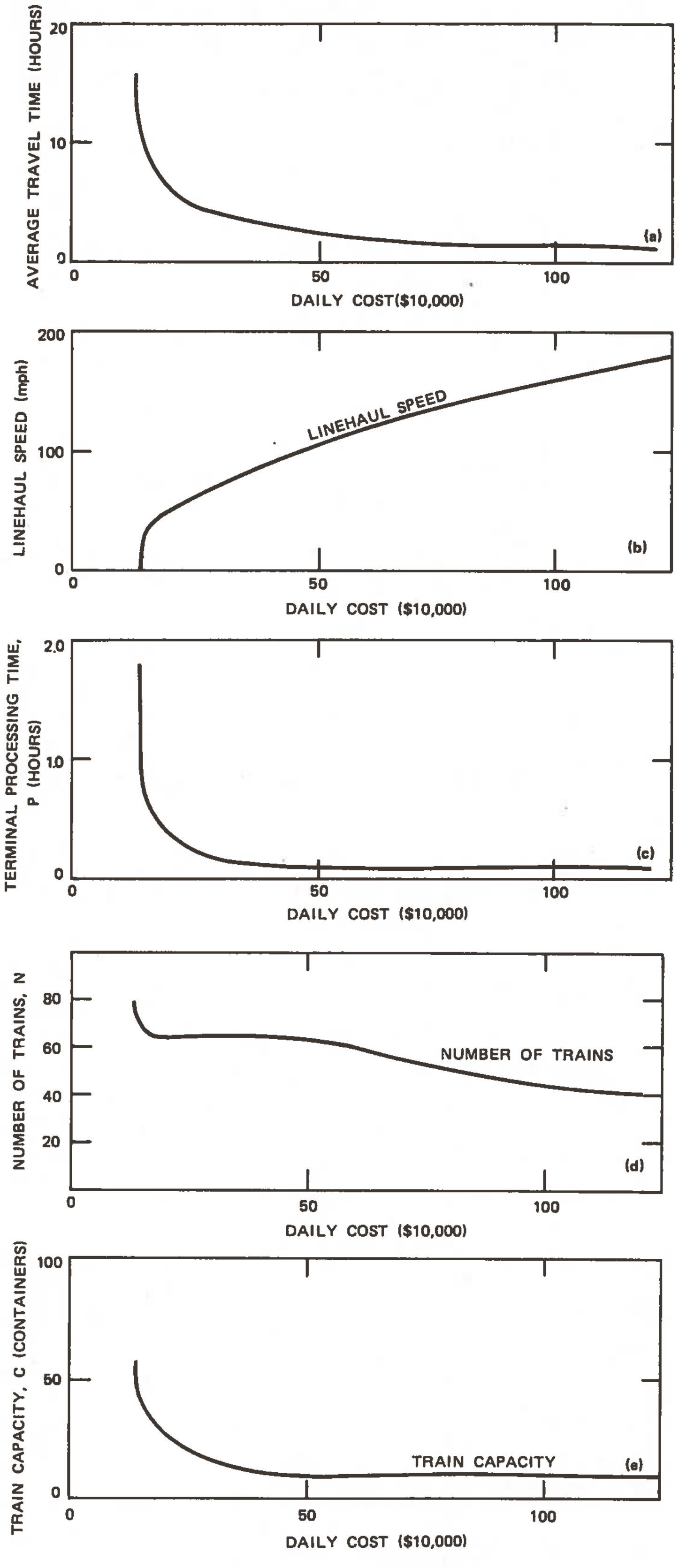


FIGURE 4 MOST COST EFFECTIVE SYSTEM

FEASIBLE SYSTEM DESIGNS WITH SUFFICIENT CAPACITY

Insight into the fundamental interrelationships and tradeoffs of system design parameters can be obtained by studying the spectrum of feasible design alternatives that have sufficient container-carrying capacity to satisfy the steady-state, 24-hour demand for container shipments. We define a system as having sufficient capacity if essentially all the containers get shipped within a 24-hour period.

It was discovered that the multidimensional system parameter space can be divided into two regions. In one region the system is capable of satisfying the demand; in the other it is not. Our analysis focused on the representation of this feasibility region in two dimensions. Figure 5 shows examples of these feasibility regions in several two-dimensional parameter spaces. The curve that separates the feasible from the infeasible region is called the feasibility boundary.

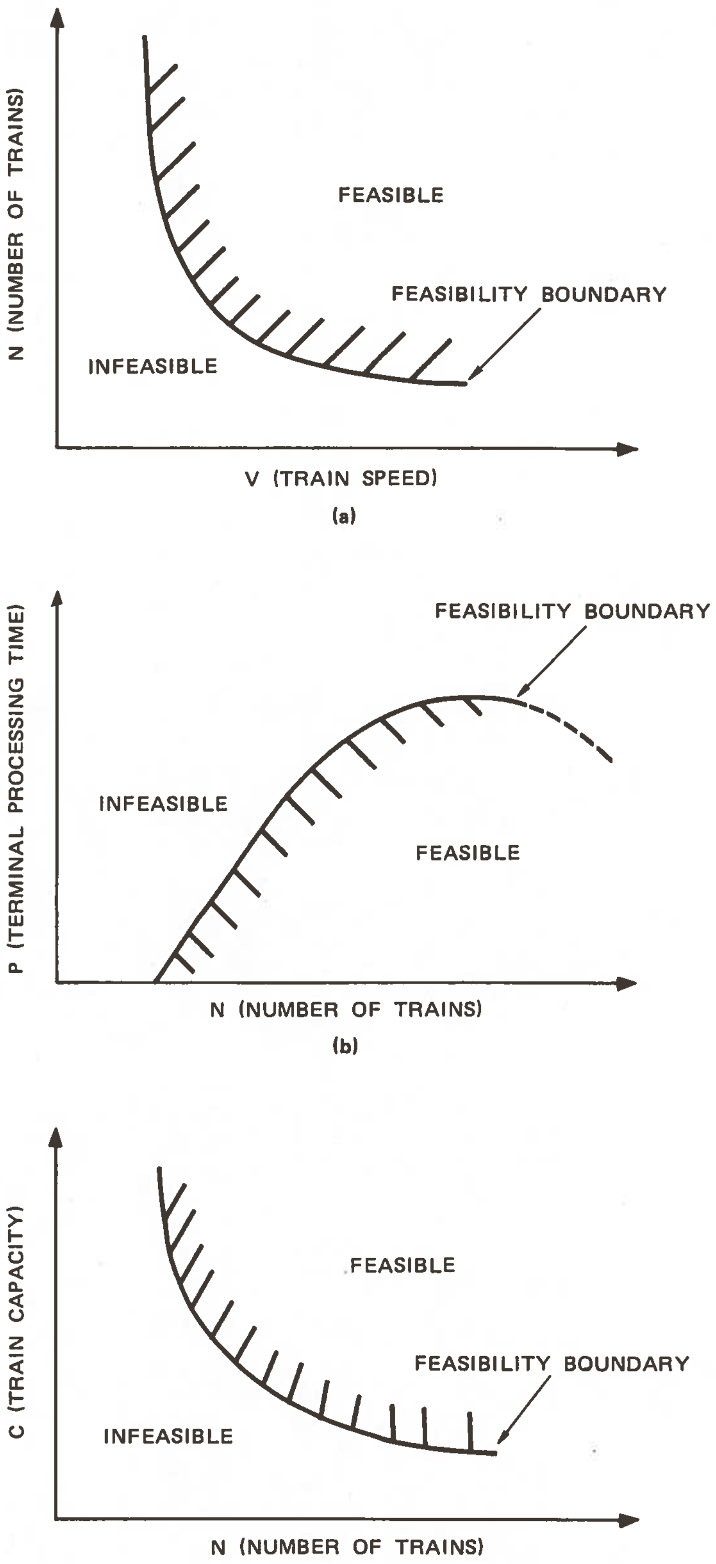
The following three examples shown in Figure 5 (a-c) are discussed below:

- (a) Number of Trains versus Train Speed (N versus V)

  In the V versus N parameter space, the feasibility boundary is hyperbolic in shape as shown in Figure 5a. The vertical asymptote indicates that a minimum train speed is required to satisfy delivery of the containers. The horizontal asymptote indicates that a minimum number of trains is required.

- (b) Terminal Processing Time versus Number of Trains (P versus N)

  In the P versus N parameter space, the feasibility boundary rises with a slope to the right before leveling off. The initial rise of the curve to the right is explained by the fact that, with few trains initially, the terminal processing time must be fast in order to satisfy the demand. However, as more trains are added to the system, the terminal processing does not have to be as fast to satisfy the delivery of the containers up to the point where the curve begins to bend to the right and level off. This bending is caused by the fact that, as additional trains are added to the system, the terminal processing time must be sufficiently fast to prevent queuing delays for trains waiting in the terminal to be processed. (In fact, a portion of our analysis indicates that the curve at some point begins to bend down.)



(a)

(b)

(c)

FIGURE 5 FEASIBILITY BOUNDARIES IN TWO DIMENSIONS

- (c) Train Capacity versus Number of Trains (C versus N)

  In the C versus N parameter space, the feasibility boundary is again hyperbolic in shape. The vertical asymptote indicates that there is a minimum number of trains required to satisfy the demand; the horizontal asymptote indicates there is a minimum train capacity.

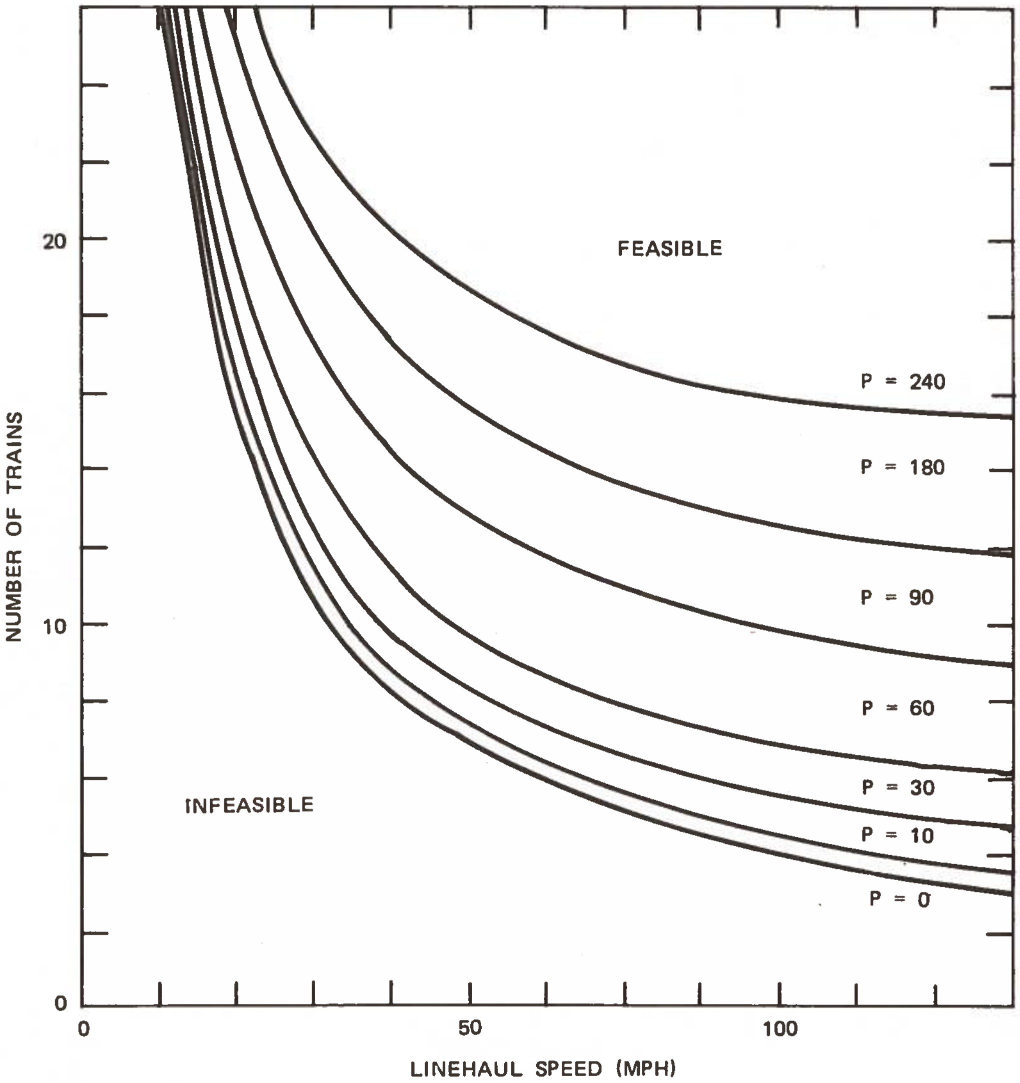
As we stated earlier, in reality the feasibility boundary is a surface in a multidimensional parameter space. Figure 5 shows only "slices" of this surface in two dimensions; the other associated parameter values are not displayed. Figures 6 and 7 provide examples of how the feasibility boundary changes in the N versus V space as either the terminal processing times decrease or the number of terminal platforms increase; in both cases the feasibility regions increase.

- Decreasing Terminal Processing Time

  In the N versus V parameter space, Figure 6 indicates the enlargement of the feasibility region as the terminal processing times decrease. We see that, as they decrease, the feasibility boundaries become a nested set of feasibility curves; feasible system designs become possible with smaller numbers of higher speed trains as terminal processing times decrease.

- Increasing Number of Terminal Platforms

  In the C versus N parameter space, Figure 7 indicates that the feasibility boundary that assumes one terminal platform is nested inside the feasibility boundary that assumes two terminal platforms. We see that the two platform system can operate with a larger number of smaller trains than is possible with a one platform system.



NOTE: Feasibility boundaries for linehaul speed versus number of trains for various processing times (P) in minutes

FIGURE 6 FEASIBILITY CURVE FAMILY IN N-V PLANE

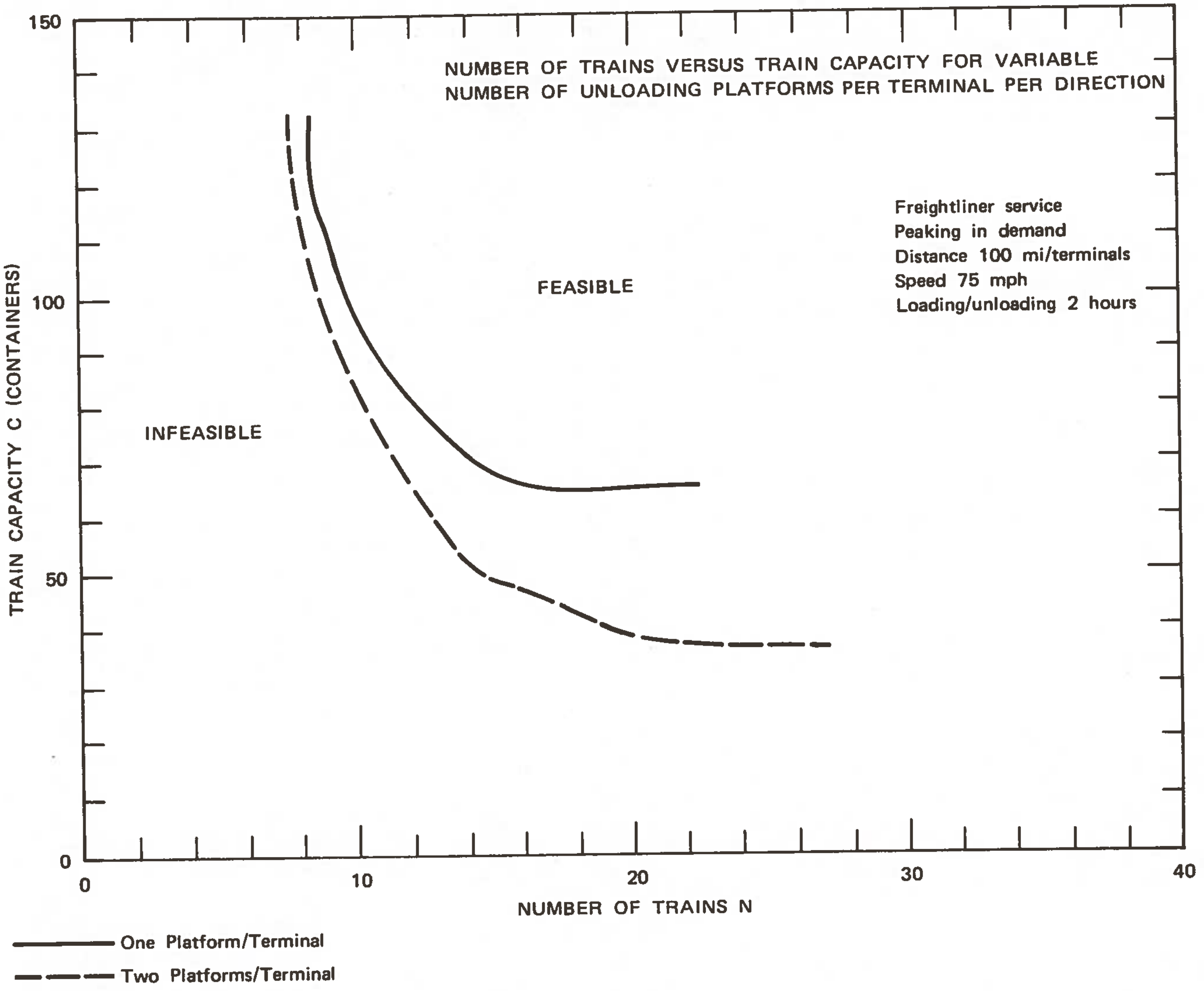


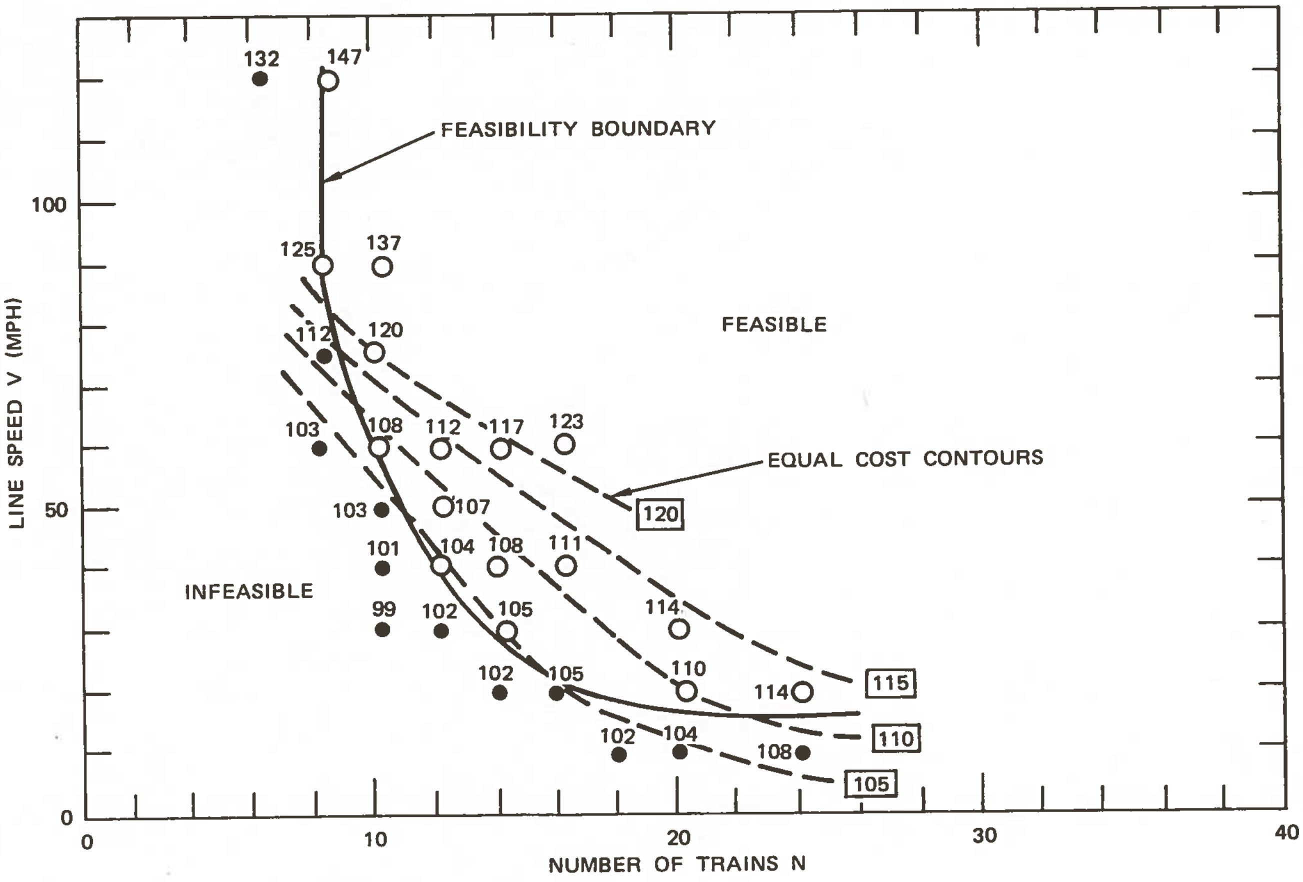
FIGURE 7 FEASIBILITY REGIONS IN THE C-N PLANE

MINIMUM COST SYSTEM DESIGNS

Figure 8 shows a typical example of a feasibility boundary and the associated equal cost contours. It will be seen that the cost curves are somewhat similar in shape and orientation to the feasibility curves, but with less curvature. It is to be noted that the system costs increase as the distance from the origin increases. It is seen that minimum system costs will be found in the "knee" of the feasibility boundary at the point where the feasibility boundary is tangent to a cost curve. It is also noted that the costs in the knee of the feasibility boundary are fairly constant throughout the knee and near the minimum cost. Thus, the knee of the feasibility curve is an area in which minimum cost designs, or near-minimum cost designs, are achieved.

It should be noted that the system designs associated with points in the knee represent a considerable range of design alternatives. In the example, the range of approximately equal cost designs in the knee extends from 11 trains at 50 mph to 16 trains at 20 mph, with perhaps the cheapest feasible solution using 13 trains at 30 mph.

It should be emphasized at this point that the minimum cost design is not necessarily the most cost-effective design. It is merely the <u>cheapest feasible solution</u>. Points in the interior of the feasible region may provide higher cost effectiveness even though at a higher cost.



NOTE: Numbers Reflect Total Annual Cost (Million Dollars)

FIGURE 8 FEASIBILITY CURVE AND EQUAL COST CONTOURS IN THE V-N PLANE

DESIGN FOR A SPECIFIED LEVEL OF SERVICE

One of the most important measures of the service effectiveness for a freight system is the average time a container spends in the system. Figure 9 shows a family of curves representing time in the system plotted against linehaul speed for a specific combination of train capacity, demand, and interstation distance for systems along the feasibility boundary. The hyperbolic shape is clearly evident and the general shape is typical. A number of useful inferences can be made from this chart:

- At low speeds, the time in the system rises rapidly as speed decreases, and reductions in processing time are not effective in reducing the time in the system.
- At speeds over 50 mph, the reverse is generally true. Increased speed does not greatly reduce the time in the system. Increased processing time either increases time in the system or requires very large increases in linehaul speed if time in the system is to be maintained constant. At those speeds, the travel time is small compared to other time components (loading and unloading time, lost time, and waiting time) and the travel time component becomes smaller as speed increases.

A chart similar to Figure 9 would be useful in the initial selection of parameters for a system designed to provide a certain level of service. For instance, for an average container time in the system of 600 minutes, a processing time of 60 minutes would require a line speed of 55 mph. Reducing processing time to 30 minutes would reduce the required linehaul speed to 45 mph. A zero processing time would still require a linehaul speed of 38 mph. On the other hand, increasing the processing time to 120 minutes would require a linehaul speed in excess of 100 mph.

It is informative to plot curves of equal time in the system for various values of terminal processing time P and transit time across a linehaul segment $\frac{D}{V}$*. Figure 10 shows such curves for a specific combination

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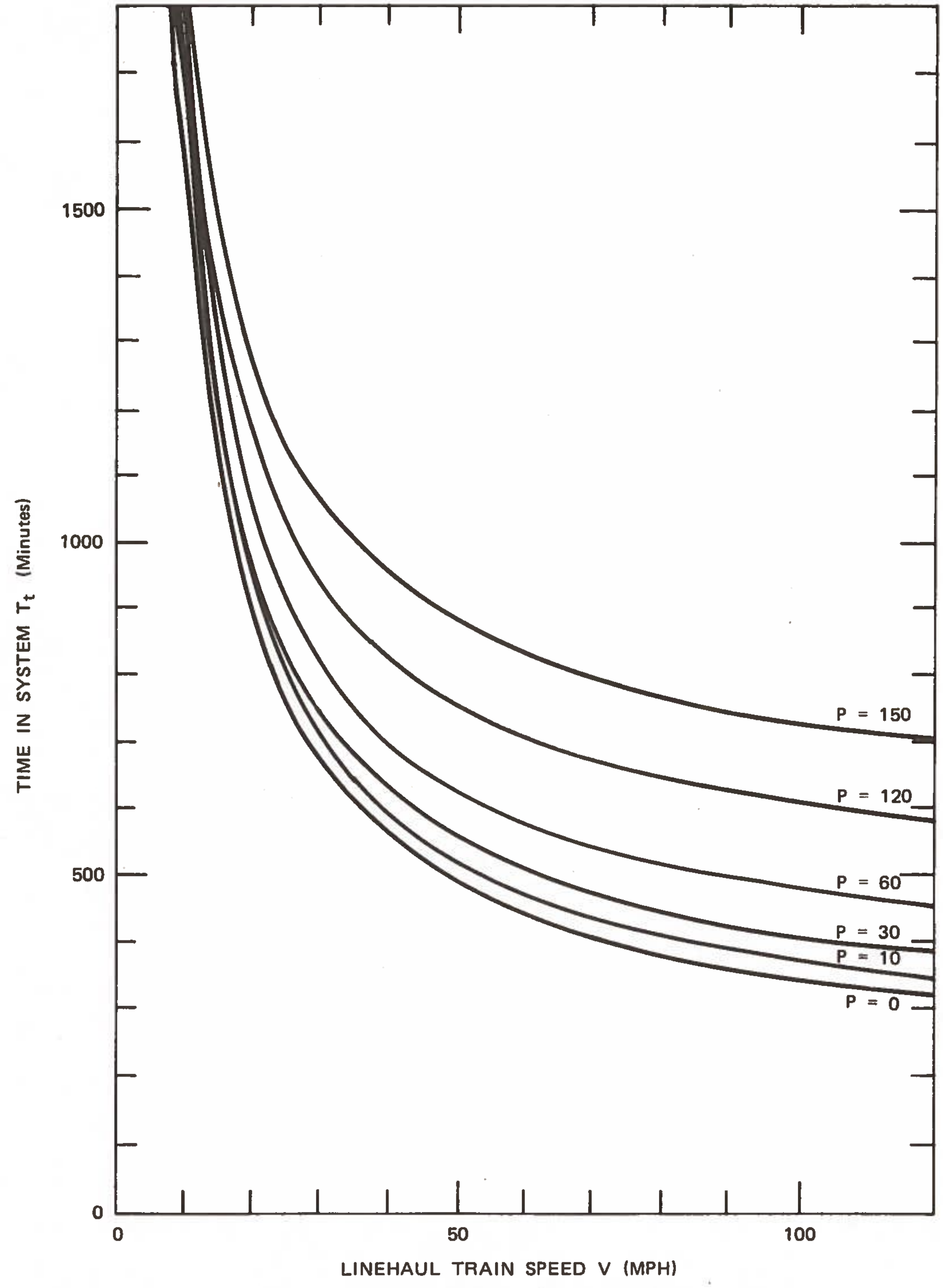
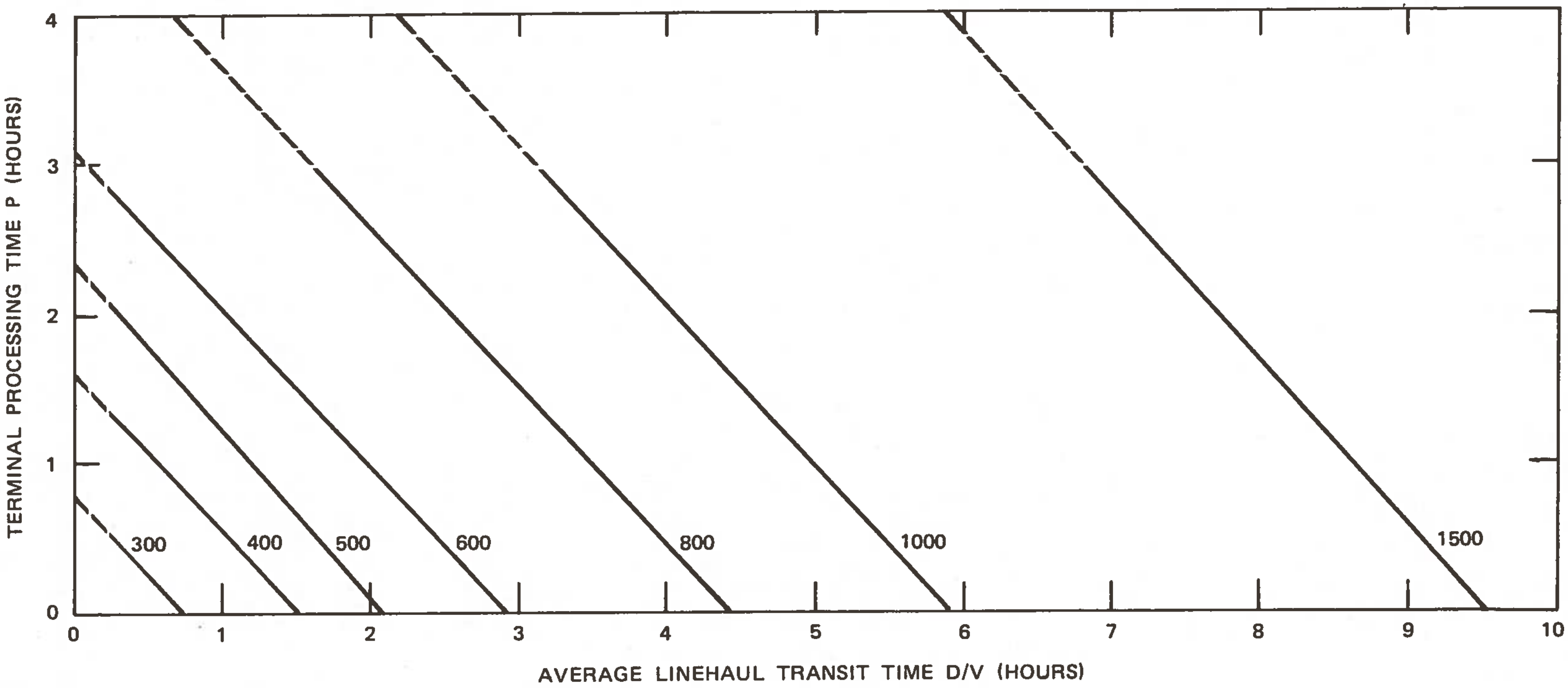
*Using the variable $\frac{D}{V}$ instead of V versus P is useful since $\frac{D}{V}$ and P are in the same units, i.e., time.



NOTE: Time in the system versus linehaul speed along the feasibility boundary for various processing times (P) in minutes

FIGURE 9 TIME IN SYSTEM VERSUS LINEHAUL SPEED



NOTE: Numbers represent time in the system (minutes)

FIGURE 10 CURVES OF EQUAL TIME IN THE SYSTEM FOR VARIOUS VALUES OF P AND D/V of other system design variables. The lines in this figure are fairly straight and evenly spaced. This should not be surprising as P and $\frac{D}{V}$ are combined linearly in calculating time in the system and heavily influence the result. This figure provides a means of rapidly determining the tradeoff between $\frac{D}{V}$ and P for any given level of service. The sections of the curves above P = 3 are unsubstantiated by LINET runs and are therefore indicated with dashed lines. We would expect that as the linehaul transit-time $\frac{D}{V}$ decreases, a "breakdown point" occurs at which the linear relationship is no longer valid. In particular, the curve should begin to bend down with decreasing $\frac{D}{V}$, indicating that the terminal processing time P must decrease to avoid train-queuing delays in the terminal.

The number of terminal platforms influences the size of the feasibility region as indicated earlier, i.e., a system with two platforms per terminal has a larger feasibility region than a system with one platform per terminal. However, it is to be emphasized that, once a system design is feasible, adding extra platforms to terminals has very little effect on the average time a container spends in the system. Thus, the number of platforms affects the ability of the system to satisfy the demand; however, once the system is able to satisfy the demand, the number of platforms has little effect on system effectiveness.

COMPARING CANNONICAL OPERATING STRATEGIES

The following three cannonical train operating strategies were extensively investigated:

(1) Direct service--All trains go directly from origin to destination terminal.

(2) Freightliner--All trains stop at every terminal along their routes, but can skip stops if there are no containers to set out.

(3) Shuttle--A small set of trains shuttle between adjacent terminals; containers beyond adjacent terminals must transfer to another shuttle.

Because actual freight operations can be considered a mix or hybrid of these cannonical strategies, it is important to study and compare their merits.

In doing so, let us first compare the nature of their feasibility boundaries. Figures 11 and 12 show the feasibility boundaries of the three strategies in the N-P plane (number of trains versus terminal processing time) and in the N-C plane (number of trains versus train capacity), respectively. The following observations can be made:

- The feasibility boundary of the shuttle strategy is nested entirely within the feasibility boundary of the freightliner strategy in both the N-P and N-C planes. This implies that, to obtain a feasible system design using a shuttle strategy, more trains, larger trains, and faster terminal processing are always required than if one used a freightliner strategy.
- We observe from the N-P plane that, for a feasible system design, the freightliner strategy can operate with fewer trains than the direct service strategy; however, the freightliner strategy requires faster terminal processing time than direct service.
- We observe from the N-C plane that, for a feasible system design, the freightliner strategy requires larger train sizes than direct service.

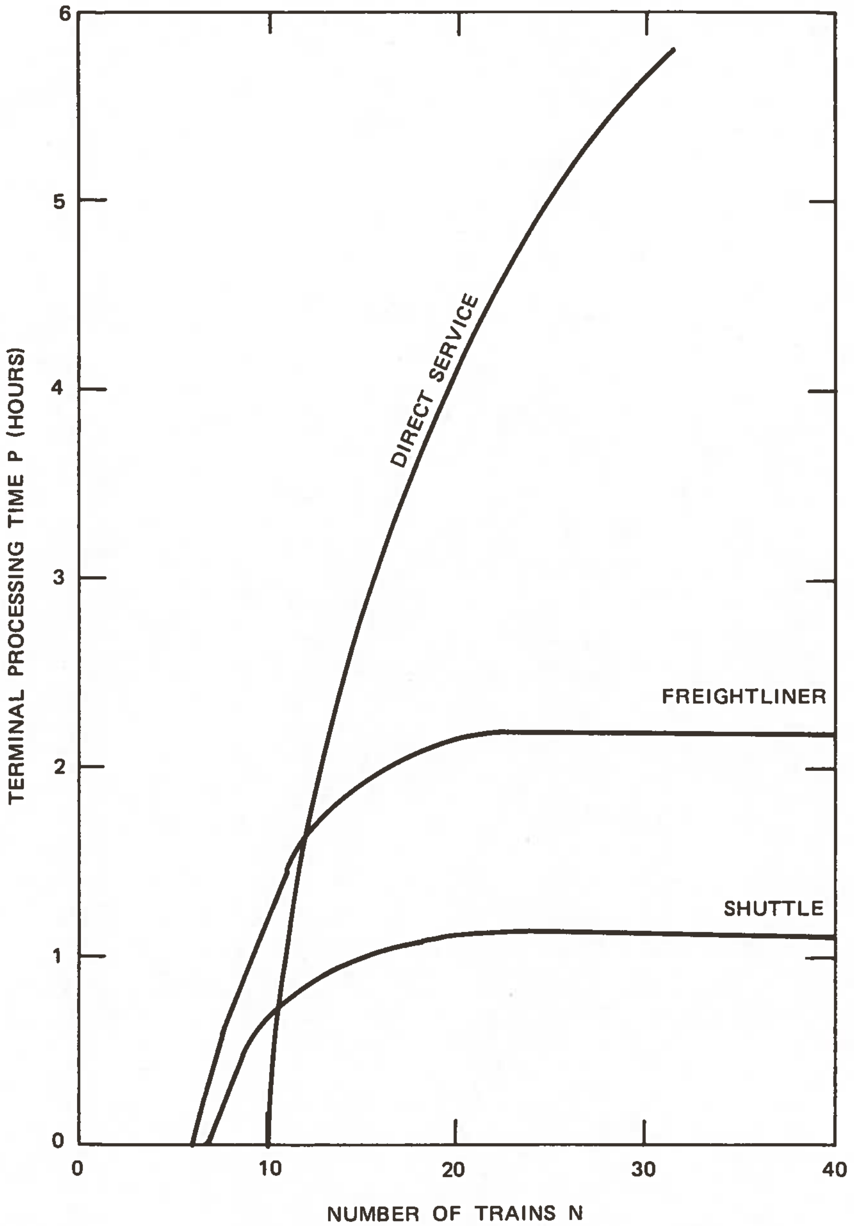
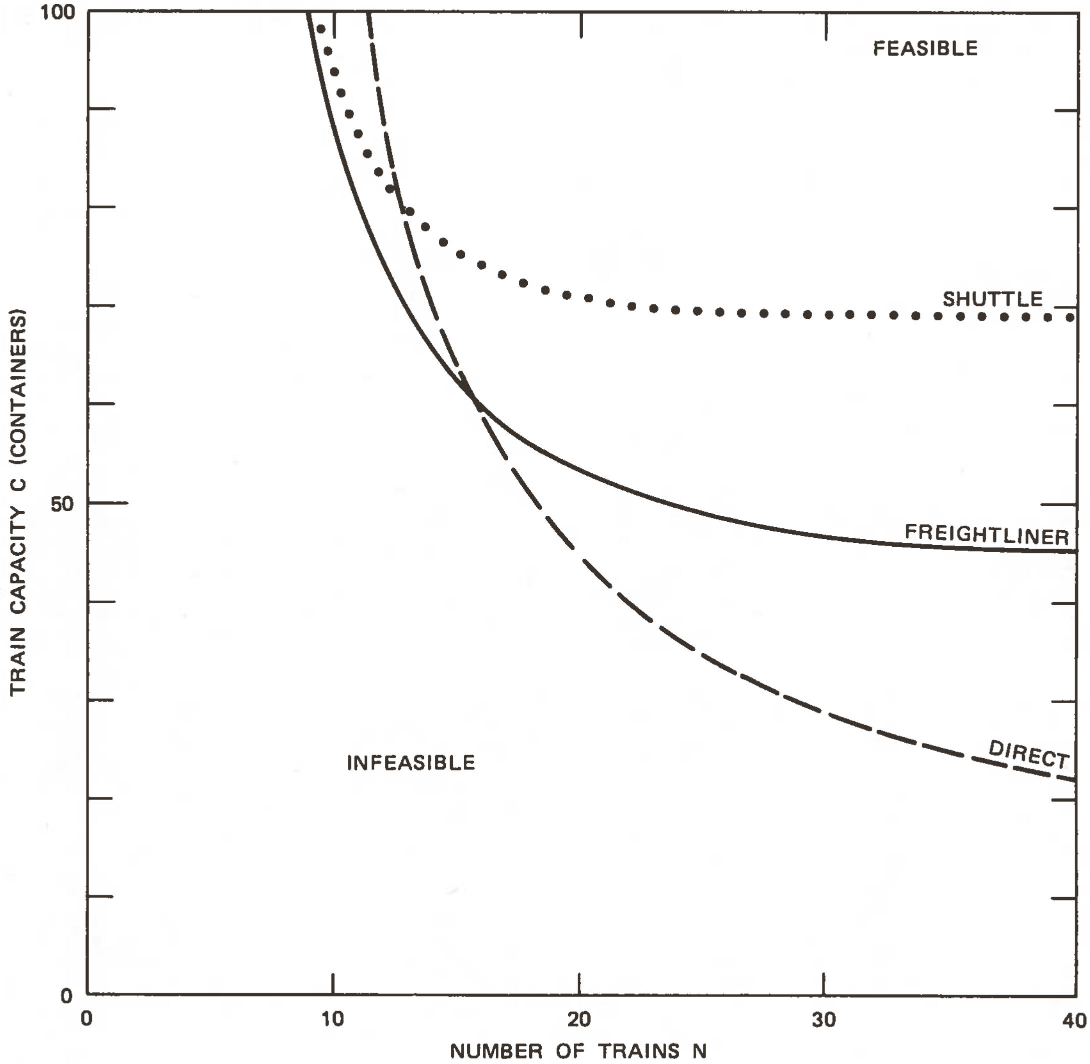


FIGURE 11 COMPARISON OF FEASIBILITY REGIONS IN THE N-P PLANE



R = .7
P = 1 hr
R = 5 cont/hr/o-D
D = 100 mi
S = 60 mph
m = 1

FIGURE 12 COMPARISON OF FEASIBILITY REGIONS IN THE N-C PLANE

Figures 13 and 14 compare freightliner versus direct service strategies and display the regions (zones) in the C-P plane (train capacity versus terminal processing time) where freightliners and direct service strategies yield less transit time or require less fleet size, respectively. We can draw the following conclusions:

- The freightliner strategy yields a smaller transit time and lower costs in comparison to the direct service strategy at short terminal processing times and larger train capacities.
- The direct service strategy yields a smaller transit time and lower costs in comparison to the freightliner strategy at long terminal processing times and smaller train capacities.
- The region in which the freightliner strategy is superior to the direct service strategy becomes larger as the demand for container shipments decrease. In particular, direct service becomes more attractive for high-volume origin-to-destination shipments.

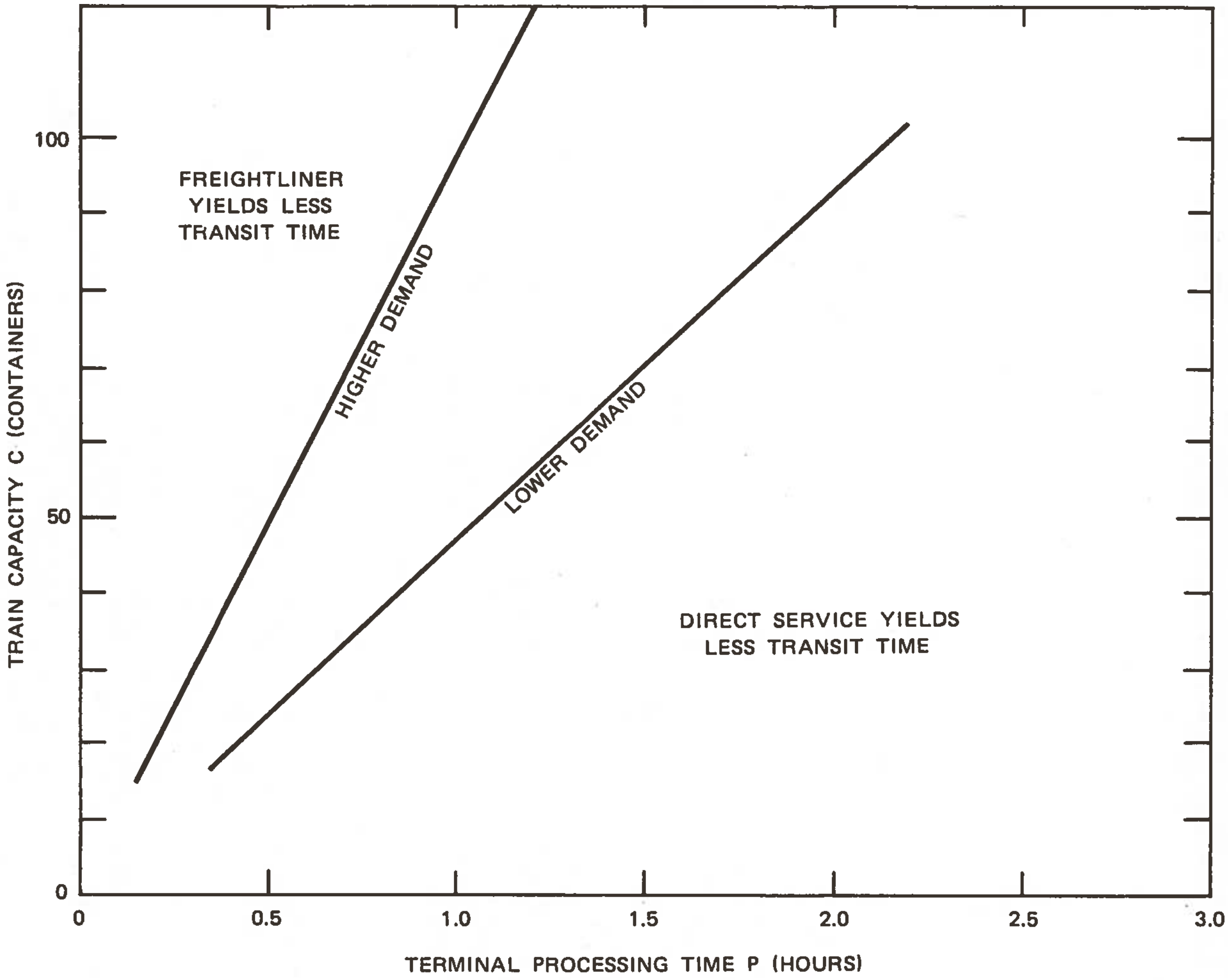


FIGURE 13 OPERATIONAL REGION BASED ON TRANSIT TIME

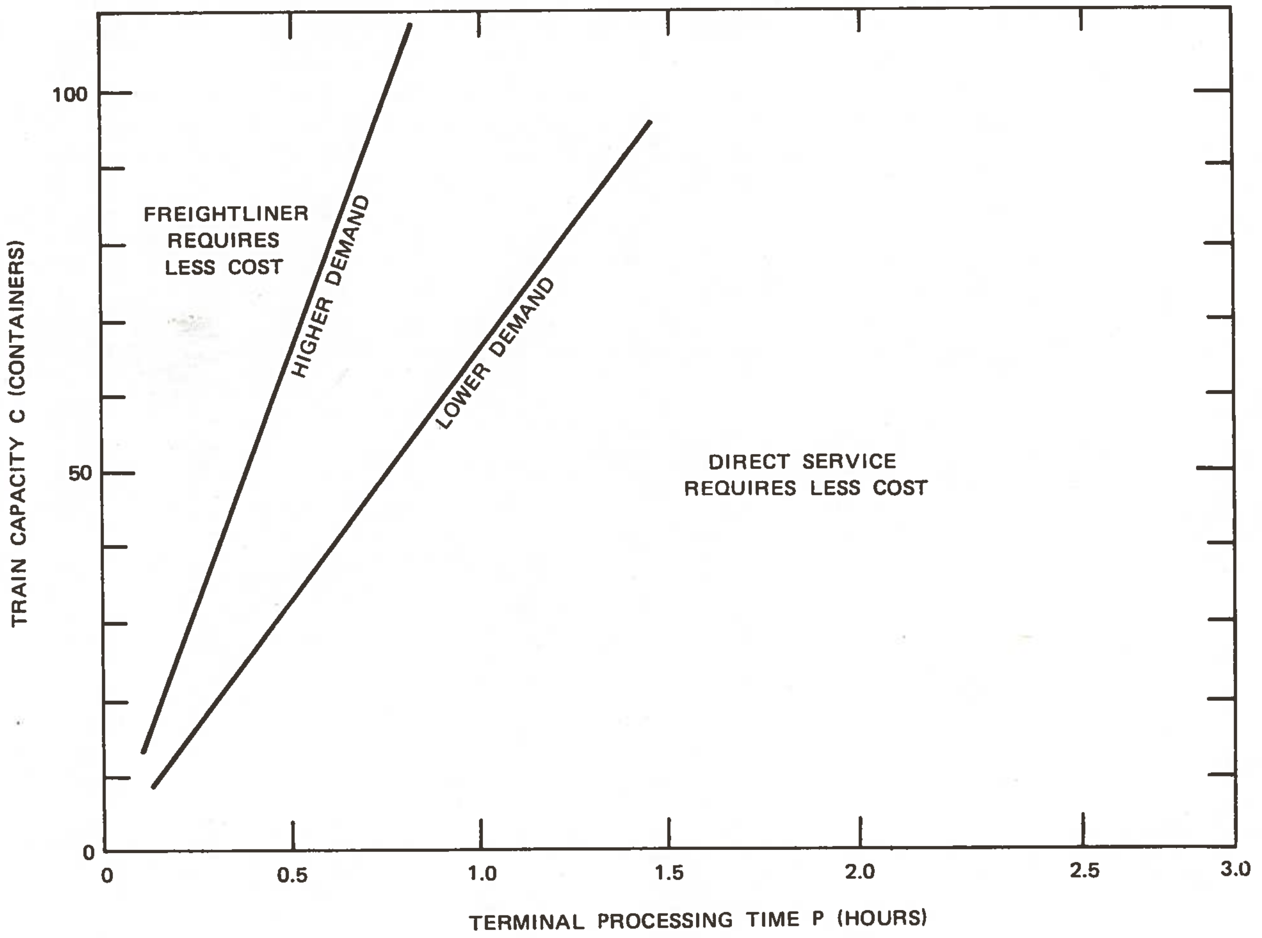


FIGURE 14 OPERATIONAL REGION BASED ON COST

CONCLUSIONS AND RECOMMENDATIONS

There is very little fundamental research being done to help our understanding of the basic interrelationships and trade-offs between intermodal freight system engineering design parameters, policy variables, and operating strategies. Without this understanding, it is difficult to make the correct decisions at both a national policy level and a detailed engineering design level to ensure the future economical and effective transport of goods that sustain the nation's economy. This is especially important in the context of today's energy and environmental concerns. This study has attempted to partially fill the "knowledge gap" in this area.

In this study we have focused on the linehaul and terminal aspects of a simple linear system. We have learned much and have developed new analysis procedures, even for this simple system. However, future studies should extrapolate the knowledge gained from this study, to a two-dimensional network which incorporates the local pickup/delivery service operation.