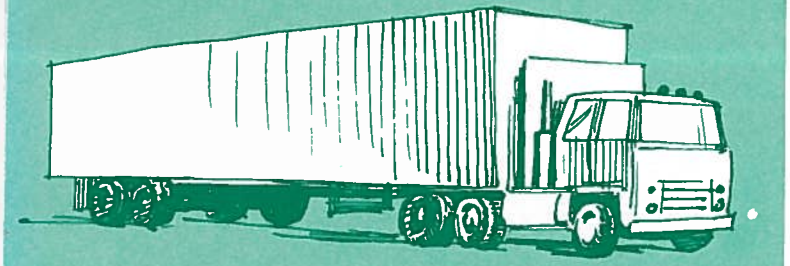
FREIGHT TRANSPORTATION

A Digest of Technical Papers



U.S. DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER

Technical Report Documentation Page

1. Report No.
DOT-TSC-OST-77-68

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Freight Transportation
A Digest of Technical Papers
Volume I

5. Report Date
October 28, 1976

6. Performing Organization Code

7. Author(s)
As noted on each paper

8. Performing Organization Report No.
DOT-TSC

9. Performing Organization Name and Address
DOT/Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

10. Work Unit No. (TRAIS)
R7510

11. Contract or Grant No.
PPA

12. Sponsoring Agency Name and Address
Office of The Secretary
Department of Transportation
400 Seventh Street, S. W.
Washington, D. C. 20590

13. Type of Report and Period Covered
Digest of Technical Papers
October 1 - 30, 1976

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This volume contains a number of technical papers dealing with intercity freight transportation. Collectively, these systems oriented papers consider a wide range of subject matter including transportation facilitation, commodity flow, regulation, automatic control, demand modeling, transportation energy, evaluation of innovation, tariff computerization, network analysis and new concepts for freight transportation.

In addition to those subjects that deal with the transportation system or process, there are papers that treat specific modal considerations. These include discussion of aerodynamic drag effects on rail piggyback operations, rail freight yard technology review, summary of motor carrier return on investment considerations in a regulated industry, results of pipeline studies and use of simulation for waterway navigation and control.

17. Key Words
Navigation
Freight
Transportation
Commodity Flow
Regulation
Automatic Control
Demand
Pipeline
Modeling
Transport Energy
Tariff
Computer
Network analysis
Aerodynamics
Freight Yard

18. Distribution Statement
Document is available from the
Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

Reproduction of completed page authorized

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Dr. James Costantino
Director, Transportation Systems Center

Message from the Director:

I want to introduce you to the Transportation Systems Center (TSC) of the U.S. Department of Transportation and some of our freight-related research work.

TSC was established on July 1, 1970 as the Department of Transportation's facility for research, engineering, transportation planning, and socioeconomic support involving all modes of transportation. The Center's work is both intra-and intermodal; it includes evaluating and developing solutions to urban, rural, intercity and international freight and passenger transportation problems. The Center's physical plant comprises six buildings on 15 acres in the Kendall Square section of Cambridge, Massachusetts. Currently operating on an annual budget of over $60 million, the Center employs more than 600 persons. These include engineers, economists, urban planners, sociologists, mathematicians and psychologists.

The following technical research papers describe some freight-related research that has been completed recently or is now underway at the Center. They provide material that augments the presentations at the December 1-2, 1976 TSC Conference "America's Freight System in the 80's and 90's–But How To Get There." You are cordially invited to contact the authors at the Transportation Systems Center for additional information on any of the papers.

Sincerely,

James Costantino

James Costantino

FOREWORD

The papers presented in this document were prepared in conjunction with the advanced transportation conference "America's Freight System in the 80's and 90's—But How to Get There" held at the Transportation Systems Center on December 1 and 2, 1976. The papers focus on the overall transportation process. Transportation facilitation is discussed by Robert K. Whitford with observations about applications to provide needed Government/Industry leadership. A concept for estimating commodity flow is outlined by Frank L. Hassler in his paper on "Transportation Patterns of Production and Consumption." This work suggests a way to forecast the macroscopic character of freight flows for longer range transportation planning. Models of freight demand are presented by George H. Wang showing the advantages of various models in forecasting. A method for evaluation of innovations applied to inercity freight systems is discussed by Domenic J. Maio.

Current advances in techniques that will have an impact on study of transportation network problems are described in a paper by Edwin J. Roberts, Louis Fuertes, and Michael Nienhaus. A discussion of applications for automatic control in intercity transportation is presented by Kenneth F. Troup and computerization for processing of tariff paperwork in both domestic and international shipments is the subject of a paper by Robert E. Thibodeau. Methodology useful for determining rail freight car investment needs is developed by James F. Oiesen providing insights that may be useful to a railroad economist. The rate effects of regulation are discussed by Russell C. Cherry and development of measures of spatial distribution for U.S. population is correlated with transport, energy consumption, and GNP in a paper by Frank L. Hassler.

Collectively, these systems-oriented papers consider a wide range of subject matter including transportation facilitation, commodity flow, regulation, automatic control, demand modeling, transportation energy, evaluation of innovation, tariff computerization, and network analysis.

In addition to those subjects that deal with the transportation system or process, there are papers that treat specific modal considerations. These include discussion of aerodynamic drag effects on rail piggyback operations by Andrew G. Hammitt and Timothy M. Barrows and a rail freight yard technology review by John B. Hopkins. Also included is a summary of motor carrier return on investment considerations in a regulated industry by Robert F. Church, results of pipeline studies by David B. Hiatt, Lawrence L. Vance, and Joseph Mergel and use of simulation for waterway navigation and control by Robert D. Reymond.

These papers are provided to stimulate discussions and to supplement the wide body of knowledge on freight transportation that is currently being developed and published throughout the country.

Robert E. Coulombre
Chief, Freight Systems Evaluation Branch
Transportation Systems Center
Editor

Robert E. Coulombre is Chief of the Freight Systems Evaluation Branch in the Department of Transportation, Transportation Systems Center in Cambridge, Massachusetts. He joined the Transportation Systems Center in 1973 and since that time has worked on rail-related research programs with emphasis on freight car management. Prior work assignments have been with the General Electric Company and AVCO Corporation in technical leadership positions on large research and development programs. Mr. Coulombre was born in Boston, Massachusetts. He received his B.S. degree in Electrical Engineering from Northeastern University and has participated in considerable postgraduate technical and management training.

FREIGHT TRANSPORTATION

A Digest of Technical Papers

U.S. DEPARTMENT OF TRANSPORTATION OCTOBER 28, 1976

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U.S. Department of Transportation *Freight Transportation Digest, October 1976*

TRANSPORTATION FACILITATION
A SYSTEMS PERSPECTIVE

by

ROBERT K. WHITFORD

BOUNDARY AREAS

We have all heard statements since 1969 to the effect that if we can land a man on the moon, why can't we get across town more easily or find a better way to move our freight.

Since most people would consider the Apollo Program a success, I would like to use it as a model with which to explore the boundaries of our facilitation problem. There appear to be three key ingredients to the Apollo success:

1. There was a clear goal established against which a design could be implemented. Regardless of the reasons for the goal, strategic, romantic, scientific, political, etc., the moon is in a known orbit, and we set a goal to land a man there and bring him back.
2. The growing integration of the research scientist and theorist with the practitioner was heightened so that they might work jointly towards the goal. The mathematician, physicist, and chemist became involved working with the engineer and all of them with the astronaut formed a multi-disciplinary team to provide a climate for more creative probing and increased understanding. Through this marriage the dynamics of the process became much better understood, and led to the safe reliable achievement of the goal.
3. There was ample public and political backing so that funding and necessary priorities were established.

BOUNDARIES IN SETTING THE GOAL

The key to any effective program is establishing goals that are both clear and precise. To explore facilitation let's start with the dictionary—the verb facilitate means "to make easier." Within DOT, the language of the Transportation Act of 1966 implies that this facilitation be approached through cooperative coordination rather than regulatory enforcement.

Perhaps one of the clearest statements was made by Assistant Secretary Judith Connor at the TDCC Forum in December 1975(1) and I quote

> "In its simplest terms, the purpose of facilitation is to provide needed joint government/industry leadership in the development and continual improvement of domestic and international intermodal transportation services. The DOT policy is based on the fact that diversity and intermodal competition are essential to an effective transportation system owned and operated by private enterprises.
>
> "DOT policy, therefore, moves—and must move—in the direction of:
>
> - increasing equal competitive opportunity on the part of each transportation mode;
> - promoting cooperation among the different modes;
> - minimizing inequitable distortions of government intervention,
> - enabling each mode to realize to the fullest possible extent its own inherent advantages and potentials."

The goals of the shipper, the carrier, the ICC, the DOT, the associations, and others are not all totally consistent. However, today's system with its morass of paper work, mounds of ever shifting tariffs, and multi-dimensional difficulties of modal choice, lead most of us to agree that there must be a more efficient way of goods movement.

One major goal for industry is to find the appropriate use of technology to make significant improvements in productivity and hence jobs and profits. However, for a company the implementation of a new system is not without its cost—cost of the system itself, cost of training the staff to use the system and the cost of the initial start-up and debugging problems. Here we need to give the manager both the alternatives analysis and a realistic implementation plan so he has an understanding of what the system will do and when.

While getting to the moon was a clear goal, the program included several incremental steps before Neil Armstrong took that "one giant step for mankind." We had Mercury, Gemini, lunar orbiters, unmanned lunar landings, and several Apollo tests larglely to build confidence in preparation for the final goal.

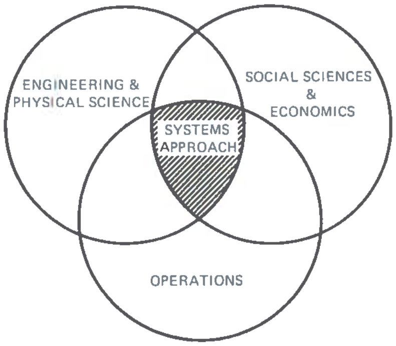
While the goal of facilitation may be clear, one would have to readily admit that it is not as precise as the Apollo goal. But the need is the same—we must build confidence as we move ahead and that can only be achieved with incremental steps of improved facilitation. The large institutional barriers will probably mean that the incremental steps will be small and the significant ones will take a long time to implement.

At the same time, however, it is important for those who have the dream and vision that one day the computers will do the rating, billing, provide management with feedback, and prepare the bills of lading and manifests to maintain that vision. It is an important part of the goal we are seeking.

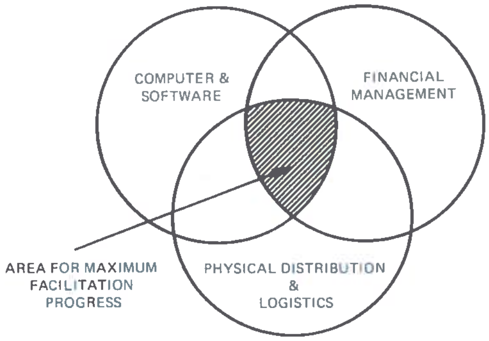
Returning to Mrs. Connor's statement, it is clear that facilitation involves far more than development of an information system. It looks thoroughly across the whole realm of commodity flow to cover broad areas of competition, regulation, cost of service, modal cooperation, technology improvements, network geography, business locations, export-import policies, etc., to improve the efficiency and effectiveness of movement for goods and passengers and in all modes. It is indeed a broad subject.

BOUNDARIES OF KNOWLEDGE AND UNDERSTANDING

There are several boundaries pertaining to what we as the transportation community know and understand. First is a communication or understanding boundary largely due to the diverse background and experience that needs to be brought to bear to solve a complex problem.



TRANSPORTATION SYSTEMS



COMPUTERS IN PHYSICAL DISTRIBUTION

Figure 1-1. System approaches.

Previously I suggested that a partial reason for our Apollo success was the marriage of several disciplines, primarily the scientist, the engineer and the operator. Figure 1-1 suggests that total transportation system understanding will occur when the technologist, the economist and the operations persons combine talents and work together as shown at the heart or intersection of the three rings. Extending the premise of multi-disciplinary effort, it would appear that until the physical distribution and logistics experts, the computer systems analysts, and financial managers can develop enough joint understanding of the full problem to be solved, we might have systems that do not work well or that cost too much and possibly set the progress of national facilitation back.

Alan D. Wheeler in his recent Transportation Journal article, "The Computer: Triumph or Terror for Transportation Managers"(2) cites his ABC's for design disaster which he labels as

> The **A**ppointed **A**postle Syndrome,
> The **B**rute Force of the **B**oss Syndrome, and
> The **C**ollective **C**onfusion Syndrome

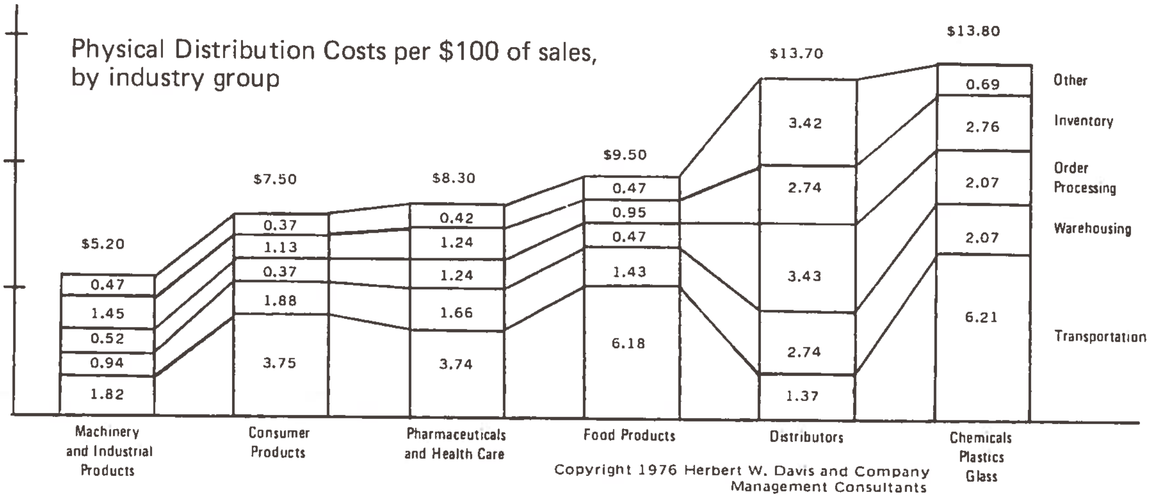
as approaches to be avoided when installing a computer system.

The research we are doing at the Transportation Systems Center involves multi-disciplinary work some of which I would like to share.

Commodity Patterns

National Flow. In order to understand commodity flows and to forecast how they may evolve for future transport system planning, it is necessary to understand the spatial relationships of production and consumption of differing commodity groups. At TSC we have attempted to categorize these flows and weight them according to "the transport potential to shrink distance."

Dr. Frank Hassler, TSC Director of Systems Analysis and Research, has developed a transport coefficient(3,4) * which he calls λ. It represents the extent to which the normal impedence of distance is made more or less important by the economic characteristics of a commodity and the transportation services available to move it from production to consumption areas. When λ exceeds unity, a strong economic sensitivity to transportation is indicated. For example, products like tobacco (λ = 0.423) and electric machinery (λ = 0.500) are either uniformly produced and distributed relative to the final market or of sufficiently high value that transportation is not a strong economic factor, while petroleum (λ = 2.3) and processed food (λ = 1.47) are much more transport sensitive. This is also implied in the cost breakdown for physical distribution (PD) shown in Figure 1-2. This analytical



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Source: Transportation and Distribution Management May/June, 1976

Figure 1-2. Physical distribution costs.

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*Reference (3) "Transportation Patterns of Production and Consumption" is published in abbreviated form elsewhere in this document.

technique helps us to look at commodity patterns in the perspective of the full system of industry, consumer and transport needs. It can be important to us in government, as a tool to evaluate the impacts of policies, regulations and technology advances.

It may also help evaluate better what commodity movements benefit most through computerization or where transport price competition may help reduce cost.

Industry Patterns. As an example of the relative importance of transportation and distribution costs in our economy, let us look at the automobile industry. This is an industry of critical importance in our economy and it is also an industry which TSC, as part of an interagency team, has studied extensively during the last two years.[5]

Using data from the 1967 Economic Input-Output table, transportation and warehousing services accounted for 5.9 percent of the final price of the product of the industry, Vehicles and Parts, or 3 billion dollars. It was the third largest input component, behind Primary Iron and Steel at 18.1 percent, but almost equal to Wholesale and Retail Trade (the sales function) at 6.2 percent.

Examination of the simplified drawing of the production and distribution process in Figure 1-3 and the material cycle of Figure 1-4 show that there are many transportation steps, some internal to the industry and some external. The systems analysts must identify those parts of the flow or process where the multiplier effects resulting from material flow or actual transport costs are most significant. Management will then be able to review the investment costs in their priority of impact for overall improvement.

Technology

The communications and computer technology is available to implement a full computerized rating, billing and auditing system which can be integrated with most internal management information systems.

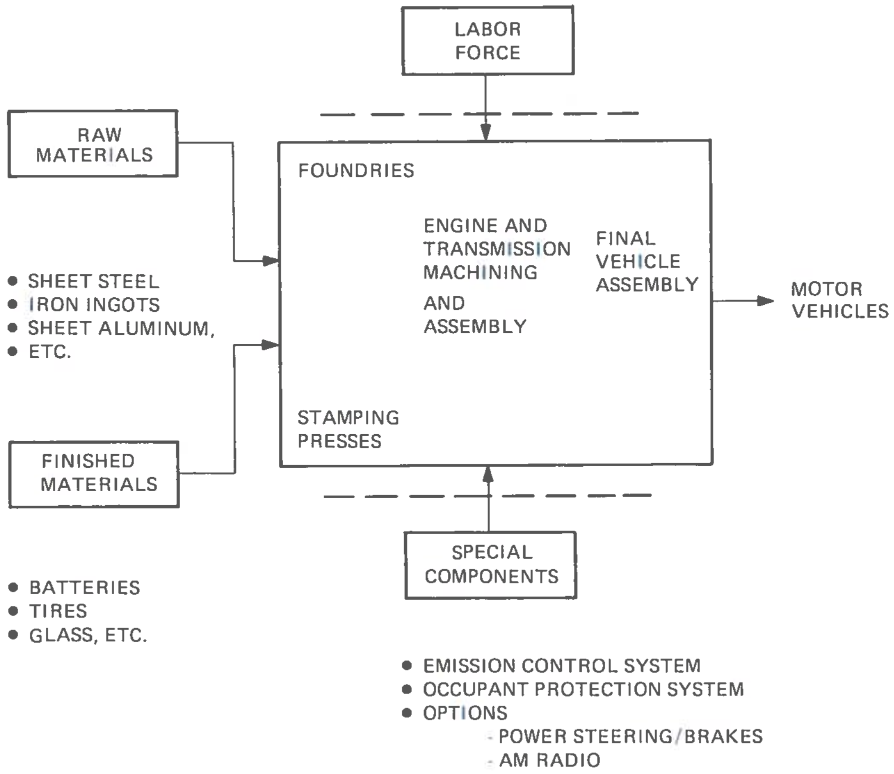

Figure 1-3. Motor vehicle production complex.

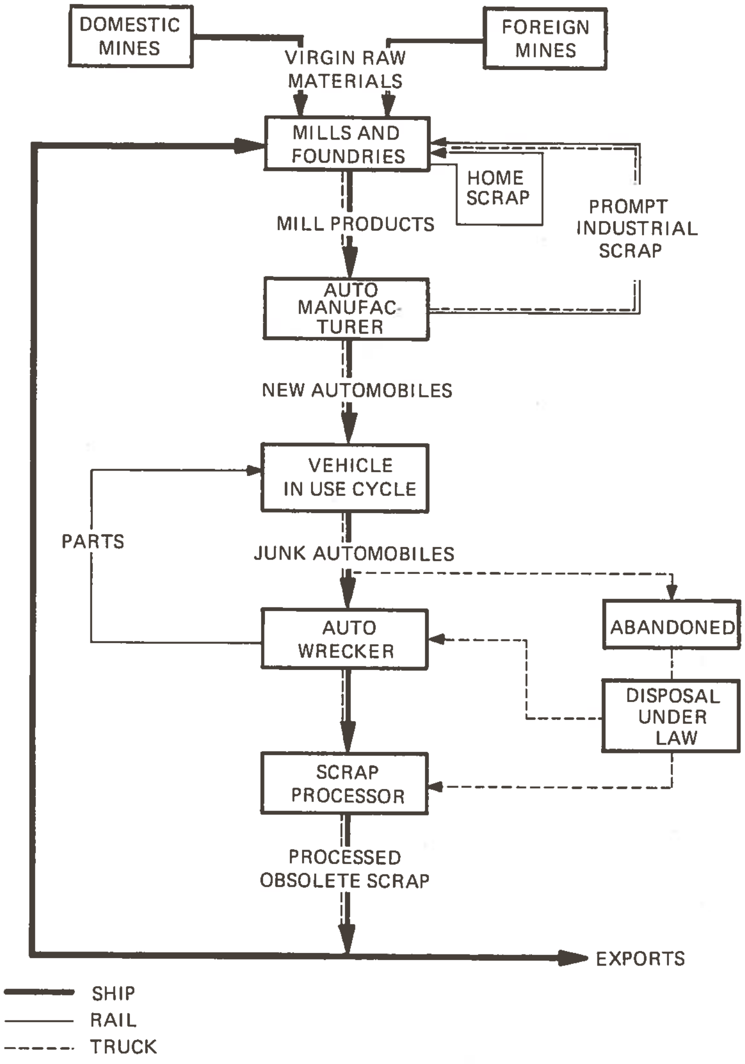

Figure 1-4. Transportation in the automobile material cycle.

You all recognize the fact of course, but are concerned about how. Many worry about how to get computers to speak to one another, especially when they use differing codes, have differing hardware configurations and usually contain some private data that needs protection. Figure 1-5 is a concept of how that problem can be circumvented. In today's technology high speed translators can be built that are controlled by the host computer but can communicate with other computers. One may well have to get started with one or two small steps within the company before developing the more complex step of connecting with a larger network. I urge an incremental plan.

In these days of microprocessors, large data bases, interactive computer use, and high speed telephone terminals, everyone has access to the full capabilities and power of the computer, generally as much as they need and in some cases more than they want.

As a footnote, I noticed in the news media that you can now buy individual microcircuits and parts of microprocessors—you can build it yourself. One store owner in Boston expected to do $80,000 worth of business his first year. He did that much in the first month alone. Even some of my accountant friends are taking up this as their latest hobby.

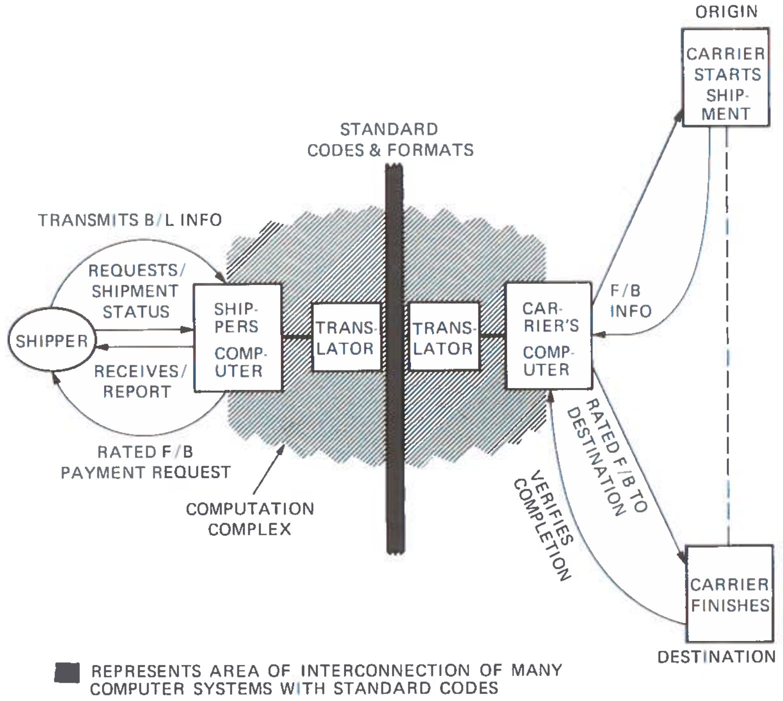

Figure 1-5. Shipper-carrier network.

Standards and Codes

Ultimately, full use of computers will require data standards; in my mind computers are relatively stupid machines and can only effectively utilize information if it is carefully packaged for them. Difficulty in the development and use of computer and data standards in transportation is serious enough to justify a few words on the subject. There are two types; namely, physical machine standards and logical standards.

Physical machine standards encompass all of the technical areas surrounding computers, hardware, software, and communications linkages. The physical machine standard area, which is extremely complex and technical, is the province of the computer industry.

It is the logical standards that seem most important today for management to understand in determining what systems can and cannot do. Further they need to understand how their authority can be eroded as technical personnel are allowed to decide such matters without sufficient management attention. The erosion begins with artificial constraints or ambiguities that are supplied by the technical person in an operational context and often result from a lack of guidance on the ultimate user who needs the information being exchanged. This goes back to the discussion of the 3-ring chart of Figure 1-1.

The basic questions in trying to create logical standards are: Is there a real market for them? Will they make a difference? Will the user community accept them and will a responsible organization maintain them? We are proceeding as if the answer is yes to all three questions. Debating the alternatives and resolving the differences for such a common language is a living and dynamic process.

A great deal of work has been and is being done in this area by DOT, TDCC, AAR (American Association of Railroads), and NMFTA (National Motor Freight Traffic Association).

BOUNDARIES IN IMPLEMENTATION

There are many boundaries in the implementation even assuming clear goals and good understanding. The most important are the biases and lethargy experienced in our well institutionalized industry. Time and demonstrations will be needed to overcome the institutional inertia. Therefore let me look at several other important issues involved in implementation.

Users With Differing Problems

In distribution systems we are dealing with an end product which will be used by private industry, therefore it must be profitable to use. In any company the cost of improving transport and distribution functions will compete with other demands for the same investment resource. Without a clear statement of the benefits, e.g., more profit sooner, the facilitation effort may have difficulty selling. Fortunately, in the Apollo program we faced no such handicap.

In terms of data acquisition and processing, shippers having a national market and a complex group of products face a much more difficult problem than those with few origin-destination pairs and few products. The volume of annual shipments is also a factor. Aggregate annual freight bills of several million dollars would probably make a large investment in automated procedures worthwhile whereas a smaller shipper may feel he cannot afford to automate his transportation data.

Some Boundaries Between Organizations

Up to this point I have been talking as if you were representing some homogeneous group of companies, which of course is not true. The interests of shippers are not those of carriers. Even among shippers or carriers there may be differences in their objectives.

First, if we consider the exchange of transportation data between firms, there is a need to protect sensitive data as well as the problem of matching different systems and different data formats to which the translator idea of Figure 1-5 speaks.

Next, in the carrier industry there is often a conflict between the rate department and the sales department. While it is to the advantage of the rate people to improve or simplify the tariffs—after all they are the persons who have to use tariffs. On the other hand, it is to the advantage of the sales department to attract traffic by offering special rates which leads to tariff complexity. While it is easy to be sympathetic to the crusaders for tariff simplification, it will take some new ideas to reconcile these two conflicts, particularly if competition becomes more keen as we reduce the regulatory limits on pricing.

Another conflict we have noticed is between two modes. This occurs especially in one of the key standardization projects—codes. Again, while the idea of a standard code for the entire industry is attractive, there are problems which occur in the usage of these codes. For example, the Standard Transportation Commodity Code (STCC) is a railroad code and does not fit the needs of motor carriers as well as the (National Motor Freight Code (NMFC). Our facilitation efforts must respond to both needs.

Relative Cost of Transport

The relatively low cost of transportation in some industries may be a barrier to improvement. Perhaps the president of the firm or the chairman of the board feels that he is in a position to absorb the 1/2 to 2 percent in costs that result from less efficient handling of transportation services. One scenario which might change his viewpoint quickly would be if the price of fuel went up 3 or 4 hundred percent. While this is hypothetical, a gradual increase does seem indicated for the next few years.

Companies would need to carefully reevaluate their production and distribution strategies to optimize revenues. Improvement of the efficiency of their transportation data processing and in the selection of carriers including the promotion of a more energy efficient modal split would be indicated.

Program Support Needs

The comparison with the Apollo example elicits one final consideration. In the Apollo Project, a high level of support had been attained among the public and the politicians.

Therefore, once the project had started, it was mainly a matter of technical achievement and program management.

Facilitation in transportation, however, has received no such mandate. Despite all of the conferences, committees, and seminars which have been held on the subject, it remains to be shown that there is clear consensus in the industry for improvement. Without this consensus we in the Federal government are forced to take a very cautious approach. In this most important area, I am tossing the ball back to you the shipper and carrier—the user. Is there really a strong demand for technology? This means demands to speed up or strengthen the efforts in facilitation improvement other than providing limited support to cooperative efforts in some critical areas. We in DOT will gladly respond to cooperative projects between industry and government provided we receive strong signals from OMB and the Congress. As far as I know Congress sees only limited progress and is subject to very little pressure from industry for help.

CONCLUSIONS

While there are limitations on how quickly facilitation can be accomplished, I believe that there is a course for the next incremental steps in moving ahead.

First. We need more research. To those who may feel we have studied too long, I say our accomplishment to date and lack of understanding indicate that perhaps we have merely scratched the surface.

Specifically, I propose that we develop much greater understanding of the costs by conducting studies of:

- current manual systems.
- cost reduction (CR) systems now in operation.
- cost variations as a function of user characteristics.

Since the computerized systems which have evolved represent the most advanced work to date, a careful case study approach would help us find out what works, how it can be done, and what sort of policy encourages it.

Any significant investment by private firms or by government will require the ability to weigh the costs and the benefits of the technical system options. It is clear that the growing success of such commercial CR systems as PEARL (Phillip's Petroleum) or TARPS (Numerax) convinces me that executives will invest in CR technology if they are presented with sound cost data.

This effort should be undertaken on a cooperative basis through the DOT's Office of Facilitation.

Second. All the research in the world will not do us any good unless we get the results out. In one word, we must educate. We need a wider dissemination of the state-of-the-art and of the needs and costs that users face at present. This institute and a handful of other activities do yeoman's work in educating, but I think we need an even more comprehensive system of collecting and distributing knowledge.

Bob Thibodeau of TSC, who participated in the preparation of this paper, has done previous state-of-the-art analysis in the topics of tariff computerization, standardization, and simplification.(6) A current study of the total cost of rates and tariffs to selected companies is being conducted by Don Lepard for the National Industrial Traffic League.(7)

I propose that a definitive document on the state-of-the-art in facilitation be prepared. The technology sharing staff at TSC under direction of DOT's Office of Facilitation could perform this task in cooperation with interested private an public organizations. The initial draft would be used as a discussion vehicle in seminars with transportation and distribution experts who would be free, indeed encouraged, to add, delete, or revise items. When the final document appears, we would have a clearer understanding of the current state of the facilitation problem.

Third. I would propose continuing the efforts on codes and standards. With the translator approach suggested earlier the national standards efforts can proceed in parallel with individual company efforts to computerize. Also we should begin planning for future demonstrations of the translator approach now in conjunction with the associations, the standards committees, the individual companies and, I believe, the Federal government under the leadership of DOT's Office of Facilitation.

Fourth. The message of support for facilitation is weak at best. The total amount of research and system achievement to date is very modest. If the first three tasks are done well the proof of potential savings would be available to help shippers and carrier PD personnel explain the benefits in their companies, professional associations, and to the Federal government.

Yes, facilitation is a complex business. There are tough barriers, but the expenditures of a few million dollars can potentially produce considerable improvement. After all, the national annual freight revenues are in excess of 40 billion dollars. We can and should do more to be efficient.

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BIOGRAPHY

Dr. Robert K. Whitford has been Deputy Director of the Transportation Systems Center of the U.S. Department of Transportation in Cambridge, Mass., since June, 1972.

Before joining the Center, Dr. Whitford had been associated for 17 years with TRW Systems Group at Redondo Beach, Calif., where his most recent assignment had been manager of the Advanced Electronic Systems Office which included management of the advanced electronic systems operations—an organization of about 400 persons engaged in the marketing, economic viability, and physical structuring of large scale electronic systems using highly advanced technology.

Dr. Whitford received his Bachelor, Master, and Doctorate of Science degrees, all in electrical engineering, from Purdue University which honored him with a distinguished engineering alumnus award in 1972.

In other executive positions at TRW, Dr. Whitford was manager of guidance and control operations from 1965 to 1968; director of the inertial guidance and control laboratory from 1961 to 1965; and manager of the control systems department from 1959 to 1961.

Throughout his TRW career, Dr. Whitford has been involved with many major aerospace systems, including NASA's manned space flight programs, the Air Force Atlas, Thor and Minuteman missile systems, and TRW's unmanned satellite systems.

Dr. Whitford is active in the Presbyterian Church, serving as a ruling elder since 1958.

Dr. Whitford taught evening courses at UCLA from 1956 to 1958 and attended UCLA's executive management course in 1960. He is an Associate Fellow in the American Institute of Aeronautics and Astronautics and a Senior Member of the Institute of Electrical and Electronic Engineers.

Dr. Whitford is married and the father of seven children. The Whitfords reside in Sudbury, Massachusetts.

U.S. Department of Transportation *Freight Transportation Digest, October 1976*

TRANSPORTATION PATTERNS OF PRODUCTION AND CONSUMPTION

—1967 Census of Transportation—
SIC 20 - 39

by

FRANK L. HASSLER

This work represents a macroscopic picture of production and consumption of manufactured commodities (SIC 20-39) from a transportation point of view. The picture that emerges is in qualitative agreement with intuitive understandings of the spatial character of the U.S. economy in 1967, the year of collection of the census of transportation data on which this study is based. (The work is preliminary and requires detailed refinement to remove source data problems.) Forecasts of potential changes in the spatial patterns are made. Research issues in energy commodity movement that impact the transportation planning of rail investments and deepwater ports and pipelines are outlined. Finally, research in four directions to expand the approach presented herein is described and related to the long range planning problem for freight movement in the U.S.

INTRODUCTION

To understand commodity flows and to forecast how they may evolve for future transport system planning, it is necessary to understand the spatial relationships of production and consumption of the differing commodity groups.

Simple transportation theory develops expressions for the flow of goods from zone i to zone j as a function of production, consumption and spatial variables. In the simplest view, the tons flowing, T_{ij}, are given by

$$T_{ij} = \frac{k\, O_i D_j}{d_{ij}} \qquad (1)$$

where k is a constant of proportionality, d_{ij} is the separation of i and j o_i is the tons produced in i, and D_j are the tons consumed in j. Often the D_j are estimated using some combination of population, income, and commercial/industrial consumption variables, while the o_i are estimated using similar variables for production.

A slightly more sophisticated model replaces d_{ij} with d_{ij}^{λ}. This reflects the view that transportation systems "shrink" distance, and hence the impedance to normal flow is reduced by some amount.

Principals of entropy maximization, initially due to Wilson,(1) give an expression

$$T_{ij} = \frac{O_i D_j}{d_{ij}^{\lambda}} \cdot \frac{1}{P_i^c} \cdot \frac{1}{P_j^p} \qquad (2)$$

$$\text{where} \quad P_i^c = \sum_j \frac{D_j}{d_{ij}^{\lambda}} \cdot \frac{1}{P_j^p} \qquad (3)$$

$$\text{and} \quad P_j^p = \sum_i \frac{O_i}{d_{ij}^{\lambda}} \cdot \frac{1}{P_i^c} \qquad (4)$$

We shall call P_i^c the transport potential for consumption in zone i, and P_j^p the transport potential for production in zone j. (Note: T_{ij} in equation (2) is of the same form as the modified version in equation (1). Equation (2) thus states that the flow from i to j is given by equation (1), reduced by some amount if the consumption in the producing region is higher than average or if the production of the particular commodity is higher than average in the consuming region.)

Equation (2) has been employed in various forms for some time, in transportation analysis, to predict flows of people as well as goods, within cities as well as between them.

We will defer until another paper, the discussion of various types of models that fit equation (2) or the alternative linear programming formulations. Instead, we would like to concentrate upon the meaning of equations (3) and (4).

W. Warntz(2) develops the concept of supply and demand potentials, V_j, V_i, by analogy to population potential.(3,4) In this approach, the potentials are given by

$$V_i^d = \sum_j D_j/d_{ij} \tag{5}$$

$$V_j^s = \sum_i O_i/d_{ij} \tag{6}$$

It can be seen by comparison of (5) and (6) and with (3) and (4) that V's and P's are similar, with the d_{ij}'s in (5) and (6) being replaced by d_{ij}^{λ} and each summation term being discounted by the appropriate P^c or P^p term. The arguments for such replacements or discounts are given above. Thus, equations (3) and (4) are seen to be transformations of "physical potentials" given by (5) and (6) that reflect the impact of transportation systems on the spatial relationships of supply and demand.

In the research reported below, commodity flow data at the two digit SIC code level from the 1967 census of transportation (state-to-state) was analyzed and the data fit to equations (2), (3) and (4) to determine λ, P_i^c, and P_j^p for each commodity group. The model calibration ensured that the mean length of haul, $\overline{\ell}$, was preserved, as were the O_i and D_j.

Plots of the P_i^c and P_j^p are provided throughout the text and rough lines of equipotential are drawn in. These plots give a graphic picture of production and consumption patterns for the various commodity groups. In the body of the text to follow, comments on the patterns, their possible interrelationships, and stability are presented. Please bear in mind that these results are very preliminary, the data are distorted by census efforts to preclude disclosure of specific information on easily identifiable companies, etc.

MAJOR COMMODITY PATTERNS

Processed Food, etc. (SIC 20)

The transportation potentials for processed food production and consumption are shown in Figures 2-1A and 2-1B. Figure 1A implies that food processing is concentrated around the food industry in Wisconsin and Illinois with small secondary centers in the Delaware, New Jersey, Maryland area and in California. This is consistent with a spatial location near the grain and meat producing areas and intermediate between them and the consuming population. The consumption potential is roughly the same as the 1970 population potential (see Figure 2-2). The value of the space variable λ, is 1.47 indicating that transport costs are a significant consideration in processed food shipping. The mean length of haul $\overline{\ell}$, is in the average to shorter distance range, consistent with the value of λ.

Figure 2-3 hypothesizes the fundamental commodity interrelationships. Subsequent analyses of the bulk commodities should reflect the above discussion. Long range future patterns should remain fairly constant. The primary uncertainties lie in limits to land yields [governed by fertilizer use and water (affected by long range weather pattern variations and large scale irrigation policies)], and in export/import policies which are expected to impact more directly on the grains themselves. The net impact of long range trends might be to move grain patterns towards the Colorado, New Mexico, Arizona area and perhaps disperse the processed foods pattern slightly. Similar minor trends to cattle fattening on potato processing waste may disperse the industry into areas near population centers like Maine, etc. However, the overall pattern appears moderately stable.

A possible alternative future state would exist if the ready to serve meals component of food were to become dominant. Then λ would probably drop to much lower values and the consumption potential maps would begin to resemble those for manufactured goods (e.g., Apparel No. 23, Leather No. 31 or Manufactures No. 34–39), which are discussed below, would probably increase somewhat.

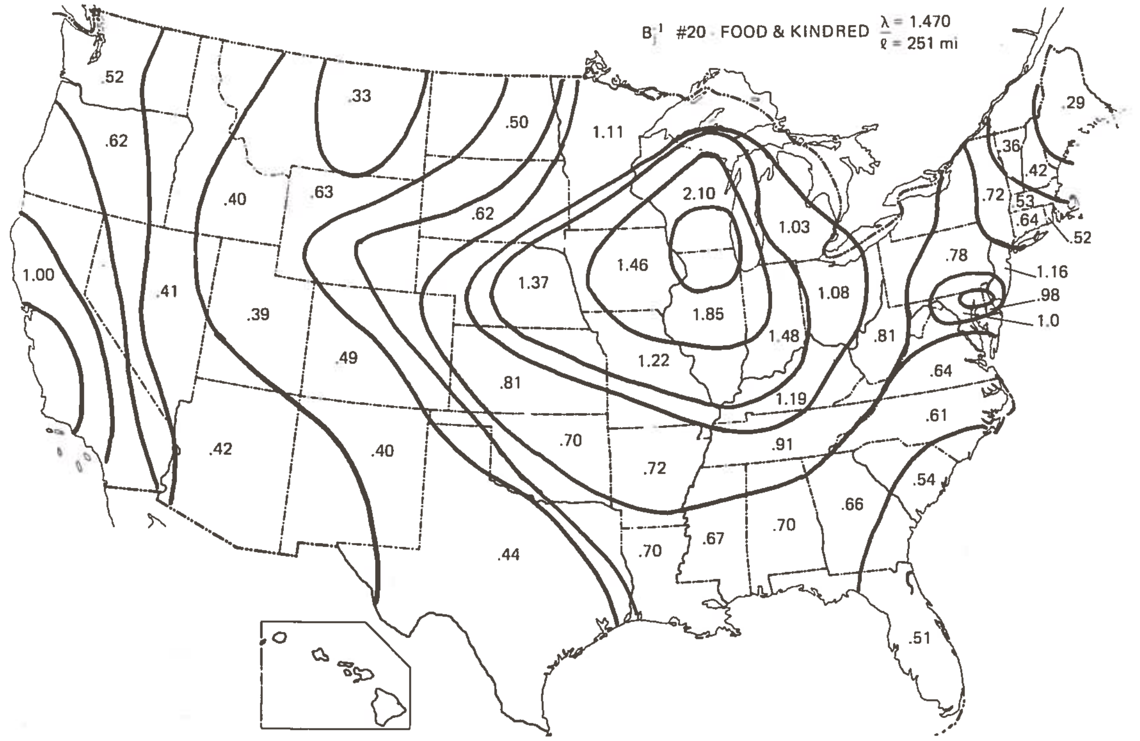


Figure 2-1A. Major commodity patterns—B_j^{-1} SIC 20 Food and Kindred

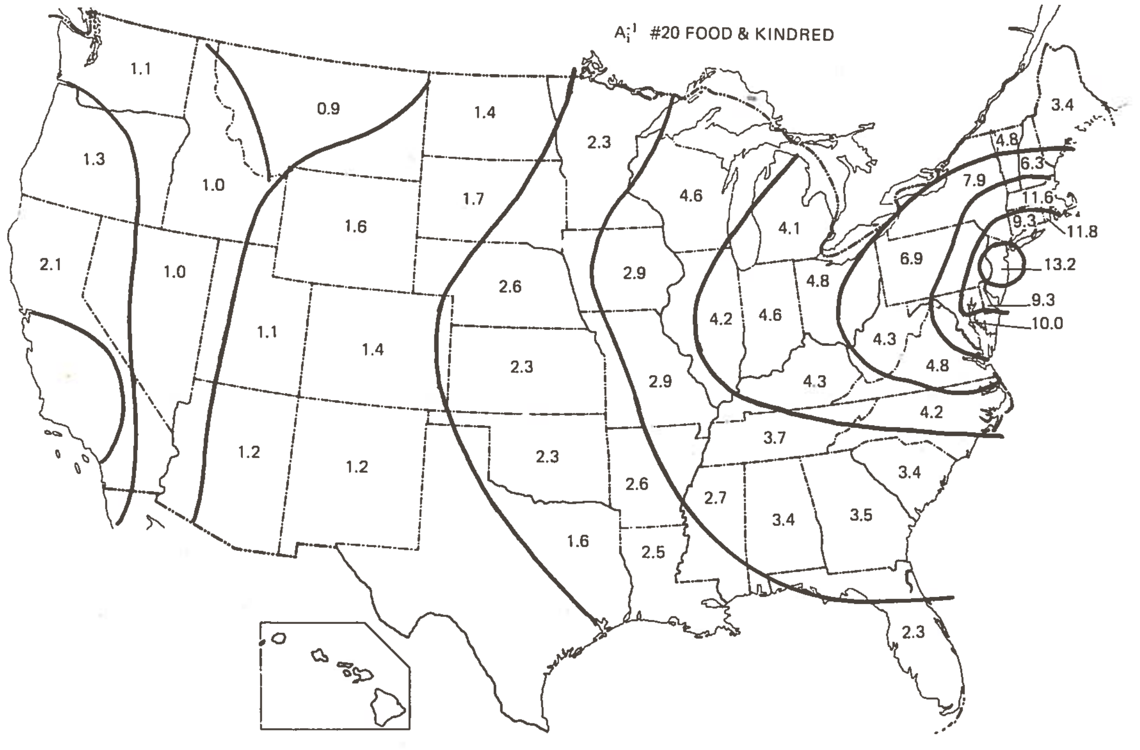


Figure 2-1B. Major commodity patterns—A_i^{-1} SIC 20 Food and Kindred

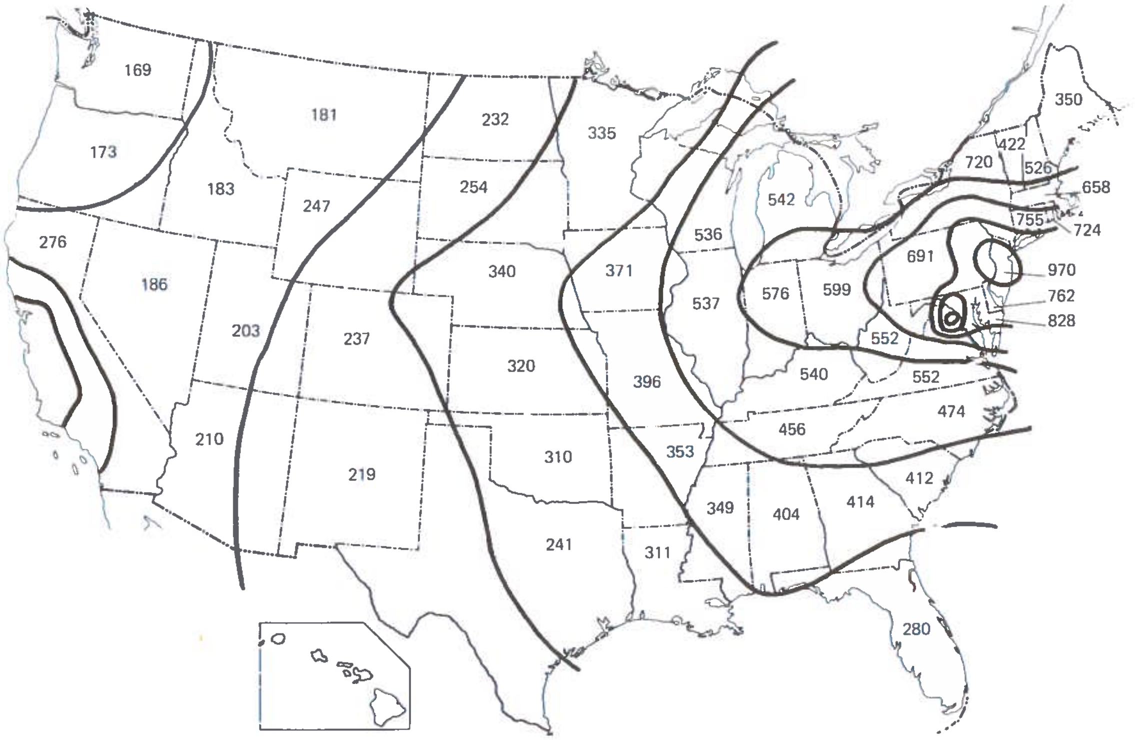


Figure 2-2. Population potential.

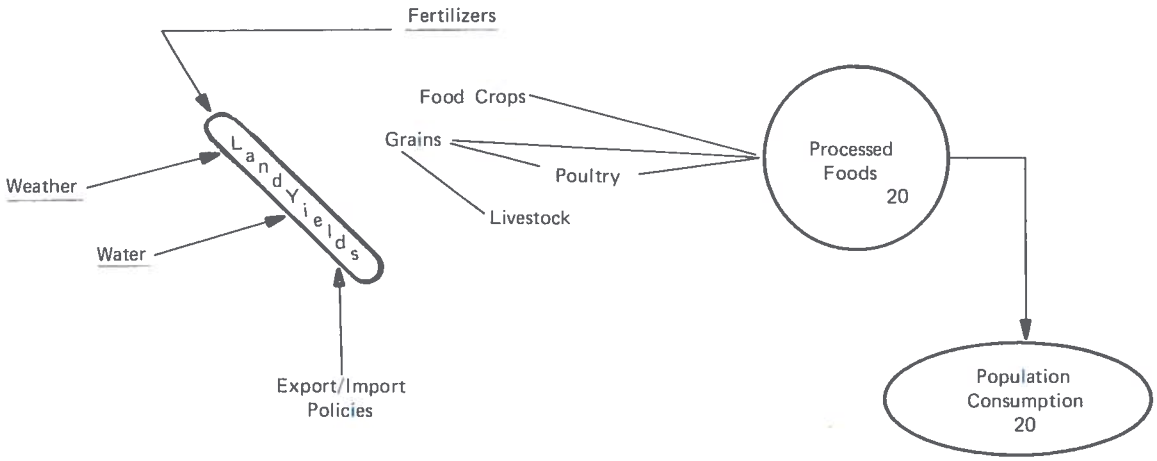


Figure 2-3. A moderately stable pattern of fundamental commodity interrelationships.

Tobacco, etc. (SIC 21)

The transportation potentials are shown in Figures 2-4A and 2-4B. Production is concentrated in Virginia and North Carolina. Costs to transport do not seem to be important relative to the value of the goods ($\lambda = 0.42$). As a consequence of the low λ value, the consumption potential is one of the most spatially uniform of all commodity groups studied. This would appear to be a very stable pattern.

Textiles, Apparel and Leather (SIC 22, 23, 31)

The transport potentials for SIC 22, 23 and 31 are shown in Figures 2-5A and 2-5B, 2-6A and 2-6B and 2-7A and 2-7B. Textile and apparel production are concentrated in North Carolina and surrounding states. The consumption potential of textile products is very similar to the production potential of apparel (a major consumer of its output). The λ of textiles (0.86) is slightly higher than that of apparel (0.81)—a higher value product of roughly the same transport characteristics. The average haul of textile mill products (232 miles) is much shorter than apparel (378 miles) reflecting its co-location with its major consumer.

By contrast the most important producing area for leather is still New England. Leather production is less sensitive to transport costs ($\lambda = 0.65$) and has a consumptive potential of similar character to apparel.

In view of the expanding use of artificial fibers in textile products, it is useful to examine the textile pattern in relation to chemicals (SIC 28) in Figures 2-8A and 2-8B. It can be seen that the focus of textile production is intermediately located between the two primary production centers of petrochemical fibers, Louisiana and the Delaware (DuPont) area slightly nearer Delaware. It has also presumably been influenced by major cotton-producing areas being in states, such as Mississippi, Arkansas, and Texas.

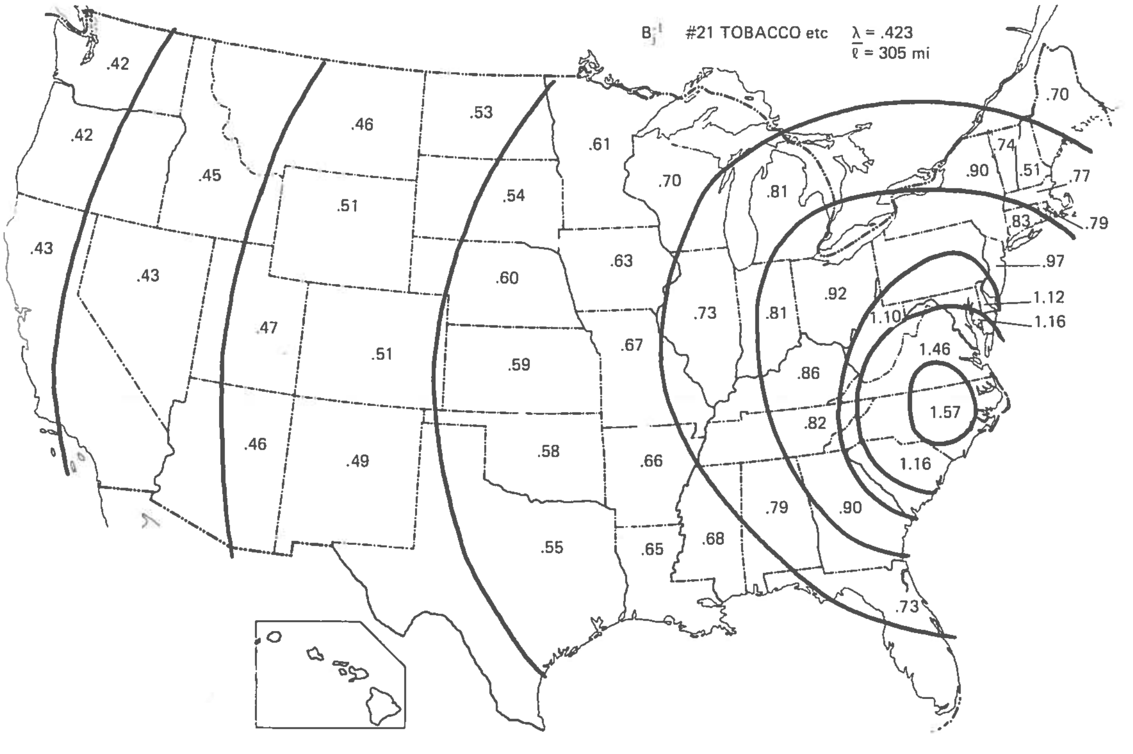


Figure 2-4A. Major commodity patterns—B_j^{-1} SIC 21 Tobacco, etc.

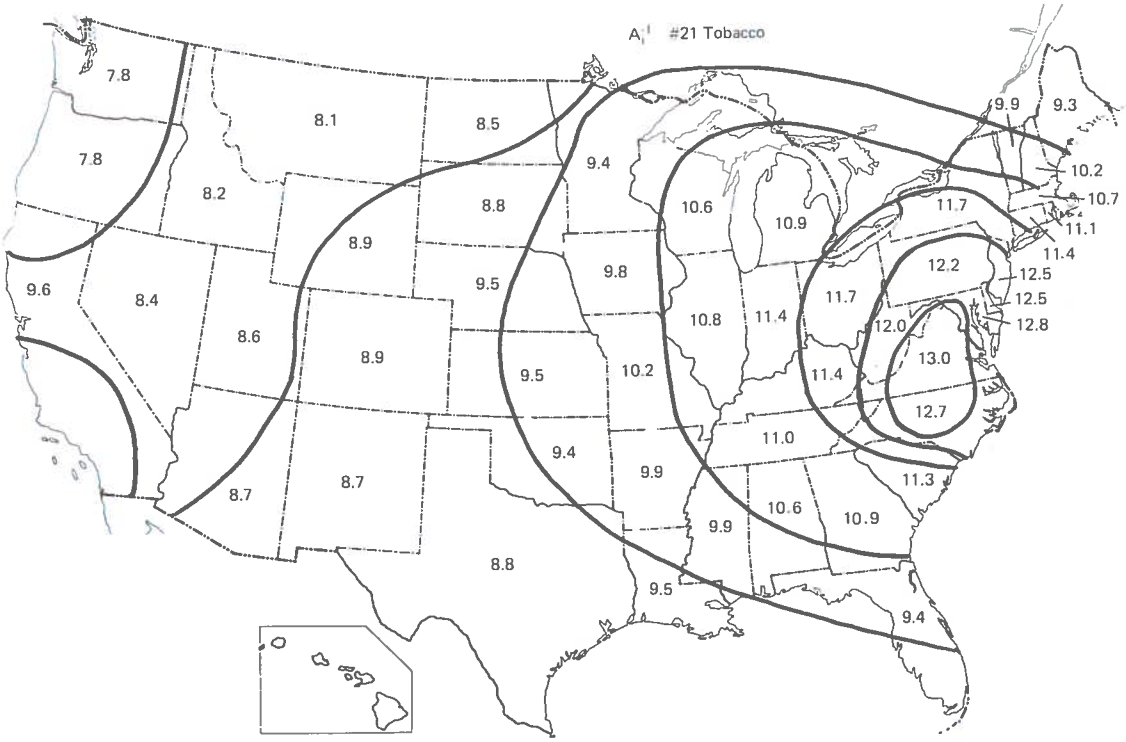


Figure 2–4B. Major commodity patterns—A_i^{-1} SIC 21 Tobacco, etc.

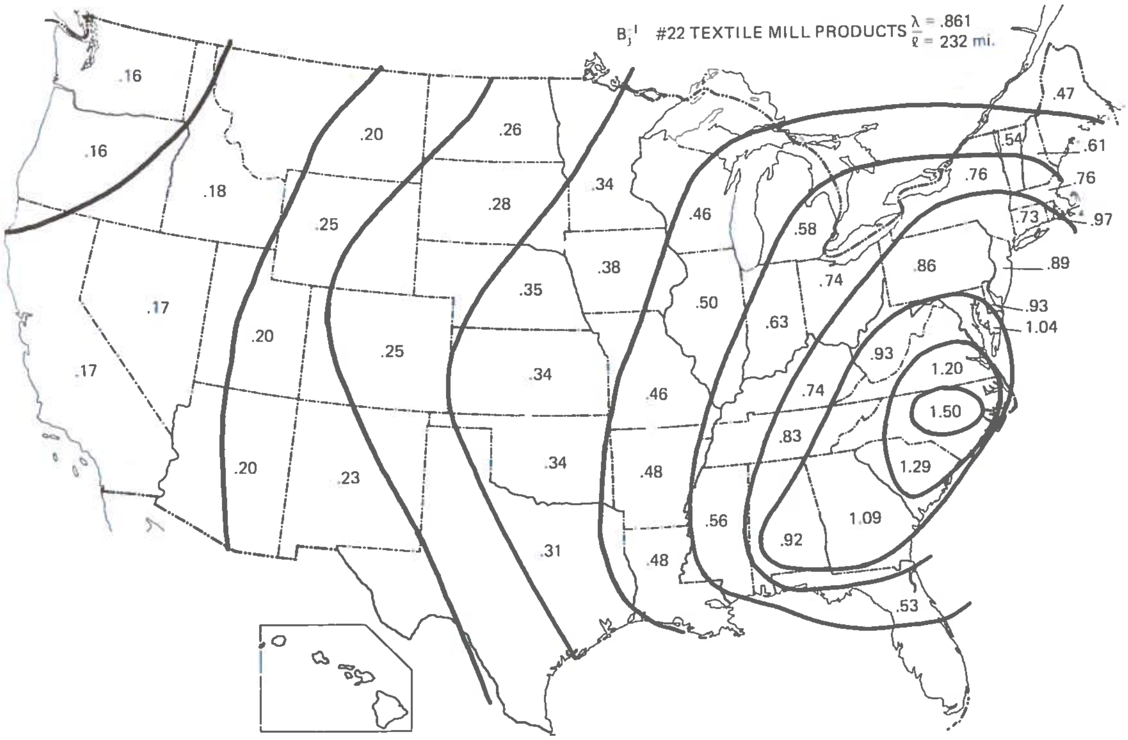


Figure 2–5A. Major commodity patterns—B_j^{-1} SIC 22 Textile Mill Products

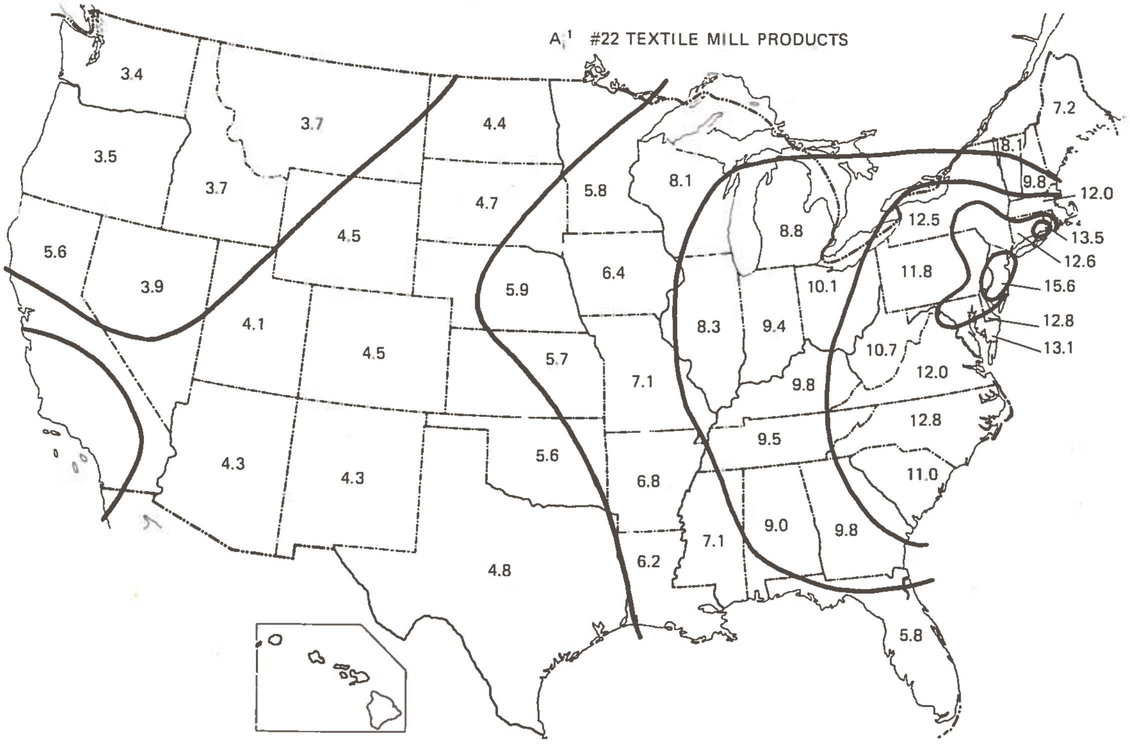


Figure 2-5B. Major commodity patterns—A_i^{-1} SIC 22 Textile Mill Products.

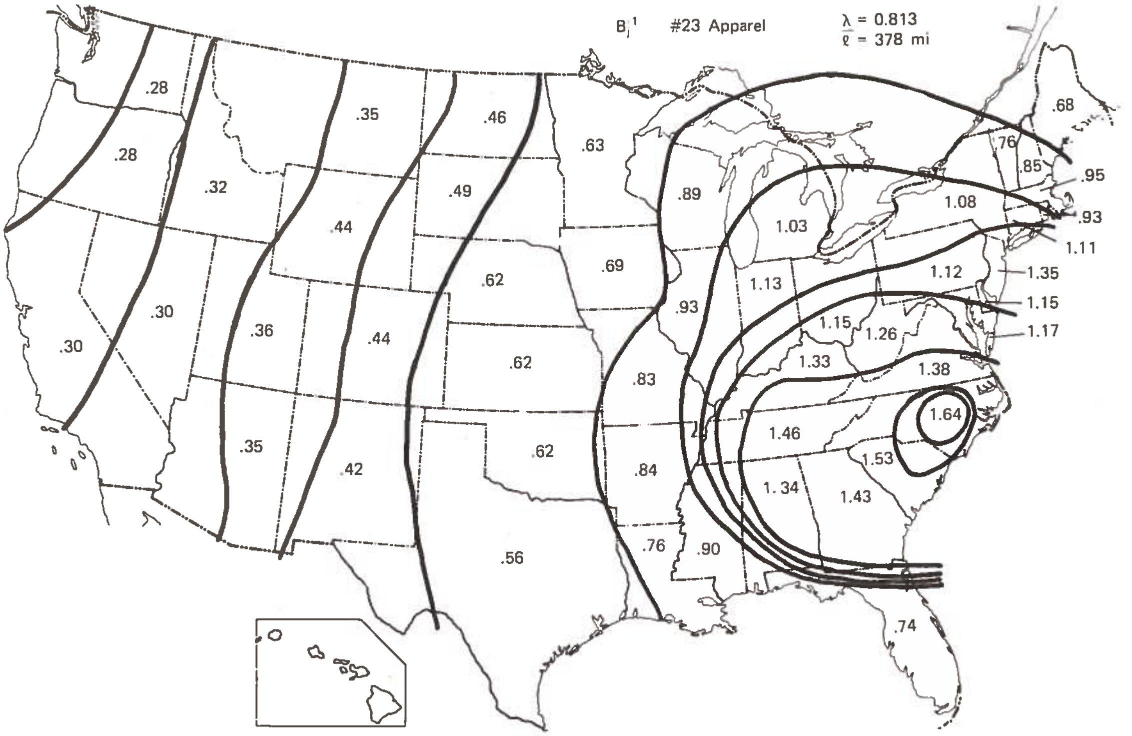


Figure 2-6A. Major commodity patterns—B_j^{-1} SIC 23 Apparel.

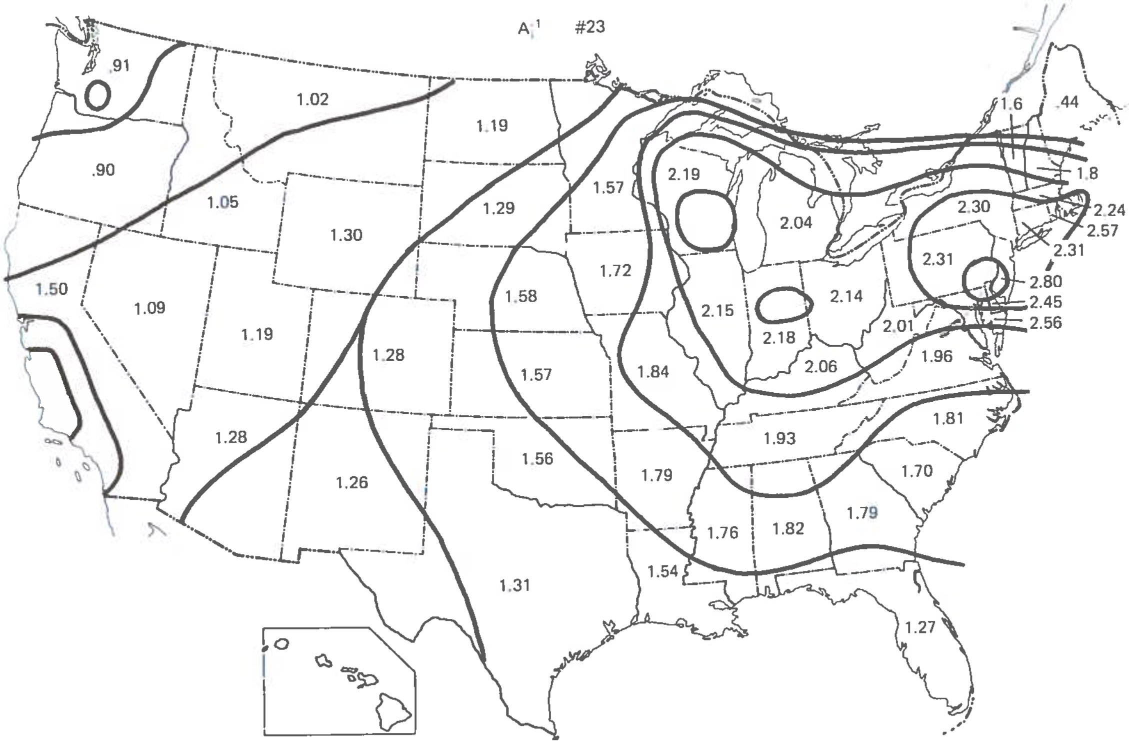


Figure 2–6B. Major commodity patterns—A_i^{-1} SIC 23 Apparel.

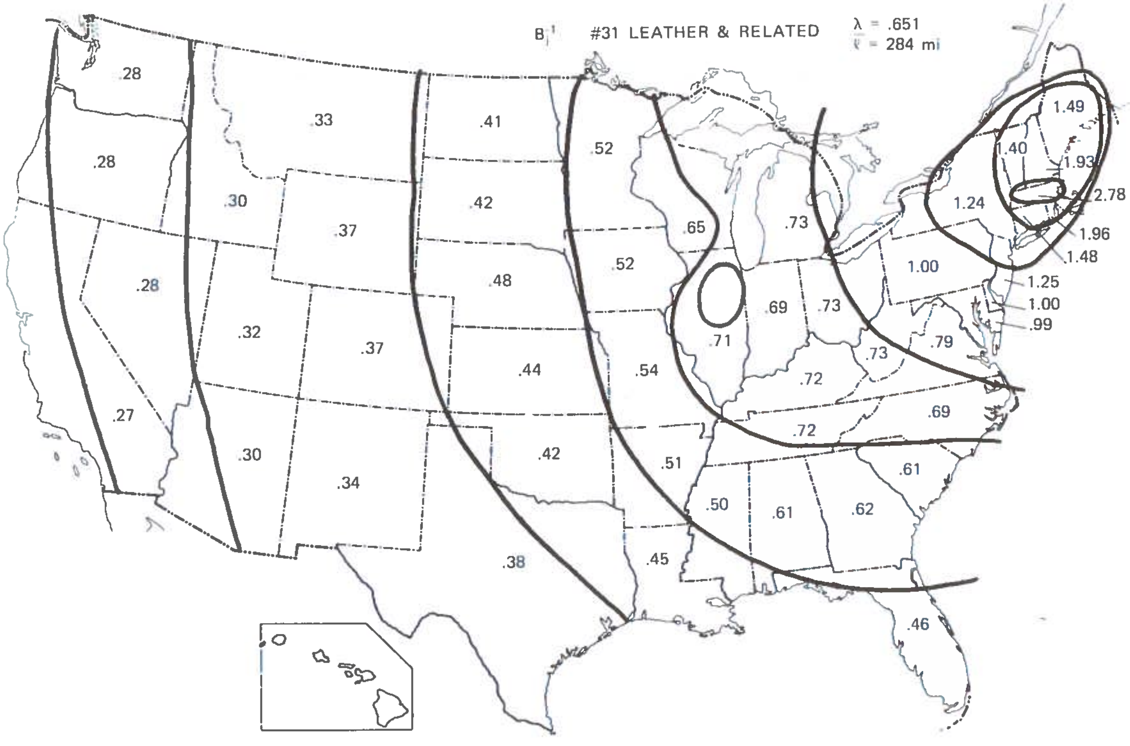


Figure 2–7A. Major commodity patterns—B_j^{-1} SIC 31 Leather and Related.

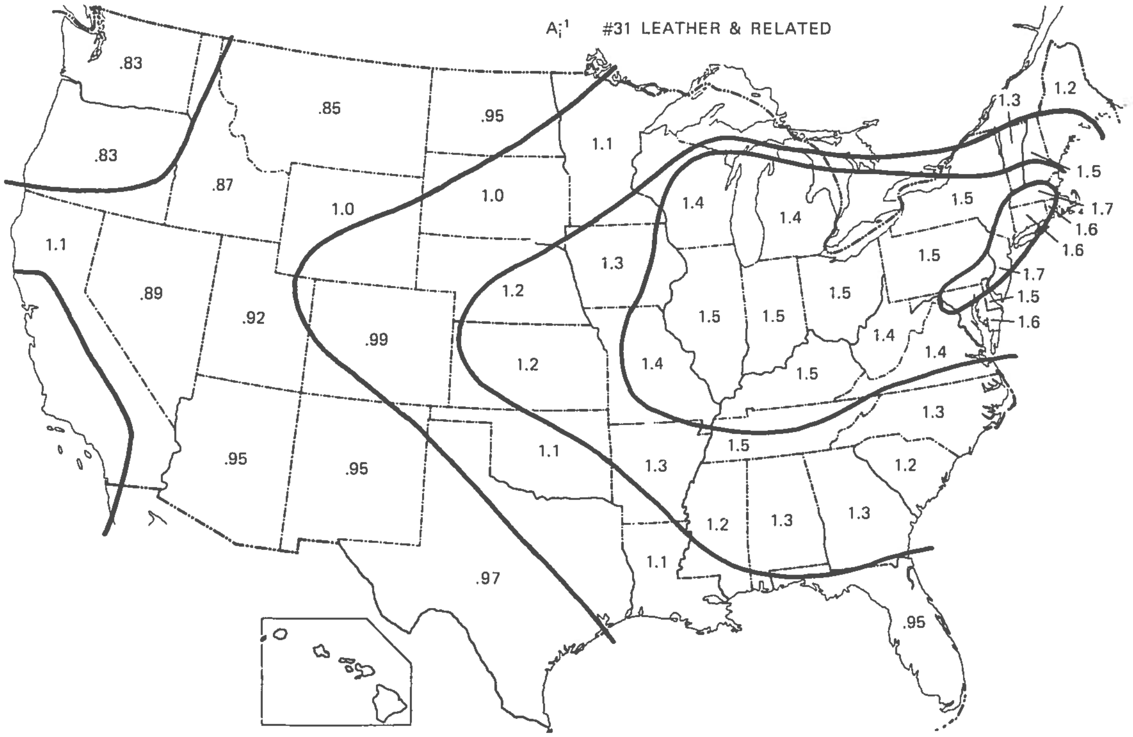


Figure 2-7B. Major commodity patterns—A_i^{-1} SIC 31 Leather and Related.

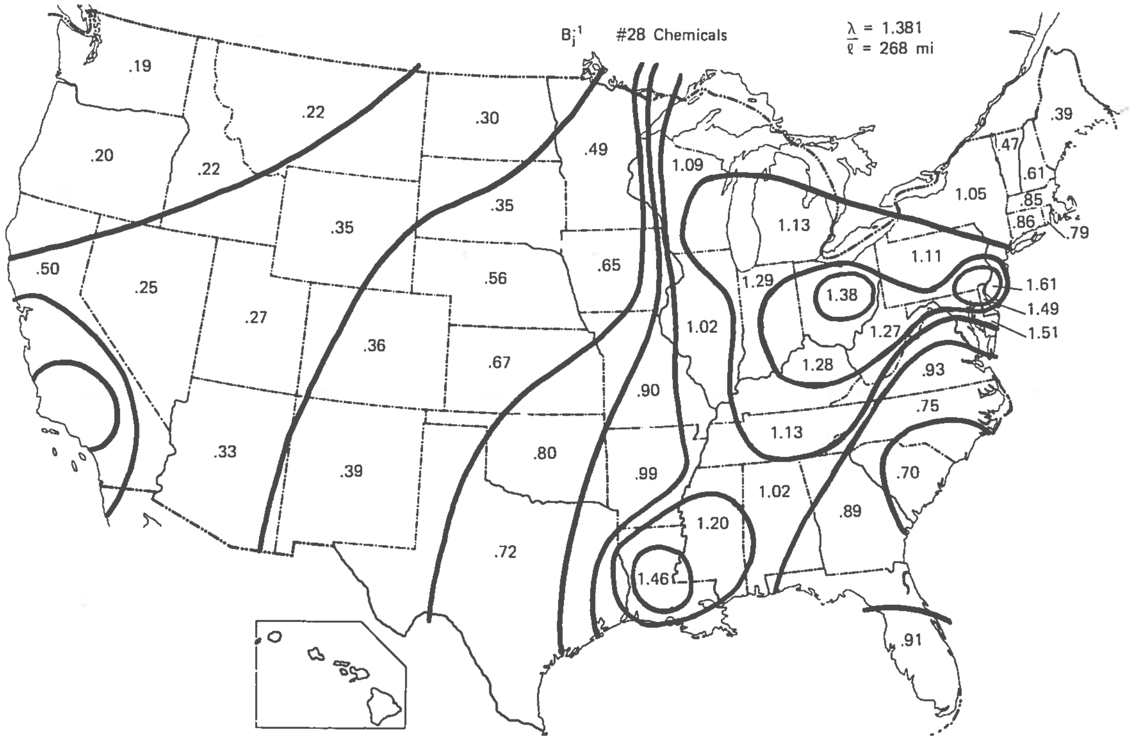


Figure 2-8A. Major commodity patterns—B_j^{-1} SIC 28 Chemicals.

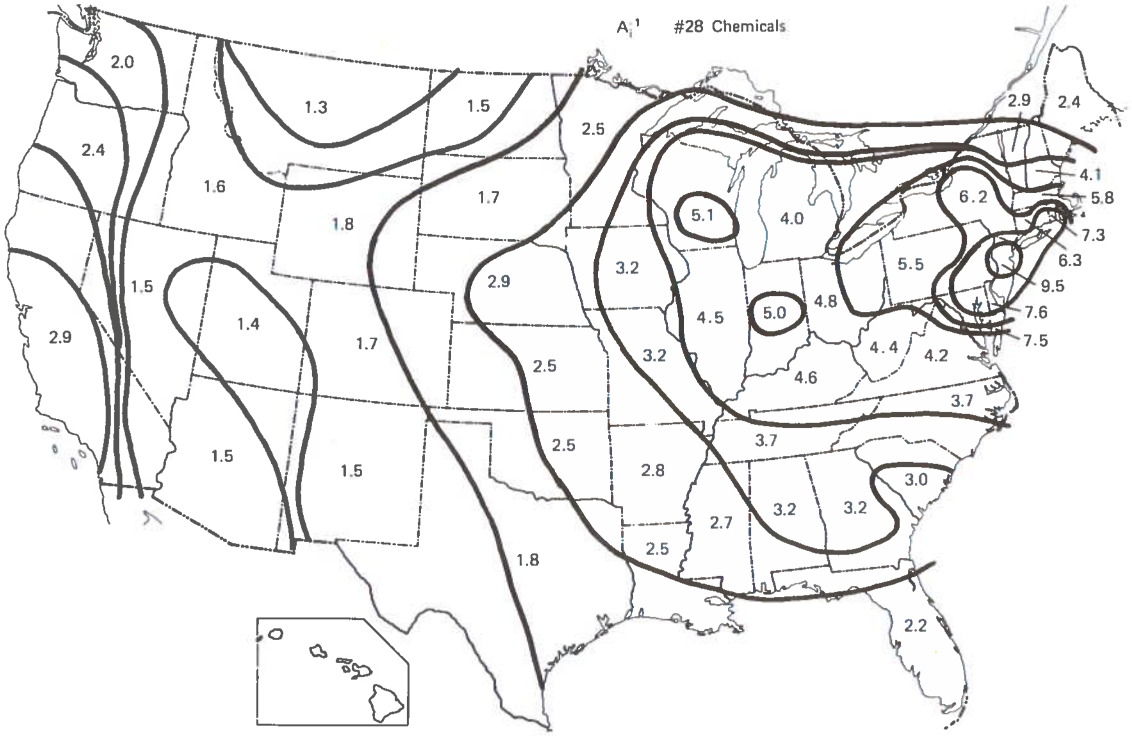
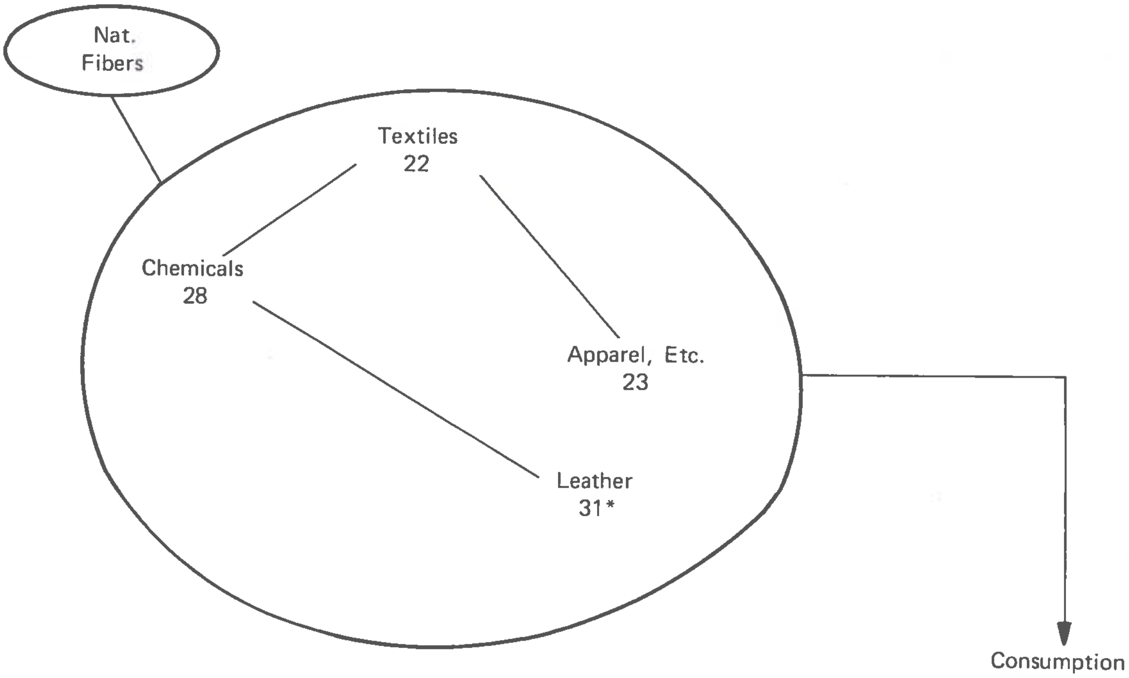


Figure 2-8B. Major commodity patterns—A_i^{-1} SIC 28 Chemicals.



* Shift to Midwest?

Figure 2-9. A potentially shifting pattern.

The leather industry would seem to be subject to much the same sort of locational instability that caused the textile industry to leave New England and locate nearer to input materials and low-cost labor. It is probable that import policies will play the key role in determining whether this industry will migrate towards the Midwest or remain where it is.

One might also presume that the apparel industry would disperse throughout the South and form a secondary center somewhere around Arkansas to co-locate with natural and artificial fiber manufactured in Texas and Louisiana, capitalizing further on lower labor and land costs. Hence our estimate that this group of industries has a potentially shifting pattern (see Figure 2-9). Consumption would seem to have largely conformed to expected patterns for manufactured goods, but reductions in transport costs (and hence λ) would produce consumption potentials more like those of tobacco.

Wood, Lumber—Pulp and Paper—Furniture and Related Printing and Publishing (SIC 24, 25, 26, 27).

Lumber production is centered in the Pacific Northwest with a second weaker production center in the southern pine forests of Mississippi and Louisiana. Further east these forests also are significant pulp producers. Paper production in New England remains viable by (drawing from northern forests), but much of that industry has shifted closer to sources of basic inputs and low-cost labor. The λ values reflect a commodity that should be transport price sensitive. Furniture and Fixtures reflect a spatial relationship governed by proximity to hardwood forests and low-cost labor, and are transport price sensitive, but much less so than lumber or pulp and paper.

The consumption potential for lumber (presumably for the residential housing construction industry), like food, is very similar to the population potential. The consumption potential for pulp and paper is less so, being intermediate between the sharply peaked population potentials and the uniform consumption potentials of tobacco. Presumably it is the manufacturing industries which are the primary consumers of cardboard boxes and much of the paper for forms, etc. Consumption for furniture and fixtures resembles the relatively flat potentials for consumption of most manufactured goods.

Again, the λ values reflect a relatively cost sensitive situation for lumber and pulpwood and paper; they are considerably less (but still reflect some sensitivity for furniture and fixtures.

All in all, the patterns for these products are considered to be relatively stable. At least in the short run, the production potentials are tied to the wood production locations. Paper and cardboard processing may migrate closer to pulp supplies but consumption patterns seem relatively stable. If cellulose fiber is more widely used as a base for plastics and other synthetic materials of the future, more processing could be located in the southern pine forests and perhaps even lead to importing cheap fiber and pulp from Caribbean Basin sources.

Petroleum Refined and Related, Chemicals, and Rubber and Related (SIC 29, 28, and 30).

Figures 2-10A and 2-10B, 2-8A and 2-8B, and 2-11A and 2-11B provide the transport potentials for this interesting group of commodities. The basic focus for production of petroleum refined and related products is Louisiana, with smaller sites in California, Wisconsin (Canadian oil?) and New Jersey. The space variable λ is 2.34, the highest value observed among all the commodities studied, indicating that transport costs are a large part of the total cost of the goods. The high value of mean haul (513 miles) that accompanies λ is due to the unique dependence of the northeast on petroleum products. The lack of pipeline data in the census data implies that careful restudy of this commodity is required.

Chemical production has primary centers in the petrochemical areas of Louisiana, New Jersey and California, and a general production concentration in the northeastern quadrant of the United States—typical of most manufactured products. Rubber has a similar

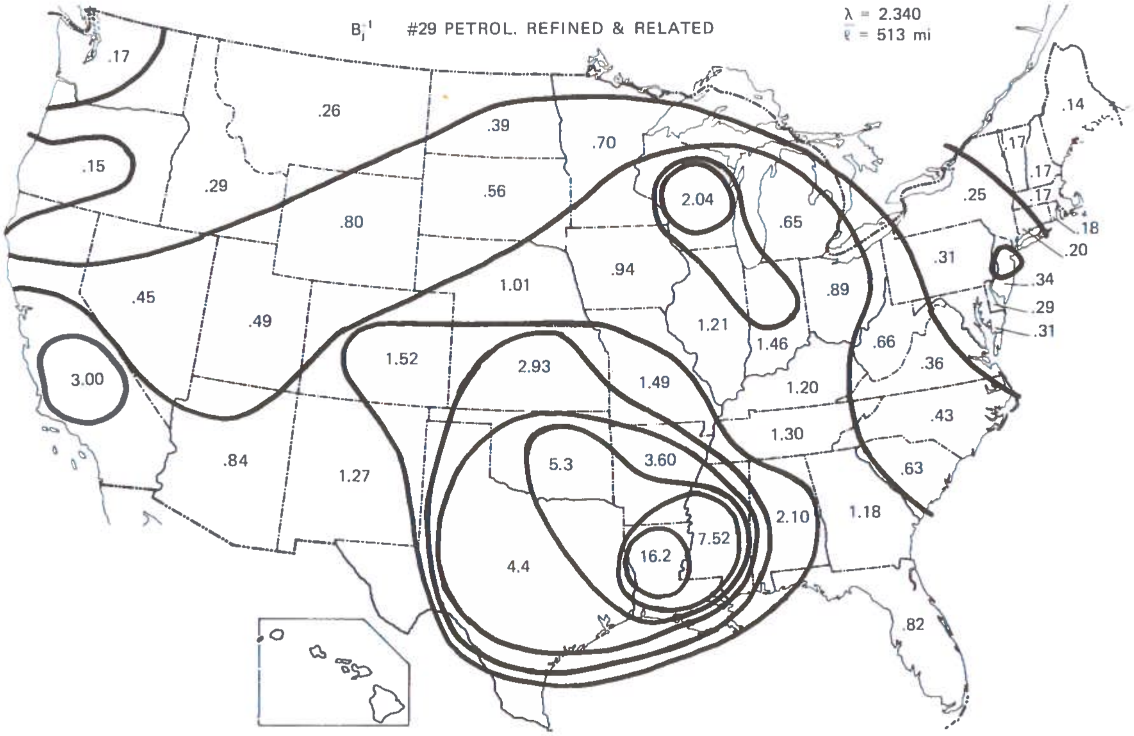


Figure 2–10A. Major commodity patterns—B_j^{-1} SIC 29 Petroleum Refined and Related.

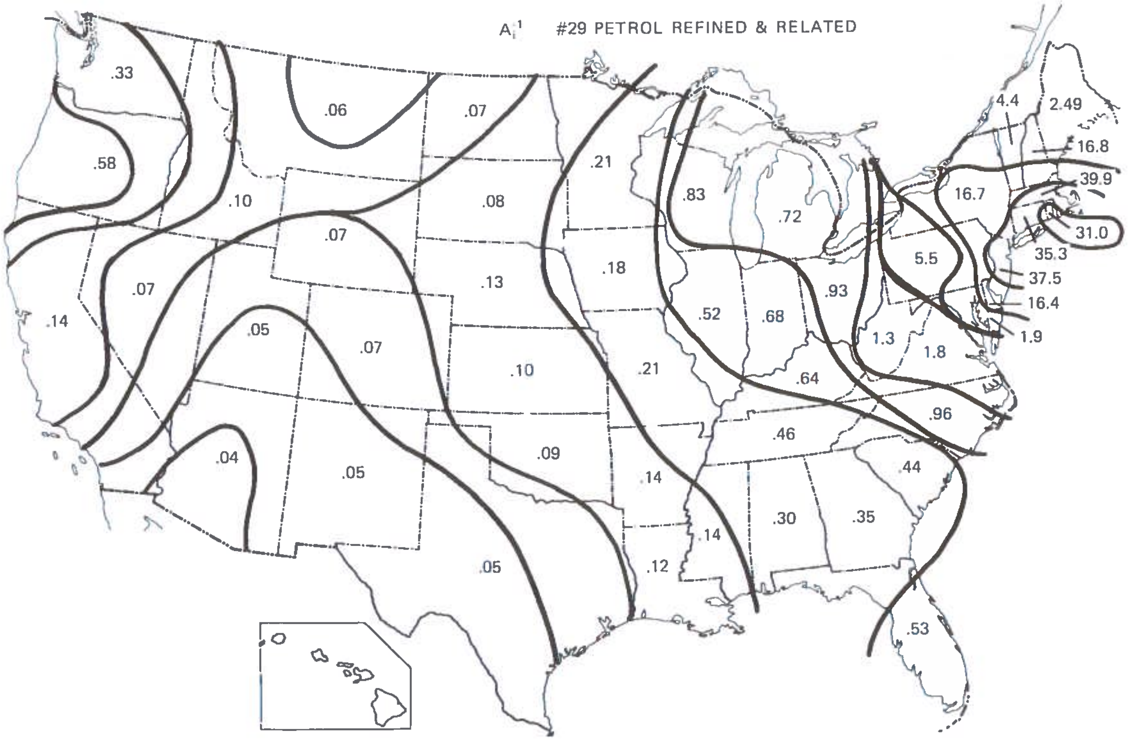


Figure 2-10B. Major commodity patterns —A_i^{-1} SIC 29 Petroleum Refined and Related.

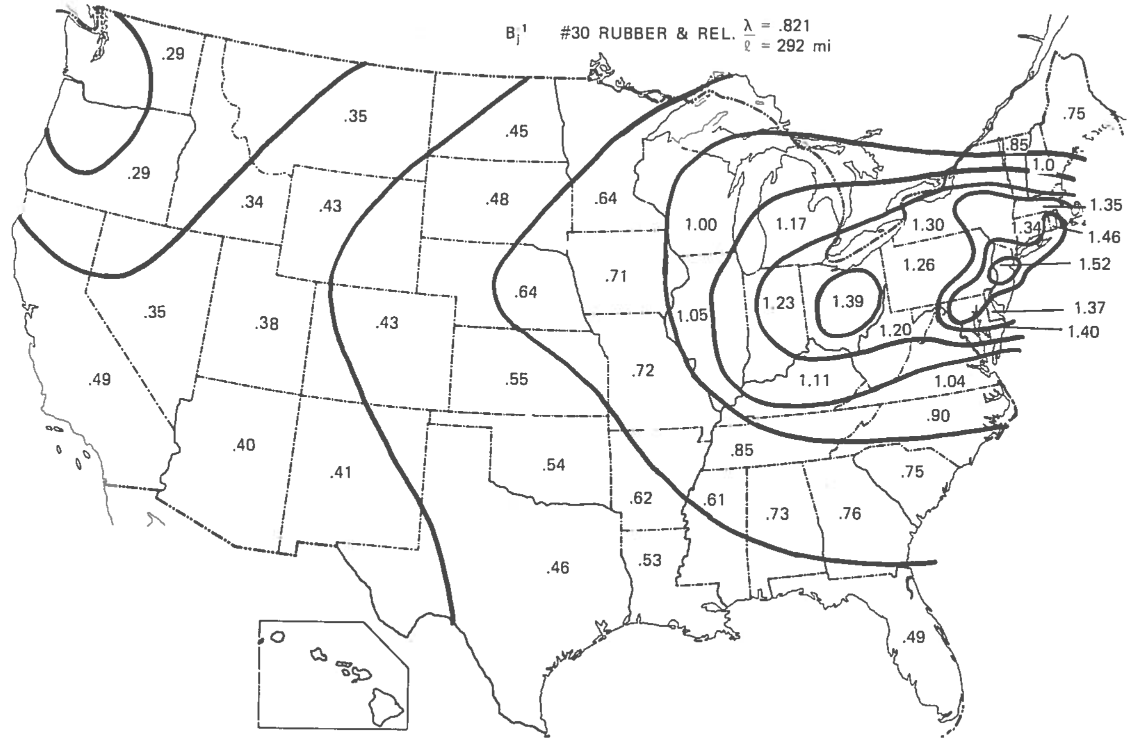


Figure 2-11A Major commodity patterns—B_j^{-1} SIC 30 Rubber and Related.

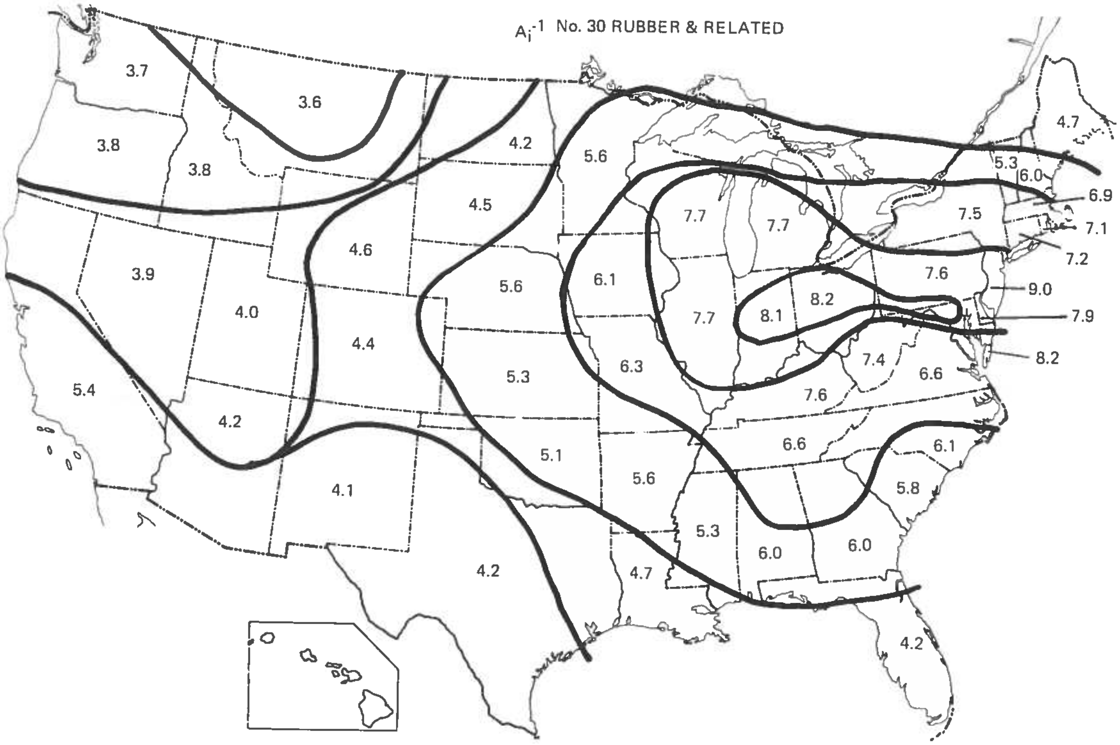


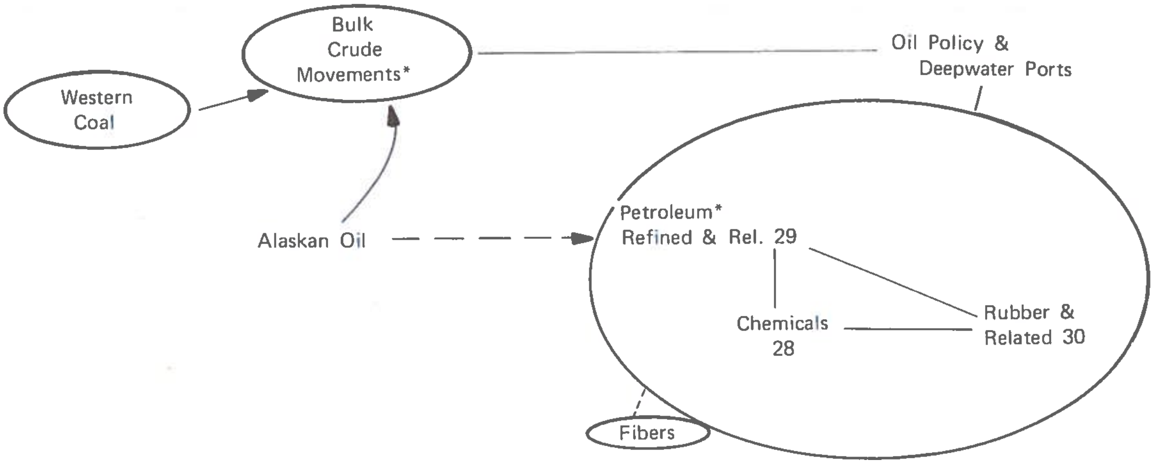
Figure 2-11B. Major commodity patterns—A_i^{-1} SIC 30 Rubber and Related.

pattern, except that Louisiana has no indicated production role, New Jersey is a stronger site, and Ohio emerges as a strong production center.

The λ values of chemicals (1.38) and rubber (0.82) are much lower than petroleum products. Chemicals would appear to be transport cost sensitive. The lower mean haul values (268 miles and 292 miles) reflect the co-location with major industrial users.

The consumption potentials of chemicals and rubber related products are quite similar to each other and to other manufactured products (chemicals being a little more confined to industrial users in the northeastern quadrant). The consumption potential of refined petroleum and related products is the most complex and spatially unique of all the groups studied. It reflects the New England dependence on domestic petroleum for heating, electricity and transportation. The bulk of the shipments enter through Rhode Island and Maine, with lesser receipts in New Jersey. It is probable that the pattern is impacted by coal use in the northern Midwest, by natural gas use throughout the rest of the country, by temperature effects north to south, and finally, as noted above, by basic distortions due to a lack of pipeline data.

Figure 2-12 shows the interrelation of the various commodities with other issues that make this set of patterns potentially the most unstable of the groups studied. Chemicals clearly are related to petroleum refining patterns, as is rubber. Rubber has a high potential for generating a secondary production center in the South and servicing an auto assembly and replacement pattern that is dispersing to a regional organization. But it is the basic pattern of petroleum products themselves that are most subject to change as the Nation's energy and environment policies emerge from the confusion of the 1970's. Shifts to higher product imports, concentration of refineries in the Caribbean, the location of deepwater ports, and shifting consumption of coal, natural gas and oil could all have major impacts. However, there will be a natural tendency to optimize existing infrastructure investments. Thus, for example,



*Pipeline Data

Figure 2-12. An unstable pattern.

the Louisiana production center is compatible with Caribbean refineries, a major deepwater port site off the Texas/Louisiana shore, and use of existing distribution means (mainly pipeline). Similarly, a deepwater port off New Jersey would similarly reinforce existing patterns. Alaskan Oil could modify the strength of western production sources. All in all, the close coupling of the three subject industries and the intense and shifting forces on oil use combine to make this area the most potentially unstable and one worthy of closest research from a transportation system impact viewpoint.

Clays, Primary Metals, and Related Manufactures (SIC 32, 33 and 34-39)

Primary metals (Figures 2-13A and 2-13B) are manufactured in the northeast quadrant of the U.S., in the middle of the industrial production zone of concentration, at the intersection of areas of ore location, limestone, high grade coal and population concentration. The λ value of 1.15 suggests that transport cost of the output itself is not highly important in its use.

Clay and related products are produced (and consumed) in a pattern very similar to primary metals and the related manufactures. The λ value of 2.15 suggests that transport costs dominate the product price (and the mean haul of 165 miles confirms it).

The production potentials of electrical and non-electrical machinery, professional and scientific equipment, and miscellaneous manufactures are similar on the national scale, concentrated in the northeast quadrant. However, non-electrical machinery has a pronounced production center in Wisconsin, and professional equipment shows a concentration in New England (as does Miscellaneous Manufacture to a lesser degree). Transport equipment (including automobiles) is dominated by Detroit truck production. The mean hauls are concentrated around 350 miles but the λ values vary considerably in a range of relative insensitivity to transport costs. As expected, the most sophisticated product (professional and scientific equipment) has the lowest λ value of all 20 categories studied (λ = 0.39).

On the consumption side, clays and primary metals have consumption potentials that match the production potentials of the related manufactures. All the derived manufactured products have strikingly similar consumption potential maps. There is little east-west or north-south variation. Peak-to-valley ratios approach 2:1, being at a relatively uniform maximum in the northeastern quadrant of the U.S., falling off gradually in all directions with a slight peak in California.

Fundamentally, the patterns of production and consumption for this group of commodities (Figure 2-14) seem stable with the minor exception of the probable dispersion of professional and scientific equipment production out of New England to a broader pattern near growing urban areas nationwide. In view of the position of production concentration at the center between raw materials and population, it seems reasonable to doubt that our national commitment to develop western energy resources would have more than a marginal impact on the location-of-manufacture of the commodities. There would of course be a more than transient consumption shift as the infrastructure was being put in place. (Note: Auto production is not included in these patterns. This important commodity deserves special study.)

FURTHER RESEARCH REQUIRED

Temporal Stability of Transport Potentials

In the discussion of Major Commodity Patterns, many inferences were made about production locations and their dependence on labor, raw materials, and markets. These can be checked to some extent by generating the same patterns using 1972 and 1963 census of transportation data. 1972 data has been run but not documented.

Also of interest in this connection is the stability of the λ values and the mean hauls. On general grounds, with the population gradually dispersing on the continental land mass, one would expect slowly increasing mean hauls everything esle being equal. It was

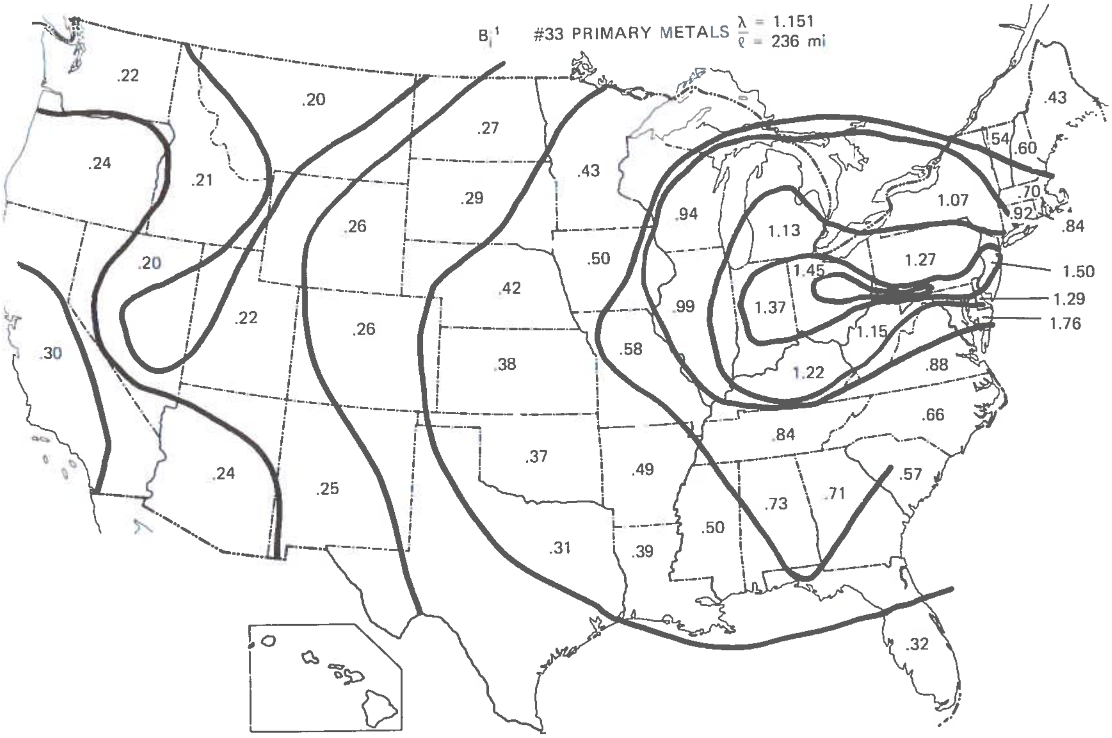


Figure 2-13A. Major commonality patterns—B_j^{-1}SIC 33 Primary Metals.

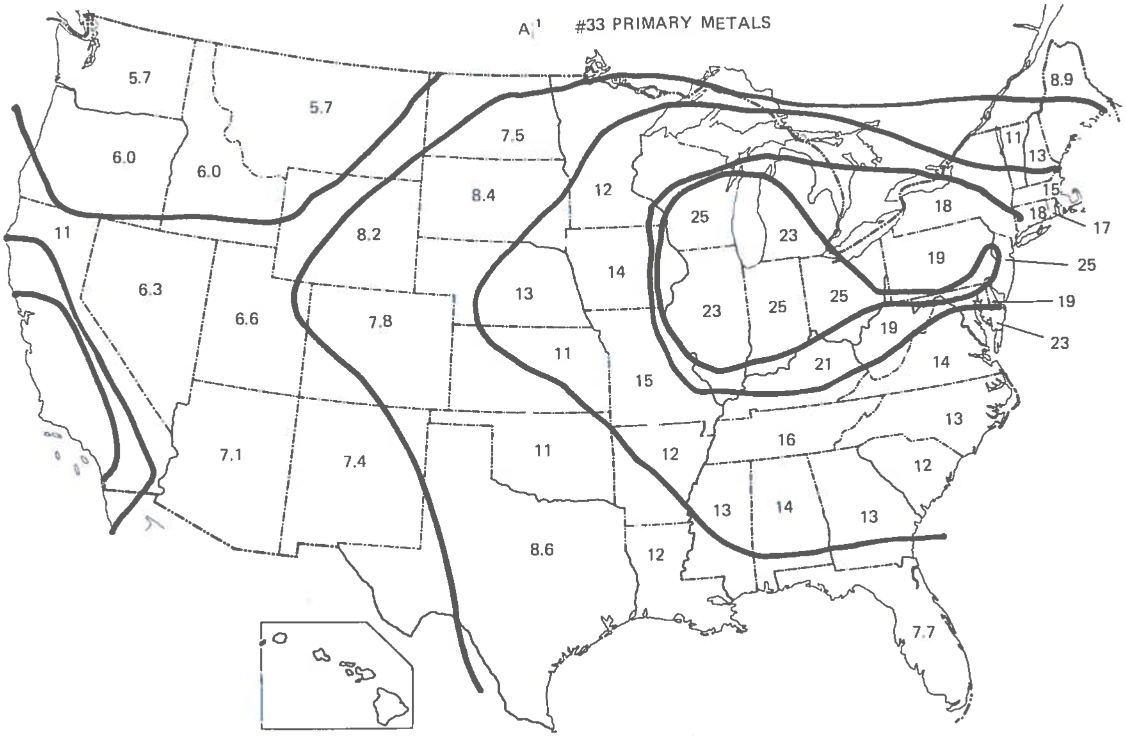


Figure 2-13B. Major commodity patterns—A_i^{-1}SIC 33 Primary Metals.

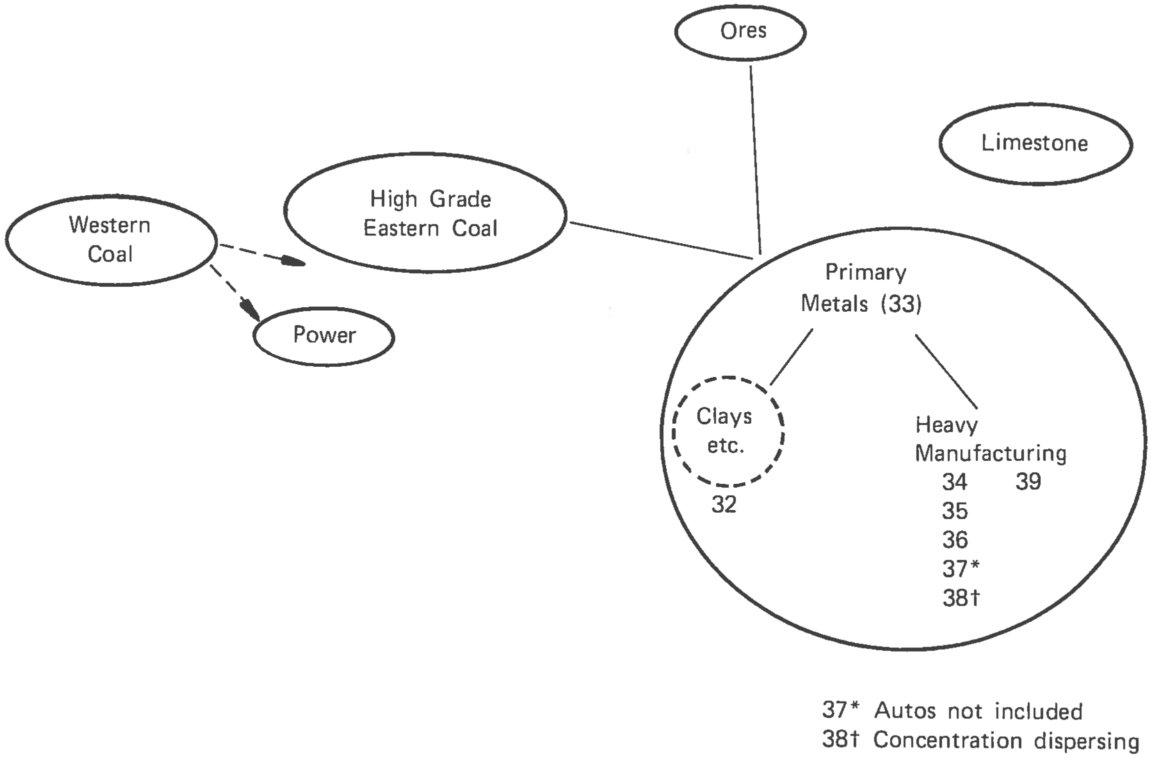


Figure 2-14. A stable pattern.

postulated in the Introduction that λ values reflect the transport costs relative to the value of the product. It should prove that λ values are very slowly varying quantities unless there is a large distortion in the price of transport relative to the other cost elements of the commodity. Initial comparison with 1972 runs strongly supports these observations.

Since study has shown that population potentials are relatively stable,(5) market shifts should be slight, reflecting increasing southern urbanization for example. Thus, only industrial migration should produce major pattern change.

Bulk Commodities

TSC has developed 1972 commodity flow data than can be analyzed in similar fashion to the above. The analysis should confirm the relationship postulated above. In general, it is expected that the bulkier, low value per pound commodities will show higher λ values than the manufactured products.

In addition, the fundamental U.S. role in supplying grain to world consumers should be reflected in a study of grain flows, with large consumption potentials for Gulf coast ports that serve as ports of embarkation for grain exports.

The fundamental interrelationships to be examined are those between fertilizer, production, rainfall, and consumption, as shown in Figure 2-3.

However, of all the bulks the energy commodities are the most important for transport policy for the next decade. As noted above, pipeline data must be acquired and factored into the analysis. It is possible that the investments to be made in coal exploitation in the remainder of the century will involve billions of dollars of transportation investments.(6,7) The alternatives and their relative value should constitute one of the highest priority research areas of freight analysis. As indicated above, attention is already being devoted to the oil policy and deepwater port issues. It is also probable that we have only begun to scratch the surface of this topic.

Modal Patterns

The type of analysis made above has been performed on a modal disaggregate basis as well but is not documented as yet. The results should show those patterns of production and consumption served by the different modal services. In passenger analysis, it is claimed(8) that network density of transportation systems are constant along lines of constant potential of population. If such relationships can be established for commodity movement, they may assist in rationalizing network structures—a topic of great current interest in the planning community. Finally, the λ values for a commodity across modes may provide valuable insight into price, service trade-offs for various commodities, adding another tool for regulatory research. Temporal change in these patterns and relationships should prove even more interesting and valuable to transport planners than those of Temporal Stability of Transport Potentials planners.

Relationship to Physical Production and Consumption Potentials and Underlying Variables

By comparing the above work to the physical potentials themselves (directly analogous to population potentials) we should be able to visualize the spatial impact of transportation. We should also be able to establish econometric relationships between production, consumption, flows, and zonal variables such as population, income, value added, employment, etc. We could thus develop transportation maps by analogy to the two digit SIC maps of employment and value added in the National Atlas(9) and show the relationships to them.

New Commodity Patterns

Thought should be given to new products and commodity patterns that may arise in the future. Waste management and recycling represent one area of significance that should be studied.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions of Howard Slavin in suggesting the entropy maximization approach to commodity flow analysis, initiating it through Michael Grossman, and offering useful advice and encouragement throughout the subsequent study. Thanks also are due Alan Kaprelian for helping to untangle the mysteries of the algorithms used in the analysis, and for the final production runs; and to Mike Grossman and his associates for the data manipulation and initial computer support.

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HASSLER

BIOGRAPHY

Frank L. Hassler is Director of the Office of Systems Research and Analysis of the Transportation Systems Center of the U.S. Department of Transportation in Cambridge, Massachusetts.

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Prior to his current assignment, Dr. Hassler was Chief of the Advanced Program Planning Division of the Transportation Systems Center.

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Dr. Hassler was born in Warsaw, Indiana. He received his Bachelor of Science degree in Physics from Yale University and his Masters and Doctorate of Science in Physics from Brown University.

He is married and the father of four children and resides in Arlington, Massachusetts.

ANNUAL AND QUARTERLY MODELS OF FREIGHT TRANSPORTATION AGGREGATES

by

DR. GEORGE H. WANG

INTRODUCTION

The first step in the planning process for our transportation system is to determine the volume of traffic that is likely to use the system. In order to plan for changes in these systems, the use of these systems under various policy scenarios must be determined. This paper presents models and forecasts of demand for aggregate measures of freight transportation uses.

There are two main uses for these models. First, long-term and short-term forecasts can be derived from the models' estimated equations. Second, for policy analysis, these models can serve as bases on which to evaluate the impacts of change in certain macroeconomic variables on the behavior of these transportation aggregates.

These models have been divided into two classes: annual models and quarterly models. Annual models include four principal modes: rail, truck, barge and air. Quarterly models have been constructed for the rail and truck modes. All models are statistically formulated and calibrated. Regression models with time series errors and parametric time series models are the major statistical techniques used in our modeling process.

In the Annual Models discussion, the specification, estimation and empirical results of the annual models will be discussed. In Quarterly Models discussion, the quarterly regression model and the time series model for rail freight will be discussed. The Summary and Conclusions evaluate and discuss plans for improvements to these estimated models.

The paper assumes familiarity with several statistical time series modeling techniques: parametric timeseries models, autoregressive integrated moving average models, and univariate time series models. For a full description of these models see (Box and Jenkins, and Fuller (1976).

ANNUAL MODELS

Model Structure and Variables

Our statistical models relate the demand for freight transportation by rail, barge, air, and truck to the general level of economic activity, production indices of certain major industries, and freight rates expressed in constant 1958 dollars. In order to derive specific demand equations for each mode, we first assumed that the long-run equilibria for all modes can be expressed as:

$$y_t^* = \alpha_o R_t^{\beta_o} \left[\prod_{i=o}^{m} x_{i_t}^{\gamma_i} \right] \left[\prod_{j=o}^{n} z_{i_t}^{\delta_j} \right] e^{u_t} \qquad (1)$$

where $u_t \sim$ iiD $(0, \sigma_u^2)$, i.e., independently, identically distributed with mean 0 and variance σ_u^2

y_t^* = equilibrium demand for freight transportation for a given mode as measured by revenue ton-miles
R_t = real freight rate for a given mode
x_{i_t} = aggregate economic indices
z_{i_t} = production indices of specific industries
V_i, δ_j = parameters to be estimated

This long-run relationship is not always observed because institutional and informational constraints may allow only a partial adjustment by shippers from the level in a given period toward the following equilibrium in the following period. We therefore introduced a Nerlove-type distributed lag into the basic equation (1) to make this dynamic process a part of the model structure. This equation form also made possible the calculation of both long and short-run demand elasticities. Our partial adjustment hypothesis was postulated as:

$$\left(\frac{y_t}{y_{t-1}}\right) = \left(\frac{y_t^*}{y_{t-1}}\right)^{\theta} \qquad (2)$$

where the unstarred variables are observed quantities and Θ is the speed of adjustment coefficient. Based on these considerations, we obtain the theoretical model for each mode as follows:

$$\begin{aligned}\log(y_t) = \alpha_0 + \alpha_1 \log(R_t) + \sum_{i=0}^{m} \alpha_{i+2} \log(x_{i_t}) \qquad (3)\\ + \sum_{j=0}^{n} \alpha_{m+3+j} \log(z_{j_t}) + \alpha_{m+j+4}\\ \log(y_{t-1}) + e_t \qquad e_t \sim \mathrm{iiD}(0.6_e^2)\end{aligned}$$

Freight transportation involves the distribution of goods from the production sector to the consumption sector. The indices of general economic activity and of specific industry outputs are logical candidates for explanatory variables in our models.

For several reasons, we chose only GNP, expressed in constant 1958 dollars, to represent aggregate economic activity. The data used in this study were available only in annual series. Consequently, since records of our dependent variable date no earlier than 1947 and no later than 1972, we had to perform all analyses with, at most, twenty-six observations per mode. This necessarily restricted the statistically useful number of exogenous variables. We also had to contend with multicollinearity among candidate variables. Finally, as we wished our models to predict the future as well as to explain the past, we needed independent variables whose future values can be reasonably projected. The selection of real GNP appeared the best compromise for a single aggregate variable.

Inclusion of a specific industrial production index into a particular model was guided by the data. As a general rule, we considered using an index if the industry accounted for over twenty percent of a mode's total revenue ton-miles. This was true for coal in rail and barge transportation; hence these equations used the Federal Reserve Board (FRB) bituminous coal production index as an independent variable. The barge model also used the indices for metallic ores and non-metallic minerals production. The truck model used the FRB petroleum and coal products index. No single industry figured so importantly for air transportation.

All models except that for barge were estimated using revenue per ton-mile, expressed in constant 1974 dollars, as a proxy for the real freight rate of a particular mode. This was necessary because suitably aggregated rate indices do not exist. Despite this shortcoming in the data, we felt it worthwhile to use the revenue figures to incorporate, at least approximately, demand shifts through rate competition into the explicit model structure. Barge models could not use even this proxy term since the revenue data have never been collected for the industry as a whole.

Our dependent variables in all cases were the total revenue ton-miles of freight for each mode for each year from 1947 to 1972. The data for air freight included mail and express; barge data were for inland waterways and the Great Lakes.

The major sources for all these time-series were Transportation Facts and Trends and various issues of the Survey of Current Business.

Empirical Results

In this section, we briefly summarize the empirical results of the estimated equations.

In general, the specification of the theoretical model equation (3) and the empirical information obtained from the data provide us with a guide for choosing the final functional form for each mode. Four estimation procedures—ordinary least squares, instrumental variables estimator (Fuller, 1976), generalized least squares and the two-step Gauss-Newton procedures (Fuller, 1976 and Hatanaka) were utilized in our estimation process. The technical details of choosing alternative estimators for the different types of models were reported in an earlier study by Wang and Epstein. The best estimated equations are reported in Table 3-1. They were judged on the signs of the regression coefficients, the statistical significance of the coefficients, R^2 and the lack of autocorrelation in the estimated residuals.

Table 3-1. Regression Equations and Related Statistics

Definitions of Variable Names

X_{1t} = real GNP, X_{2t} = coal production index, X_{3t} = real freight rate
X_{4t} = production index for metallic ores and non-metallic minerals
X_{5t} = dummy variable, $\tilde{u}$ = residual, Y_t = revenue ton-miles

The values in parentheses are calculated "t" statistics

Rail Model

Estimated Demand Function:

$\log(y_t) = -2.29 + 0.24*\log(X_{1t})$
$\quad(-4.19)\ (8.10)$
$\quad +0.56*\log(X_{2t})$
$\quad(12.7)$

$\rho_1 = 0.475$
SER = 0.0215
DW = 1.82, method: GLS

Forecasting Equation:

$\log(Y_t) = -2.29 + 0.24*\log(X_{1t})$
$\quad + 0.56*\log(X_{2t})$
$\quad + 0.475*\tilde{u}_{t-1}$

Barge Model

Estimated Demand Function:

$\log(Y_t) = -2.57 + 0.45*\log(X_{1t})$
$\quad(-1.73)\ (3.20)$
$\quad + 0.37*\log(X_{2t})$
$\quad(4.20)$
$\quad + 0.48*\log(X_{4t})$
$\quad(2.88)$

$\rho_1 = 0.297$

$\rho_2 = 0.413$
SER = 0.0391
DW = 1.76, method: GLS

Forecasting Equation:

$\log(Y_t) = -2.57 + 0.45*\log(X_{1t})$
$\quad + 0.37*\log(X_{2t})$
$\quad + 0.48*\log(X_{4t})$
$\quad + 0.297*\tilde{u}_{t-2}$

Air Model

Estimated Demand Function:

$\log(Y_t) = -6.92 + 2.10*\log(X_{1t})$
$\quad(-3.67)\ (5.94)$
$\quad -0.56*\log(X_{3t})$
$\quad(-2.40)$
$\quad + 0.33*\log(Y_{t-1})$
$\quad(3.30)$
$\quad + 0.13*(X_{5t})$
$\quad(2.50)$
SER = 0.0561
$R^2 = 0.996$, method: OLS

Forecasting Equation:

$\log(Y_t) = -6.92 + 2.10*\log(X_{1t})$
$\quad -0.56*\log(X_{3t})$
$\quad + 0.33*\log(Y_{t-1})$

Truck Model

Estimated Demand Function:

$\log(Y_t) = -0.20 + 0.20*\log(X_{1t})$
$\quad(-0.83)\ (2.30)$
$\quad + 0.82*\log(Y_{t-1})$
$\quad(13.47)$
SER = 0.0309
$R^2 = 0.993$, method: OLS

Forecasting Equation:

$\log(Y_t) = -0.20 + 0.20*\log(X_{1t})$
$\quad + 0.82*\log(Y_{t-1})$

where
ρ_1 = estimate of the coefficient of its order serial correlation
SER = standard error of the regression
DW = Durbin Watson statistic, an estimate of serial correlation in the estimated residuals
GLS = generalized least squares, a method of estimation that takes into account the serial correlation modelled in the error terms
OLS = ordinary least squares estimation
R^2 = the proportion of variance of the dependent variable explained by the independent variables

Table 3-2. Elasticities and Speed of Adjustment Coefficients

Dynamic Models

	Adjustment Coefficient	Elasticity of Real Freight Short-run	Rates Long-run	Elasticity of Real GNP Short-run	Long-run
Air	0.67	-0.56	-0.82	2.1	3.0
Truck	0.18	—	—	0.20	1.1

Static Models

	Elasticity of Real GNP	Elasticity of Coal Production Index	Elasticity of Ores Production Index
Rail	0.23	0.56	—
Barge	0.45	0.37	0.48

The demand elasticities of each mode with respect to their corresponding independent variables are shown in Table 3-2.

We now consider the economic meaning of the empirical results.

The coefficients of real GNP are positive and statistically significant in all equations. The short and long-run elasticities of the air model are larger than one. This shows that, other things being equal, the change in air freight traffic is more than proportional to the change in real GNP. We found that rail, barge and truck are inelastic with respect to real GNP. These differing elasticities are probably due to different demand elasticities of the major commodities shipped by each mode. For example, commodities shipped by air freight generally have greater elasticities than those commodities shipped by other modes. This explanation is plausible since transportation is a derived demand.

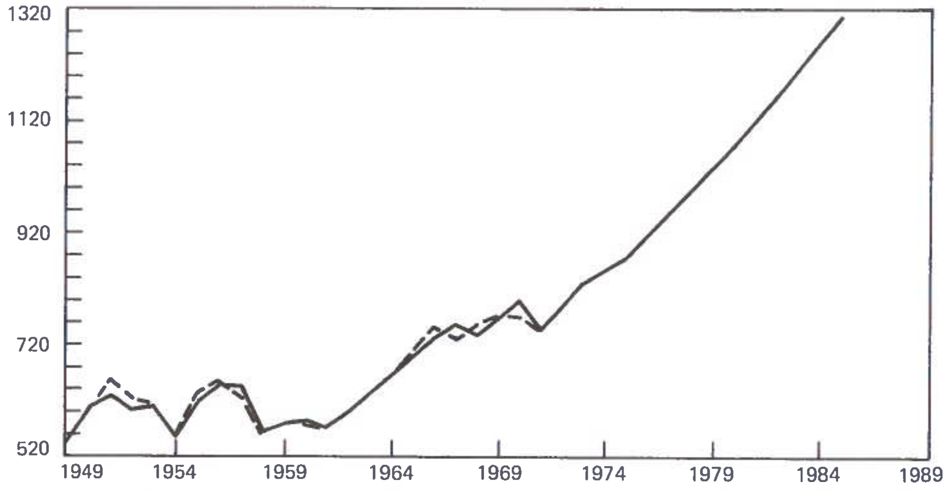
Real freight rates were statistically significant in only the air equation. We offer three possible explanations. Real revenue per ton-mile is perhaps a poor proxy variable to an actual freight rate. Real freight rates themselves may be only a part of the total transportation cost incurred by a shipper. To test this, we would like to try a total shipping cost index in place of a rate index, if one could ever be constructed. The third possibility is that governmental regulatory policies of minimizing aggregate inter-modal rate differences have simply eliminated rate competition in many markets and have thereby ruled out this factor in mode choice. This could also explain why estimated coefficients of interactive rate terms were never statistically significant in our study.

Forecasting

Our forecasting procedure consists of two steps: the extrapolation of independent variables under varying assumptions, and the substitution of these extrapolated variables into the estimated demand equations. Our forecasts assume implicitly that the basic structural relationships among the variables for the 1947–1972 period will remain unchanged through 1985. We note, however, that government rate regulation policies over our historical period have tended to minimize aggregate inter-modal rate differences. Relaxation of these policies could make freight rates a significant variable for all modes in the future but this would not be reflected in the forecasts.

Forecasts by Data Resources, Inc. provide values for future real GNP. We have projected both real air freight rates and the ore-production index to increase 2.5 percent annually. Future coal production is projected twice through alternative growth rates which assume 1972 production (1) to double by 1985, (2) to increase fifty percent by 1985. These growth rates are based on the fact that coal is increasingly being substituted for scarce oil.

The performance of and the forecasts of these four modes during the 1948–1985 period are displayed in Figures 3-1 through 3-4.



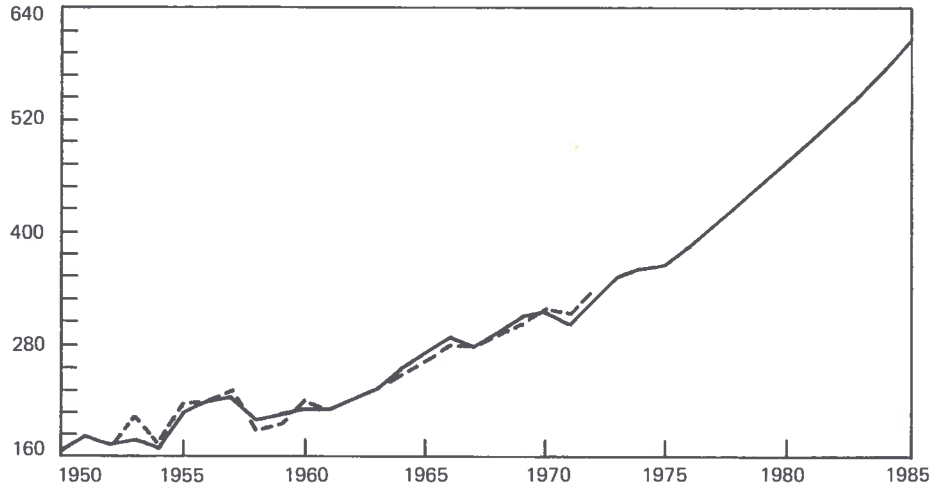
TIME BOUNDS: 1949 TO 1985

SYMBOL SCALE NAME

– – – – historical
—— estimated and forecast

(a) assumes coal production to increase 100 percent–1973 to 1985.

Figure 3-1. Rail freight demand (in billions of revenue ton-miles).



TIME BOUNDS: 1950 TO 1985

SYMBOL SCALE NAME

– – – historical
—— estimated and forecast

(a) assumes coal production to increase 100 percent–1973 to 1985.

Figure 3-2. Barge freight demand (in billions of revenue ton-miles).

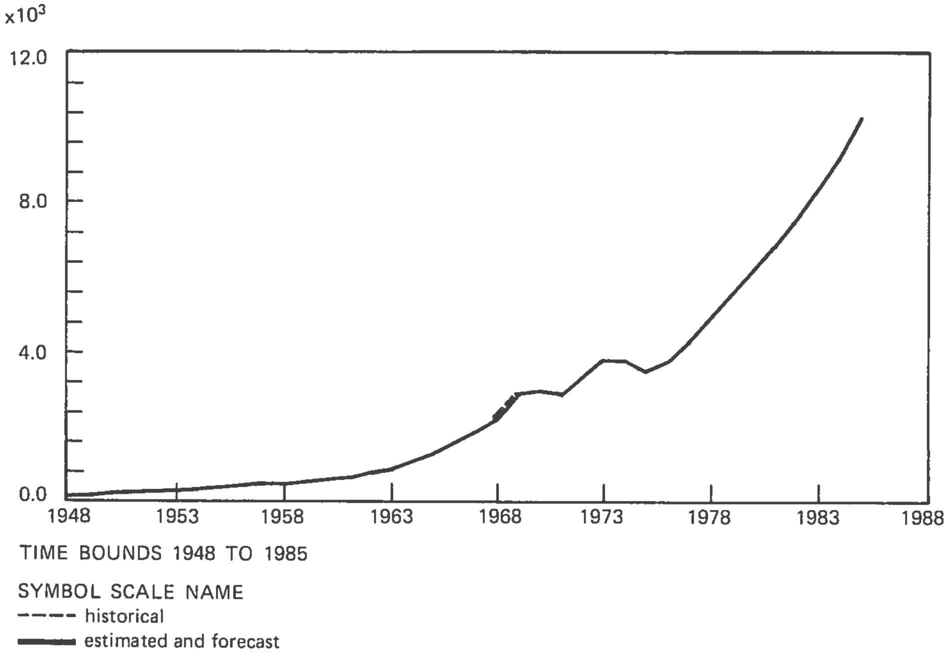


Figure 3-3. Air freight demand (in millions of revenue ton-miles).

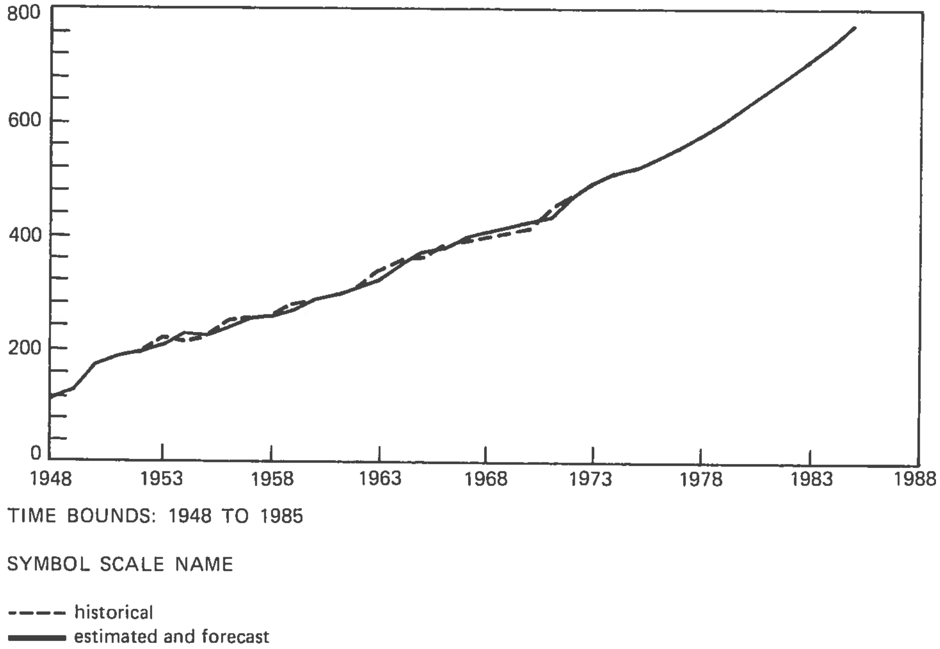


Figure 3-4. Truck freight demand (in billions of revenue ton-miles).

QUARTERLY MODELS

There are several reasons for interest in quarterly models. First, government policy decisions have sometimes been influenced by the latest changes in quarterly economic data; more systematic and rigorous analysis of quarterly data through the construction of a quarterly model would reduce the hazards of using quarterly data in an ad hoc manner as is usually done. Second, short-term forecasts are likely to be more accurate if they are made using a quarterly model rather than an equally good annual model. Third, in a quarterly model, there is less simultaneity involved in the system of economic relationships than in an annual model so that the estimation of quarterly models by single-equation estimation procedures would suffer less simultaneous equation bias (if simultaneity exists). Finally, quarterly models provide us with a detailed picture of quarterly fluctuations in the behaviors of transportation aggregates. This picture provides useful information for short-run planning of manpower requirements, operating costs and revenues, and utilization and allocation of transportation equipment.

Because of the space limitation, we present only the empirical results of the regression model and the autoregressive integrated moving average (ARIMA) model for rail freight. (Boeing, Box and Jenkins)

Dynamic Regression Model with Time Series Errors

The Model. The quarterly rail freight demand is specified as

$$Y_t = \beta_0 + \beta_1 + X_{1t} + \beta_2 X_{2t} + \beta_3 X_{3t} + \beta_4 Y_{t-1} + \sum_{i=1}^{4} \delta_i D_{it} + u_t \qquad (4)$$

$$0 < \beta_4 < 1$$

where u_t is assumed to be a stationary time series with zero mean.

Y_{1t} = Rail freight shipments in billion of revenue ton-miles (Class I railroads). The quarterly data from second quarter 1954, to first quarter 1975 are available from *Business Statistics 1973* (published by the Department of Commerce) and various issues of *Survey of Current Business.*

X_{1t} = Gross National Product measured in 1958 dollars. It is available from various issues of *Survey of Current Business*.

X_{2t} = A quarterly bituminous coal production index. The monthly data are available from various issues of the *Federal Reserve Bulletin*, published by FRB.

X_{3t} = The dummy variable for major railroad strikes. The rail strike information is available from Car Service Division, American Association of Railroads.

and $\sum_{i=1}^{4} \delta_i = 0$, This implies

$$D_{tj} = \begin{cases} 1, \text{ if observation t occurs in quarter j} \\ -1, \text{ if observation t occurs in quarter four} \\ 0, \text{ otherwise.} \end{cases}$$

The reasons for the inclusion of X_{1t} and X_{2t} as independent variables in equation (4) are similar to those given for the annual model. Rail freight, lagged one period, is added to the model in order to pick up the effect of the lagged responses of rail freight demand due to imperfect adjustment. Seasonal dummies are specified to take into account the effect of fixed seasonal patterns; the stochastic seasonal effect is handled by modeling the error structure of the residuals. Further, there are no quarterly data available for measuring the service characteristics of rail freight and its competing modes. Thus, these omitted variables are naturally contained in the error term, u_t, of the models. For our purpose—building forecasting models—the effect of omitted variables can be properly handled through the modeling of the systematic elements in the error terms. Therefore, special attention will be directed toward modeling the parametric structure of the error terms throughout the modeling process.

The Empirical Results. It is a well-known fact that ordinary least squares estimates (OLS) suffer two weaknesses when there is autocorrelation in the model's error structure: (1) OLS produces inconsistent estimators and (2) the estimator of the variance of the estimator is inconsistent; hence the calculated t statistics are biased. Therefore, the first thing we tried was to identify statistically the nature of the error process, U_t. The instrumental variables procedure was used to obtain consistent estimates of U_t which will be denoted as $\hat{U}_t$. Then four alternative error structures were specified:

$$U_t = \rho U_{t-1} + e_t$$

$$U_t = \rho U_{t-4} + e_t$$

$$U_t = \sum_{j=1}^{4} \rho_j U_{t-j} + e_t$$

$$U_t = \rho_1 U_{t-1} + \rho_2 U_{t-4} + \rho_3 U_{t-5} + e_t$$

Based on asymptotic t statistics, we find that the error structure is

$$\hat{U}_t = \underset{(0.11)}{0.23}\ \hat{U}_{t-1} + e_t \tag{5}$$

To reinforce our confidence, sample autocorrelations of the estimated residuals the $\hat{U}_t$ were also calculated and they supported the hypothesis that U_t is distributed as a first order autoregressive process. Thus, we applied an asymtotically efficient procedure—the two-step Gauss-Newton procedure—to estimate the parameters of the model equation (4). The resulting equation is:

$$\begin{aligned} Y_t = {} & \underset{(5.67)}{28.066} + \underset{(0.012)}{0.050}\ X_{1t} + \underset{(0.069)}{0.302}X_{2t} - \underset{(0.69)}{5.897}D_{1t} \\ & + \underset{(0.81)}{6.868}D_{2t} - \underset{(0.76)}{3.69}D_{3t} + \underset{(0.08)}{0.51}\ Y_{t-1} \\ & - \underset{(1.47)}{10.364}X_{3t} - \underset{(0.13)}{0.031}\hat{U}_{t-1} \end{aligned} \tag{6}$$

where:

$\hat{\rho}$ = 0.23-0.03 = 0.20 (estimate of coefficient of serial correlation)
SER = 3.84
F (8/73) = 235.48
D.W. = 2.06

The numbers in parentheses are estimated standard errors of the coefficients. The estimated coefficients are all statistically significant at the 1 percent level. Further, the signs of the coefficients are consistent with our prior expectations. As expected, rail freight shipments increase as GNP and coal production increase. The strike variable has a negative impact on rail freight shipments. In terms of seasonality, rail freight traffic in second and fourth quarters is relatively high compared with the first and third quarters.

The elasticities of demand for rail freight with respect to GNP and the bituminous coal production index are reported in Table 3-3.

Table 3-3. Demand Elasticities for Rail Freight with Respect to GNP and the Coal Production Index*

Variables	Short-Run	Long-Run
GNP58	0.178	0.42
Coal Production Index	0.163	0.384

* Note: Elasticities are calculated at the mean.

From Table 3-3, we see that the responses are inelastic both in the short and long-run. This implies that the increase in rail freight shipments is less than proportional to the increase in GNP of the coal production index. As expected, the rail freight elasticities estimated from quarterly data are smaller than those estimated from annual data.

The Forecasts. Forecasts of rail freight demand over a period of eight quarters are computed from the following equation:

$$\begin{aligned} Y_t = {} & 28.07 \times 0.8 + 0.50\ X^T_{1t} + 0.302\ X^T_{2t} \\ & - 5.997\ D^T_{1t} + 6.868\ D^T_{2t} \\ & - 3.696\ D^T_{3t} + 0.51\ Y^T_{t-1} \\ & - 10{,}364\ X^T_{3t} + 0.2\ Y_{t-1} \end{aligned} \tag{7}$$

where the superscript T beside the variable represents the transformation of the original variable, i.e., $X^{T}_{lt} = X_{lt} - 0.2\, X_{lt-1}$ and $D^{T}_{lt} = D_{lt} - 0.2\, D_{lt-1}$ and so forth.

The validity of these forecasts rests on the assumption that the estimated relationship is likely to continue in the next two years. The future values of GNP are obtained from quarterly forecasts of GNP in 1958 dollars from DRI, Inc. The bituminous coal production index is assumed to increase 3 percent quarterly.

Finally, Figure 3-5 displays the performance of the quarterly model of rail freight and behavior of eight quarterly forecasts generated from this model.

Parametric Time Series Models

We fitted ARIMA models for quarterly rail freight movement along the lines of the Box-Jenkin approach. The main iterative modeling stages are as follows:

1. *Model Identification:* Examine the data to see whether it is a stationary or nonstationary time series and to see which model in the class of the ARIMA process appears to be the most appropriate. The major identification tools are autocorrelation and partial autocorrelation functions.
2. *Estimation:* Estimate the parameters of the appropriate models by nonlinear least squares.
3. *Diagnostic Checking:* The estimated model is considered adequate if the residuals from the estimated model can be considered as white noise. Otherwise, alternative models will be considered and step (1) to step (3) will be repeated again.
4. *Forecasting:* The l-step-ahead forecasts can be calculated recursively from the final satisfactory model.

Based on the sample autocorrelation functions of the original series and three differenced series, two appropriate models were specified. Nonlinear least squares were used to estimate the parameters of these models. The resulting models are presented in Table 3-4.

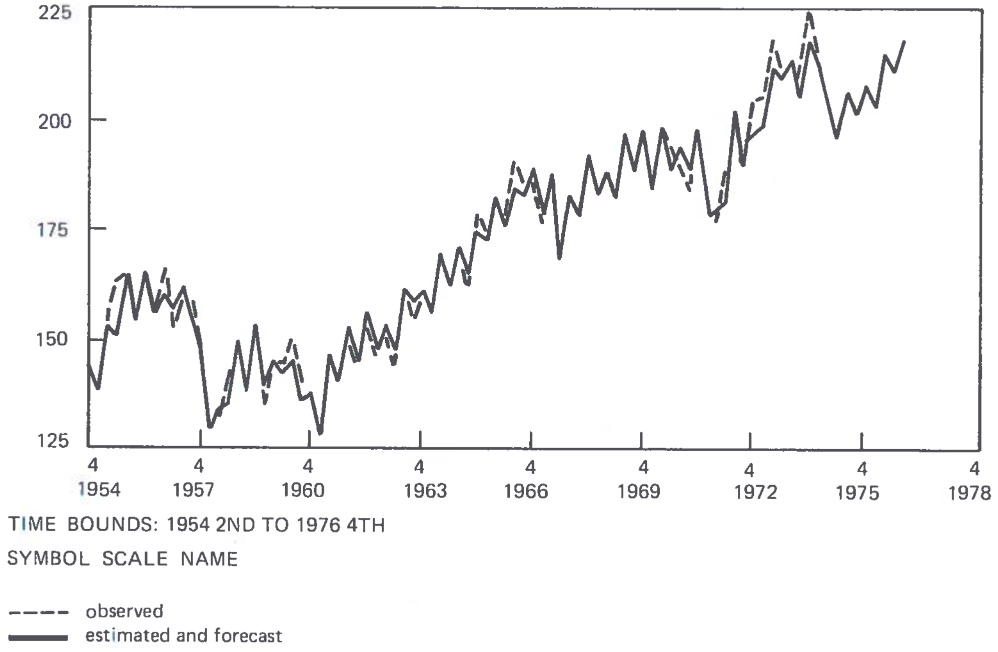


Figure 3-5. Quarterly regression model for rail freight demand (in billions of revenue ton-miles) 1954:4-1976:4.

Table 3-4. Fitted Time Series Models

ARIMA Models	Test of Residuals Q	DOF	Estimated Standard Errors
$(1-0.899B)(1-B^4)Y_t = (1-0.69B^4)e_t$ (0.056) (0.09)	20.18	24	6.673
$(1-0.847B)(1-0.95B^4)(Y_t-248.7)$ (0.056) (0.036) (79.18)			6.549
$= (1-0.703B^4)e_t$ (0.092)	18.90	22	

B denotes lag operator (i.e., $BX_t = X_{t-1}$).
Y_t denotes quarterly data of rail freight and e_t represents white noise.
The number in parentheses under each estimated parameter is the associated estimated standard error.

Two tests were performed on the autocorrelation of the estimated residuals from each model. First, individual autocorrelations were compared to their respective standard errors, based on the Box-Jenkins and Fuller approaches; second, the test statistics

$$Q = \frac{1}{N}\sum_{K=1}^{J} \hat{\gamma}^2 (K)$$

were calculated. $\hat{\gamma}(K)$ is the Kth order autocorrelation of the residuals from the fitted model; J the number of autocorrelations computed; and N the sample size of residuals. Then a joint overall test was performed and the residuals were compared to the λ^2 statistics at a 5 percent level of significance, with J-P degree of freedom (DOF), P is the number of para-

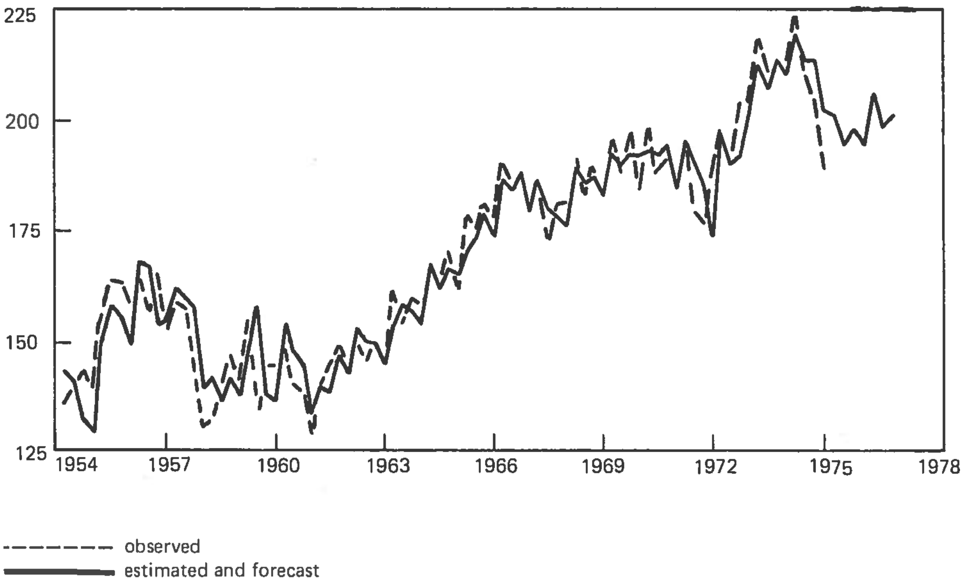


Figure 3-6. Parametric time series model for rail freight demand 1954:3-1976:4.

meters estimated in the model (Box-Pierce). Examination of the test results suggests that both models are adequate. This serves to illustrate that there is no unique time series model representative of any given time series.

Equation (9) was used to generate forecasts and the eight quarter-ahead forecasts are shown by the solid lines in Figure 3-6.

The univariate time series model can not serve as a tool for policy analysis because the model does not take account of the effects of related variables. However, it is useful for short-term forecasting purposes. In our case, the univariate time series model is employed as a norm of forecasts which can be compared with the forecasts generated from econometric models.

SUMMARY AND CONCLUSIONS

The empirical results presented in previous sections support the popular belief that the level of aggregate freight demand depends on the general economic activity and the economic situations of specific industries being considered as major shippers on a given mode. For example, the demand for rail freight service will increase as the national production and consumption of coal increases. The change in future demand for freight service will depend on the change in future economic structures.

The annual models are used for long-run forecasting and quarterly models are employed for short-term forecasting. These models are generally satisfactory in at least the following three aspects:

1. The estimated parameters of the models are in accordance with prior expectations.
2. These equations ably explain the variations of the endogenous variables during the period of observation.
3. They provide reasonable forecasts after the period of the observation.

The annual models will be updated when the new data become available and the tests of structural change of the models with new data will be performed.

As to quarterly models, we are currently working on multivariate time series models of demand for rail freight services by major commodities and a quarterly model of air freight demand.

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BIOGRAPHY

George H. K. Wang received his Doctorate in Statistics and Economics from Iowa State University, Ames, Iowa. Since 1974 he has been staff member of the Research Division, Transportation Systems Center. Currently, he is working on quarterly forecasting models of transportation aggregates and monthly demand models of rail freight services by major commodities.

RECENT ADVANCES IN TRANSPORTATION NETWORK MODELING

by

LOUIS FUERTES, DAVID M. NIENHAUS AND DR. EDWIN J. ROBERTS

INTRODUCTION

This paper describes research conducted on four large scale network optimization models under the Transportation Network Analysis Project at the Transportation Systems Center. The project is a sub-program of the Transportation Advanced Research Program (TARP), sponsored by the Office of the Assistant Secretary for Systems Development and Technology. From its inception the goal of this project has been to develop vastly improved computational methods for network models, in order to overcome problems which traditionally have limited their use in transportation planning.*

The kind of models that have been feasible for extremely large networks, such as highway and transit networks for large cities (over 10,000 arcs), or the national rail network (over 15,000 arcs), have typically been overly simplistic and of limited utility. Moreover, even these limited models have been very expensive to run.

Some success has been obtained in making network models more realistic by the introduction of "capacity restraint" features, which model congestion effects. Early heuristic methods for capacity restraint were exhorbitantly expensive and little is known about the quality of solutions they produce. More recently, several authors have formulated capacitated traffic assignment models as mathematical programs. Versions of these models have been implemented for the computer by the Urban Mass Transportation Administration (UMTA) in its "UMTA Transportation Planning System", and by the University of Montreal. These models have been run successfully on medium-sized networks (3000 to 5000 links).

Exact solutions for normative models (models which solve for optimal policies) such as network improvement or design models, have been virtually impossible for all but very small networks. The four models reported in this paper are of this type and represent some important advances to extend the range of normative models to large scale network problems. These models were selected because of our belief that they have great potential applicability to freight system planning problems.

Two of the models described in this paper, the network improvement model and the optimal staged network investment model were developed by Control Analysis Corporation of Palo Alto, California, under the direction of Dr. George B. Dantzig. Both models are based on well-known formulations gathered from a fairly extensive literature on network design and investment staging models. The unique feature of this work is the development of new computational techniques based on decomposition. *Decomposition* refers to methods that partition a problem into subproblems which are solved separately, and then pieced together, sometimes by means of a master problem which is much smaller than the original problem. The process may be an iterative one, with successive solutions of master and sub-problems until convergence, or a satisfactory approximation to the exact answer, is obtained. Problems with special structure, e.g., decomposability into sub-problems such as single commodity flow problems or minimum path problems, having particularly simple computational requirements, are sometimes susceptible to dramatic improvements in computational efficiency via decomposition.

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*The authors would like to acknowledge their gratitude to a succession of enlightened program managers, John J. Fearnsides, Robert J. Ravera and Robert W. Crosby of the Office of the Secretary of Transportation (TST-45). Their keen technical insights, managerial support, and constant encouragement has made possible the research described herein.

The other two models described below, the fixed-charge network design model and the vehicle routing model, are being developed by the Massachusetts Institute of Technology, under the co-direction of Professors Robert W. Simpson and Thomas L. Magnanti. The unique aspect of this work is the attempt to extend very difficult and potentially useful integer-programming models to realistically sized problems. Decomposition methods are being employed on the network design model, and results to date are very preliminary. Dramatic success has been achieved in improving heuristic methods for the solution of the vehicle routing problem and in the development of statistical methods for estimating the quality of the heuristic solutions.

NETWORK IMPROVEMENT AND INVESTMENT STAGING

The first project to be reported concerns *network improvements* and the *staging of network investments*. The network improvement problem can be stated in general terms as follows: Given a network and a set of links that could be improved plus the costs of each potential improvement, decide which links to actually improve. The investment staging problem is the further refinement of this; given budgets for several time periods, decide the order in which improvement projects should be undertaken.

The network improvement problem is a type of automatic cost-benefit model. The benefit measurement is the result of two things, the choice of criteria and the method of stimulating the use of the network which sets the values for the criteria. There is a wide latitude of choices for the modeler in both of these things. Even the costs of network improvement, which are relatively straightforward, present modeling choices, chiefly between continuous and discrete variables.

The current research has concentrated on continuous formulations, leaving discrete variables for the more difficult network configuration problems to be introduced later. Continuous formulations lead to faster solution techniques so that bigger networks can be solved. Continuous formulations rule out zero-one investments, fixed charges, and any network use simulation involving discrete variables. This is a simplification for any potential application. It is nonetheless desirable for situations in which the need to maintain network detail (number of links and nodes) outweighs the need for the lumpiness being assumed away.

The kinds of investment that might be treated this way include highway re-surfacing or lane additions, and railroad line and yard rehabilitation or capacity expansion. These could have freight applications for the truck and rail modes. Using rail as an example, it seems that rail line-haul rehabilitation problems are good candidate applications when the decisions to be made involve choosing between alternative routes, since copious network detail is helpful for such decisions.

The staging-of-investment problem is a multi-period generalization of the network improvement problem. Here these are separate budgets for each of the several periods; the static improvement problem may or may not use a budget constraint. The main formulation question is how to weight the various end-of-period states of the network. The choice of formulation made can affect both the range of application and the success of particular solution techniques. For multi-period problems like this both heuristic techniques and dynamic programming are common solution techniques.

A recent legislative trend is the requirement that multi-period programs include specific year-by-year budget allocations. Thus, investment staging models should find ready application.

Control Analysis Corporation (CAC), as reported in [3], has devised specific continuous formulations for both the network improvement and investment staging problems. CAC has also produced solution algorithms for both problems. In the network improvement problem, link improvements are subject to increasing costs; i.e., $I_j = h^j(Z_j)$, where h^j is a convex function, I_j is investment expenditure on link j, and Z_j is the amount of improvement on link j. The network use simulation is based on 1) a given trip table that represents the fixed origin-to-destination demands for the use of the network, 2) representing freight moving on the network by a one-dimensional continuous flow (e.g., tons), and 3) routing the flow through the network to satisfy the trip table and minimize total impedance. (Impedance measures the "cost" of using the network, although in applications it could be transit time or energy use or whatever, instead of total money cost.) For each link there is a "cost" function that represents a nondecreasing relationship between cost (or time) and level of flow, i.e., $T_j = x_j \cdot f^j (x_j)$, where T_j = total impedance on link j, x_j = flow on link j, and f^j is a convex function.

Link improvement affects the cost-flow relationship on the link. The improvement might affect free-flow speed or cost, e.g., filling in pot-holes, removing slow orders; or might affect capacity, e.g. adding a lane or a track. Thus we have $T_j = x_j \cdot f^j (x_j, z_j)$ with $f^j (\cdot)$ decreasing linearly as z_j increases.

The entire network use simulation problem is then

$$\text{Minimize} \sum_{j=1}^{J} T_j$$

by choosing

$$x_{rj} \quad r=1,2, \ldots, R;\ j=1,2, \ldots, J$$

subject to

$$(1) \quad T_j = x_j \cdot f^j (x_j, Z_j) \quad j=1,2, \ldots, J$$

$$(2) \quad x_j = \sum_{r=1}^{R} x_{rj} \quad j=1,2, \ldots, J$$

$$(3) \quad \sum_{j \epsilon A} x_{rj} - \sum_{k \epsilon B} x_{rk} = \phi_{ri} \quad i=1,2, \ldots, I$$

$$(4) \quad x_{rj} \geqslant 0 \quad r=1,2, \ldots, R;\ j=1,2, \ldots, J$$

Here

x_{rj} is the flow on like *j* coming from origin *r*.
ϕ_{ri} is the demand flow from node *r* to node *i*.
A is the set of links entering node *i*.
B is the set of links leaving node *i*.
I is the number of nodes.
J is the number of links.
R is the number of origin.

This is usually called a system-optimized traffic assignment problem. CAC solves it by means of the Frank-Wolfe algorithm [1].

There are two ways of setting up the network improvement problem. One way is to use an objective function that includes both the "costs" from the network simulation and the investment costs; i.e., $\sum_j T_j + \lambda \sum_j I_j$.

Here λ is a weighting factor that is needed if the T_j are not money costs or if the two kinds of costs are paid by different groups that are weighted differently by the decision maker. The other approach is to minimize transit costs only, subject to a budget constraint. CAC used a Lagrangean multiplier technique for the budget constraint approach. Thus the only difference between the two formulations is that in one the budgeting factor is given at the outset, while in the other it must be deduced iteratively, as a multiplier, by comparing expenditures with the budget constraint.

The method of solution is called *link decomposition.* First the value of the weighting factor is fixed. Then a function $Z_j = g^j (x_j)$ is found for each link that is a candidate for improvement. This function gives the optimal amount of link investment as a function of link flow. It can be shown that this function is convex. It is found by solving a problem.

Minimize

$$x_j \cdot f^j (x_j, Z_j) + \lambda h^j (Z_j) = g^j(x_j; \lambda)$$

by choosing

$$Z_j$$

subject to

$$L_j \leqslant Z_j \leqslant U_j$$

L_j and U_j are lower and upper bounds.

Note in passing that if a more general form of the h (·) function were used, the $g^j(\cdot)$ function could not be found explicitly. The pleasant fact, is however, that we can obtain an explicit $g^j (\cdot)$ from any convex $h^j(\cdot)$ we would be likely to want.

Perhaps the most useful case is that in which $f^j(\cdot)$ is a step function. Since $f^j(\cdot)$ is convex and this is a minimization problem, it is well known that we can write the problem as

Minimize

$$\sum_{m=1}^{M_j} C_j^m x_j^m + \lambda h^j (Z_j) = g^j (x_j; \lambda)$$

by choosing

$$x_j^m, Z_j$$

subject to

$$(1) \sum_{i}^{M_j} x_j^m = x_j$$

$$(2)\ L_j \leqslant Z_j \leqslant U_j$$

$$(3)\ x_j^m \leqslant K_j^m + b_j^m Z_j$$

$$(4)\ x_j^m \geqslant 0$$

Here:

k_j^m is the "capacity" of the mth piece of the $f^j(\cdot)$ function.

C_j^m is the value of $f^j(\cdot)$ on that piece.

x_j^m is the flow allotted to that piece.

$b_j^m Z_j$ is the addition to capacity from the investment.

Notice that an improvement in free-flow speed can be captured by having the "cheapest" step have $K_j^m = 0$.

The next step is to solve the system optimized traffic problem. Now for each link the cost function had the form

$$C^j = x^j \cdot f^j (x_j Z_j).$$

Substituting into this the optimal investment function, it becomes

$$C^j = x^j f^j (x_j, g^j [x_j])$$

$$C^j = x^j f^j (x_j)$$

Because both f^j and g^j are convex, so is f^j. Thus the solutions of this traffic assignment problem will not only route the various flows but will also set the level of investment on each link. This approach was originally used by Steenbrik [2] in a more limited context.

If the budget constraint approach is being used, the proposed expenditures must be compared with the budget and the weighting factor changed if necessary. The entire interaction cycle is then repeated.

This algorithm has been tested on networks of up to 400 nodes. It is expected to be practical on problems of up to 2000 nodes without further development. A 1000-node problem should be solvable in 20-30 minutes of computer time; the exact results, of course, being dependent on the type of machine, and the details of the particular network. Prior to this there were no comparable network improvement methods capable of working problems of over 100 nodes. Therefore, this research has made possible a new kind of transportation network analysis.

The existing formulation is already useful for some freight problems. One clear direction for further research is the following: What kinds of network-use simulations could be put inside this network improvement framework, and still have the algorithm work? Even with more complicated simulations, large problems would still be practical as long as the one-shot link decomposition was still workable.

The investment staging formulation is relatively simple. The final network configuration may be considered given or it may be selected by the model; here it will be selected. There are T periods t = 1,..., T, and these are ordered according to their importance. For example T, 1, 2,..., T-1 is one obvious ordering, but any ordering can be used. Let $B_1, \ldots, B_T$ be the cumulative budgets up to period t. Take the first-ranked period, e.g., T and solve a network improvement problem with a budget constraint of B_T. Take the second ranked period, e.g., 1, and solve a network improvement problem with budget B_1, with only links improved by period T as candidates for improvement. Continue with the periods in order.

In general, suppose the periods are ordered as $\alpha_1, \ldots, \alpha_T$ and that period *t* is now being treated. Let *s* be the latest period before *t* already treated and *u* the first period after *t* already treated. The network design problem to be solved uses $B_t - B_s$ as a budget, the network completed by period s as the original network, and the links improved by period w as the candidates for improvement.

Intertemporal decision-making is difficult to model from either the descriptive or normative point of view. Nonetheless, there is broad agreement that weighting of future periods by exponentially declining weights, "time discounting", is the best approach. The lexicographic approach used by CAC, which was just described, is a simplification beyond this, and is thus not completely correct. It does permit the analyst to treat each period only once. Once again the desirability of network detail can be traded off against a simplifying assumption.

Implicitly we have assumed that the investment staging problem would be wrapped around the same network improvement problem that was discussed earlier. It could just as well, however, be attached to any other network improvement model, even a model using discrete variables. Of course it is true that the slower the improvement model, the smaller the investment staging model that can be considered, both in the number of stages and in the network detail.

The solution technique used in the investment staging problem was adequately defined by the problem formulation itself. It can be viewed as a decomposition of the problem into single-period, network-improvement problems, solved in sequence by dynamic programming. No period needs to be solved more than once.

This technique has been tested on a 400-node, 4-stage problem. When used with the previous network improvement problem, computing time is roughly equal to the number of stages times the computing time for the network improvement problem. The technique also was tested against a heuristic technique developed for UMTA and FHWA by a private contractor. In this test the CAC approach produced lower costs at intermediate stages, but was more expensive to use.

In this section research on network improvement and investment staging models has been reported. The emphasis was on continuous problems that permit the solution of large networks at the cost of the loss of some realism in the treatment of other things. This work is expected to have application to freight problems concerning infrastructure investments or rehabilitation in rail, highway, or multi-modal contexts. Potentially useful algorithms have already been coded, and further research should stretch the range of useful application.

NETWORK FREIGHT FLOW RESEARCH

Research by the Control Analysis Corporation focused on the use of decomposition techniques to develop optimal network improvements. Research currently being performed by the Massachusetts Institute of Technology under TARP concerns the optimal configuration of a freight network and the flow of freight on the network necessary to meet a specified set of demands.* The network configuration decisions include the construction of links and transfer nodes on the network. Unlike other research currently underway, these network configuration decisions are conceptualized in this research as a set of discrete choices.

The facility establishment decision is whether or not to build the link of transfer facility and (0, 1) integer variables represent these decisions within the mathematical model that addresses this problem (capacity considerations are not present in the current model framework). Movement of freight on the links and through the transfer facilities at the modes incurs costs, which increases with increasing levels of flow. The goal of the current research is the development of an algorithm for arriving at the network structure and freight flow pattern that minimizes total system-wide costs for facility construction and freight movement.

This type of problem has several important applications to current freight movement problems . The optimal location of transfer facilities is a question that confronts

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*Full documentation of the findings of this research will be presented in the final report of contract DOT-TSC-1058, forthcoming.

many operators of freight systems. In addition, the costs of constructing and maintaining transportation links are considerable for railroads. Whenever strategic planning must be performed to evaluate possible reconfiguration of a rail network, the fixed costs associated with maintaining a section of track within the network must be considered. Other modes of freight transportation, such as truck and air freight systems, incur significant route-operation costs that are independent of the level of freight traffic on the route. These fixed "route-operation" costs are analogous to the "link construction" costs which are present in the freight-flow models presently being analyzed. Thus, there are numerous potential applications for this research.

The research treats a series of issues that have been explained by previous research in slightly different formulations. The major technical difficulties present in the current research result from the nature of the cost functions for the network arcs and nodes. The fixed cost elements necessitate the use of integer variables for both link and node establishment. Present research focuses on techniques for decomposing the overall problem into two sub-problems. The first sub-problem deals solely with link and node construction, and the second sub-problem deals with the flow of freight on the network developed in the initial sub-problem. Freight flow solutions to the second problem must be non-negative, but link and node flows are not restricted to integer values once the corresponding facility has been constructed. The logic of the problem is captured by the mathematical formulation below:

Minimize

$$Z = \sum_{(i,j)\,\epsilon\,A} \sum_{k} \sum_{l} C_{ij} X_{ij}^{kl} + \sum_{(i,j)\,\epsilon\,A} b_{ij} Y_{ij}$$

Subject to

$$(1) \quad \sum_{j} X_{ij}^{kl} - \sum_{j} X_{ji}^{kl} = \begin{cases} 0 & i \neq K,\ i \neq l \\ R_{kl} & i = K \\ -R_{kl} & i = l \quad \text{for all } k,l \end{cases}$$

$$(2) \quad X_{ij}^{kl} \leqslant R_{kl} Y_{ij} \quad \text{for } (i,j)\ \epsilon\ A, \text{ for all } k,l$$

$$(3) \quad X_{ij}^{kl} \geqslant 0 \quad \text{for } (i,j)\ \epsilon\ A, \text{ for all } k,l$$

$$(4) \quad Y_{ij} = 0,1 \quad \text{for } (i,j)\ \epsilon\ A$$

where

i,j,k,l	are node indices.
X_{ij}^{kl}	is a variable denoting the amount of flow routed over the link (i,j) whose origin is k and destination is l.
Y_{ij}	is a 0-1 variable that will be 1 if the link between i and j is added to the network and 0 otherwise.
A	is the set of candidate links for the network.
R_{ij}	is the amount of flow that must be routed between nodes i and j.
C_{ij}	is the cost per unit of flow that is routed over the link (i,j).
b_{ij}	is the fixed cost of constructing the link (i,j).

In this formulation transfer nodes are represented as special links with cost characteristics appropriate for transfer facilities. Flow costs for both arcs and nodes are assumed to be directly proportional to levels of freight flow. Constraint (1) establishes flow requirements to the nodes of the network and constraint (2) requires that link flows are consistent with link construction decisions. Constraints (3) and (4) specify the nature of the decision variable for freight flow and link construction.

The solution approach currently being investigated is a variation of the decomposition approach developed by Benders [4]. The algorithm first gives non-zero values to selected link construction integer variables and then solves for optimal freight flow on the resulting network given flow requirements in and out of nodes. Subsequently, improvements are made on the initial link construction decisions based on analysis of cost improvements possible if specific links are added, and link flows are re-calculated for the new network. The algorithm continues until no further improvments can be made in total system costs.

A major objective of the current research is the development of techniques for improving the efficiency of current decomposition algorithms for these problems. The number of cycles for which the two subproblems must be solved can be prohibitively large for moderately sized problems. Methods of making improved decisions in the link construction sub-problem are presently being evaluated. Advances in this area will reduce the number of iterations necessary to reach optimality, and will permit analysis of many freight flow problems which previously could not be solved. Research for this problem is currently focusing on relatively small (10-node, 45-link) problems so that alternative solution algorithms can be compared. Results of initial computational exercises will then be extended to larger problems. Documentation and conclusions for this phase of the research are anticipated before the end of 1976.

VEHICLE ROUTING PROBLEMS

The research discussed in previous sections of this paper concerns the movement of freight on networks. These models of the line haul portion of freight shipment assume that freight is generated and consumed at individual nodes on the network. In practice, goods frequently must be collected from or distributed to a number of points which are collectively idealized as a single node in the transportation network. These collection and distribution activities are frequently the most expensive movements in the freight transportation system on a cost-per-ton-mile basis, but they are ignored by many freight analysis models. Recently completed research sponsored by TARP has developed procedures for attaining efficient vehicle routing patterns during the collection and distribution phases of freight movement.

The vehicle routing problem can be stated simply as the problem of making a given set of transportation services (pick-ups's or deliveries of goods, for example) at a given set of geographically distributed points in the most efficient way possible. In the general statement of the problem, a set of vehicles operate out of a number of depots. The solution to the problem is the set of routing sequences that provide the required services in the least cost or least distance manner. Additional constraints (dealing with vehicle capacity and sequence of stops) can be added to the basic structure depending on the particular application of interest. A special case of this family of vehicle routing problems is the traveling salesman problem, which considers a single vehicle operating out of a single depot, with a set of transportation service requirements which all must be honored in the least-cost fashion before the vehicle can return to the depot.

The traveling salesman problem, despite the simplicity of its statement, is an exceedingly difficult problem to solve. The number of possible routing combinations increases factorially as the number of nodes increases, and the development of optimal "tours" is very expensive or unfeasible for large networks. Past research in this area has focused on techniques for developing good solutions which, although not optimal, come close to the least cost solution of the problem. TARP sponsored research during the past year at MIT has developed advanced heuristics which provide the analyst with very good solutions to the vehicle routing problem for large networks.* Special techniques have been used to develop solutions at greatly reduced computation times.

The research-developed requirements in the heuristic vehicle routing algorithms developed by Clarke and Wright [6]. The Clarke-Wright algorithm for a single vehicle, single depot problem starts with a very simple vehicle routing pattern. The service vehicle moves from the depot to each individual service point and returns directly to the depot, whence it travels to the next service point until all service points are individually served via a

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* The results of this research are documented in detail in Golden [5].

direct trip from the depot by the service vehicle. The resulting tour meets the requirements of the problem, but is quite expensive in terms of transportation costs. The costs of this initital solution are reduced by routing the vehicle to two service points prior to returning to the depot. The two service points which produce the greatest distance or cost reductions when joined are the first to be linked. Additional service points are added to the first two until a tour is generated. The methodology does not produce an optimal tour, but it produces reasonably accurate solutions for small problems. The accuracy of the solution declines with increasing service nodes in the network, however, and the data storage requirements limit the number of nodes which can be analyzed using the algorithm and current computers.

The major modification made by MIT to the Clarke-Wright approach involves the storage of node-proximity data within the programs. The closest nodes to a particular node are listed rather than stored in a matrix in the traditional fashion. This greatly reduces the amount of storage space required and results in very fast tour generation. In addition a grid structure is super-imposed upon the service node network, and only those nodes within neighboring rectangles are confidered for subsequent routing decisions. The computer coding of the Clarke-Wright algorithm was altered to exploit the data storage techniques used, and very rapid computation times were experienced.

By means of comparison, a heuristic algorithm developed by Lin and Kernighan [7] has been used to produce exact solutions to a 100-node problem with 99 per cent confidence in three to four minutes running time on a GE 635. The heuristic developed at MIT produces solutions to 130 node problems with 7 percent of optimality in under 40 seconds. This is noteworthy because the storage requirements of the Lin-Kernighan procedure preclude the analysis of problems larger than 110 nodes.

Detailed statistical analysis of results developed with the MIT heuristic indicates that the solution lies within 10 percent of the optimum routing cost, and frequently within 5 percent. The grid structure used to develop node-proximity lists for each service point can be altered to yield different routing patterns. A series of grid orientations and resulting routing patterns can be economically generated, and the minimum tour distance of the different vehicle routing patterns can be taken to produce improved solutions. The Lin-Kernighan approach appears to produce more accurate traveling salesman tours than does the new MIT heuristic for comparable problems but the new heuristic is much faster and can treat much larger problems.

The heuristic has been extended to treat more general vehicle routing problems. A 100-node, 2-depot problem (which was solved in 227 seconds by Gillett and Miller [8]) was solved using the new heuristic in 6 seconds on the same model computer as was used in the earlier study. Further extension to multi-vehicle and capacitated vehicle problems also appears to hold potential computational savings as well. The speed of the algorithms, the size of problems which can be addressed, and the reasonable accuracy of the resulting solutions suggest that the TARP vehicle routing research will contribute to the analysis of freight collection and distribution activities.

CONCLUSION

The four areas of research described above indicate the types of freight transportation problems currently being studied under TARP sponsorship. These initiatives, and parallel research into passenger transportation, will be continued in the hope that transportation analysts will soon have the tools necessary to address transportation issues which currently cannot be considered because of problem scale and complexity. Greater efforts will also be made to improve the realism of transportation analysis models so that the gap between the mathematician's capabilities and the transportation planner's needs can be reduced. These efforts together reflect the goals of the Transportation Advanced Research Program to advance the capabilities of the transportation analysis community and to improve the quality of transportation planning decisions.

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BIOGRAPHY

Louis Fuertes was born in Dallas, Texas in 1948. He attended Brown University and received a B.S. in Civil Engineering in 1971. He attended the Massachusetts Institute of Technology and received an M.S. in Civil Engineering in 1973. His education focused on optimization techniques and analysis of transportation systems. Major areas of academic research included network analysis of link additions to urban freeway systems, optimal facility location and service patterns for public systems in metropolitan areas, and analyses of alternative urban goods pick-up and delivery systems. He is currently an Operations Research Analyst at the Transportation Systems Center where he has worked since January of 1976. His research at TSC concerns the analysis of transportation networks.

BIOGRAPHY

Michael Nienhaus received a B.A. in Mathematics from Washington University in St. Louis in 1966. He has a Ph.D. in Economics from Northwestern University (1973). His dissertation concerned the economies of production-to-order firms. He taught economics at the State University of New York at Stony Brook from 1970 to 1974. Since 1974 he has been an economist for the U.S. Department of Transportation in Cambridge, MA. His main research interests there have been railroad problems and transportation network analysis.

BIOGRAPHY

E.J. Roberts was born in New Rochelle, N.Y. in 1931. He attended the University of Notre Dame, receiving a B.S. in Civil Engineering in 1953. He also holds an M.A. in Mathematics from Columbia University (1963), and a Ph.D. in Mathematics from the University of Houston (1970). Dr. Roberts was a mathematician with the National Aeronautics and Space Administration in Houston, Texas prior to joining TSC.

He is currently Chief of the Special Studies Branch in the Office of Systems Research and Analysis. His current personal research interest is the application of network analysis techniques to planning problems in intercity transportation.

TARIFF COMPUTERIZATION IN FUTURE FREIGHT SYSTEMS

by

ROBERT E. THIBODEAU

INTRODUCTION

Possibly the most unproductive area in freight systems has been the paperwork which is required for freight shipments. The processing of the paperwork for both domestic and international shipments is inefficient and costly, as this paper will show. In addition to its own high cost, the paperwork problem creates further costs by impeding progress in other aspects of transportation information processing, such as, real time shipment tracing or sophisticated distribution analysis. Since this paperwork function is already a burden in the existing freight systems, it can only become worse as these systems increase in speed and complexity. Unless improvements are made, the gains accruing from technological advances in future freight systems will be offset by the delays, errors, and overall costs of the paperwork function.

One aspect of shipment documentation which is particularly criticized is the rating function; the retreival of the correct rate and the construction of the freight charge on a freight bill (F/B). Because this step occupies such a central importance in the flow of freight data, we have focused this paper on the rating problem as it applies to domestic shipments by rail and motor carrier.

Two aspects of the paper should be stated clearly at the outset. First, the primary target of this work is not the current rate level or rate structure. It is, instead, the use of rates in freight shipments - rate processing.[1] Second, it has been assumed that the profit incentive is the best guide to each firm's decisions within the guidelines of national transportation policy. Therefore, solutions have been preferred which would build from the bottom up, allowing individual firms to solve their own internal problems.

CURRENT PROBLEMS IN RATING

A layman reading the conference proceedings and articles on computerization in transportation which appeared during the 1960's would get the impression that great strides in automated rating, billing, and payment systems were around the corner. While it was recognized that the publication, storage, and retrieval of rates entailed certain technical difficulties, overall confidence was high that solutions were imminent. Computer firms were eager to investigate the problem, carriers and private shippers were funding exploratory efforts, and federal government shippers were negotiating for simpler rate structures to alleviate their payment and audit problems.[2]

The actual progress has been modest. There are existing Computerized Rating (CR) systems which handle all or some of the rating of shipments for shippers and carriers. Most firms, though, use essentially the same rating methods that they have used for many years. This suggests that the costs and benefits of converting from manual to CR systems may have been misunderstood by the early enthusiasts, since the majority of the firms have not found it profitable to make this conversion.

In an attempt to get at these true costs, we interviewed shippers, carriers, and others concerned with rates. The key piece of information would have been the *transaction cost,* i.e., the monetary cost of rating a freight bill or quoting a rate. Very few references to this specific cost have been published.[3] Even if estimates of these costs were available, they would have to be judged within the context of the particular firm's operations, since rating is never performed as an end in itself but rather as a part of a broader operation. The particular steps in the rating-billing-auditing sequence will vary from firm to firm. Since no estimates were forthcoming on the costs of the transactions to the firms, the interviewees were asked about two items which seemed to be good proxies of the seriousness of the rating problem:[4] the percentage of freight bills in error and the amount of overage/underage claims. Surprisingly, there were few specific answers to even these questions. Either the firms had not developed such primary figures or they were unwilling to reveal them. The responses are summarized in Table 5-1.

Table 5-1. Estimates of the Percentage of F/B's in Error

Source	Estimate
1. Large shipper	30 percent of a large sample had an incorrect freight charge. Overcharges and undercharges were evenly distributed.
2. Large shipper	30 percent of sample of 3,000 were incorrect in freight charge, counting both overs and unders.
3. Large shipper	Using a $10 minimum rule, a 1-month sample showed issuance of overcharge claims on 20 percent of F/B's. This was felt to be usual; 10 percent more 'average'. A 9-month sample showed overage claims on 12 percent of F/B's.
4. Service agency	Average of 15 percent with wide variation among carriers.
5. Service agency	14 percent errors among rated F/B's 70 percent of these are overcharges.
6. Large carrier	27 percent F/B's wrong in sample of 200.

Even though the responses were not obtained by direct measurement in a controlled environment, they still offer evidence that many firms in the transportation industry operate at an error rate of 20 percent or more on their freight bills. "Error rate" refers to the percentage of freight bills having an incorrect freight charge. Four main causes were suggested by the interviewee; 1) the filling out of the original bill of lading, 2) the act of rating the freight bill by the carrier, 3) the structure of the tariffs, and 4) the method of making changes in tariffs. Each of these causes is elaborated in the following paragraphs.

1) The filling out of the bill of lading was identified as a prime source of error in the recording of the commodity description, in the weight, and in the notes and special conditions. The commodity description itself is often written improperly and even when it is correct, "Commodity descriptions in freight classifications and other tariffs are known for their inconclusiveness and ambiguity."[5] It was reported that an early attempt at computerizing all motor freight tariffs was able to match only 35 percent of the commodity descriptions on a large sample of bills of lading with the descriptions stored in a computer. Since the bill of lading (B/L) is the initial source of shipment information, many developers of CR sysems have stated that the quality of the bills of lading would have to be first improved to permit efficient processing.

2) The act of rating a freight bill often occurs under circumstances which produce further errors. Rating is still done by most carriers in a decentralized manner using semiskilled clerks. A large number of freight bills may have to be rated in the course of several hours, giving little incentive to spend time on the occasional difficult item.

Lack of central control and of experienced ratemen contribute to a high error rate. The problem of training and keeping skilled ratemen has been described as serious by private shippers, government shippers, rail carriers, and motor carriers. Bright young people have little interest in working in the rate room due to the cumbersome nature of the tariffs and the perceived low status of the traffic department in corporations. If it is difficult to cope with the rating process now and if the quality of ratemen declines while the volume of traffic and of tariff changes increases, the problem will only get worse.

3) The application of tariffs to rating freight bills can be difficult because of the way that the information is structured in the tariffs. There is no guarantee that a search of class and commodity rates by mode, territory, commodity, origin, destination, and rate will produce the final correct rate. One report on tariff computerization stated that:

> Part of the problem . . . was determined to be caused by the unwieldly structure of the tariff library. In any rate search there is a fixed number of basic variables that normally come into play, i.e., origins, destinations, and commodities. However, the search criteria, whether manual or by computer, involves many different tariffs that contain items that fit the variables in question. A graphic example of this problem was developed by research performed in conjunction with FMC Corporation and the Manufacturing Chemists Association. This research indicated that the necessary rate information maintained by a company on six commodities being shipped from 39 different origins requires a rail tariff library of 91 different tariffs . . . .[6]

This complexity and ambiguity make the determination of a unique rate very difficult in some cases. Indeed, there are rate specialists who audit freight bills (F/B) looking for high or low charges in return for a percentage of the refund claimed. These auditors, sometimes referred to as rate "sharks", can often find a new interpretation or combination of the waybill information which will result in a different legal rate than that on the F/B.

Some of the people interviewed cynically referred to the 'correct' rate as the lowest one accepted to date. Examples of difficult tariff applications include multi-line movements, 'transit' movements, mixed shipment deficit weight rules, and special carrier agreements or exceptions. Other classic rate problems are the aggregation of intermediates and the long and short haul rules.[7] Even so, ratemen may deny that the existing tariffs are difficult to apply. Since most traffic is repetitive, even difficult rates can be calculated once and stored for future use. However, this rate "guide" or rate "pony" must still be updated during the frequent rate changes, which requires a significant effort. Furthermore, the rise of such practical devices has not solved the rating and auditing problem for many shippers and carriers, as Table 5-1 indicates.

Another indirect proof of the problematic nature of tariffs is the difficulty with which they are computerized. Putting such a massive data problem on the computer requires formalization of the data formats and of the rules by which the user operates. Early efforts at actually reproducing a ratemen's search were unsuccessful, due not to technical limitations in the computers but to the inability to logically index the various items in the tariffs. As many CR managers have expressed it, the major difficulty in storing, retrieving, and updating is the lack of a consistent 'hook' (index to the rate information).

Such an index has been attempted in the new Canadian Freight Association Tariff 600.

ITEM 18550C(S9) **STCC 3241115** **ITEM 18550C(S9)**

CEMENT, AS DESCRIBED IN ITEM 18540.

FROM STATION	FROM SPLC	TO STATION	TO SPLC	RATES COL. A	RATES COL. B	ROUTE	CODING FOR SIN
NB Havelock	015588	ME Madawaska	111003	64	64	766	18550 GC
ON Clarkson	044742	MI Detroit	318100	63	63	6	18550 GF
ON Clarkson	044742	NY Massena	170511	(2) 67	(2) 67	4	18550 GJ
ON Picton	042036	NY Buffalo-Black Rock	185405	46	46	10	18550 GK
ON Picton	042036	NY Cheektowaga	185371	46	46	10	18550 GL
ON Picton	042036	NY Depew	185375	46	46	10	18550 GM
PQ Montreal	030000	CT Eagleville	162168	59	59	724	18550 GN
PQ Montreal	030000	CT Farmington	163433	67	64	(H4)	18550 GP
PQ Montreal	030000	CT Hartford	163240	61	60	(H4)	18550 GS
PQ Montreal	030000	CT Montville	165254	60	60	724	18550 GW
PQ Montreal	030000	CT New Haven	167530	67	64	(H4)	18550 GX
PQ Montreal	030000	CT Norwich	165220	60	60	724	18550 GZ

(2) INCLUDES MASSENA TERMINAL RY. SWITCHING.
(H4) VIA ROUTES 10, 20. (P) 66.
(EC.31743).

Figure 5-1. "Coding for SIN." Each of these shipments is uniquely identified for rating or updating purposes.

This index is called SIN (Single Item Number) and offers a unique indentifier for each shipment by commodity, origin, destination, and weight. (See Figure 5-1.) Each user of SIN notifies the Association as to the SIN numbers they are using. Following that, any tariff changes affecting these particular shipments are sent to the user but other changes are not. Therefore, SIN is helpful in tariff updating and in rate retrieval. It must be noted that SIN does not improve the actual computation of a freight charge nor does it do away with notes, exceptions, and other items which affect the rate search.

4) There are also problems arising from the tariff publication format and procedure. Since tariffs serve a legal function as well as a pricing one, the specific numbers printed in the pages are the correct ones. This means that rate pages which began as scales (a relationship in price and distance) have often become distorted during general increases because of rounding effects or clerical error.[8] The new tables do not reflect the original numerical relationship but have become large sets of unrelated numbers.

Another hurdle to easy access to the correct rate is the tendency to publish tariff supplements rather than reprinting the tariff. This engenders a rate search wherein three, four, or more pages must be referenced after the original rate is found. Also there are usually *ex parte* increases already in effect by the time that a tariff is re-published, meaning that the rate must be checked against each set of notes for possible further computation. The rate on a rate page is often an *index* to the real price, not the price itself.

The tariff publication cycle that rail and motor rates require adds uncertainty to the quotation of the proper rate. Filing an *ex parte* increase often creates just an interim rate, pending final ruling by the I.C.C. In the meantime, the rate room must maintain several sets of rates to keep their sales people informed.

The ICC has been working on these problems with good results. Several ratemen commented that scales are maintained more accurately in recent general increases. Also, carriers have been encouraged to republish older tariffs rather than to extend a large number of supplements. A recent problem beyond the powers of the Commission has been the frequency of rate increases.

In summary, the discrepancy between the hopes of the 1960's and the continuing problems of today is difficult to explain. If the present methods are cumbersome and inefficient, why aren't they changed? If the present tariffs are confusing and ambiguous, why aren't they revised and standardized? Some answers have been suggested earlier. One set of answers refers to the high cost of changing elements in the rate and tariff complex. These emphasize the actual costs of resources - staff, hardware, etc. An alternate explanation focuses on the environment within which tariffs are used. Ernest Olson of the ICC has stated this position:

> Without a deep perception of the fundamentals of the rate tariff publication 'system', the rate bargaining procedure and folk customs, the flexibility in

Table 5-2. Indications of the Volume of Tariff Changes

Name	Type of Rates	Number of Changes
GAO	all types	1967 figures showed 200 new tariffs and 36,000 supplements monthly on 50,000 tariffs overall.
Phillips P.	mainly commodity	From Jan. to June 1974 their computer rate file containing 225,000 rates had received changes in 2,500,000 individual rate items.
Prairie Village Commodity Office (Dept. of Agriculture)	mainly commodity	in recent years their 3,200 tariffs have received 300 changes a day

> ratemaking and the economic opportunities and consequences which shippers and carriers measure in negotiating and formulating rates and rate structure in the regulatory framework, the hoped-for objective (tariff computerization) will be virtually impossible to achieve.[9]

The existing tariffs fill certain needs. The problems with commodity classifications, for example, become understandable when it is realized that one method for achieving a preferable rate is by negotiated changes in the classification of an item. Further, proposals for changes in rates or tariffs are bound to affect powerful forces in the transportation industry. Innovations must be politically as well as economically feasible if they are to be widely used in the industry.

Efforts at coping with and improving the current situation are discussed in the next section but they should be seen as operating in a general rate environment which is somewhat resistant to change. Tariff simplification and standardization will generate this type of support only if they are of value to individual firms. Although theoretical arguments about their advantages will not insure their usage, such discussion is helpful in charting the course to follow in the future.

CURRENT SOLUTIONS TO THE RATING PROBLEM

The Systems Aspect of the Problem

Any solution to the rating problem must satisfy two sets of criteria for the firm. First, it must be a valid technical approach ot the rating problem itself, i.e., it must provide the proper legal rate and must be technically and economically feasible. Second,the solution must coordinate with the other internal processes in the firm. There have been computer systems which satisfied the first criterion but not the second, because of data transmission problems or failure to deliver the information to the right place on time. Although computer oriented systems are emphasized in this report (for certain classes of users), it is not suggested that any firm can solve its rating problem by grafting a computerized rating (CR) system onto its current operating system. As an example, a shipper will integrate its rating-payment-audit function with its accounting and physical distribution systems for overall optimal efficiency. This report will often deal with the narrower technical problem (the rating problem) but the reader should keep the overall setting of this one function in proper perspective.

There are two main schools of thought on how the rating problem itself can best be handled. These are exemplified by a conversation between a carrier executive and a computer expert in the transportation industry. The executive stated, "We cannot work with the existing tariffs. Standardization and simplification must come first, then computerization may not even be necessary." The computer expert replied, "I haven't seen any signs of progress in those areas worth mentioning. You'd better computerize soon or you won't be able to handle the mess."

More Elementary Solutions

Before one gets to the level of rate computerization or simplification, there are responses to the rating problem which do not involve hardware changes at all but rather managerial improvements in the processing of shipment information. An example would be the publication of the standard commodity descriptions within a company for items shipped frequently. This publication may be as a listing for shipping clerks or as a series of pre-printed bills of lading (B/L's). Another technique, which is popular among carriers, might be called semi-automated. Here the rating of freight bills is centralized by transmitting the rating information over a CRT network, having an experienced rateman rate the shipment, and transmitting the result back to the loading dock.

At another level there are approaches which use hardware applications. Microfilm applications involve the replication of tariffs, tariff information, or specific rates on sets of microfiches. This technique is used by several hundred companies, although the specific application may vary. The Rocky Mountain

Motor Tariff Bureau has been very aggressive in this application, claiming more than 150 customers. The main advantage seems to be the smaller storage space required for tariffs. However, the information is still carried in its present form and there is no serious improvement in the overall rating methods. Microfilming does not attack the indexing and maintenance problems resulting from the tariff structure which hamper the storage of rates in a computer.

The publication of tariffs by computer does not directly further the rating process, either, although it does offer definite cost advantages over the normal publication methods. The computerization of rail tariffs, in particular, demonstrates the difficulties of adjusting current tariff information to facilitate technological improvements. The Joint Railroad Tariff Computerization Committee (JRTCC) worked on the problem of computerizing the publication of existing rail tariffs from 1966-1971. This work led to the successful filing of a test tariff in 1970 and the subsequent conversion of many rail tariffs to computerized publication. The JRTCC recommended a method of computerized rate retrieval which has become known as Rep-Rate, the most promising advance in rail rate processing to date.

These steps were not achieved without resistance. The computer-printed tariffs were criticized for illegibility and for difficulty in usage by ratemen. The first point was quite valid and was answered by the use of a new typeface. The second point seemed to reflect a reluctance by some ratemen who were used to the existing system and wanted no changes, good or bad. The JRTCC had formatted some of the information in tariffs to ease their revision and to pave the way for the storage of tariffs in computers. Some ratemen felt that this made the tariffs worse. This is still a sore point between different factions in the rate complex.

Both microfilm applications and computerized publication are of modest value in themselves. However, they demonstrate that any requirement for handling tariffs precisely and mechanically reveals the cumbersome nature of the current tariffs and puts pressure on the ratemakers and publishers to improve them.

Computerized Rating (CR) Systems in Domestic Surface Freight

Contacts were made with representatives of many of the existing CR systems in the U.S., as well as defunct ones and those still being constructed (our definition of a CR system was one in which rates are stored and retrieved by computer. Here we will also include systems which border on this). The present section describes the major aspects of the current generation of CR systems.

Basic Elements. Although these systems differ considerably from each other, there are basic elements necessary to any such endeavor. A CR system has to contain the pieces of rating information, the means to access these for rating, and the means to update them. Examples of these elements are the following:

Rating Information^{10}
rate tables (class rates, commodity, exception)
notes
routes
codes (commodity, location, maybe carrier or vendor)

Means of Access
printed output (ponies)
terminals with direct entry to files
terminals with access to rateman
batch processing of F/B's

Rate Update
substitution of new tariff "page" for old
tariff changes coded by rateman
specific rate changed, if necessary.

Also of importance but more difficult to classify is the linkage of a CR system with a firm's Management Information system (MIS). Because the uses of information vary so much from firm to firm it is simply indicated that the CR system is involved in a MIS system. This includes the functions of traffic analysis, distribution analysis, order entry control, shipment tracing, and others.

The manner in which rate information is stored is a critical decision by the designers of the system. This choice implies the type of indexing that will be used for retrieval and update and the manner in which the tariff information will be structured for data entry purposes. Therefore, one can tell what "kind" of CR system it is by knowing how it stores the rates. In practice no system is purely one type or the other.

Taxonomy of CR Systems

At one end of the spectrum is the "stored-rate" approach, basically a pony system. It is the most widely used method of coping with the demand for rating. The rates in storage are only those which have moved traffic. These systems handle stable commodity rates and repetitive movements well; retail-type traffic patterns are a problem. Stored-rate systems tend to be somewhat less concerned with standard codes (since they do not operate from a tariff format) and with being able to rate every F/B that passes through the system. Manual inputs are often mixed with the computer operations, e.g., the daily preparation of rate changes in the pony, prepared by experienced rate analysts.

At the other end of the spectrum are "generative" CR systems. These feature the storage of enough tariff information and sufficient logic to actually "find" a correct rate and build the freight charge in the computer. In its ideal form this type of system would replicate the rate search as a rateman would perform it. Although there were many generative systems proposed in the early 1970's, only a few were successfully cut over. These systems store the data in a form akin to its representation in the tariffs, have near-complete rating of all F/B's on the computer, and handle a more diverse traffic mix than stored-rate systems. This approach is preferable for a service organization having many clients.

The stored-rate systems vastly outnumber the generative ones at present and this trend seems to be continuing among the developing systems. CR systems having a broad coverage - all rates for all carriers in a region, for example - do not exist yet. This appears to be a problem of operating costs and marketing rather than technical feasibility.

A very important aspect of CR systems is that they are easily linked to Management Information Systems at many levels. Computerization of the rating step makes available the shipment information in a form that is suitable for statistical analyses. Several users claimed that the best selling point with management was improvement in traffic analysis or rate analysis rather than the lower cost of rating a F/B.[11] Also, rating may be combined with other functions in a CR system. Rating and billing is a natural combination of functions for carriers; rating and auditing for shippers. The rating function has been extended to prepayment agreements for some shippers.

Generalizations on the Current CR System

Over 50 CR users were identified. While the exact total is hard to determine since firms cannot freely reveal the names of their clients, and companies developing their own systems tend to be somewhat secretive at first, this number is still large enough to suggest that the first generation of operational CR systems has arrived.

On the basis of our initial survey the following generalizations are suggested, pending further research.

a. Shippers are entering CR applications fairly rapidly, especially those with a large annual freight bill. Service firms have successfully entered this market for large and medium sized firms but it is debatable whether small shippers can economically do CR yet.[12] Firms have successfully used both the stored rate and generative approaches. The choice of technique seems to vary with a company's shipment types. Shipments taking commodity rates can be handled better by ponies. Shipments taking class rates and nationwide traffic may require a generative method.

b. Some railroads are entering CR using the RePrate technique. This is a pony containing waybill information on repetitive movements. Rail carriers are satisfied if they can rate 70-80 percent of the F/B's by CR, since this allows enormous savings in time, accuracy, and overage claims. About a dozen carriers hope to have an operational CR system by 1976.

c. The motor freight industry has certain characteristics which have retarded the expansion of CR. There are relatively few large firms, therefore, relatively few who can afford CR. The bulk of motor freight traffic is LTL (*L*ess than *T*ruck *L*oad) and not highly repetitive. Finally, although easier (class) rates prevail, the actual freight costs often involve accessorial charges or other special charges, making computation of the freight charge complex. Consequently, very few CR systems have been successful in trucking firms. Service firms have recently entered this market on a regional basis.

d. The firms using CR systems appear to be much more interested in tariff standardization and simplification because they face the problem of indexing a rate in a unique manner for retrieval and updating. Although there is no overwhelming consensus among CR users to support standard codes, support there, is better than in the industry overall.

e. There are factors other than size of firm, mode (for carriers), or type of shipments (for shippers) which encourage the development of CR systems. One example is that large shippers already engaged in advanced logistics systems find the manual rating step a hindrance and support the CR effort.

f. Several groups have initiated discussions concerning shipper-carrier linkage systems. These would capture information at order entry and run through the rating /billing/payment steps.

Rate and Tariff Simplification

While rate computerization emphasizes technical improvement in the processing of rates, rate simplification involves changes in the rates and tariffs themselves. This report will use the terms *rate simplification* to cover both rates and tariffs. Such efforts have been directed in the development of simpler rates (usually scales) where possible, making the computation of the rate easier. The revision of tariff formats and publications requirements allow better ordering and indexing of the data items in the tariffs.

Rate Structure Simplification. One approach to rate simplification is *formula rates.* Such researchers as Whitten, Wharton, Johnston, and D'Anna have recognized that many of the present rates are based on scales (simple distance-price relationships) but that these scales have been distorted during general rate increases by rounding and by occasional errors.[13] Therefore, sets of rates with underlying mathematical relationships become sets of unrelated prices.

The formula rate researchers also try to determine how much each of the current (tariff) rates deviates from the basic formula. The results to date, both published and unpublished, show a very good fit. The next point to determine is which rates are amenable to this treatment, i.e., have minimal distortion, and what is the least painful way to reestablish the true scales. Since the existing rates do contain some distortion in their published prices, readjustment to a "true" scale would involve small changes in these prices, on the order of 1 or 2 cents for the best cases.

This approach could be of significance in CR development. As noted above, scales do underly many of the existing rates, although there are many different scales. The potential is here for condensing many class rate pages into a few base numbers and a mathematical expression. This would reduce storage requirements, enhance proper computation, and ease tariff maintenance.

Tariff Format Simplification. This leads to another approach to tariff simplification, i.e., accept the prices as they appear in a new tariff but try to handle the changes to the tariff so that they do not unduly complicate the rate search. One bureau, the Middle Atlantic Conference (Motor), has published a scale rate tariff which it will try to maintain as a true scale through tariff changes. The Southern Freight Conference (Rail) is trying a similar approach in a tariff on a particular commodity; they will try to maintain the scales accurately throughout tariff changes.

Edward Kreyling has suggested an even broader approach. He proposes that even if the original set of rates do not fit an underlying mathematical relationship, it is useful to maintain the set as a "scale" (here meaning a table of fixed numbers) and to apply successive rate changes as tables of factors, preserving the original "scale." The original relationships could be altered but only by specifically writing this into a rate change. This idea would combine pricing flexibility with the ability to store rate tables in a more logical manner.

Another example of rate simplification is FAK rates and unit train rates. These apply a simple classification to the total shipment and simple mileage/price relationship for determining the basic rate. They are, indeed, a model for the industry in those situations where it is feasible to apply them. However, their growth has been slow in the private sector.

Still another approach would be to purge the tariffs of "unused" rates. In 1970 Alan Boyd suggested the purge of rates which had not moved traffic in the last three years. This was generally well received by transportation officials with the qualifications that carriers and shippers still might want to retain some of those rates. Even rates which do not move traffic may serve a purpose, such as establishing a negotiating point for price bargaining.

Finally, the most aggressive and far-reaching research in formula rates is the attempt to develop scale rates based on the actual costs of the shipment to the carrier. While this work has not gone beyond the research stage in the U.S., the French rail system has already implemented rates of this type.[14]

Other Aspects of the Problem

Ocean Carriers. Ocean carriers also face a rating problem due to the tariffs they have created. These tariffs tend to be individualistic, with no consistency in codes and commodity descriptions. The disparity between commodity descriptions on inbound and outbound shipments, for example, has long been a sore point between the trading nations. Standardization apparently must precede any other systems improvements in information processing. To foster this, pending legislation requires the FMC to engage in tariff simplification, starting with commodity codes. There is also a joint effort between DOT and FMC aimed at standardization of the major shipping forms.

Within the tariffs limited use is made of SITC[15] codes. Individual carriers have progressed as far as the transmission of bill of lading information and the development of an automated billing and payment system.

Air Freight Carriers. Air freight rates are basically simpler than surface transport rates. Because the rates are point-to-point and there are a limited number of commercial airports, the totality of domestic freight rates is fairly small. Efforts are being made to standardize the commodity codes; most carriers now use the Brussels nomenclature.[16] Since practically all of the domestic freight rates are published by the Airline Tariff Publishers, simplification and standardization are easier to achieve. The Civil Aeronautics Board (CAB) is moving ahead on two aspects of tariff simplification, formula rates and simplified tariff formats. Individual airlines themselves have recently begun to develop CR systems for freight. American, Flying Tiger, Eastern, and United all have projects underway in this area.

Non-Computerized Carriers. The brevity of the survey period limited the number of interviews and biased the sample toward the "activists" in the industry. It is worthwhile, therefore, to summarize the comments of several motor carrier firms and bureaus who have chosen not to computerize.

For the large carriers handling a diverse traffic mix, rating is admittedly a problem. They cope with it, but that is all. It does not appear economically feasible for most carriers to computerize their rates at present. The two main influences on the cost of rating, volume of shipments and size of rate file, seem to cancel each other out. A firm must have a large volume of shipments before CR would be economical. However, as the volume of traffic grows, the size of the rate file is apt to grow also, increasing the cost of CR. If bureaus or other agencies offered CR services, carriers might buy it depending on prices. Most large carriers are avoiding CR by centralizing their rating function with CRT (display tubes) transmission.

Small motor carriers appeared to be outside of the present market for CR. The small carrier's processing of shipment information, accounts receivable, and traffic analysis are usually done at a level well below that requiring automation. The investment in CR would be beyond their means and the gain from it minimal.

Small Shipments. It was emphasized at the start that the rating problem would impact various firms in the transportation industry quite differently. One way of categorizing these firms would be by the type of shipments they process. Small shipments, for example, are a distinctive shipment type.

This traffic has been priced out of the reach of rail common carriers and is causing problems with motor carriers. A recent study[17] supported the contention that the costs of the shipping services exceed allowable rates in many cases. "Overhead and paperwork costs represent a very high proportion of the small shipment total expenses, and they vary almost entirely with number of shipments and not weight."[18]

The report went on to suggest new organizations and systems techniques which might ease the problem. The possibility of a common computer system for rating, waybilling, billing, collecting, labelling, tracing, claims, and inter-company settlements is mentioned. While this is just a proposal it is still significant that improvement of the rating process and the other document processing is recognized as a key factor in the reduction of costs.

POLICY IMPLICATIONS

After reviewing all of the current efforts, there are several observations which can be made concerning the relationships between the standardization, simplification, and computerization of tariffs. First, none of these three is absolutely necessary for the achievement of the other two, although all of them complement each other to some degree. Second, while there is an excellent case for standardization and simplification at the industry level, there is relatively little economic reason for individual firms to do either. Finally, following the second point, it is extremely important to differentiate between activities at a multi-firm level and at an individual firm level in evaluating solutions to the rating problem.

As an example, let us view standardization efforts. Many people define "standardization" to mean use of commonly defined items at an industry level. However, standardization can be achieved within individual firms through the use of pre-printed commodity descriptions on the bills of lading, through centralization of the rating function, etc. At the industry level, standardization is being attempted via standard codes and documents. However, these attempts encounter the same resistance that faces any proposal for changes in tariffs. While very few interviewees argued against the concept of standard codes, (there were some dissenters) most were cautious about actually using the codes. Some expressed doubt that it was worthwhile to convert to standard codes before more work is done in the area. Some had even constructed translation tables between STCC and their internal commodity codes but were not using them yet. We received the impression that these codes will not be used for the sake of being progressive nor will they in themselves lead to advanced rating methods. Instead, the codes and other forms of standardization will be accepted and used when there is a practical need for them. One particular item may bring about such a need.

Advances in computerized rating systems will create a demand for standardization. This will be particularly true when the systems begin to communicate with one another. Considering the discussions that are now occurring, the next level of computer system—linking many shippers and many carriers—is not far off.

All of the available evidence—interviews, articles, conference proceedings—shows that the users of CR systems are more sensitized to the problems inherent in the existing tariffs. While all rate rooms use similar tariffs, those firms which have computerized their operations are faced with the additional problem of using rates and updating rates automatically. These systems are less able to use the shortcuts and temporizing that a manual approach allows; inter-communicating they will generate pressure for data standardization. Because the CR systems are forced to survive within the pressures of the transportation industry, the improvements they generate will be technically and economically feasible. While the rate of progress in this evolutionary approach to tariff standardization-simplification-computerization may be slower than some hope for, the gains will be ones which have been tested and approved by the users themselves.

The implementation of CR systems is to be encouraged for these reasons, but the decision by any one firm to computerize or not should remain an individual one. Any DOT proposals here must be flexible enough to assist innovative efforts without penalizing those companies who find it uneconomical to computerize. Shippers and carriers acting in their self-interest, within the bounds of national transportation policy, will generally develop efficient and reliable methods of operation. In the existing CR systems these individual needs have been met—at a price—and the companies are able to cope with their rating problems. In fact, the current generation of CR systems appears more viable economically because they have been tailored to their operating environments.

The next phase in computerization will involve exchange of information between companies. In such a linked arrangement—perhaps conference is the most descriptive word—the freedom of data standards permitted individual firms must be modified. If two companies exchange information through their computers, obviously there must be agreement of data standards, including codes and record formats.

Such standards might be developed conference-by-conference, in an eclectic manner. This would mean that firms belonging to several conferences would be forced to maintain several sets of translation tables; it would also impede eventual communication between conferences. It is more reasonable to encourage the use of standard codes and data formats in all of these multi-user systems.

Will such codes and formats be available for users? Among other results, DOT and the National Committee on International Trade Documentation have developed a U.S. Standard Master for International Trade from European prototypes. The American Association of Railroads is developing the Standard Transportation Commodity Code (STCC), the National Motor Freight Traffic Association is doing the Standard Point Location Code (SPLC) and Standard Carrier Alpha Code (SCAC), and the Dun & Bradstreet identifier is a patron code (DUNS). The Transportation Data Coordinating Committee has been greatly responsible for fostering the use of these codes.

At present these codes are used internally but not between firms. Among CR users, there is some degree of usage but in an augmented form, i.e., by adding information to the basic code items. STCC was used the most; SPLC was the most problematic. While many firms in transportation recognize the need for industry-wide control of data standards, it is a matter of individual decision and costs at present. Furthermore, the proper level of control seems unresolved. As an illustration, try to imagine a general commodity code which would be sensitive enough to capture the product delineations of every shipper and the pricing requirements of every carrier. The code would be lacking structure if it were that extensive. This does not negate the usefulness of a standard commodity code, but it shows that such a code will invariably be modified by some users for their internal processing.

The critical question is how much variability can be allowed in the code. TDCC has responded to this problem by emphasizing the development of a list of commodity descriptions (a thesaurus) which would permit entry into all of the major commodity codes. Also, they have permitted the use of suffixes in order to capture finer gradations than their basic generic item allows. There is still work to be done on the cost of implementing these codes.

Another result of the piecemeal development of CR systems is that most users have had to pay the entire cost for creation and maintenance. These projects typically cost from $500,000 to over $1,000,000 for a large company with many tariffs. If this cost could be reduced or shared and if prospective users were guaranteed reliable updating of the rate files, the number of CR sites would increase greatly.

One way to accomplish both goals is to build rate files jointly, where possible, and to maintain them as a central data base. These data bases would include rates, routes, carriers, shippers, notes, special charges, etc. These files would be broader in scope than the existing ones, possibly regional and multimodal, and they would offer access to many different users. Such rate utilities would offer cost sharing plus greater reliability. The costs referred to involve file creation and maintenance.

Two final points should be discussed. First, there was some reluctance concerning standard codes because this might hurt the pricing techniques of shippers or carriers. This is based on the feeling that the use of standard codes such as STCC would impair one's ability to negotiate favorable rates since commodity classifications are sometimes adjusted to allow a change in the pricing of a particular movement. This problem should be recognized for what it is—a classification problem. The development and maintainence of a standard set of commodity names would not impede such activity. The Classification committee would be the decision-maker here, not the code committee.

PROGRAM RECOMMENDATIONS

The Need for Research

Because a knowledge of the current "transaction cost" is so important in assessing the potential worth of CR projects or rate "utilities" and because this information is apparently highly confidential, we suggest that the representative groups—NITL, AAR, ATA, etc.—conduct their own confidential surveys to gather this information. This would provide at least a starting point in evaluating the cost of current rating methods to shippers and carriers.

The other research task would be to examine the economics of CR applications. Here DOT could participate actively. The costs of rating manually, by CR, and within a network of rate utilities (such as a service system) would be measured. The systems requirements for successful CR applications would be examined and the future demand for such systems could be projected. Since the computerized systems which have evolved represent the most advanced work to date, a careful case study approach could be used to examine what works, how it can be done, and what sort of policy encourages it. The variation of costs as a function of user characteristics would be an important element in this study, since any significant investment by private firms will depend on their ability to weigh the costs and benefits of CR to their own situation. This effort should be undertaken on a cooperative basis through the DOT's Office of Facilitation.

The Need for Education

All the research in the world will not do us any good unless we make the results known. In one word, DOT must educate. A wider dissemination is needed of the state-of-the-art and the needs and costs which users face at present. It is recommended that DOT prepare a definitive document on the state-of-the-art in rate and tariff processing. The technology sharing staff at TSC under direction of DOT's Office of Facilitation could perform this task in cooperation with interested private and public organizations. The initial draft would be used as a discussion vehicle in seminars with transportation and distribution experts who would be free, indeed encouraged, to add, delete, or revise items. With the final document, DOT would have an inclusive statement of the problem and an important step towards its solution.

The Need for Implementation

Dot should continue its support for the development of standard codes and data formats. By using a translator approach, the national standards efforts can proceed in parallel with the efforts of individual companies to computerize. DOT should begin planning now for future demonstrations of the translator approach. Such demonstrations could be planned cooperatively between shipper and carrier organizations, code committees, individual companies, and the Federal government. Among other results, these demonstrations would show what is required of individual companies in bridging the gap between their internal needs and the existing codes. It would also indicate to what degree the codes themselves would have to have built-in flexibility to be responsive to many different users.

ENDNOTES

[1] Even if it were demonstrated that the present rates and tariffs are difficult and costly to use, the fact remains that they are being used. There is a valid question, "Why are tariffs (and rates) in their present condition?" This question must be dealt with eventually but is beyond the scope of this report.

[2] The reader may gain a feeling for the optimism of the period by reading the Proceedings of the Transportation Research Forum - Ohio Chapter, the University of Wisconsin Rate Seminars, or the Transportation Data Coordinating Committee Annual Meetings.

[3] See the Texas Transportation Institute study.

[4] The rating problem refers to the difficulty in finding the correct rating or building the correct freight charge, with the accompanying costs for this failure.

[5] Herbert Whitten, *The Railroad and Motor Carrier Freight Rate Complex,* p. 6.

[6] Joint Railroad Tariff Computerization Committee report.

[7] For the reader unfamiliar with tariffs here are some brief explanations. The long and sort haul clause states that a common carrier shall not charge more for transporting goods between two points than he charges to transport similar goods to a further point along the same route. The aggregate-of-intermediates rule states that the legal rate for a shipment may be a through rate or the sum of the intermediate rates, whichever is lower. Both of these rules were established to combat discriminatory practices. In the current rating environment they are sometimes employed in extremely clever fashion to produce a lower rate than one's competitor has. This is done by piecing together an alternative combination of moves which would sum up to less than the stated rate. There are ratemen who are expert in this technique for various regions of the country. Transit rules are a means of giving an intermediate point on a route the same storage or processing rights as are available at either the origin or destination. Transit rules can have different applications. One type states that goods coming into location X and going on to location Y, perhaps after a delay, can receive a more preferable rate from X to Y than goods simply shipped from X to Y. Besides the problem of applying information retroactively, there is sometimes a problem in verifying that the commodities referred to in several tariffs match up. Another application of transit would be in a shipment of grain from Minnesota to Memphis, where it is stored temporarily and finally shipped to New Orleans for export. The Shipper can claim through-rates from Minnesota to New Orleans and also credit from the payment for the first movement. Interline movements are very common and often simply share the freight revenue based on some formula reflecting terminal costs and line haul. However, if there are three or more carriers and if special handling is required during the movement, the apportionment of revenue can be tricky.

[8] Whitten, *The Impact of Rail Ex Parte Rate Increases.*

[9] Ernest Olson (ICC), personal letter to Robert E. Muldron (DOT), dated March 29, 1974.

[10] These items of information could be collapsed into a rate predetermined by the ratemen which would be stored in the computer.

[11] See "EDP & PD: How the Professions Communicate," *Traffic Management,* August 1973. This point was also mentioned by at least six of the interviewees.

[12] One service firm supplying CF services for shippers gave the following rough criteria for the lower bound of their potential market. They generally found that firms having under 1 million dollars in annual freight payments, or under 1,500 F/B's per month, or under twenty million dollars total sales, were not interested in CR.

[13] Whitten, *Impact of Rail Ex Parte Increases.*

[14] Herbert Whitten has examined a marginal cost rate structure based on the relationship

$$R = k e^{-n/40} T_o + T_d + M(1\text{-}D\{M/100\})$$

where R is the rate in cents per hundredweight, k is the basic cost associated with the mode, e is the logarithmic base e, n is equivalent to the classification of the good, T_o is the originating terminal cost, T_d is the destination terminal cost, M is distance, and D is a percentage discount for distance. A group led by Joseph Goldman at GAO is working on a cost-based rate also.

[15] Standard International Trade Classification. This is the United Nations' classification of commodities moving in international trade. It derives its nomenclature from the BTN (see below) and is correlated with it by number.

[16] Brussels Tariff Nomenclature. The commodity code used by the European Common Market. It is the standard for international trade.

[17] See *Small Shipments: A Matter of National Concern.*

[18] *Ibid,* p. 95.

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BIOGRAPHY

Mr. Thibodeau received his B.A. in Economics from San Francisco State and his M.A. in Economics from Boston College. He is currently a Ph.D. Candidate at Boston College. His work experience before DOT was as a systems programmer/analyst in commercial computer systems. Among other firms, he has worked for Pacific Telephone and Telegraph and Fireman's Fund American.

Since coming to DOT's Transportation Systems Center in 1974, he has been primarily engaged in freight rate research. Tariff computerization/simplification is one of his specialties. He has given a presentation to the TRF on this topic and maintains his contacts in this area with such groups as rate bureaus and code committees.

THE RATE EFFECTS OF REGULATION: INTERSTATE AND INTRASTATE REVENUES COMPARED

by

RUSSELL C. CHERRY

INTRODUCTION

The study compares average revenues per ton-mile from firms in both interstate and intrastate commerce. Since costs and, hence, revenues vary with average loads, distance, and other exogenous variables, the average revenues were corrected to take this into account. After the appropriate corrections were made, it was found that intrastate average revenues were higher than interstate average revenues. This does not allow any unqualified inferences about rate levels to be made because of factors for which it was not possible to compensate, such as the traffic between intrastate and interstate.

Recently there has been considerable comment from economists and legislators to the effect that Interstate Commerce Commission (ICC) regulation has an adverse effect on resource allocation and at the same time causes higher rates. The ICC and the trucking industry through the American Trucking Association have issued many rebuttals denying this. Usually these rebuttals allege that without regulation the industry would lapse into chaos.

A recent instance of this exchange took place when an article entitled "Highway Robbery—Via the ICC" by Mark Frazier appeared in the *Reader's Digest*. The charges levied in this article apparently played a role in causing the Subcommittee on Government Activities and Transportation of the House Committee on Government Operations to hold hearings to examine ICC influence on the trucking industry. ICC Commissioner George M. Stafford was requested to appear before the Committee to rebut the charges. His rebuttal was largely a recitation of the legislation that created the ICC.

Frazier cited entry control, as have many economists, as the practice which contributes most to raising motor carrier rates above competitive levels. Commissioner Stafford's reply on this issue was

> Entry control is an essential part of the Commission's efforts to insure good transportation service. A certificate accomplished two important objectives. First, it governs the adequacy and quality of service by requiring the authorized carrier to provide service upon reasonable request. Second, the protection it affords the carrier encourages investment in equipment and facilities needed to render adequate service. Historically, entry control and the certification process has been necessary in order to insure adequate service to the entire public, including the small shipper, on a nondiscriminatory basis; and there is nothing to show that it is not necessary today.
>
> The headnote of the Frazier article charges the ICC "throttles competition" thus driving up prices across the board. That is hardly the case. The Commission attempts to foster a healthy competitive climate in the regulated trucking industry, and in doing so, it grants at least in part a substantial number of the motor carrier applications for motor carrier authority that are decided.

Commissioner Stafford goes on to defend the Commission's entry policies by saying,

> . . . On the other hand, if an applicant simply offers an additional service, without any identifiable improvement, in an area already amply

> served by existing carriers, the Commission is more likely to deny the application in order to protect the health and stability of the existing transportation system.

Commissioner Stafford notes that common carriers

> . . . must make their services available at reasonable, non-discriminatory rates. In return, these carriers, although always under the prod of reasonable competition, are protected from the kind of *unwarranted and destructive competition* that would threaten the stability of the system. [emphasis added]

Private carriers and exempt carriers, he notes,

> . . . have none of these obligations. If they were allowed to compete indiscriminately for the back-hauls of regulated carriers, they would likely destroy the present high level of regulated carrier service and create a chaotic state in the motor carrier industry.

Commissioner Stafford's statements are classic examples of ICC and industry rebuttals to criticisms. The rebuttal evidence is often based on subjective observations of the industry. Little or no analytical research has been done on any of these issues, since the purpose of this study is to generate analytical evidence about one of the common points of contention. This study makes some inferences about the effects of intrastate regulation on average revenues as compared to interstate regulation. The limited extent to which quantitative data are available circumscribed the scope of this inquiry considerably.

RESEARCH DESIGN

Previous Research

The principal quantitative study comparing regulated and unregulated motor carriers was done by James Sloss (1975), and it compared unregulated and regulated Canadian provinces with the ICC-regulated United States to determine the effect of regulation on rates. This study used the voluntary reports of Canadian carriers to provincial authorities as a source of information on several variables which are exogenous to the revenue per ton-mile for each firm. These exogenous variables were specified as independent variables in a regression equation with average revenue per ton-mile across firms as the dependent variable.

The Sloss study performed two significance tests on the regression residuals. The two methods were a Student's "t" test performed pairwise across regulatory regimes and a Chi-square test on a contingency table of expected and observed residuals where regulation was hypothesized to produce positive residuals. The Chi-square test was included as a non-parametric alternative to the "t" test should the underlying distributional assumption be inappropriate.

Using these two methods of statistical inference, Sloss concluded that significant differences do exist between the rates in regulated provinces in Canàda, and between unregulated Canadian provinces and the ICC-regulated United States. A similar study was done by J. Palmer.[1]

An Alternative Methodology

If we accept the assumption that the regression analysis adequately "captures" (or uniformly omits) the effects of regulation, other methods allow us to formulate hypotheses about these effects more selectively. For example, a comparison of average revenues can be accomplished with the analysis of variance (ANOVA), since it is designed for multiple comparison of means. But the ANOVA alone would be inappropriate since there are valid reasons, other than regulation, for average revenues to differ in a given geographical area. The 'legitimate'—or non-regulatory—reasons that rates might vary are captured in the exogenous independent variables in the regression equations.

These exogenous variables are: 1) average haul, 2) average load, 3) average license cost per vehicle, 4) average state and federal full tax per vehicle, and 5) average wage. In the context of the regression design, a number of hypotheses can be tested using the analysis of covariance (ANCOVA). For example, one can pose null hypotheses of equality of regression coefficients across "cells" (i.e., interstate vs. intrastate data), equality of regression intercepts (conditional on the assumption of equal regression coefficients), and simultaneous equality of both regression coefficients and intercepts across cells; the latter hypothesis is the most restrictive of the three and should fail if any one of the across-cell estimated parameters differs significantly.

These ANCOVA are common in econometrics—and are often called the "Chow test"—and are used as a test of aggregation. Less well-known is that ANCOVA can also be used to compare dependent variable means *less* the influence that independent variables have; that is, the dependent variables may be corrected for the variation explained by the independent variables, or may be adjusted for covariate influence, and the F test may be performed on appropriately defined sums of squares. The ANCOVA may be equivalently viewed in two ways; 1) Finding the values of the dependent variables when all the independent variables are held at their mean values, and then testing for the dependent variables' significant differences. 2) Performing an ANOVA on adjusted dependent variables. The standard econometric use of ANCOVA is discussed in Johnston; the noneconomic uses of ANCOVA are described in Pazer and Swanson (1972), Kendall and Stuart (1966), Scheffe (1959), and Rao (1965).

The econometric use of ANCOVA encompasses the use of dummy variables so that separate intercepts are specified for each cell. The residual sum of squares of the aggregate (across cell) dummy regression equation is compared to the residual sums of squares for each individual regression equation computed separately. The dummy variables allow for testable variation in individual cell regression coefficients.

The ANCOVA dummy regression may be written

$$Y = D\alpha + X\beta + e \qquad (1)$$

where

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \cdot \\ \cdot \\ \cdot \\ Y_N \end{bmatrix} \qquad \alpha = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \cdot \\ \cdot \\ \cdot \\ \alpha_p \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdot \\ \cdot \\ \cdot \\ \beta_k \end{bmatrix} \qquad X = \begin{bmatrix} X_{11}, & X_{12} \ldots & X_{1k} \\ X_{21}, & X_{22} \ldots & X_{2k} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ X_{n1}, & X_{n2}, & X_{nk} \end{bmatrix}$$

$$e = \begin{bmatrix} e_1 \\ e_2 \\ \cdot \\ \cdot \\ \cdot \\ e_n \end{bmatrix}$$

and

$$D = [D_1, D_2, \ldots . D_p]$$

where

$$D_i = \begin{bmatrix} 1_1 \\ 1_2 \\ \cdot \\ \cdot \\ \Delta_m \\ 0_{m+1} \\ 0_{m+2} \\ \cdot \\ \cdot \\ \cdot \\ 0_N \end{bmatrix}$$

and p equals the number of subclasses; k equals the number of independent variables; N equals the total number of observations, and the α_i equal the cell intercepts; β is the regression coefficient vector across cells; X equals the matrix of independent variables; e equals the regression error vector; D is the matrix of dummies and Y equals the dependent variables.

The D matrix consists of vectors whose elements are zeros and ones, concatenated by column; for each cell *ones* appear in the (for example) 1st to mth places, and *zeros* elsewhere; the remaining D elements are similarly constructed. For a regression equation with five cells; five dummy variables are needed (or alternatively, four dummies and an intercept).[2]

The F test for equality of coefficients across cells (the first null hypothesis discussed) is

$$F\alpha\ [\xi, (\xi-\Sigma\nu_i)] = \frac{(SSR_D - \sum_{i=i}^{m} SSR_i) \,/\, (\xi-\Sigma\nu_i)}{SSR_{D/\xi}} \tag{2}$$

where SSR_D equals the residual sum of squares from aggregate dummy equation; SSR_i equals the residual sum of squares from ith individual cell computed separately; ξ equals the degrees of freedom for the dummy regression, and ν_i equals the degrees of freedom for individual regression equations.

The individual across-cell regression equations may be written

$$y = X\beta + S \tag{3}$$

and

$$y'y = \beta X'\ y + S'S \tag{4}$$

The residuals from the dummy regression are

$$y - D\widehat{\alpha} - X\widehat{\beta} = e \tag{5}$$

Partitioning in the obvious manner gives

$$y'y = \alpha\ Dy\ \widehat{\beta}'\ X'\ y + e'e\ . \tag{6}$$

The reduction in sum of squares produced using the dummy variable specification is

$$S'S - e'e = \alpha \leqslant D'y + (\beta'\ X'\ Y) - (\beta' X' y)\ ; \tag{7}$$

this information can be used to test intercept homogeneity as

$$\frac{(S'S-e'e)/(p-1)}{e'e/(mp-p-k+1)} \tag{8}$$

where p = number of cells
m = number of observations and
k = number of regressors

A complete exposition of this use of dummy variables, as well as a definition of the appropriate test for overall homogeneity (coefficient plus intercept) are found in Johnston (1974).

Analysis of Covariance on Corrected Means

The analysis of covariance on corrected means may be equivalently performed either by an analysis of variance on corrected means, or as a complete ANCOVA on the data. For the former method, the corrected dependent variable means are

$$\widehat{\bar{\bar{Y}}}_i = \bar{Y}_i - \sum_{j=1}^{k} \beta_j\ (\bar{X}_j - \bar{\bar{X}}_j) \tag{9}$$

where $\widehat{\bar{\bar{Y}}}_i$ = adjusted mean for each cell
Y_i = actual mean for each cell
β_j = jth regression coefficient, $j = 1, \ldots, k$
$\bar{X}_j$ = cell mean for each regressor
$\bar{\bar{X}}_j$ = total sample mean for jth regressor

In matrix notation this may be written

$$Y_c = (Y'\ \text{-} X_c\beta) \tag{9a}$$

where X is the within-cell deviation of each cell observation from cell mean; Y_c is now the vector of corrected values rather than the corrected mean value.

In this example, ANOVA may be performed on the corrected dependent variables. Since the cells have unequal sample sizes, the ANOVA must be modified to take this into account. Since this is a one-way ANOVA and interaction played no part in the specification, this is no problem.[3]

Heteroscedasticity

A test for heteroscedasticity revealed this to be a significant problem. One possible solution to heteroscedasticity is to use a robust regression technique—a more sophisticated approach than the usual econometric procedures for treating heteroscedasticity, such as weighted least squares or Parks procedure. In the robust procedure, the weights which minimize the sum of squares are iteratively selected. This procedure was applied and the results are reported later. The use of this experimental technique raises some unanswered questions about estimator distribution.

Robust regression techniques are designed to produce coefficient estimates that are insensitive to outliers and modeling inaccuracies. The regression model is fitted by solving for a vector of coefficient estimates which satisfy

$$\min \sum_{i=1}^{n} p_c G_R \alpha \, (Y_i - X_i) \, \hat{\beta}/S \qquad (10)$$

where P_c is a user-selected criterion function and S is a scale estimate.

Several criterion functions may be selected in the TROLL econometric computer program used here; the one chosen is the Huber function. Once a criterion function is chosen, the algorithm proceeds iteratively until the necessary conditions for a minimum are satisfied. A more complete discussion of the TROLL algorithm may be found in *TROLL Experimental Programs Robust and Ridge Regression* (1975); and also in Andrews, Bickel, Hampel, Huber, Rogers and Tukey (1972).

Since the testing and confidence interval computations associated with ordinary least squares (OLS) regression analysis are dependent on the assumption of asymptotic error normality; there is no general procedure for testing hypotheses when this assumption does not hold. Tests which involve first moments (See Theil, 1971, pg. 615)—such as "t" tests, are more robust under departures from normality than those which involve second moments, such as F tests (See Geary also).

DATA AND DATA SELECTION

The original intent of this study was to compare unregulated intrastate trucking with regulated interstate trucking. The state of New Jersey does not regulate intrastate trucking at all, and this seemed to be an ideal source of data for the study. Unfortunately, the state does not collect any data on intrastate trucking.

As a consequence of the absence of data in the only unregulated state of any size (Delaware is also unregulated) we consider states which do have intrastate regulation, but in which the method or level of regulation differed from that in interstate regulation.

A Review of Intrastate Regulation

A number of states have the statutory authority to set rates after a hearing; these states have statutes which are either modeled after the ICC motor carrier statute, or are very similar. The statutory authority to set maximum, minimum, or actual rates is granted to the states of Arkansas, California, Colorado, Hawaii, Kansas, Maine, Mississippi, Missouri, Nebraska, Nevada, New Mexico, New York, Pennsylvania, Rhode Island, Tennessee, Texas, Utah, Virginia, and Washington. Most of these require the carriers to file annual reports of some sort. The exact format of the annual report is crucial to data collection for a study of this sort, and form of the formats differs radically among the states. No source of information exists which catalogs the data series collected from the annual reports, consequently, a telephone survey was conducted of public utility commissions and departments of transportation in states which seemed likely candidates.

Many candidate states did not collect sufficient information to permit a uniform quantitative study of rates. States which collect sufficient data were soon narrowed to California and New York. California has a high percentage of gross revenue (42% of total gross revenue) derived from strictly intrastate traffic, and the requisite data are readily available. Regulation in California is discussed below.

Intrastate Regulation in California

The California Public Utilities Commission (PUC) sets minimum rates that may be charged by common carriers in intrastate traffic. The PUC has a Cost Studies Section in the Transportation Division, which prepares cost standards based on mileage and weight. If these cost standards are accepted by the PUC, then subsequent to a hearing, they become an official Minimum Rate Tariff (MRT). The PUC has seventeen minimum rate tariffs which cover truckload (TL) and less-than-truckload (LTL) movements of general freight as well as other freight classifications, such as livestock, household goods, petroleum products, dump truck rates, fruits and vegetables, cement, furniture, vacuum trucks, vehicle rentals, and drayage. Minimum Rate Tariff-2 (MRT-2) covers both TL and LTL shipments of general freight.

Permitted and *certificated* are the two general categories of regulated trucking in California. Their permitted category has had almost completely free entry since 1970. The certificated category requires that entrants be granted certificates that are very similar to, and patterned after, ICC certificates. Some observers feel that California entry requirements are less stringent than those of the ICC.

The PUC requires certificated carriers to file annual reports whose format is virtually identical to the old ICC forms. The data contained in these reports are not audited systematically, and, consequently, many contain missing or incorrect data. On the plus side, the PUC separates carriers into primarily TL and LTL carrier classes, which provides an important additional classification.

Data from forty-six carriers, specializing in both LTL and TL, were selected from those classified by the predominant type of traffic handled. Carriers in the California sample in either category had more than an 80 percent specialization in that traffic class; in most cases the specialization rate exceeded 90 percent. The sample includes twenty TL carriers, and twenty-six LTL carriers; Table 6-1 summarizes the operating characteristics of California TL and LTL general freight carriers, based on an annual PUC study.

Table 6-1. Comparison of 1974 Operating Statistics As Reported by Selected Class 1 and 2 Motor Carriers of Property in California Intrastate Regulation (Dollars in Thousands).

Number of Carriers	Type of Transportation Service	Periods Ending in Year	Total Operating Revenues	Total Expense	Net Operating Revenue	Operating Ratio Percent
20	Intrastate—General Freight	1974	209,418	206,668	2,750	98.7
20	Intercity—LTL	1973	186,615	182,195	4,420	97.6
6	Intrastate—General Freight	1974	13,494	13,220	274	98.0
6	Intercity—TL	1973	11,447	10,854	593	94.8
27	Intrastate General Freight	1974	62,021	59,612	2,409	96.1
27	Short Line + Local Drayage—LTL	1973	60,499	58,183	2,316	96.2
8	Intrastate—General Freight	1974	9,662	9,592	70	99.3
8	Short Line + Local Drayage—TL	1973	9,648	9,540	108	98.9

Intrastate Regulation in New York

New York intrastate regulation is virtually identical to ICC regulation. Until 1970, regulation of motor carriers in New York was conducted by the New York Public Utilities Commission; at that time the New York Legislature transferred responsibility for motor carrier regulation to the New York State Department of Transportation (NYDOT). New York has approximately 2,000 motor common carriers in Classes I, II and III, a majority of these are smaller carriers in Classes II and III. The New York classification is currently identical to the old ICC method of classification.

Because of the similarity of New York regulation to ICC regulation, there is *a priori* reason to suspect that there is little difference between the effects of New York state regulation and interstate regulation. the NYDOT staff did report a subjective impression, derived from discussions with motor carriers, that New York rates were generally lower than analogous ICC rates.

Using a list of New York Class I and II carriers, we selected a universe of seventy firms. When the annual reports for these firms were examined, forty-one reports had sufficient data to be included in the study. New York had not conducted any field studies to enable us to classify carriers into TL and LTL categories.

RESULTS

Descriptive Statistics on Regression Variables

A number of descriptive statistics were computed for each α set collected in the regulatory subdivisions, or cells, and the means and standard deviations of each variable across cells are summarized in Table 6-2. Average revenues per ton mile are recorded in Column 1. The rank of these (from lowest to highest) is:
1) unregulated, California TL, (0.0726), 2) regulated, ICC Pacific Southern, (0.2662); 3) regulated, ICC Middle Atlantic North (0.4659), 4) unregulated New York (0.5317) and 5) unregulated, California LTL (0.5383).

Column 2 lists the average haul in each cell; this conformed rather well to *a priori* expectations that carriers on the Eastern seaboard would have shorter hauls than those in the West. Interestingly, California (total) carriers had the longest average haul among the carriers sampled, 195.37 miles, and also had the largest average load.

Column 3 is the average federal and state fuel tax per vehicle production workers.

Column 4 is the average wage.

Column 5 lists average license costs for carriers; the absolute size of this figure is an indicator of firm size, as is the average federal and state fuel tax listed in Column 6. These

Table 6-2. Descriptive Statistics by Regulatory Area: Standard Deviation in Parentheses.

Cell	Av. Rev. per ton mile	Av. Haul	Av. Load	Av. Wage	Av. Lic. Cost	Av. Fed & State Fuel Tax
ICC Mid Atlantic N.	.4659	110.95	7.24	13,530.	32,245.1	34,823.5
General Freight	(.4263)	(96.53)	(4.44)	(3,626.24)	(42,434.5)	(56,066.2)
(102 Observations)						
ICC Pacific S.	.2662	169.67	9.96	13,929	64,724.	62,155.20
General Freight	(.3143)	111.96	(5.89)	(2,412.29)	(71,477)	(73,478.7)
(58 Observations)						
California Certificated Carriers						
LTL	.0726	150.09	7.08	14,669.3	83,261	83,367.7
	(.3848)	(133.54)	(5.92)	(4,324.83)	(193,217)	(201,779)
TL	.3358	254.24	25.94	15,084.9	68,191.7	60,053.2
	(.3737)	(163.91)	(22.31)	2,102.63	(148,421)	(468,455)
TOTAL	.3358	195.37	19.63	14,904.	76,709.2	73,231
(46 Observations)	(.3737)	(154.84)	(35.91)	(3,224.4)	(173,489)	(167,195)
New York Common	.5317	139.43	10.6285	12,970.	76,709.2	23,858.6
Carriers	(.7673)	(138.92)	(10.9705)	(3,036.1)	(173,488)	(24,317.7)
(41 Observations)						

Table 6-3. OLS Regressions Relating Average Revenues to Exogenous Explanatory Variables

UNIT		INTERCEPT	1. AV. HAUL	2. AV. LOAD	3. AV. FUEL TAX PER VEH.	4. AV. LICENSE COST PER VEH.	5. AV. WAGE	SSR	R_2	F
1. California LTL (26)		2.5492	-.3845**	-.4087**	-1.0057**	.1994	.3752	3.559	.7639	17.8**
	t	(.3837)	(-2.8558)	(-3.1602)	(-4.0024)	(1.1039)	(.5485)			
2. California TL (20)		-10.3586	-.0371	.0831	.0545	-.0453	.7645	9.039	-.2526	;234
	t	(-1.2684)	(-.1349)	(.2579)	(.2318)	(.2017)	(.9827)		(.0770)	
3. New York (41)		-1.8651	-.0014	-1.0265**	.0886	-.1385	.2749	28.539	.5728	11.728**
	t	(-.4107)	(.0097)	(-5.8294)	(.3530)	(.7932)	(.5365)			
4. ICC-MidAtlantic N. (102)		2.8241**	-.5109**	-.6572**	.0759	-.0118	3.1738 E-07	18.651	.7162	51.98**
	t	(6.9122)	(-7.3938)	(-8.2869)	(1.6889)	(-.2249)	(.0252)			
5. ICC-Pacific S (58)		-10.2099**	-.2159**	-.9669**	.0051	.1428	1.2092	9.355	.8005	46.747**
	t	(-3.2374)	(2.1013)	(-.92848)	(.0389)	(.2206)	3.6699			
6. Pooled with Dummies (247)	1.	.0966	-.2925**	-.7482**	.0272	.0030	.1628	91.27	.67997	59.07**
	t	(-.0625)	(-5.2146)	(-12.2701)	(.5032)	(.0463)				
	2.	-.8664								
	t	(.5613)								
	3.	-.4890								
	t	(-.3233)								
	4.	.0049								
	t	(.0032)								
	5.	-.3531								
	t	(.230)								
7. Cal V. N.Y. with Dummies (87) For Total Cal., N.Y.	1.	-4.1708	-.2172	-.0490	-.1530	-.1573	.5691	138.43	.0274	1.405
	t	(-.7985)	(-1.2829)	(-.3063)	(-.8574)	(-.7982)	(1.0364)			
	2.	-3.9117								
	t	(-.7643)								
8. Total California (46)		4.1232	-.0415	.5096**	-.1678	-.1011	-.4296	55.25	.1636	2.76
	t	(.4725)	(-.1603)	(2.7124)	(-1.4771)	(-.3806)	(-.5015)			
9. Cal TL LTL with Dummies	1.	2.0485	-.1625	.1366	.2512	-.2886	-.0853	45.0	.3168	4.478**
	t	(2.588)	(-.6859)	(.6602)	(-1.050)	(-1.1674)	(-.1091)			
	2.	3.4305								
	t	(.4348)								

variables were divided by the number of vehicles operated by the firm, so that these variables can be expressed in units of dollars per vehicle.

Regression Results

The OLS regression equation (specified in log transform) for this study are summarized in Table 6-3. The values of coefficients are reported beneath each variable with the computed 't' statistic below it; a single asterisk denotes significance at the 5 percent level; two, significance at the 1 percent level. The same convention was adopted for reporting the computed F statistic. The residual sum of squares SSR and the corrected coefficient of determination R^2 are also reported.[4]

Equation 1 related California LTL average revenues to the independent variables. The regression coefficients for the first three independent variables, average haul, average load, and average fuel tax per vehicle, are significant at over the 1 percent level; the coefficients of average license cost per vehicle and average wage are not significant; the regression itself is significant at over the 1 percent level and the associated R^2 is rather high for cross-section data. A comparison of the matrix of simple correlation coefficients with the R^2 indicates that collinearity is not a problem; the pairwise correlation coefficients are considerably lower (in absolute value) than R^2, a rough test for collinearity suggested by Goldberger (1964). However, these results do seem to be the result of heteroscedasticity; using Theil's (1971) F test on data ordered by firm size, the null hypothesis of homoscedasticity cannot be accepted.

The heteroscedasticity problem is exacerbated for the California TL sample. In that regression equation the coefficient was significant and the regression itself was not significant. The regression for New York data is similar to the analogous California regression (equation 8), although only the average load coefficient is significant. The same is true for the pooled California regression, although both equations are significant at over the 5 percent level for California, and over 1 percent for New York.

The ICC data (Equations 4 and 5), behaved in a manner similar to intrastate data. The coefficients in both ICC equations have sign agreement except the coefficient for average license cost per vehicle. This coefficient was negative for Middle Atlantic North data and positive for Pacific South data.

Equations 6, 7, and 9 are pooled regression equations using dummy variables for each cell. Pooled regressions were performed for an aggregate of all data (Equation 6), California and New York (Equation 7), and California LTL and TL (Equation 9). The purpose of these aggregate regressions is to provide the residual sums of squares necessary for the Chow test.

Robust Regression Results

The ANCOVA F test results are summarized in Table 6-4, but before we look at these results, some discussion of the robust regression technique is appropriate. The difficulty in using robust techniques, as was noted previously, is that we have no unambiguous understanding of their effect on estimator distribution, so that exact tests of significance

Table 6-4. Hypothesis Tests Using Analysis of Covariance All Subsets of Data.

Hypothesis	Source	d.f.	M S	F
Slope Homogeneity $H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5$ For all data	Pooled (Summed Separate) $SSR - \Sigma SSR_i = 31.482$ Summer Separate $= \Sigma SSR_i$ $SSR = 59.998$	Total–ΣDF 20	1.5741	5.7136**
$H_0: \beta_1 = \beta_2 = \beta_3 = \beta$ Cal v. N.Y.	53.278–3.559 + 9.039	217 35 10	1.2141	Reject 2.0364* Reject

Table 6-5. Huber Robust Regressions Relating Average Revenues to Exogenous Explanatory Variables

Cell	Variable Number		Intercept	1. Av. Haul	2. Av. Load	3. Av. Fuel Tax/Vehicle	4. Av. License Cost/Vehicle	5. Av. Wage	WSSR[a]	WR^2[b]	WF[c]
1. California LTL			1.0142	–.2988	–.5051	–.4609	.1473	.3924	.00066	.9997	15841.5
	(26)	S.E.	(.3770)	(.0056)	(.0057)	(.0233)	(.0187)	(.0344)			
2. California TL			-8.5938	–.2048	.4636	–.1232†	.0152†	.6340	.0009	.9985	1839.99
	(20)	S.E.	(.1540)	(.0056)	(.0107)	(.0070)	(.0059)	(.0155)			
3. New York	(41)	S.E.	3.9904†	–.0037	–1.1486	.1411	–.0562	–.4005†	.0026	.9997	28460.8
			(.1843)	(.0054)	(.0034)	(.0080)	(.0063)	(.0225)			
4. ICC Mid Atlantic N	(102)	S.E.	2.4313	–.3223	-8388	.0789	–.0183	-7.369E-06†	.00307	.9988	15417.2
			.0381)	(.0062)	(.0079)	(.0027)	(.0018)	(8.821E-07)			
5. ICC Pacific S.	(58)	S.E.	–12.2393	–.2060	–.9657	.0911	.1518	1.4067	.0018	.9990	10981.8
			(.7074)	(.0102)	(1.0124)	(.0198)	(.0151)	(.0732)			

a weighted sum of squares
b weighted sum of squares
c F test performed with weighted sum of squares—interpret with caution due to untested distributional assumption

†Denotes Sign Change as Compared to OLS Values

have not been developed. Consequently, the weighted F test (WF) reported in this table must be interpreted with caution. The 't' statistic is likewise not completely appropriate; the numbers in parentheses below coefficients are standard errors. As Kendall and Stuart (1966, vol. 2) note, the effect of nonnormality on 'F' tests is not fatal, although it is more serious with the F test than with the 't' test.

One alternative to the use of the 't' test is a confidence bound and test of significance derived from Tchebycheff's inequality, which may be written

$$P\ (X-\overline{X} \leqslant k\delta) \geqslant (1-1/k^2). \qquad (11)$$

The implication of this is that the percentage of any distribution contained in a band around the mean defined by k standard deviations, must equal or exceed $(1\text{-}1/k^2)$ regardless of the probability distribution. This means that two standard deviations imply a 75 percent confidence band. Conversely, we may solve this equation for the 'k' which produces a given confidence level. For example, $k = 4.4721$ implies significance at no less than the 95 percent level. Using this criterion on the robust coefficients reported in Table 6-5 against the 95 percent and 99 percent k ($k = 10$) values, all pass a 95 percent test and a majority pass the 99 percent test.

Coefficient values which changed sign as compared to OLS coefficients are marked with a dagger; there were five sign changes.

Results of ANCOVA

The F test for across-cell coefficient homogeneity compares the pooled regression sum of squares, less those of individual regressions, divided by the pooled sum of squares, each divided by the respective degrees of freedom. The test result is reported in the first set of entries in Table 6-4. Coefficient homogeneity can be rejected at over the 1 percent level. This may be interpreted to mean that there is a significant difference in the relationships between dependent variables and regressors across cells and that therefore aggregation of data cross cells would not be appropriate.

Table 6-6 summarized the ANOVA on corrected means with unequal sample sizes. The results indicate that no significant difference exists between the adjusted means across cells. A test for coefficient homogeneity across New York and California data was also rejected.

Table 6-6. ANCOVA on Adjusted Means

Source	SS	DF	MS	F
Rows	1.818858E-16	3	3.3462891E-16	1.9779E-16
Error	41.144	235	.175081	

Nonparametric Tests of Differences in Means

It is unsatisfying to be unable to find significant differences between average revenues despite this extensive analysis. The robust regressions produced superior results—as judged by coefficient significance—but further testing of those results was initially stymied by the lack of an appropriate test distribution, and so another test methodology was employed.

Some nonparametric tests are appropriate in an ANOVA test situation, the Kruskal-Wallis statistic is

$$H = 12/\sum_{i=1}^{p}\eta i \ \ (\sum^{p} i+1)\ \ [\sum_{i=1}^{\eta} Ri^2/\eta i] \qquad (12)$$

$$- 3\sum_{i=1}^{p} \eta i+1$$

where

$\sum_{i=1} \eta_i$ = Total number of observations

R_i = rank of ith observation

p = number of subdivisions or cells.

The usefulness of this statistic derives from the fact that its value is zero for data with an equal sum of ranks across cells. The Kruskal-Wallis statistic is distributed as X^2 (p-1) (See Walsh, or Pazer and Swanson).

The results of the Kruskal-Wallis test on corrected means from both OLS and robust regressions are summarized in Table 6-6. Using the corrected means from OLS regression corrections, no difference was detectable confirming the parametric results; the tabulated Chi-square values are

$$X^2_3, (0.05) = 7.81$$
$$X^2_3, (0.01) = 11.3$$

There was a significant difference between the robust corrected means across cells. This confirms the subjective impression that an improved inference is possible by using robust regressions in the presence of heteroscedasticity.

CONCLUSIONS

The average revenues require extraordinary care in analysis in order to detect any difference. Only after robust regression coefficients are used to adjust the dependent variables do any significant differences in across-cell means become apparent (this was the result of the Kruskal-Wallis test report in Table 6-6).

The difficulty in detecting significant differences between corrected means using parametric statistics seems to lie in the fact that the data are "noisy;" that is, the variances are large in relation to the mean. This also was apparent in the large coefficients of variation—these change little when they are computed using corrected data.

In addition to the large variation, the data are skewed. The skewness of a distribution is measured by the third moment about the mean; if it is positive, the distribution is skewed right toward higher values—if negative, toward lower values. The third moment for the robust corrected means is 56.4302 indicating right skewness. The statistic β_3 is an absolute measure of skewness, defined as $[\Sigma(\chi-\chi)^3]^2 / [\Sigma(\chi-\chi)^2]^3$; This had a value of 573,328.0, indicating considerable skewness.

Although there exist statistically significant differences in average revenues under intrastate and ICC regulation, caution must be used in interpreting this result because factors other than regulation could account for these differences, such as different mixes of traffic across cells, aggregation bias between micro- and macrovariables, and reduced form misspecification. Clearly, the negative results of the coefficient homogeneity test allow the inference that there are important differences in across-cell regression relationships.

The most notable feature of the OLS regressions is that within the California sample, the LTL equation indicated that the independent variables had greater explanatory power than in the TL case. Therefore, we infer that if there had been some method of sorting carriers according to specialization, the regressions would have been more conclusive.

A second contribution to the difficulty of obtaining results was the aggregation bias, (see Theil, 1972, Ch. 11) which results from the averaging of "micro" level data to obtain the observed "macro" data. The direction of bias is impossible to assess in the absence of the micro level data. The micro level observations in this case, for example, are the revenue for each individual haul, the length of the haul, etc.

The most important single data problem is the absence of data on the mix of traffic which generated the observed revenues. An attempt was made to correct for this by selecting the ICC sample from both the West and East. In this way, a greater likelihood that the mix of traffic would be similar was insured.

In summary, several changes in methodology could result in improved inferences. First, data on the traffic mix must be collected, or alternatively, average revenue and independent variable data should be collected by commodity samples as well as across cells. It is evident that commodity flow data on which there were no available information are one of the major variables which could influence the results. Second, it is important to separate carriers according to whether they specialize in TL or LTL traffic.

END NOTES

1. Palmer, 1973 reviews Sloss' method and findings and criticizes them on the basis that Sloss made some deletions from the data set after testing—thereby

subjecting the results to a pretesting bias and, secondly, may have specification error that accounted for the residual signs, rather than regulation.

Sloss got negative coefficients because the average license cost per truck is variable. Palmer feels that this is the result of forcing a nonlinear, specifically hyperbolic, relationship to be linear, and that this misspecification also causes the residual result which was attributed to regulation by Sloss. Palmer's contribution is the suggestion that the hyperbolic specification may be appropriate, and also that revenues might vary inversely as the average load.

Palmer is able to confirm the Sloss results, but qualifies them because data for two unregulated provinces, data Sloss rejected as unreliable, proved troublesome. The conclusion of the Sloss original article were also confirmed in the reevaluation by Sloss which was done with updated data.

2. If an intercept term is used (as is common), the number of intercept dummies must always be one less than the number of cells to avoid collinearity among terms. Consequently as Johnston (1974) points out, care must be exercized with econometric software packages that automatically specify an intercept if the user does not.

3. Of course, the usual ANOVA with equal sample sizes could be conducted by reducing all samples to the size of the smallest, but this would be discarding useful information.

4. The R^2 for this equation was 0.0770 uncorrected, and -0.2526 corrected. Of course, R^2 cannot be negative and the output shown is the output of a mechanical correction routine which should, but does not, contain an instruction to print zero when the correction process produces a negative number.

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CHERRY

BIOGRAPHY

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Mr. Cherry is a native of Texas and received his undergraduate degree from Cornell University in 1963, the degree of Master of Science from Texas A&M University in 1965 and the Doctor of Philosophy degree in economics from Brown University in 1972. His doctoral dissertation investigated the effects of regulation on the motor carrier industry, and his current research interests are in the area of quantitative microeconomics and the effects of regulation on industry. He is the author of several articles in scholarly journals, and a number of working papers and staff studies while at TSC.

U.S. Department of Transportation

Freight Transportation Digest, October 1976

MEASURES OF THE SPATIAL DISTRIBUTION OF U.S. POPULATION 1790–1970 AND THEIR CORRELATION WITH TRANSPORT, ENERGY CONSUMPTION, AND GNP

by

FRANK L. HASSLER

INTRODUCTION

This study is one of a series examining the historical growth of Transportation in the United States and its correlation with the national and urban economy, hoping to show some of the basic relationships quantitatively. Clearly the location of population determines in part, the location of industry and the spatial patterns of cargo flow. This study examines ways to characterize the spatial character or order of the population and how it changes over time. A companion paper examines the cargo implications of this approach. The fundamental speculation presented here and supported by evidence from several diverse sources, is that population potential and its related variables are useful macro variables for characterizing the *spatial order* of populations, and that the spatial order can be related to the *economic order* of such a population at equivalent macro levels of analysis through the variables of physical transport systems.

Considerable research has been conducted concerning the influence people exert upon one another and how this influence is affected by the distance of separation between people. The research concepts are first noted in 1858 and have been developed over the years into a body of theory now variously called "social gravity," "demographic gravitation," or "population potential," etc. (See "Distance and Human Interaction" p. 43–74, Gunnar Olsson, Regional Science Research Institute, 1965, for an extensive discussion of the origins and development of this set of concepts.)

The modern form of the theory of population potential was developed by the Princeton physicist John Q. Stewart.[1] Using a direct analogy from Newtonian physics, Stewart defined demographic force, F, corresponding to Newton's gravitational force as:

$$F_{ij} = G\,\frac{P_iP_j}{d_{ij}^2} \qquad (1)$$

where

G = constant,
P_i = population of the city i,
P_j = population of the city j, and
d_{ij} = distance between i and j.

Later, Stewart also developed the concept of demographic energy, E_{ij}, corresponding to Newtonian gravitational energy, defining it as:

$$E_{ij} = \frac{G}{2}\,\frac{P_iP_j}{d_{ij}} \qquad (2)$$

and demographic potential, V_i, corresponding to gravitational potential as:

$$V_i = G\,\frac{P_j}{d_{ij}} \qquad (3)$$

It can be seen from equation (3) that V_i defines the potential created upon a person in city i by the population of city j. (To determine the influence of other people in the same cities, similar calculations are required. See below.) To measure the total potential of i one merely sums over all j's; i.e.:

$$V_i = G\frac{P_1}{d_{ij}} + G\frac{P_2}{d_{i2}} + \ldots + G\frac{P_n}{d_{in}}$$

$$= G\sum_{j=1}^{n}\frac{P_j}{d_{ij}} \qquad (4)$$

The literal physical meaning of the above equations of force, energy, etc., is offensive to many readers for a variety of reasons, some treated in Olsson's paper. For the purpose of this work and related pieces, we will adopt a literal interpretation and explore the consequences of such a position.

POPULATION POTENTIAL COMPUTATIONS: USA 1790–1970

Equation (4) was employed to compute population potential at the center of each state using state census data from the U.S. Statistical Abstracts. In the computation, G was set equal to 1.0 and the results were normalized by dividing each result by the total U.S. population for the period. Maps of the potential for each year from 1790 in the dicennial census were prepared. Figures 7-1 to 7-3 are examples of such maps. Lines of equipotential for values of .5, 1.0, 2.0, 4.0, 6.0 and 8.0 are also shown (units are all $\times 10^{-3}$).

At first glance, the curves are all very similar. After detailed study, one sees that in the beginning of our Nation, the concentration of population on the East Coast results in a ratio of East Coast to West Coast potentials on the order of 17 to 1. In modern times, with the spread of population into the available land mass, this ratio has dropped to approximately 5 to 1. This can be seen by examining the East to West profiles of population potential per capita from New York to California presented for various years and plotted in Figures 7-4 and 7-5.

A second feature, not as pronounced as the first, is the shape of the contours east of the Rocky Mountains from the period 1880 onwards. From 1880 the curves stabilized almost completely except for a slight bulge of the 2.0 equipotential line through Nebraska

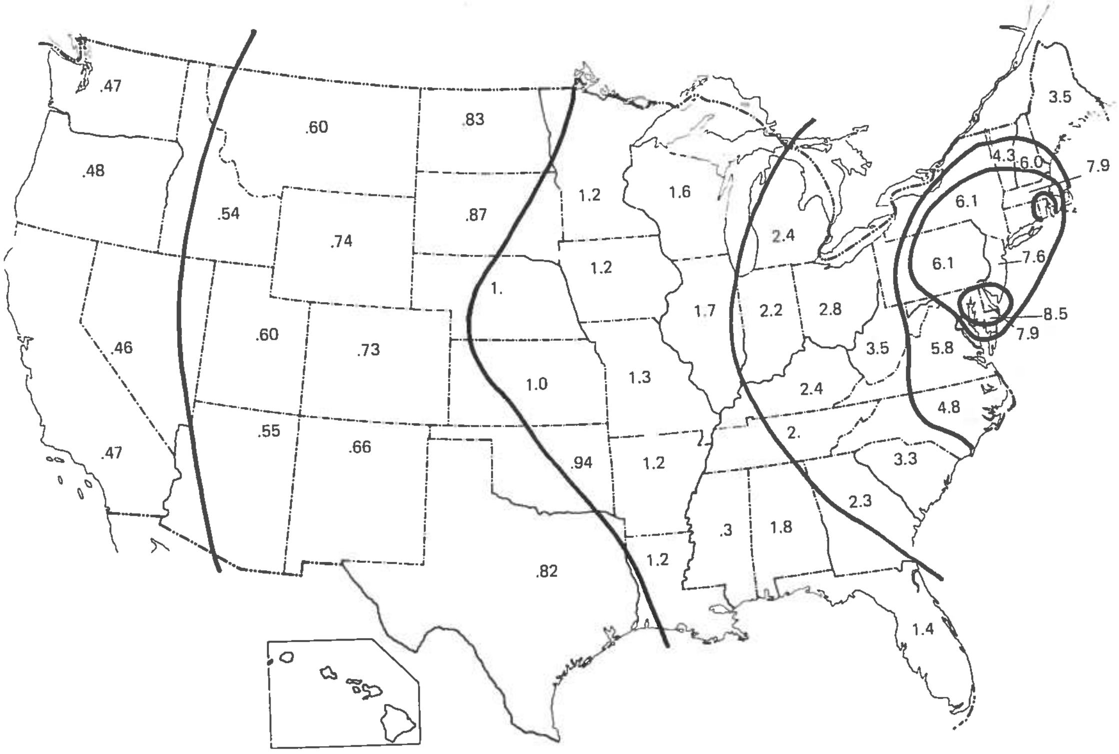

Figure 7-1. Population potential—1790 per capita.

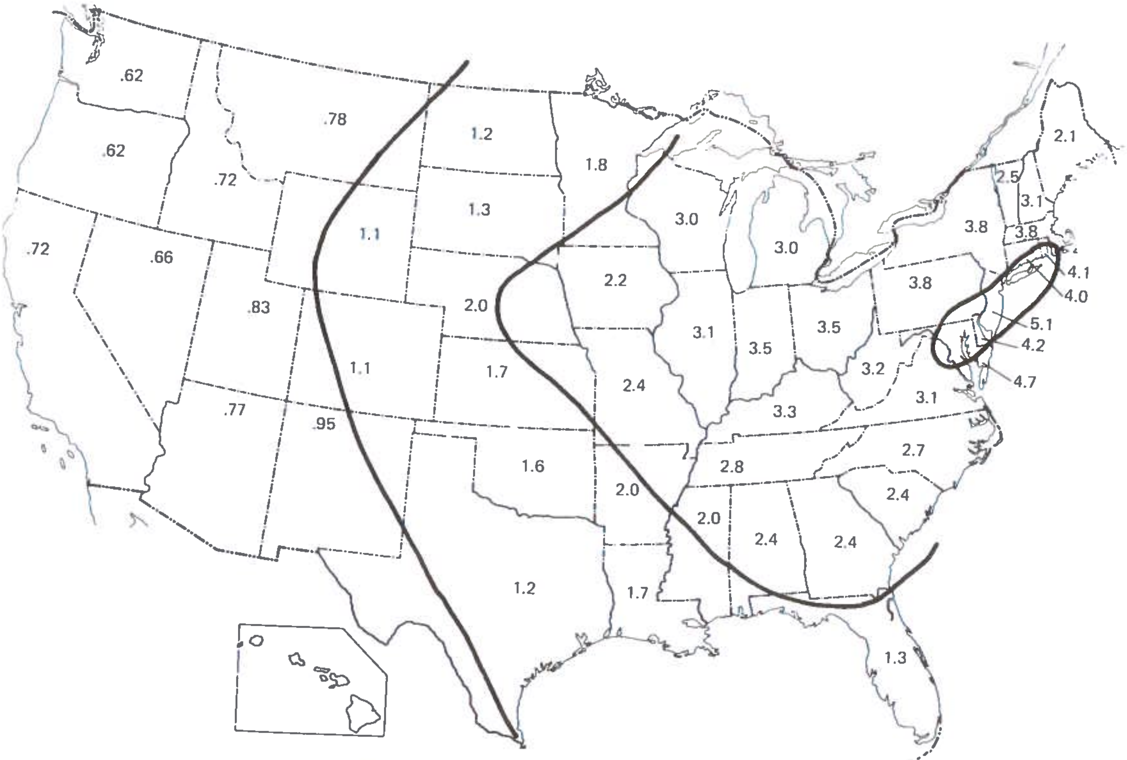

Figure 7-2. Population potential—1880 per capita.

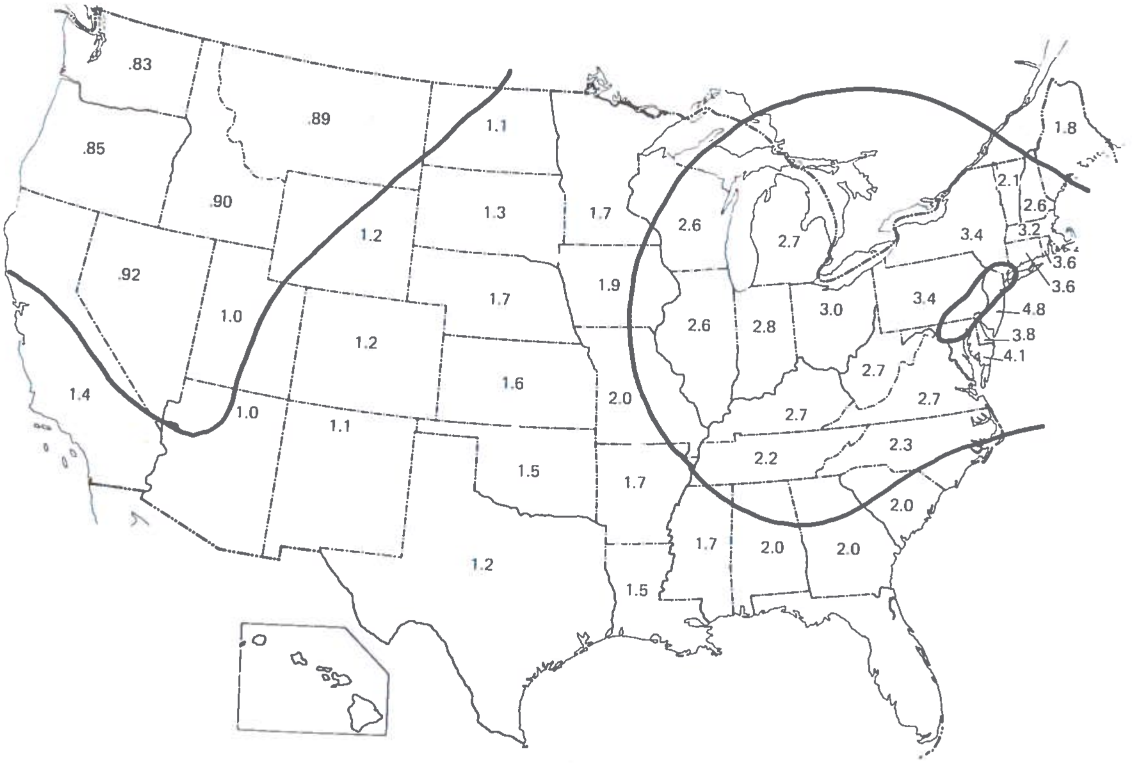

Figure 7-3. Population potential—1970 per capita.

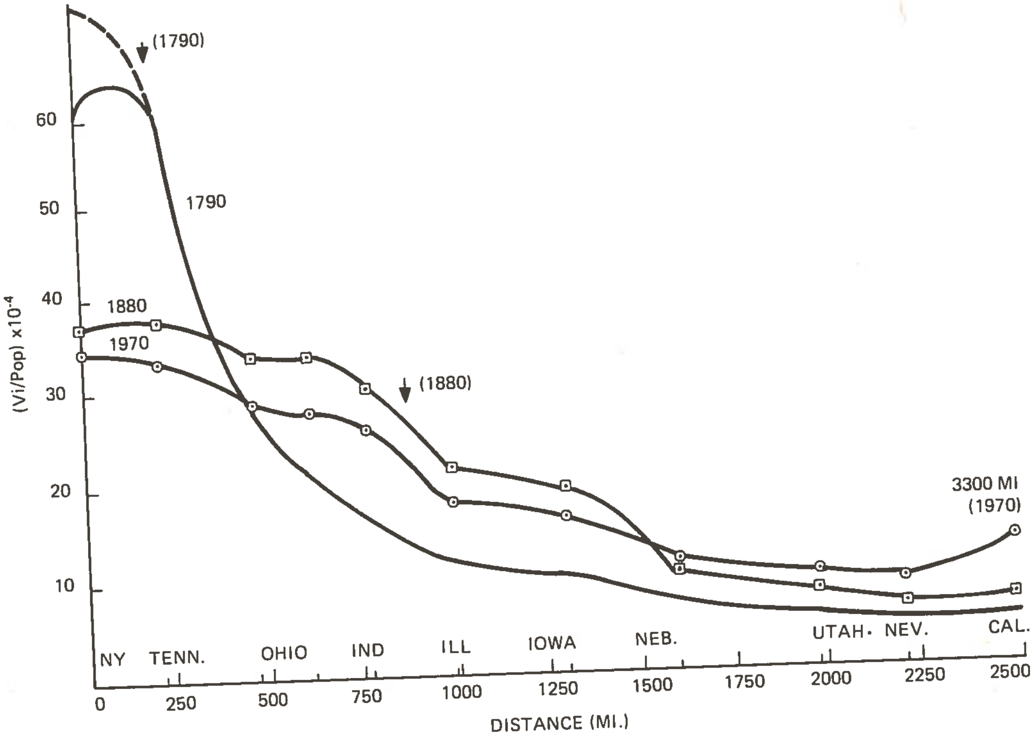

Figure 7-4. Population potential per capita vs distance from New York.

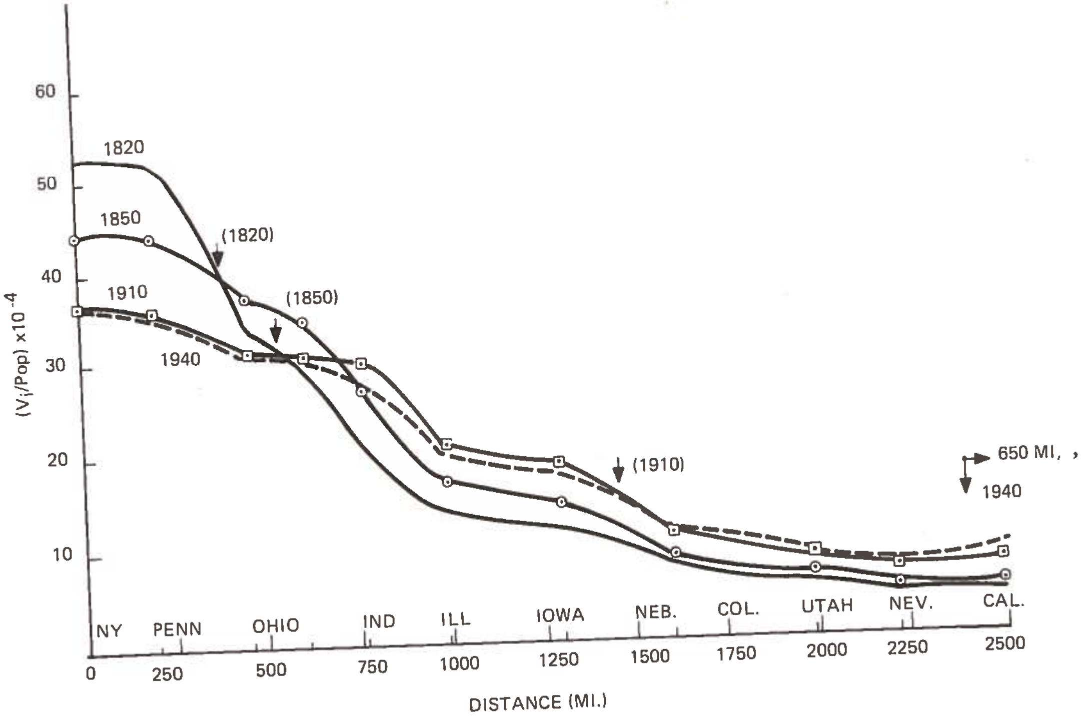

Figure 7-5. Population potential per capita vs distance from New York.

that persists until about 1910 and then recedes slightly.

A third feature of the graphs is the emergence of a West Coast peak in California around 1920–1930, which is still growing in magnitude relative to the East Coast peak.

Bear in mind that the absolute magnitudes of the maps that reflect national population growth would be obtained by multiplying each map value by total U.S. population. The normalized values result in maps that stress the changes in spatial distribution of population, not the growth in pure numbers. The maps per se are just spatial pictures of an index, if you will, related to poplation distribution.

Migration and Migration "Waves"

Population potentials for states are plotted for selected states in Figures 7-6 to 7-9. The results are qualitatively what one would expect, namely, that eastern states have been steadily losing potential relative to other states, western states have been steadily gaining, and intermediate states have experienced a peak and subsequent decline as the wave of westward migration engulfed them and passed them by.

Figure 7-10 plots the year in which the peak of the potential wave passed through the state. In some western states the first wave peak shown in parenthesis has been distorted by subsequent growths in potential as the westward diffusion continues.

Distances between adjacent states were computed along the lines of expansion shown in Figure 7-10 and time differences were computed to record "instantaneous velocities" of the "migration wave." The results are shown in Figure 7-11. The "wave velocity" increased from values around 6 miles per year in the early 1800's to values of approximately 35 miles per year in the early 1900's.

Shown for comparison on Figure 7-11 are plots of intercity freight and passenger velocities based upon estimates for the period made in "Population Distribution and Potentials."[2] The agreement is startlingly close and indicates to the author strong evidence that

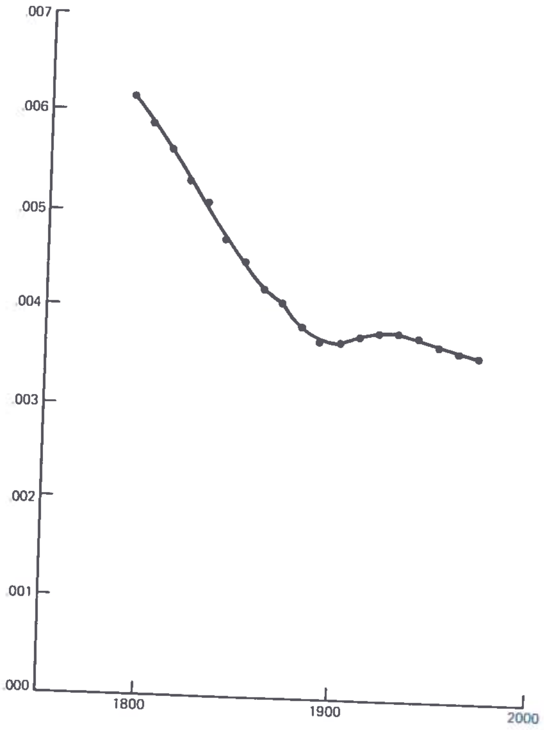

Figure 7-6. Population potential per capita for New York.

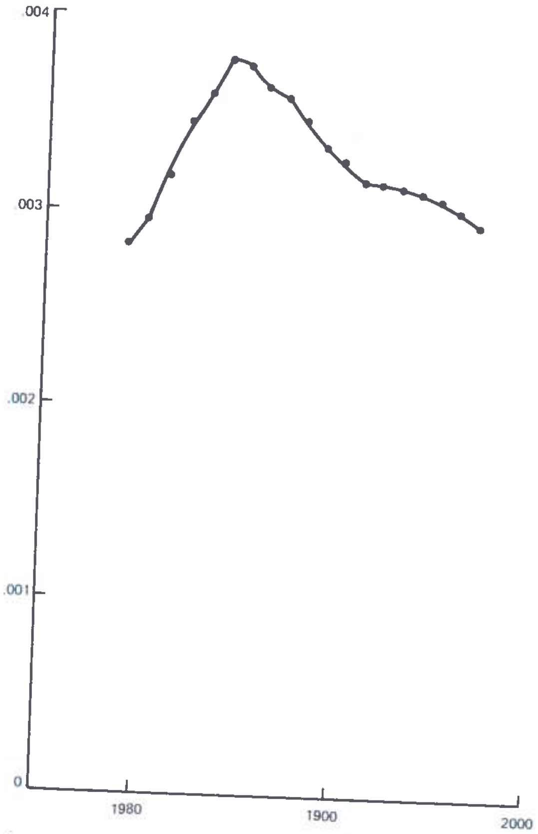

Figure 7-7. Population potential per capita for Ohio.

velocities of migration are determined by the velocities of the underlying transport systems.

In Figures 7-4 and 7-5, the arrows labeled with the date corresponding to the same year as the population potential profile indicate the position of the crest of the "migration wave" at that time.

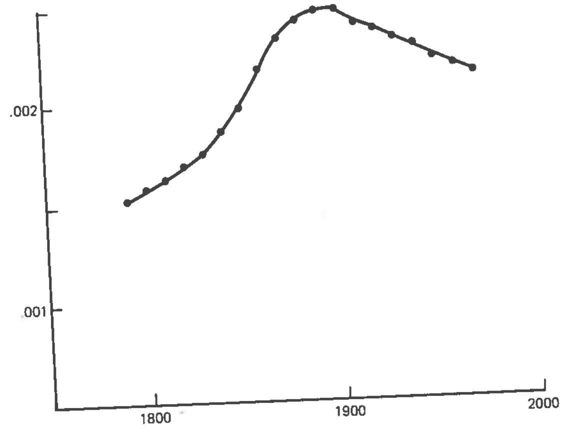

Figure 7-8. Population potential per capita for Nebraska.

From an examination of Figures 7-4 and 7-5, it is clear that the basic westward expansion of U.S. population was nearly complete by 1910, except for relatively minor migrations to the far west that have continued into the present. This coincides with the arrival of the crest of the "migration wave" at the eastern edge of the Rocky Mountain barrier. The relative shape of the profile east to New York has not changed since that time.

The crest of the "migration wave" struck the California coast around the middle of the great depression and since that time, travelling at its current velocities, has had time to reflect back as far as New York, traversing a distance in 35 years or less that had previously taken 160 years since the birth of our country.

In systems of physics, thermal equilibrium is established in a container when the basic movements created by inhomogeneities have traversed the container on the order of three to five times. If migration phenomena resemble the behavior of physical systems, we would be led to predict that fundamental net migrations will have ceased at a future time, somewhere before the year 2000 or 2050. These estimates presume no fundamental changes in the trends in average transport velocity and no major new external forces that might exert a migration pressure on the population.

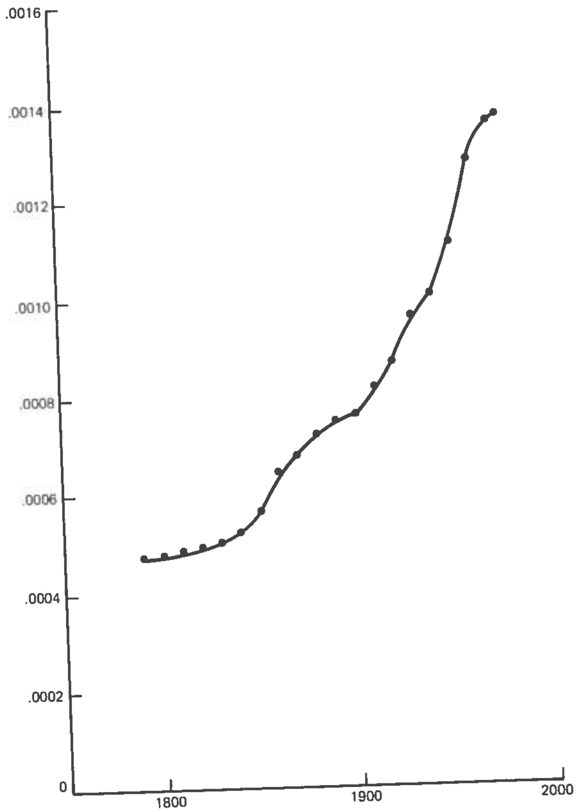

Figure 7-9. Population potential per capita for California.

A comparison of Figures 7-4 and 7-5 with Figure 7-12 indicates some additional relationships that may be involved in determining the stable population distribution. First, population is obviously a minimum in the mountainous arid portions of the West. (The Pennsylvania barrier is not as high and contains more passes with broader valleys for settlement—and water-borne transportation in a period of initial settlement when water was the dominant intercity mode of transport.)

Second, the similarity between the stable population potential profile and the annual precipitation profile is striking. (Some of the Colorado precipitation is even piped to California for drinking and irrigation.)

If land fertility is primarily a function of precipitation, and if agriculture provides a

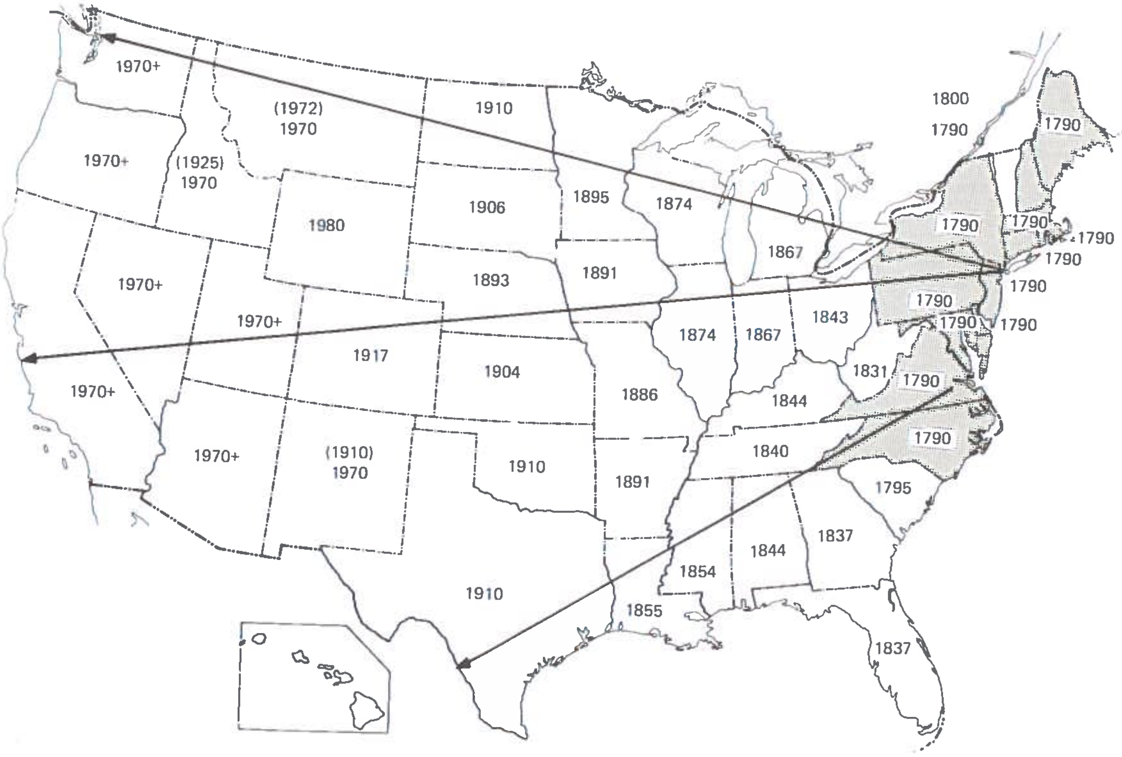

Figure 7-10. Year of peak population potential per capita in each state.

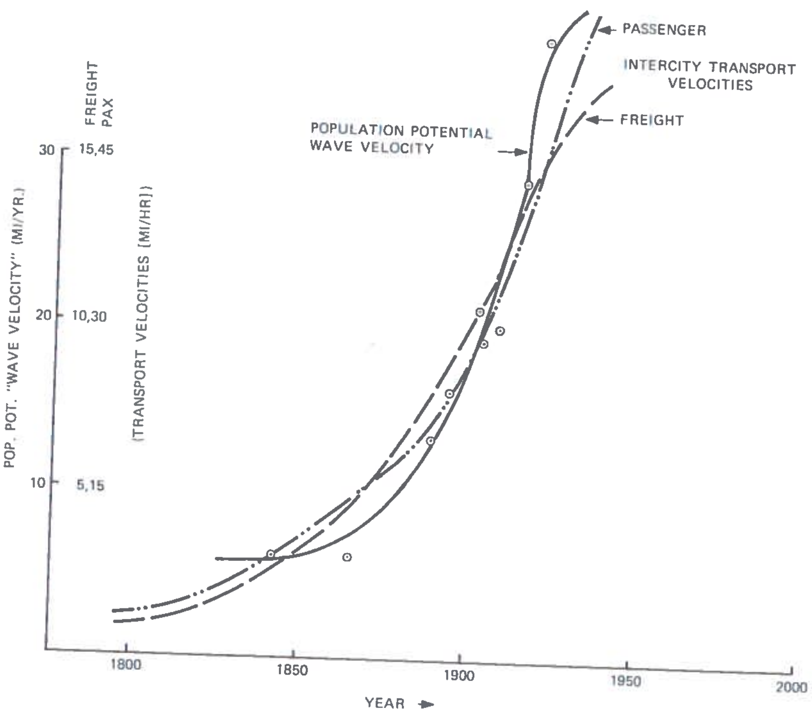

Figure 7-11. Instantaneous velocities of the migration wave.

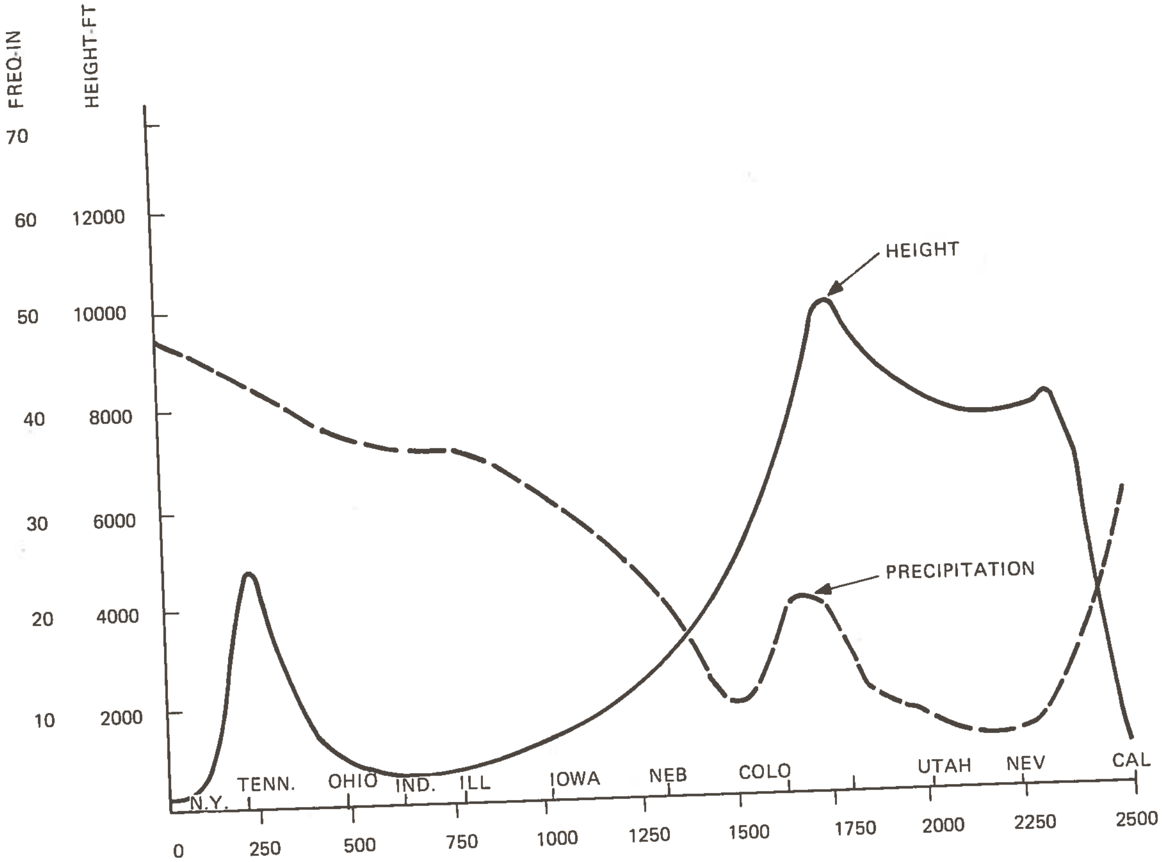

Figure 7-12. Physical profile and precipitation.

spatial basis for urban settlement and a determinant of basic land values, then it represents a good proxy for the capacity of the land to support population, and the relationship observed can be interpreted as indications that the population distribution has conformed to the sustaining capacity of the land itself, (or almost so, since there would appear to be some capacity yet to be used in the far west).

Dispersion of Population

From equation (4) one can derive a measure of the distance of separation of one person at the point i from the rest of the population.

$$V_i \Big/ \sum_j P_j = \frac{\sum_j P_j / d_{ij}}{\sum_j P_j} = \frac{\hat{1}}{d_i} \qquad (5)$$

Taking a population-weighted average of (5) we obtain

$$\sum_i P_i V_i \Big/ (\sum_i P_i)^2 = \frac{\hat{1}}{d} = \frac{2E}{P_T^{\ 2}} \qquad (6)$$

$$\text{or} \quad \left(\frac{\hat{1}}{d}\right)^{-1} = P_T^{\ 2} / 2E \equiv d \qquad (6A)$$

Using equation (6A) and the population data above, assuming relatively uniform intrastate population distributions (the contribution of urban and state "self energies" is small but is estimated separately below), average separation distances of one citizen from the remainder were computed. Figure 7-13 presents this data and the slopes of the curve during various periods in the country's evolution.

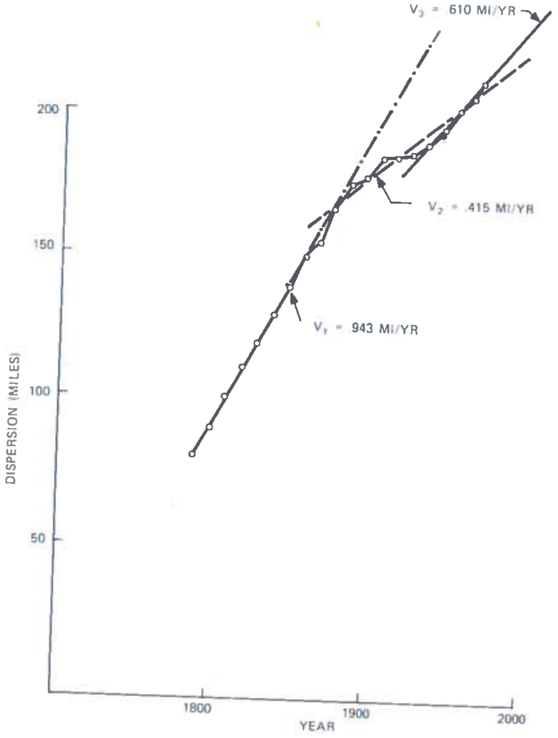

Figure 7-13. Average separation distances.

It should be observed that if the population is uniformly distributed over an area A, the average separation of one person from all others would be on the order of $\sqrt{A/2}$. For the continental U.S. this quantity is approximately 850 miles.

Note that the crest of the "wave" of westward migration was approaching the Great Plains area around the late 1800's when the first break in the curve in Figure 7-13 appears. The second break, around 1935, occurs roughly at the time the "wave" reached the Pacific Ocean.

Therefore, one interpretation of Figure 7-13 is that the population dispersed into the available land mass, faltered and slowed down when the Great Plains/Rocky Mountain area was encountered, and has now resumed its dispersion (at a slightly slower rate) now that the natural barrier has been "overcome."

Demographic Energy

The total demographic energy of the U.S. population distribution is given by equation (2) summed over all i and j. (This quantity must ultimately be modified by an improved treatment of state and urban self energies—see the next section.) The demographic energy is plotted in Figure 7-14 and compared to total U.S. population. The formula:

$$E = 0.149\ P^{1.78} \qquad (7)$$

is a close empirical fit to the observed data. Upon comparing this with equation (6A) we see that the implication is:

$$d \approx 3.36\ P^{0.22} \qquad (8)$$

Using historical population growth rates we can conclude that the average separation distance of people in the U.S. increases at the rate of about 0.3% per year.

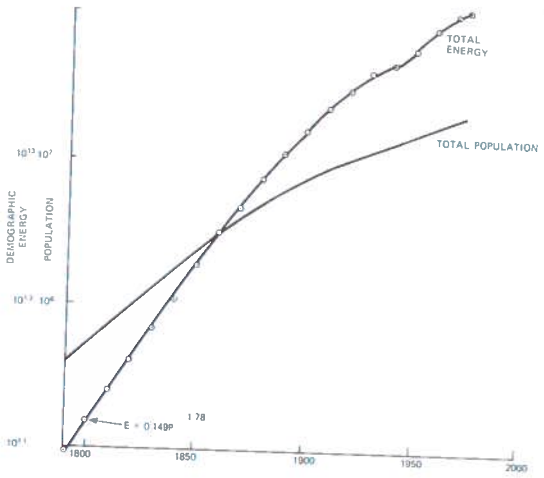

Figure 7-14. Demographic energy compared to total U.S. population.

Self-Energies or Self-Potentials

In the physics analogues of demographic energy, the issue of self-energy has a long and complex history. One practical way around these complexities in our present case, is to go to much smaller areas (e.g. counties) and compute the appropriate potentials (neglecting county self-potential). Such computations, while feasible, add enormously to the computational burden.

A small experiment was run on 1970 county population data for Alabama, Arizona and Arkansas, and the results show that the state value without self-potential closely approximates the average county-by-county value for the state. On the other hand, the state value with self-potential closely approximates the values near the state centroid of population if urban self-energies are included and would probably be a closer approximation of a population-weighted county average. We concluded that our state self-energy calculations are reasonable estimates.

Urban Energies

To analyse the impact of urban formation of National Demographic computations, we turn to a study of urban form.

In analyzing urban spatial form, Bussiere and Snickars[3] have used a theoretical argument maximizing urban "entropy" to show that residential population density is an exponentially decreasing function of distance from the city center:

$$\rho(r) = \rho_0 \, e^{-k \cdot r} \tag{9}$$

assuming only that the population is fixed and that the cost of movement within the city is proportional to distance moved. TSC analysts tested the exponential density relationship for 35 of the largest cities in the United States and two in Canada, using detailed 1970 census tract data.[4,5] The fit was excellent in all cases. Values of P_0 and k for each city were derived. See Reference 3 for a discussion of the limitations of this view. An analytical definition of total urban area population, P_T, not subject to the vagaries of areal definition can be derived from (9):

$$P_T = \frac{2\,\pi\rho_0}{k^2} \tag{10}$$

The demographic force thesis was employed to compute demographic self-potentials and self-energies for urban areas, using the observed exponential residential density relationships. Self-potential (at the city core) is given approximately by the expression

$$V_0 = kP_T \tag{11}$$

and falls off as $1/r$ at distances beyond two city radii. Self-energy is approximately

$$E_D = 1/4kP_T{}^2 \tag{12}$$

P_T and V_0 and E_D exhibit rank-order behavior although rank-orders for P_T, V_0, and E_D differ. From this we consluded that P_0 and K must be correlated. Bussiere[6] has shown for selected European and Canadian cities that this is indeed the case, and the consequence is a steadily declining central population density and a gradual dispersion of the exponential form. This is in qualitative agreement with observations of United States cities, and with the expectation that automobile technology (and transit technology before that) has made possible a more dispersed lifestyle.

Equation (12) was employed to compute urban demographic corrections to the national estimates based on state population data, and the corrected estimates are included in the following section.

Demographic Energy, Physical Energy Consumption and the Economy

If the concept of demographic energy is to be taken literally, it represents the energy involved in "human interaction." It was felt that this quantity, if literally valid, would correlate directly with energy consumption in the society. Further, if the outputs of the societal activities were correctly evaluated relative to one another, it was felt that "constant dollar" GNP would be a second valid measure of the energy involved in "human interaction."

Energy consumption was analyzed and compared to the sum of urban and interstate demographic energies. The relationship is:

$$(\text{BTU's}) = C.U_D^{\,0.91\pm0.03}$$

$$R^2 = 0.988 \qquad (13)$$

The comparison of total demographic energy and GNP in 1958 dollars indicates a relationship given by:

$$(\text{GNP}) = C' \cdot U_D^{\,1.13\pm0.04}$$

$$R^2 = 0.988 \qquad (14)$$

Figure 7-15 shows the historical correlation of energy consumption and GNP. The ratio of GNP to energy consumption can be viewed as the mechanical efficiency of the macro-economy. Clearly this quantity hasn't changed much in 100 years. (By comparison, the ratio of energy consumed to labor hours worked in the economy is a measure of mechanical advantage in the economy and accounts for more than 80 percent of the labor productivity gains in the last century).

If we extrapolate these curves as indicated we obtain very close agreement with the current long range forecasts of U.S. GNP (DRI Control Long 10/75 estimate) and energy consumption (Ford Foundation's Energy Policy Study,[6] 1974 Historical Growth Energy Forecast).

Figure 7-16 presents the demographic energy plot and an extrapolation based upon census population projections (also indicated). The shaded band of the demographic energy plot indicates the urban self-energy contribution estimated for all United States cities. It is evident that increasing urbanization in the United States is reflected in the increased urban contribution to the total demographic energy.

In the Ford Foundation study of U.S. Energy Futures, two alternatives to the historical growth scenario were developed. One called the Technical Fix Scenario results in energy consumption growth as indicated in Figure 7-17. Such a forecast is consistent with the historical relationship of demographic energy and energy consumption. If

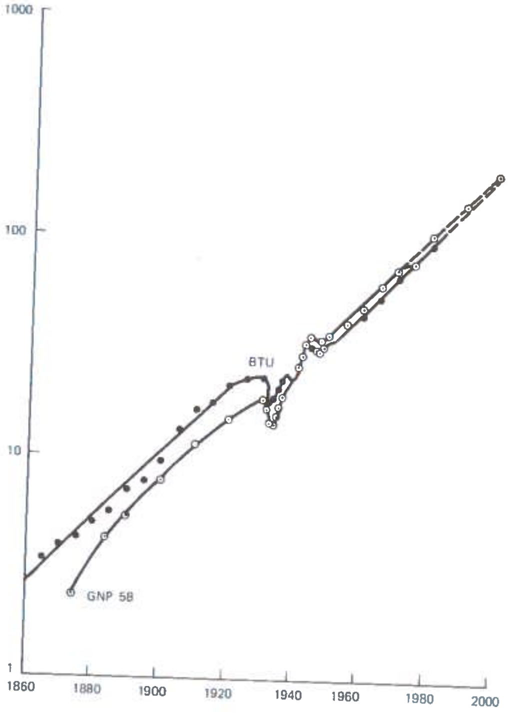

Figure 7-15. Correlations of national macro-variables.

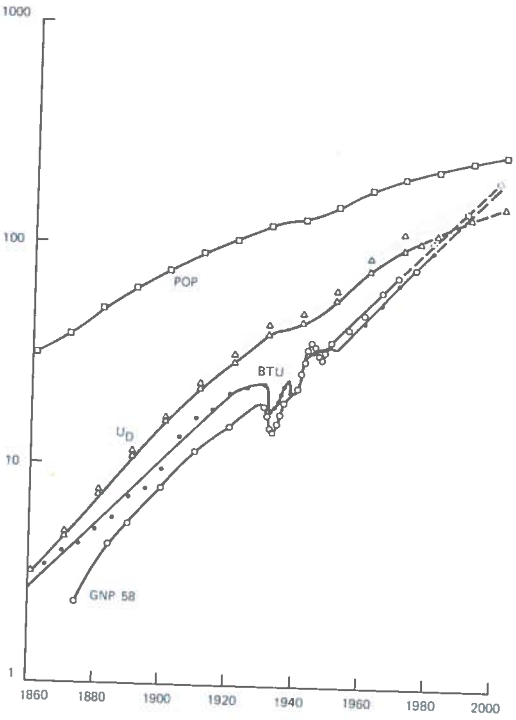

Figure 7-16. Correlations of national macro-variables.

mechanical efficiency remains relatively unchanged the GNP will continue to correlate directly with energy and demographic energy.

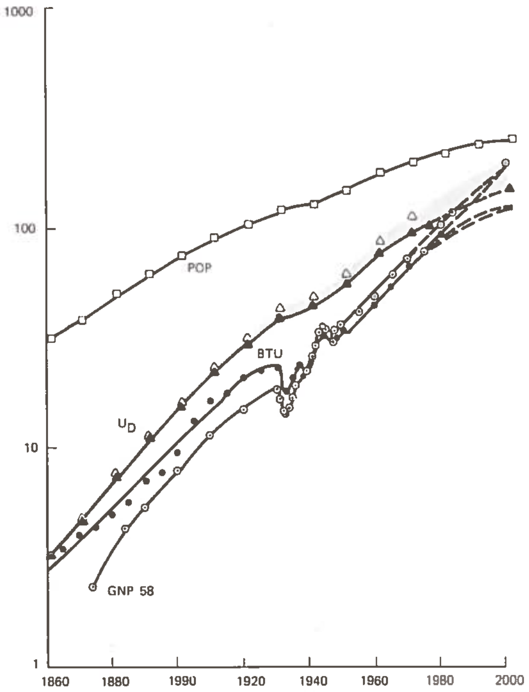

Figure 7-17. Correlations of national macro-variables.

The third Ford Foundation Energy Future, called Zero Energy Growth, flattens out 20 percent below the technical fix level. Should such a future occur without offsetting gains in mechanical efficiency, significant impacts on per capita GNP gains and urbanization would be felt. In particular, smaller cities and towns would have to grow at the expense of larger ones in order to preserve the rough equivalence of demographic energy with physical energy consumption and economic value generated.

The value of time in economic production is closely related to labor productivity. In fact, productivity should be inversely related to the time it takes to do something. If the *basic interactions* between individuals in the economy are constant over time, and if they gradually drift apart physically, the characteristic time of interaction is given by their average separation divided by the average velocities of transport (physical transport velocities for physical interactions). Table 7-1 gives some rough calculations of these various parameters gleaned from the various references cited.

It can be observed that the agreement between labor productivity and an estimate based upon average separation time of individuals is quite good.

CONCLUSIONS

In the work outlined above we have described some macroscopic variables that seem useful in characterizing the spatial order or spatial relationships of people. These demographic variables seem to be closely tied to transportation, energy, and the economy in general.

Table 7-1

Year	Av.*[2] Velocity (MPH)	Av. Separation Distance (Mi.)	Time (Hrs.)	(Const)** (Av. Time)	Labor**[6] Productivity
1800	1.5	93	62	2.2	—
1830	3.0	121	40	3.4	—
1860	6.4	153	24	5.7	—
1890	11	177	16	8.6	8.6
1920	22	186	8.6	16	14
1950	45	196	4.4	31	28
1970	75	208	2.8	49	46

*Rough Average of Passenger and Freight
**Arbitrary units

The evidence indicates that intercity transportation technology increased the speed of migration that gave rise to the cities and towns of our nation, and increased the rate of human interaction making greater labor productivity possible.

Within cities, the impact of transportation costs with distance gives rise to an exponentially declining residential density from the city center. It is probable, but not yet demonstrated completely, that the development of urban transportation technology has been the causal force in dispersing the compact urban form.

The forecasts of reduced population growth, now used as baselines for government planning are consistent with the evidence above of the damping out of large regional migrations, and the saturation in the growth of demographic energy.

The historical correlation of demographic energy and the macro-properties of energy consumption and GNP is remarkable. Should this correlation continue, energy consumption and GNP should grow at rates significantly below historical rates. Increasingly severe constraints on future energy availability are consistent with a reduced rate of growth of demographic energy implying a more reduced population growth rate, a more rapid reduction in magnitude of regional migrations and "flight" from the larger urban areas.

Hence, the fundamental speculation presented here and supported by evidence from several diverse sources is that population potential and its related variables are useful macro-variables for characterizing the *spatial order* of populations, and that the spatial order can be related to the *economic order* of such a population at equivalent macro-levels of analysis through the variables of physical transport systems.

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[6] "A Time to Choose, America's Energy Future," Energy Policy Project of the Ford Foundation, 1974.

BIOGRAPHY

Frank L. Hassler is Director of the Office of Systems Research and Analysis of the Transportation Systems Center of the U.S. Department of Transportation in Cambridge, Massachusetts.

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Prior to his current assignment, Dr. Hassler was Chief of the Advanced Program Planning Division of the Transportation Systems Center.

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Dr. Hassler was born in Warsaw, Indiana. He received his B.S. degree in Physics from Yale University and his M.S. and Ph.D. in Physics from Brown University.

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THE APPLICATION OF MANAGEMENT INFORMATION AND PROCESS CONTROL SYSTEMS TO INTERCITY FREIGHT TRANSPORTATION

by

KENNETH F. TROUP III

INTRODUCTION

The movement of cargo from one place to another by either truck or rail is a complicated, expensive, time-consuming, and labor-intensive process which seemingly has great potential for better control and automation. Truck and railroad intercity transportation cost the United States $60.3 billion in 1973, or about 5% of the gross national product.[1] The costs of transportation are rising, both for the carriers themselves and for their customers. Fuel costs have risen sharply as a result of the world petroleum situation. Labor and equipment costs have spiralled as part of the 1974-75 recession and the general economic inflation during recent years in the United States. Railroads, for example, received general rate increases of about 30 percent during an eighteen month period in 1974-75. Motor carriers also had significant, but less striking increases. The application of information control systems can help reduce (or control) costs, and can also improve service. This paper deals with present and potential applications of automatic control systems to the movement of freight by railroads and by trucks.

Control in intercity freight transportation takes two forms: management information or process control. The use of management information, the most critical control function, deals with information about the shipment which is required to move it efficiently from its origin to its destination, and to reconcile freight charges as expeditiously as possible. Process control, on the other hand, deals with control of the movement of the transportation vehicle and the sorting and distribution of the cargo being carried.

Management information is the key control function, especially during the next ten years. Computers play a vital role in the physical distribution process of major manufacturing companies. Virtually every company uses computers for inventory control and order processing.[2] This is in impressive contrast to the situation in 1971 when only 75 percent of major companies had computerized distribution systems. Transportation companies have similar management information needs, and these are the main focus of concern in this paper.

RAILROADS

Of the transportation modes, the railroads currently have the most automatic control, and are inherently most suitable to such control. The fixed guideway characteristic of railroads offers significant long-range potential for automatic control. Before indicating the applications of this control to railroading, it is appropriate to briefly examine how a railroad operates in moving a car to its destination.

The flow of rail operations begins when the shipper places an order for a particular kind of freight car. Figure 8-1 is a simplified diagram of the flow of operations. After a shipper has ordered a car to load with cargo, an empty car is assigned and moved to the shipper's siding from empties on hand near the shipper. After he has loaded the car, the shipper notifies the railroad who picks up the car with a local train. Once in the origin terminal, the car is classified into a train with other cars heading for the same general destination. Trains depart yards according to schedules and policies established by the railroad. In some cases, trains depart when a certain number of cars, for example 75 cars, have been accumulated. In other cases, trains leave at appointed times regardless of the number of cars they have accumulated.[3, 4]

Trains generally move toward their destination terminals through one or more intermediate yards. Cars for intermediate destinations are dropped off, crews are changed,

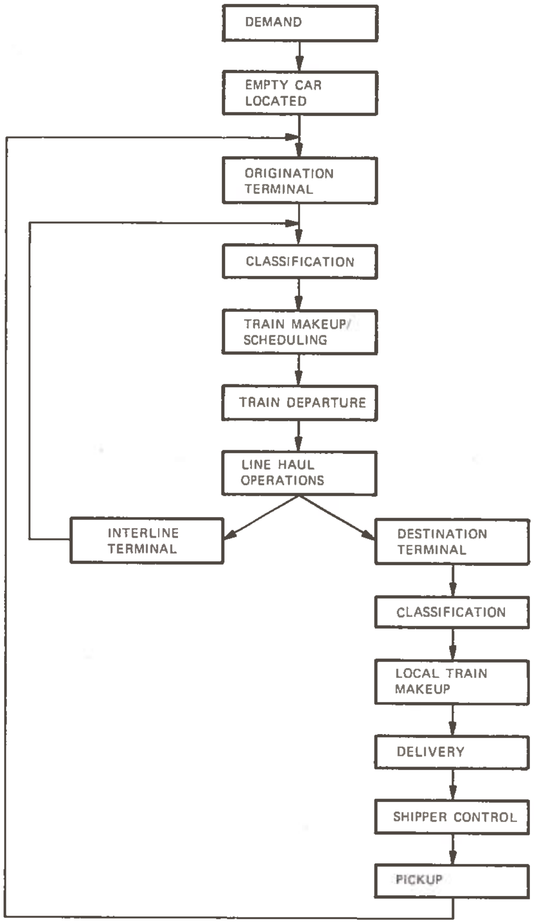

Figure 8-1. Flow of railroad operations.

and trains are inspected at these yards. If the destination for a car is on a different railroad, the car must be "interchanged" or passed to the next railroad at an intermediate terminal. The classification, train make-up, train departure, and subsequent yard activity occur as many times as necessary in moving a car to its destination. The average car goes through at least two yards.[5] The attempt is made to keep the number of yards to a minimum, as yards significantly increase transit times for a car.[6] The major problem in railroad operations is the terminal—both intermediate yards on the same railroad and interchange gateways when other railroads are involved in the car movement. Such terminals are a key focus of automatic control in railroading.

As noted above, the railroads are important users of automatic control. Yet they also have the greatest needs and potentials in transportation for additional applications of automatic control. Individual railroads use sophisticated management information systems to aid in the control of their own individual car movements.[7] The problem is that there are about 60 major railroads with 60 different information systems, and, as noted above, freight cars very often move on other railroads. Major railroad information systems currently in use or being implemented are on the Southern Pacific, the Missouri Pacific, and the Grand Trunk Western Railroads, to name a few.

Some classification yards have sophisticated process control systems. Developments in the last several years include new major automated yards on the Santa Fe at Barstow, California[8] and on the Southern Pacific at West Colton, California.[9] It is usually the large, gravity-assisted classification yards that have automatic control. There are some 116 in large yards in the country (yards which handle more than 700 cars per day).[10] By contrast, there are more than 1113 smaller flat switching, industrial and support yards, most of which are manually controlled. The large yards (called hump yards because there is a steep incline leading to the classification tracks down which cars are pushed and roll to their proper tracks), use both management information systems to control which cars are to be placed on which tracks and process control systems. The process control systems are used to regulate mechanical retardation devices controlling car rolling speeds, to automatically position switches to properly classify cars, to weigh cars while in motion, and to detect equipment malfunctions or alarm conditions automatically.[11,12]

The railroads have made some attempts toward integrated industry-wide national information systems as a result of their needs to send cars to the lines of other railroads. The Association of American Railroads operates an information system for the industry which has the objective of aiding in nationwide car distribution and providing other car movement information coordination.[13] This system is still evolving since it became operational in 1975. The data input requirement from individual railroads and the format differences among the various railroads are among the roadblocks to complete acceptance and success for the system.[14] The railroads in Chicago, with Federal assistance, have installed an information system to improve information exchange about cars to be interchanged among the 28 railroads in that major rail terminal.[15] That system has experienced severe input problems and as a result has been less than successful in achieving its objectives to date. A similar system for aiding the interchange process has been proposed by the railroads in Kansas City.[16]

The actual movement of trains on the line-haul portions of their trips is still a very labor-intensive process. It has been supported by several automatic control aids, however. Some 40,000 miles of the main line trackage in the United States have centralized train control signalling which allows remote detection of the presence of trains in specific areas of the track.[17] Both signals beside the track and in the cab inform the engineman of the track occupancy condition ahead. Some locomotives also have automatic train stop features which stop the train without engineman action in case the signals are violated.[18] Hot box detectors are remote devices located beside the track which warn the train crew of overheated wheel bearings on the train which, if they failed, could lead to derailments. In recent years, there have been several new railroads built for hauling coal from mines to power plants which use completely automated locomotives without any crews. These are special applications which would not really be possible for general freight movements at this time, both for operational and labor contract reasons. They demonstrate, however, that such control can be used successfully and may become part of our future rail operations.

One of the most important control needs of the railroads is for remote and/or automated input devices for present information and control systems. Most of the present information systems in the industry are IBM card based and require clerical effort to provide the input of car movement and freight billing information. Some elements of the industry, led by the Missouri Pacific, are moving toward Cathode Ray Tube (CRT) terminals as the primary input device. Of course, even CRT's require clerical effort. Automatic car identification scanners[19, 20] and wheel sensors are sometimes used in or near yards to remotely and automatically capture information about car movements. Both of these applications have been less than successful. In part, problems have involved hardware performance, the rugged environment in which the devices must operate, and the cost. Also, the devices have suffered to some extent in gaining acceptance on railroads which have heavily centralized systems with sophisticated error correction. It is often the view of these railroads that their systems have such low error rates that they do not need remote devices such as ACI or wheel sensors. These claims in many cases have not been substantiated, but have nevertheless acted to deter the implementation of these devices in the industry. What is certainly clear is that better application of such devices and/or the development of new devices which solve the problems of present devices is necessary.[21]

Another important railroad control application is in improved operations planning, particularly for gateway terminal control. As noted earlier, the avoidance of intermediate yards can significantly improve car transit times. Improved train and car scheduling, particularly for interline car movements is an important need which is gaining increasing attention in the industry. The Missouri Pacific, widely thought to have the state of the art in control systems in the railroad industry, is developing a computer-based individual car scheduling system. The Federal Railroad Administration is supporting the development with the intention of making the software packages and concepts which result available without charge to the rest of the railroad industry. The Grand Trunk Western Railroad is also receiving support from the FRA for its information system development, which includes computer-based train scheduling. These scheduling systems require extremely detailed information about car movements through all parts of the railroad. At the present time, the car scheduling techniques have not been extended to cars traveling on other railroads in interchange service. This is the real area of need and the key to successful control of railroad operations. The less-than-completely-successful application of industry-wide systems does not bode well for such interline coordination. This is a key area worthy of research and analysis.

Since cars usually have to pass through origin and destination yards as a minimum, as well as gateway yards for interchanges, another important control need is improved car handling in yards in order to reduce car delay. Recent new yard control systems such as those at Barstow and West Colton are designed to improve movement time of cars through the yard and thus reduce their detention times. At major interchange terminals, traffic control systems are needed to speed the interchange process and reduce congestion on the rail networks in the terminals. The average time required for a freight car to move through a major terminal such as Chicago or St. Louis is on the order of 35 hours or more.[22] The traffic control function at these terminals can be train control and dispatching; and information exchange to formalize and improve the interchange activity, or preferably both. The Chicago system discussed above provides some of the information needed to improve the interchange process, but is far from a control system for the railroads in Chicago. Kansas City, on the other hand, has a traffic control system which controls the movements of most of the interchange trains. The railroads there have proposed an information exchange system to help reduce car detention time through Kansas City.[23] Most of the other major rail terminals in the country have neither the information exchange system nor the traffic control function. This is an important railroad control need.

Information exchange by computer among rail carriers and between railroads and shippers is another control need. As just described, the need exists especially at terminals. Information exchange is also important for interline car scheduling and the transmission of waybills and the necessary shipment data such as destination, consignee, and routing. The railroads pay each other rent for the use of other railroads' cars (per diem) and negotiate the division of the revenues from a shipment among all of the roads involved in the movement. Information exchange relating to the billing information can result in faster settlements by the railroads which in turn reduces interest payments and improves the cash flow situation of the railroad. Distribution of empty cars is enhanced by the exchange of car movement information with the owner of cars on the lines of a given railroad. A number of railroads have experimented with computer-to-computer information exchange. Several Western railroads regularly exchange car movement and per diem data.[24] The most significant effort of this type was the so called Clearinghouse Experiment conducted by the Southern, the Milwaukee, and the Missouri Pacific Railroads during 1974-75.[25] The FRA is currently working with the Car Utilization Research and Demonstration Program being managed by the Association of American Railroads on expanding the scope of the Clearinghouse Experiment to other railroads.

The most significant information exchanges between shippers and railroads involve major rail shippers such as Ford or General Motors, or Hercules.[26,27] The Car Location Message system was developed by the railroads to supply daily car location and status information to shippers via teletype. Some thirty railroads provide CLM information to most major shippers. There is less exchange of information about shipping instructions. A very notable exception is Phillips Petroleum and the Missouri Pacific Railroad which have placed a CRT terminal tied into the MoPac's control system which will automatically prepare waybills in response to a minimal data entry by the Phillips' clerical forces.[28]

The major problem with data exchange, whether between railroads or between a railroad and a shipper, is that of data formats and standardization. Each company, though it has more or less the same types of information needs, has slightly different data requirements and formats. Computer-to-computer exchange, therefore, requires a reformating and reprogramming effort by one or both of the exchange partners. This is a deterrent to the kind of improvement data exchange can bring. Almost as important is the major sensitivity toward the proprietary nature of transportation-related data. There is a feeling among railroads and to some extent among shippers that a competitor would gain a market advantage by learning of another railroad's car movement or shipping data. This feeling, while perhaps an over-reaction, nevertheless acts as a major deterrent to intercompany data exchange. Major control needs are for improved data standardization and security techniques.

There has been some limited application of simulation modeling in the railroad industry for facilities planning, equipment scheduling, train dispatching, etc. The operations to be simulated are quite complicated and, therefore, have significant data requirements. Development of these data and their preparation for treatment in models is often a time-consuming and expensive process.[29] The data may not be readily available, and may require special collection techniques. The successful application of such models and techniques has been limited to a large extent because of the lack of involvement of the management of the railroad from the beginning of the modeling activity.[30] The most successful applications of modeling techniques in the railroad industry are the studies done by the Massachusetts Institute of Technology on Railroad Reliablility[31] and the control system and modeling applications in the Missouri Pacific's Transportation Control System.[32]

TRUCKING

The trucking industry is far more diverse in its operations than the railroads. To begin with, trucks operate on a much more flexible network than do the railroads. Virtually the entire highway system of the country is on the trucks' network. For this reason alone, there is less potential in trucking for automatic control, especially the kind of process control involved in line-haul railroad train movement. A major portion of the trucking industry is exempt from economic and service regulation by the Interstate Commerce Commission. In addition, a great deal of trucking is private trucking conducted in fleets of company-owned trucks by manufacturers. The trucking industry carries more and smaller shipments than railroads, and generally the higher-valued commodities.[33] There are many more trucking companies than there are railroads and they range from individual owner/operators to the major firms such as Consolidated Freightways or the Yellow Freight System. While there are service restrictions in the trucking industry (the ICC grants operating rights to certain geographical areas), there are a number of transcontinental carriers, and truck shipments are usually dock to dock, or at least origin terminal to destination terminal on the same carrier. This simplifies the information requirements of the trucking industry and allows the trucks to provide more reliable service than the railroads. The trucking industry conducts the majority of pick-up and delivery service between shippers and consolidation terminals of the major trucking companies, or the trailer or container facilities of the railroads.

Just as with the railroads, the terminal is the main problem to which information and control systems can be applied in trucking. At terminals, less-than-truckload shipments are consolidated; pick-up and delivery operations also originate here. The classic warehousing inventory control problems exist in controlling the location and movement of the shipment within the terminal complex. The role of private trucking is increasingly important. Private trucks almost always move dock to dock as the manufacturer is transporting his own products. The emphasis in these private trucking operations is on efficiency, and since the trucks are under the complete control of the shipper, costs can be held to a minimum and the trucks can be made an integral part of the distribution system of the company.[34,35]

Despite the fact that trucking has fewer control needs than does railroad transportation, the trucking industry has major applications of management information. The large carriers have their own information systems which they use for equipment control and allocation, shipping documentation transmission, shipment scheduling and dispatching, demand forecasting, and maintenance scheduling.[36, 37] For the smaller - to - medium size trucking companies, which cannot justify their own dedicated management informations systems, computer service firms have been established to provide the essential functions of shipment information, billing data, and other management control information. Many of these service firms also provide rate and tariff information for use by the trucking firms and their shippers.[38] Manufacturing firms which employ their own private truck fleets have established fleet operations control systems as a vital link in the computerized distribution control systems of these companies.[39]

Both the needs and future applications of management information systems to intercity trucking are of less significance than those of the railroads. The primary need for the trucking industry is in shipper-carrier computerized data exchange. The needs are both in the area of shipment orders and freight billing information as well as shipment status and pick-up and delivery notification. The problems impeding trucking industry/shipper data exchange are similar to those described earlier in discussion of railroad data exchange. The needs for this data exchange will also be discussed below in conjunction with control of trucking terminal operations.

The break bulk truck terminal, at which major trailer load motor carriers pick up and deliver consolidated shipments for distribution within a metropolitan area, is the most significant trucking application of automatic control.[40] The types of trucking terminals to be included in this discussion include intermodal terminals for railroad trailer and container on flat car movements, marine container and break bulk terminals at ocean-going ports. Movements of trucks into and out of these terminals are often monitored and controlled using computer-based systems to direct a truck to the proper dock of a warehouse or to the proper parking location for the trailer or container. The same type of automatic car identification scanners used on the railroads have been successfully employed by two container shipping companies to control access to and maintain inventory in their terminal facilities.[41] The U.S. Maritime Administration helped sponsor the development of a control system for the container port at Howland Hook, Long Island, New York. Management information and process control are combined to provide vehicle movement control and container inventory within the terminal.

The typical vehicle movement control application in this type of terminal involves gate control at the entrance to the terminal area. Trucks are identified either automatically if they are suitably labeled or by manual review of truck shipping documentation. The essential information about the truck is entered into the management information system for the terminal which supplies the gate operator with instruction for movement of the truck into the terminal. If the truck is bringing a trailer or container to the terminal for shipment, the driver is given instructions as to the parking location in the terminal area where he is to take the trailer. If the truck carries multiple shipments for consolidation in the warehouse, a dock assignment is made. If the truck's assignment is pick up of a recently arrived shipment, the driver is given the location of that trailer or container in the terminal yard. The computer-based gate control speeds the input processing of trucks, which is particularly important during the late afternoon peaks when truck queues can cause significant delays and possible traffic congestion. This also serves an important security function by reducing the probability of trailer or container hijacking. An unauthorized driver is denied entrance to the terminal which reduces the opportunity for trailer theft. Trucks leaving the terminal are similarly controlled at the gate and are not allowed to exit if they are not pulling the correct trailer. Not only is theft reduced, but mistakes are also discovered before the costly movement error can occur. Besides the Howland Hook application, this type of gate control exists at the Sealand Service container terminal at Elizabeth, New Jersey; at the U.S. Postal Service bulk mailing center at Oakland, California; and the Mystic Container Port in Boston.[42] There are relatively few control applications of this type in the U.S. at present. The systems which have been installed to date have operated successfully. There is a need for more widespread application of automatic vehicle movement control at trucking terminals, especially those which involve intermodal container or trailer shipping.

The other major truck terminal process control application is in shipment sorting within the warehouse area.[43] Management information systems are employed within the terminal as the inventory control system which keeps track of shipment location and provides sorting instructions. Automated conveyer systems are employed extensively in terminals to move shipments to and from storage locations and shipping docks.[44] Several trucking companies including Bilkays in New Jersey and St. Johnsbury in Cambridge, MA have automated conveyer systems in use. Automatic sorting of shipments is often tied into the conveyer systems.[45] The management information concerning shipment type or destination cause the process control functions to actuate the diversion hardware which routes shipments around the conveyor system of the warehouse. Some companies also employ automatically controlled vehicles within the warehouse for moving shipments around. A typical automatic vehicle is optically guided through a scan of light-sensitive tape or paint placed on the warehouse floor in the route of desired travel for the vehicle.[46]

TRANSPORTATION INFORMATION EXCHANGE

It was noted in both the discussion of trucks and of railroads that data exchange among the carriers and between the carriers and shippers was an important automatic control need. A great deal of paper changes hands in transportation. While shippers, railroads, trucking companies, and banks all have their own sophisticated computer-based systems, the documentation aspects of freight transportation have not advanced and remain a costly constraint to efficient and less expensive freight operations. The banking system in the United States has made significant advances in automated information transfer. It would seem reasonable for freight documentation processing to experience similar advances. There are, unfortunately, data base format problems, which have been alluded to above, which deter these types of developments. There are also legal and institutional needs (and traditions) concerning paper bills and shipping documents. Despite the advances in banking, these same types of institutional problems exist with respect to automated funds transfers.[47] There seems to be a public distrust of computers which causes a lack of acceptance of paperless banking. The transportation industry is similar in that much of its management and operating personnel, which began their working careers during periods of computer infancy, do not adequately understand or have confidence in the ability of automatic control systems to perform required data transfers. Railroads run on waybills which travel with the train. Truck drivers still carry freight bills for the shipments on their trucks. The need in this area is more for education and understanding of paperless data exchange than for technological innovation.

The process of determining the charges for a freight shipment is a particularly complicated one. It is a largely manual procedure which involves long years of experience on the part of the rate clerks who gain an intimate familiarity with the many tariffs which apply to the movement of various commodities. The two transportation industries and the shippers have undertaken cooperative programs to simplify, standardize, and computerize the rate making procedures in transportation.[48,49] A number of shippers have made rate retrival part of their distribution systems. Some 42 percent of major companies have the procedure computerized, and it is identified as a major need by many other companies.[50]

Interestingly enough, the data exchange phenomenon has been given more emphasis in the international shipping arena than in domestic freight transportation. The Department of Transportation is working with the U.S. Customs Office and several foreign governments on a Cargo Data Interchange System of CARDIS which would eliminate much of the paperwork which changes hands in international trade. Several experiments have been conducted; the most notable of which is a data transmission program in conjunction with air freight shipments between New York's Kennedy Airport and London's Heathrow Airport.[51] The Transportation

Data Coordinating Committee (TDCC) is a joint industry/government committee including shippers and carriers from all modes which conducts standardization activities in an attempt to encourage data exchange in domestic transportation. While the work of the TDCC is generally supported, particularly by shippers, it appears at this date that individual transportation companies are more concerned with the implementation of their own individual data systems than with standardizing formats and procedures to eliminate much of the paperwork involved in moving freight.

FUTURE DIRECTIONS

The future for automatic control in frieght transportation seems to be very bright. The Department of Transportation is involved in several efforts which deal with advanced concepts of freight transportation. Virtually all of the advanced concepts involve automatic control.

An important study sponsored by DOT relates to the terminal control concepts described earlier in this paper. A feasibility study has been completed on the concept of a Transportation Facilitation Center—essentially a large multi-modal distribution point for shipments incorporating the most recent concepts of shipper/carrier data exchange and process control in the terminal.[52,53] All modal operations are combined in an efficient processing terminal to facilitate the pick-up and distribution function in transportation, the line-haul use of the most efficient modes for the distance and type of shipment involved, and highly automated data exchange and management information to significantly improve labor productivity and reduce the paperwork involved in transportation.

There appear to be two courses for future development of freight systems. One is evolutionary, building on the best aspects of the present freight transportation modes but moving to more automation and increased equipment and labor productivity. The other course is that of radical changes based on high technology which would in effect create entirely new transportation modes compared with those we know today. Automatic control is a key part of either development option. For the near term—the next ten years—one can foresee continued evolution of present advances in railroads and trucking. The carriers will probably implement new advances in management information systems, in terminal process control systems, and, as the institutional barriers come down, in computer to computer data exchange. In the near term, the modes can expect to experience economic limitations which will determine the pace of the evolution. As the evolution continues into the 25-50 year time frame, one can envision more automation, some vehicle improvements, and an emphasis on increased labor productivity and an elimination of all paperwork associated with shipments and their payment procedures.

Inherent in the radical, technology-based developments is a long time horizon in the 25-50 year time frame. A radical freight transportation system concept can be expected to be automatically controlled (probably with no driver at all); feature much higher line-haul speeds than today; operate on a fixed guideway, though not necessarily steel rails; transfer shipments at highly automated terminals at origin and destination; and require no paperwork to complete the shipment or its billing. The radical concepts will require many years to implement and huge capital investments for the construction of guideways and terminals facilities. There will be a multitude of institutional problems, not the least of which is the present work force in freight transportation which numbers in excess of three quarters of a million people.

The Department of Transportation is currently initiating a research program into advanced concepts of freight transportation at the Transportation Systems Center. The program will deal primarily with the radical concepts which involve the application of technological advances. In July 1976, the TSC program was aided by a conference of the National Academy of Engineering Committee on Transportation which met to discuss research planning and the program approach to be followed by TSC in the advanced freight systems area.

Time will tell whether the types of radical advanced concepts to be examined and analyzed by TSC can be implemented in the United States in the next 25 years. Implementation will be inevitably tied to constraints of the environment, energy shortages especially in petroleum, and the economic situation which exists in this country between now and 2000. In any case, automatic control, particularly in the area of management information, has significant potential for improving intercity freight transportation in the future.

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BIOGRAPHY

Kenneth Troup has been involved in research at the Transportation Systems Center related to freight transportation for the past five years. His emphasis has been on the use of information systems in freight transportation, and on railroad operations. He has been responsible for planning, management and conduct of a variety of freight and railroad oriented projects including analysis of agricultural commodities transportation during the 1973 grain crisis, terminal information and control systems in freight transportation, railroad freight car operations, and institutional aspects of the rail/highway grade crossing safety program. Before joining TSC in 1971, he was with the U.S. Air Force involved in the development of meteorological data collection systems. He has his BS degree in Engineering from Purdue and MS degree in Engineering Management from Northeastern University.

U.S. Department of Transportation *Freight Transportation Digest, October 1976*

EVALUATING TECHNOLOGICAL INNOVATIONS FOR FUTURE INTERCITY FREIGHT SYSTEMS

by

Domenic J. Maio

BACKGROUND

The Transportation Systems Center has been conducting a comprehensive study of intercity freight transportation. This study, which reviews the performance of the transport services from the perspective of the needs of the goods distribution industry, has been conducted in support of a TST R&D Policy Office multi-year evaluation of the Department's freight-related R&D programs.

The initial phase of this study produced a systematic characterization in terms of cost and service attributes of the available and evolving modal services, an assessment of the relationship of the mode choice decision to these attributes, and estimates of the potential for system improvements.(1, 2, 3)

Freight systems service and cost performance should be evaluated in terms of its ability to meet the collective objectives of the private sector suppliers and users of the services, and of the collective goals of the public sector. Any proposed single mode or multi-modal system innovation should be evaluated in terms of carrier profitability, market satisfaction, and public benefits, while giving full consideration to the potential performance of competing services.

It has become abundantly clear that neither the supply side nor the demand side of the transportation/distribution process can be adequately described as a homogeneous body amenable to single measure characterization. There are many markets (each multi-faceted) with distinctive and changing requirements, which dictate the service and cost attributes of viable freight transportation services. Public planning, guidance, and support of future system developments are complicated not only by the interaction of so many conflicting private sector requirements, but also by the absence of a clearly defined national objective for intercity freight transportation.

One national objective may be synthesized from the literature—to establish "balance" in the system. Balance, in terms of modal market shares, is a highly variable judgment which must be politically defined on the basis of current perceptions of optimality of service quality, capacity, prices, resource conservation, environmental protection, system viability, and the general economy.

The means of establishing balance in intercity goods movement most often identified is the introduction of high performance intermodal rail/highway and/or air/highway systems utilizing van-sized intermodal container units. These intermodal systems are envisioned as sharing the markets with direct truck, rail, water and pipeline systems.

The ability of such proposed intermodal systems to compete effectively with the several direct highway services (i.e., common, contract and private carriage) in each of the various markets is very much a function of the service/cost attributes of the proposed systems. The service/cost relationship of the given system is, in turn, very sensitive to the specific trade-offs between line-haul and collection/distribution attributes.

There are indications that the market opportunities for high-performance intermodal rail/truck service may be large if the quality of dock-to-dock service required by the various types of markets can be provided within specific cost ranges. A TSC staff study investigated the competitive range of markets for a range of hypothetical rail/truck intermodal systems.[4] This study evaluated the sensitivity of the competitive relationships between these new systems and the several competing highway services to the possible trade-offs between line-haul and collection/

distribution functions, to capacity utilization, and to commodity attributes.

The primary focus of this TSC project, to date, may be characterized briefly as identification of current system deficiencies, definition of future system cost and service performance requirements, and formulation of an objective process for evaluation of any future system innovation. The remainder of this paper outlines such a process for screening proposed technological innovations in intercity freight transportation. The process concentrates on those variables which appear to be quantifiable while recognizing the need for the decision-maker to factor in more subjective considerations in the final evaluation.

INTRODUCTION

The evaluative process described herein assumes that there is concern for the total societal effects of a proposed technological innovation. Consideration is given to changes in user costs which impact total cost of goods distribution as well as to changes in carrier profits which may result. The evaluative process is conceived as an interactive process which uses computer models, data files, and manual computations to identify (1) the potential modal shifts, (2) the changes in the transportation cost and other distribution costs, and (3) the changes in carrier profits which result from alternative systems. It subsequently compares the aggregate of these changes with the cost of implementing the innovation in order to rank-order the benefit/cost indices of proposed alternative system innovations. Near-term and long-term technological innovations should be evaluated in this manner, giving consideration to quantifiable societal benefits and disadvantages, and to the total cost of implementing the innovation.

System near-term innovations are envisioned to be basically modifications of existing systems through relatively modest improvements in components of the basic technology, or improvements in operational and managerial relationships between the functional (or network) elements. Such innovations might include, for example, the implementation of a computer-based, industry-wide rail car management system; they might also include an integrated rail/truck or an air/truck system using existing technologies, but incorporating a traffic routing and scheduling system which coordinates transfers, from pickup through line-haul to final delivery, of all shipments, whether by a single carrier or by several carriers.

Long-term innovations are considered to be those involving major new technology, substantially different in concept from those currently in use by the intercity freight systems. A new technology freight system may be an amalgamation of subsystems (or components) currently in existence in other industries performing other, but analogous, functions, or it may require completely new innovative technology not yet in existence. For example, a long-term innovation involving a major new technology might be a high average trip speed network based on a highway collection and distribution subsystem, a fixed guideway line-haul subsystem, semiautomated terminal transfer subsystem, and intermodal van-sized containers under the overall control of a sophisticated computer scheduling routing and tracking subsystem. This hypothetical system might provide consistent door-to-door service better than today's surface system, yet at prices lower than today's air services.

In both the near-term and the long-term innovations, a proposed innovation need be described somewhat abstractly only in terms of its cost-related and service-performance-related characteristics. The cost and service parameters of the proposed systems may be quantified either in absolute values or in terms of the incremental *changes* to component elements of cost or service of existing systems. This evaluative process requires that an adequate systems engineering study be performed to provide, as input to the process, realistic estimates of the cost and service characteristics relationships of the system to be evaluated.

THE EVALUATIVE PROCESS

The process places the proposed system innovation in the context of the dock-to-dock transportation system network for the particular group of commodities affected, and, in turn, places the transportation service in the context of the goods distribution process. The perspective of the goods consumers and suppliers (the ultimate users of the transportation services) is given consideration. It is assumed that the consumers' interest is primarily in availability of a broad spectrum of services at the lowest possible prices, and the suppliers' interest is in maximizing the size of his markets and minimizing the total cost of distribution of goods. This perspective forces a consideration of the size of the trade-offs made by different groups and types of shippers and consignees between inventory and other ownership and handling costs, and the direct costs of transportation to markets.

The evaluative process is therefore composed of two essential parts. The first part estimates the total system (or total societal) benefits (i.e., transportation cost reductions, service improvements, and change in carrier profits) of the proposed technological innovations. The second part involves comparing these benefits against the full research, development and demonstration costs, and the initial investment for the proposal. While the benefits to the physical distribution system are estimated as annual savings in total cost over the life of the project, the R&D expenditures and the investments are made prior to the period when the benefits are realized. Therefore, the net benefits (i.e., sum of all benefits minus the sum of all costs) in future years are discounted to the present. A present value of the aggregate of all future costs and benefits is calculated for each of several system options for rank ordering of the options. Also, this present value of net benefits permits the ultimate decision maker to compare investment of public funds in one of these projects as an alternative to investment in other transportation, or even non-transportation, projects.

This process of evaluating system options or technological innovations requires an in-depth understanding of the interaction of the supply and demand characteristics of the total system. It requires the availability of a comprehensive information base on the service quality and cost characteristics of existing and evolving intercity freight system options available to shippers; the mode choice determinants of different groups of commodities; types of users; and types of markets. It also requires certain analytical tools (models) which assist in the construction of possible future traffic demand scenarios based on changing regional growth patterns, changing mixes of commodities, changing network, and corridor traffic flows. It also requires analytical tools for estimating potential shifts in modal shares which may result from these demand changes, as well as from changes in the relative service quality and price of available services.

A block diagram representing twelve functional components of the evaluation process for intercity freight systems options is depicted on Figure 9-1. The comprehensive TSC study, "Cargo Transportation Systems and Physical Distribution," for TST R&D Policy Office, is designed to develop most of these component models and information files. They are being developed to a level of refinement suitable for screening likely technological innovations and for evaluation of these innovations in terms of potential economic viability. Other TSC staff study papers published under this project treat each of these areas individually. Each of these blocks is discussed in numerical sequence.

Block 1 represents the development of future demand scenarios which provide not only estimates of the change in total volume of origin-to-destination flows, but also an estimate of the changing mix of commodities whose transportation characteristics will dictate requirements for the future systems. These demand scenarios will reflect a range of input assumptions regarding the growth rate and character of the national economy and the relative growth of different regions and industries. The demand scenarios will include the total mix of all commodities (i.e., bulks, manufactures, and farm products) disaggregated at the two-digit STCC code level (i.e., between 20 and 30 commodity groups).

The second block represents the development of a comprehensive and consistent set of cost and transit time functions for a representative set of some 20 to 25 separate systems (or service options) within the rail, highway, and air modes for movement of manufactures and

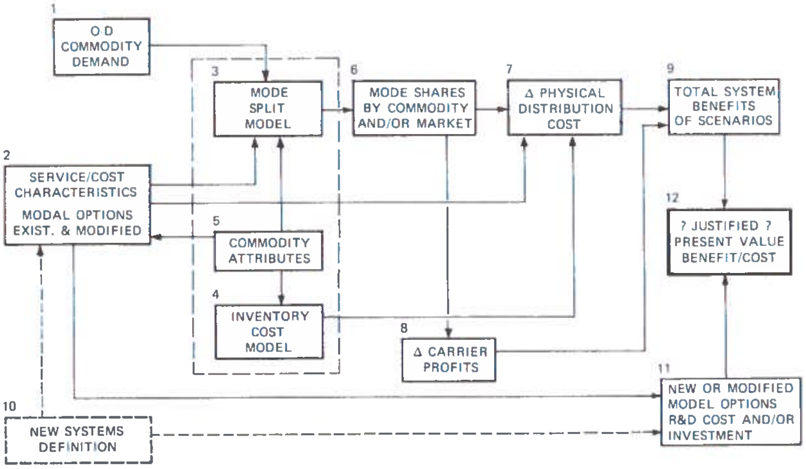

Figure 9-1. Evaluation Process For Intercity Freight Systems Options.

perishables. The cost and service characteristics of existing and currently evolving systems are represented in sufficient operational function detail, factor input detail, and market-type detail to construct supply side cost and service estimates for any number of commodity O-D markets. This effort provides capability for estimating changes in the total trip characteristics caused by a specific change in a functional component of one factor input.

Blocks 3, 4, and 5 represent an attempt to develop an analytical tool which relates the mode choice behavior of transportation users to specified supply side service and price characteristics and to specified attributes of the shipments (e.g., shipment size, distance, and value). Given a forecast of regional O-D flows of commodities grouped by like characteristics (from block 1), a file of service and price estimates for the system options available to each market (from block 2), and a file of commodity attributes (block 5), then a mode split model, or models (block 3), will provide estimates of the change in system market shares (block 6) resulting from any change in the available supply side options. Block 5 represents a file of 5-digit STCC commodity codes with estimated 1972 dollar-per-pound values and average density (pounds per cubic foot) and a distribution of tonnage by shipment weight blocks. The value-per-pound and shipment-size attributes are a direct input to the mode share equations, whereas density enters indirectly through its effect on the price of the service.*

There are several approaches which can be taken to determine mode split and estimate changes in modal shares which might result from the introduction of a new or modified system. The first is the development of an econometric model such as a LOGIT multivariate formulation which depends upon availability of adequate data on historical mode choice behavior. Such a model is currently under development at TSC, and involves trip time and cost of service options as well as shipment size, distance, and value of the aggregate movements. The objective of this effort is to obtain a set of statistically sound equations which adequately explain the mode choice decision of aggregations of shipments, and which display a sensitivity to the abstract service quality and price characteristics of the supply and demand sides as expressed by the above-mentioned variables.

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*Although the statistical model equations are estimated from prices (i.e., rates) actually charged for service at the time the mode choice was made (i.e., 1972, it is believed that engineered economic costs (in constant dollars) are more stable surrogates for price of future services.

The second approach is the development of a "normative" model. This model attempts to represent the major elements of the total cost of distribution of goods for different types of commodities and different types of users in different market situations, and estimates the least total cost mode for each movement. Such a model is under development by P. Roberts and H. Marcus of MIT under another DOT project, and involves most of the same variables and many of the same input data files. The difference between the two is that the latter provides a perspective of an optimum modal split, given the inputs and a rational decision process. The former purports to reflect the real-world behavior, given its distinct characteristics and given sufficient data on historical performance. Both of these models are anticipated to be applicable to some aggregate level of commodity grouping, and at some aggregate regional pair O-D flows. Each of these models represents a link, or corridor, approach to mode split analysis.

The third approach to determination of mode shares is the development of a multimodal network traffic flow simulation model which assigns commodity O-D flows to routes through the networks based on the least cost paths. The link impedances represent costs which are the summation of supply side costs for transporting the particular type of shipment and the demand side opportunity cost of capital tied up in the goods in transit. The network link and node cost and speed characteristics would be estimated from the functions and data developed in block 2. The nodes in each modal network would represent sources and sinks for the commodity flow and interchange points for the intermodal moves. The links in each modal network would represent the total capacity of all routes between the selected nodes. The model should be capable of handling intermodal flows where specific link and node impedances make such multimodal trips the least-cost route from origin to destination. It is not clear at this time whether the capability to handle simultaneously more than two modes is a necessary requirement of the model. A binary choice between rail and highway or a combination of links on the two networks and, conversely, between highway and air or a combination of links on these two networks may be adequate. However, making the three-way choice between rail, motor carrier, and private truck modes (all three of which have distinctive cost and service characteristics) may dictate a more complex model. The total size of this model must be limited to a capability for traffic assignment over several hundred (rather than several thousand) links encompassing the multimodal network. In applying the model to specific regions of the country or to the total U.S. networks as a whole, the objective would be to estimate the effect on modal shares (block 6) of changes to specific link and node cost and service characteristics. This would also involve identification of particular groups of commodities and the total volume of traffic which might be attracted by a particular technological innovation for line-haul or for terminals (or for that matter an entirely new network) which significantly changes the performance characteristics of available service options. Expectations are that all three approaches will eventually be available to the Department, and that their use in concert will bracket the range of values which represents future reality.

Potential shifts in modal shares are of interest in determining the market attractiveness of new system options in order to plan system infrastructure. However, estimates of mode shares in themselves do not provide the complete answer to total system economic benefits. The impact on the total national costs of physical distribution of all the goods moved in the system (or in a portion of the network studied) must be estimated. Block 7 represents the aggregation of all transportation-related costs for all the goods flowing in the system plus the goods ownership cost (i.e., inventory or opportunity cost of capital) for the time in transit. The transportation-related costs can obviously be calculated from the tonnages by mode (from block 6) and from the costs (from block 2). The user cost, which, together with the transportation costs, represents the total physical distribution costs, must be derived by an Inventory Cost Model (block 4). If either of the first or third approaches (i.e., econometric model split model or network simulation model) is used, a separate inventory cost estimating capability is needed. If the second approach (i.e., normative model split model) is used, the inventory cost computation is an integral part of the mode split decision process within the model. The inventory cost model may be very simple, as is the case of the illustration used in Reference No. 5 (i.e., the product of total dollar value of all affected commodities, some fixed annual percentage representing opportunity cost of capital, and a fraction of the year to represent the time involved). It may be a more sophisticated logistic cost formulation which accounts for different warehousing, inventory, and ordering practices of different types of industries and size of firms. The latter approach is taken in the previously mentioned research effort by Roberts and Marcus of MIT. It is expected that this inventory cost model of their total modeling effort will provide DOT with more accurate estimates for block 4.

The evaluation of alternative systems scenarios could be made at this point on the basis of the change in the total cost of distribution resulting from the changes from the status quo base case. However, there is one more element which should be considered before judging the relative worth of a new technology system or a service innovation. This element is the impact on the total profits of our private sector carrier industry. Not only must the change in total cost to the eventual consumer of goods be considered, but the loss (or gain) in profits to the suppliers of the very services DOT is attempting to improve must be considered. The increases in profits for one group of carriers resulting from cost reductions and increased traffic are estimated, and the loss in profits for the rest of the carrier industry resulting from the estimated diversions to the new system are also estimated. Block 9 therefore involves computation of the changes in costs and revenues to all interest groups, and these changes, in the aggregate, represent the total system benefits.

Block 10 represents a group of activities providing, through systems engineering studies, the abstract service and cost performance characteristics of advanced technology freight systems. These cost and service performance functions provide inputs to block 2 through which the new systems enter the evaluation process. Block 11 is the definition of the capital requirements to translate a system concept into an operating reality over a period of years.

Block 12 is the focal point where the annual system-wide benefits and the total R&D and capital investments are discounted to present value and compared to determine whether the benefits justify the costs. The form of the comparison is either a present value of net benefit of proposed projects or a discounted benefit/cost ratio, or both.

LEVELS OF EVALUATION

The evaluation of a system innovation may be performed at any one of four levels of aggregation. The choice of a level of evaluation will be determined by how detailed an answer is sought to a policy question (i.e., the more accurate or precise the answer needs to be, the more detailed the evaluation must be).

Level One

The first level is the most aggregate level which relies on national system averages for cost and service characterizations and gross modal definitions. Also, all commodities are treated as one homogeneous mass or, perhaps, are subdivided into three major classes (i.e. bulks, manufacturers, and perishable food stuffs).*

Level Two

The second level of analysis is more detailed in that it treats individual origin-to-destination flows (between some defined economic regions). It distinguishes between 20-30 commodity groups based on major transportation-related attributes, and distinguishes between the three to six services which compete for each of the twenty-odd commodity groups. There may be as many as 20-30 modal systems in total across all commodities and O-D pairs. This level is basically an isolated corridor analysis, or a simple O-D link

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*An illustration of this level of evaluation is contained in Reference No. 5

flow analysis, with no consideration given network flows or modal network interactions. It depends upon a modal split model* which is sensitive to service and price characteristics of the competing services and the attributes of the commodity markets (e.g., distance, shipment size, and commodity value per ton).

Level Three

The third level of evaluation involves the interaction of multimodal networks with intermodal terminals. This depends upon the application of a network traffic flow simulation which assigns traffic based on least-cost paths for all O-D commodity flows.** Of necessity, in order to handle more than one modal network, a highly aggregate mainline representation of each modal network must be used, and the cost functions for each link must be simple. The primary objective of this level of analysis is to estimate the effectiveness of changes in the cost characteristics of certain network links or nodes in attracting certain commodity flows to a particular network. This process provides a means of determining whether the minimum quantity of traffic volume required to produce the estimated average costs appears to be feasible. The traffic volume on a particular link or collection of links affected by the technological innovation, at this level of analysis, will be the aggregation of all attracted commodity flows between a number of O-D pairs capable of joining their paths over the links in question. At this third level of analysis the "mode split" estimate is obtained by virtue of the multimodal network descriptions (including their link and node cost characteristics) and the relative impedances (transport and time costs) of the alternative paths that are available to each commodity O-D flow.

Level Four

The fourth level of evaluation follows in logical sequence. After having survived the first three levels of evaluative analysis and an estimate has been developed of the quantity of traffic and the character of the mix of commodities attracted by the technological innovation, it remains to analyze the new modal network in more detail. Therefore, a more sophisticated and more detailed single mode main line network/cost model is required to establish more specific performance requirements for the proposed system and to determine whether the earlier cost and service performance estimate were reasonable. Where level three envisions a multimodal network traffic flow simulation model of several hundred nodes, level four envisions a single mode network flow simulation model of several thousand nodes. It is not suggested that this single-mode network analysis can be conducted in complete isolation from interaction with the other modes. It is contemplated, rather, that after having performed the first three levels of analysis, a single-mode network will be extracted from the multimodal network and analyzed in greater detail (given the flows and intermodal interchanges defined by the previous analysis). Iteration back through the multimodal network analysis may be in order, if the network parameter values change significantly. Table 9-1 summarizes this concept of four levels of evaluation.

Table 9-1. Level of Evaluation

Level	of Nodes	Detail
1	2	Single Origin—Destination Flow Single Homogeneous Commodity Gross Modal Description National System Averages
2	10-99	Multiple Origin—Destination Flows 20-30 Commodity Groupings 3-6 Modal System Options Per Movement
3	100-999	Multiple Origin—Destination Flows 20-30 Commodity Groupings 3-6 Modal System Options and Combinations Per Movement Multimodal Networks Intermodal and Modal Terminal and O-D Nodes
4	1,000-20,000	Multiple Origin—Destination Flows 20-30 Commodity Groupings Single Mode Network Routing and Operations Options Network Configuration Options

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*An econometric or normative mode split model of the type referred to in the previous section.

** A multimodal network traffic flow simulation model of the type described in the previous section is mandatory for this level of analysis.

CONCLUSION

The evaluative process outlined in this paper is the result of logically assembling ongoing component analyses of the supply side and demand side and their interrelationships into a systematic framework. It is based upon available data and analytical models which are currently under development within the Department and in the private sector. The paper suggests a new modeling effort (i.e., multimodal network model) which is within reach in that it could evolve out of current network modeling efforts at TSC.

This paper focuses attention on the fact that evaluation of a proposed innovation can take place at any one of several levels of detail, depending on the accuracy or precision needed in answering a policy question. Certainly, if preliminary screening of classes of system changes is in question (e.g., improving rail yards or rail line-haul), then level one may be detailed and accurate enough. However, if substantial funding commitments for long-term technology R&D are in question, then analysis should proceed down through the levels until the quality of the answers is commensurate with the level of funding in question.

The development of this evaluative process has been, and should continue to be, a guide to incremental advancement of the analytical tools and data bases described. These tools are needed to identify genuine opportunities for technological advances and operational improvements in intercity freight systems. Also, this project has provided the framework for a coordinated DOT program for continued advancement of this analytical capability. This analytical capability is essential if the Department is to stimulate the private sector in pursuing the needed technological advances. It is a prerequisite if DOT is to provide general leadership to the anticipation and solution of future freight service problems and needs.

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BIOGRAPHY

Domenic J. Maio received his B.S. degree in Civil Engineering at Northeastern University in 1954 and, in 1967, his M.S. degree in Civil Engineering at the University of Washington, where he majored in Planning of Transportation Systems. He is a registered Professional Engineer in Massachusetts and Washington. He has had 22 years of professional experience ranging from facilities construction-oriented planning and design for highways, railroads and missile systems to cargo airplane-oriented market research, and most recently federal policy-oriented intermodal cargo system analysis. He has been employed two years with the U.S. Army Corps of Engineers, six years with the Boston Consulting firm of Charles T. Main, and nine years with the Boston Consulting firm of the Boeing Company in Seattle. For the last five years he has been with TSC, where he has been responsible for a broad program of analysis of operations, economics and demand for surface and air cargo transportation systems.

WIND TUNNEL TESTS OF THE AERODYNAMIC DRAG OF CONTAINERS AND TRAILERS ON FLAT CARS

by

DR. ANDREW G. HAMMITT AND DR. TIMOTHY M. BARROWS

INTRODUCTION

This paper represents a summary of recent test results, concentrating on the problem of railroad train aerodynamic drag. A more complete report giving information on other aerodynamic forces and additional configurations will soon be released through the National Technical Information Service.

The measurement of the tractive resistance of railroad trains has been a subject of interest for more than 100 years. Notwithstanding this long history, enginneering data are not yet available for making accurate predictions of such resistance. The rolling resistance is hard to measure, and the parameters which affect it are hard to control. The wind tunnel is a good way of measuring aerodynamic forces, but has not yet become a thoroughly reliable and trusted means of measuring aerodynamic forces for railroad trains. The principal reasons for this are the lack of proper ground-plane simulation and the old classic problem of Reynolds number extrapolation. In full-scale tests of total resistance, it is difficult to separate aerodynamic from rolling resistance.

One of the early full-scale measurements of freight train resistance was done by Professor Schmidt at the University of Illinois in 1910 (Reference 1). Many of these early results have been compiled by Davis (Reference 2) in his 1926 paper. While much of the early work consisted of overall resistance measurements, the work of the Electric Railway Commission (Reference 3) is noted as an early and careful attempt to measure aerodynamic resistance alone. A street car was suspended by means of a balance on a railway flatcar and the aerodynamic resistance of the street car measured as the flatcar was moved at different speeds.

A surge of interest in the aerodynamic resistance of railway trains occurred during the 1930's, particularly with respect to high-speed streamlined passenger trains. At this time, several investigators used wind tunnels as means of determining the aerodynamic effects. The work of Tietjens and Ripley at Westinghouse (Reference 4), Klemin at New York University (Reference 5), and Johansen at London Midland and Scottish Railway (Reference 6) are all examples of the application of wind tunnel aerodynamic testing to determine and improve the aerodynamic resistance of passenger trains.

These were not the first uses of the wind tunnel to test the aerodynamic resistance of trains. Even before the wind tunnel had been developed for testing of airplanes, W.F.M. Goss had built a wind tunnel at Purdue in 1896 and performed tests on railway trains (Reference 7).

Following World War II, the interest in the aerodynamic resistance of trains was somewhat reduced, particularly in the United States. There have been a few wind tunnel tests of special train configurations such as that of Lesher at the University of Michigan (Reference 8) and that of Burlage at Case Institute (Reference 9). Since the 1960's, interest in Europe and Japan has increased. The Japanese have done considerable work particularly aimed at the development of their high-speed Tokaido line (Reference 10), and the French have built a special wind tunnel at Saint Cyr L'Ecole for the testing of railway trains (Reference 11). The test section of the usual wind tunnel is too short relative to its diameter to be used efficiently for railroad train testing. The French tunnel is designed to overcome this difficulty by providing a long test section and a boundary layer control system to make this long test section effective.

In recent years the interest in the aerodynamic resistance of freight trains has increased in the United States. One reason for this has been the introduction of new car designs which have a higher aerodynamic resistance. Rack cars and piggyback cars are examples. Practical experience on the railroads has shown that the power required to pull a train of rack or piggyback cars is higher than for the standard cars. Wind tunnel tests were made by Matthews and Barnett (Reference 12) in 1968 on automobile rack car configurations. These tests did demonstrate the high aerodynamic resistance of rack cars, and showed ways in which it could be reduced.

The work of Davis (Reference 2) in 1926 is classic in the field and is the principal reference even today. The situation is complicated by the introduction of a different relation, referred to as the "Modified Davis" formula by the AREA (Reference 16), which seems to have been originated by the Canadian National Railroad. The two formulas as applied to conventional freight cars are as follows:

$$\frac{R}{Wn} = 1.3 + \frac{29}{W} + 0.045\ V + 0.0005\ A\frac{V^2}{Wn}$$

Davis

$$\frac{R}{Wn} = 0.6 + \frac{20}{W} + 0.01\ V + 0.07\frac{V^2}{Wn}$$

"modified Davis"

where R is resistance in pounds, W is weight per axle in tons, n is number of axles, and V is velocity in miles per hour. Davis quotes authority for his selection of the parameters, but the considerable difference between his values and the so called "modified formula" is disturbing. Figure 10-1 shows the total resistance of a 75-ton freight car, the weight of a loaded TTX car, calculated by both of these methods, and the contributions made by the different terms.

There are some recent results particularly applicable to the TOFC and COFC operations. The work of Luebke (Reference 13) and that done by the Erie Lackawanna (Reference 14) are in this class. In both of these instances total resistance has been determined, and then the aerodynamic part calculated by subtracting out the rolling resistance using the "modified Davis" formula. Luebke gives the following results for the aerodynamic coefficient K, the coefficient of the V^2 term in the "modified Davis" formula. The relation between K and C_dA will be discussed later.

	K	C_dA	
		(ft^2)	(m^2)
TOFC (C & O tests)	0.16	63	5.85
COFC (NYC tests)	0.0935	37	3.44
TOFC (EL tests)	0.20	78	7.24

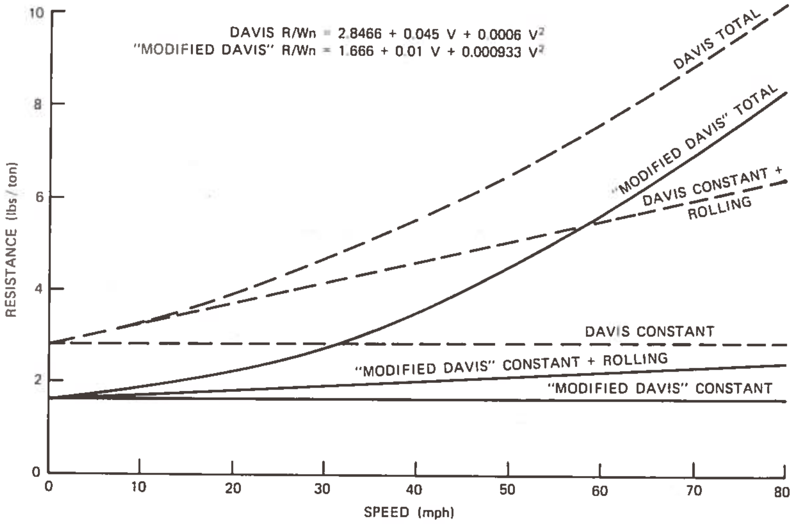


Figure 10-1. Resistance of 75-ton 4-axle freight cars from Davis and "Modified Davis" formula as a function of speed curves show the effect of different terms in formulas.

Luebke justifies the difference between the Erie Lackawanna results and the Chesapeake and Ohio results by the fact that Erie Lackawanna only used data from runs at about 50 mph, and he shows that the Chesapeake and Ohio results give about the same coefficient when only the data from runs at this speed are considered. While this may explain the difference between the two results, it is disturbing in that it suggests that, with data reduced in this way, the aerodynamic coefficient depends upon the speed at which the tests are run.

The aerodynamic basic relation for resistance is

$$R = \frac{1}{2}\rho V^2 C_d A$$

where C_d is dimensionless, and the other quantities may be in any consistent units. To reduce this to the form of the Davis formulas, a particular value of the density of the air must be assumed. If the air density is taken as 0.002377 slug/ft^3, the relation becomes

$$R = 0.002556\ V^2\ C_d A$$

in which R is in pounds, V is in mph, and $C_d A$ is in ft^2. $C_d A$ is called the drag area, and is a convenient quantity in which to work, especially for shapes for which a basic characteristic area is not well-defined. The relation between $C_d A$ and K, the resistance coefficient of the "modified Davis" formula, is

$$C_d A\ (\text{ft}^2) = 391.1\ K, \text{ or } C_d A\ (\text{m}^2) = 36.33\ K$$

The drag area is the quantity that will primarily be used to specify the resitance in this report.

ECONOMIC EFFECT OF A CHANGE IN RESISTANCE

A reduction in required power reduces the cost of railway operation in two different ways. It reduces the fuel expended, and it reduces the maintenance and operating costs of locomotives. The fuel costs are almost directly related to the change in power. The capital and maintenance costs depend more on the number of power units used on a particular train than on the actual power used. It is reasonable to assume that the number of power units will be reduced as the power required is reduced but, since locomotives come only in integral units, small reductions in required power may not allow a reduction in power units. If the power unit is sized by the requirement to climb a governing grade at low speed (where aerodynamic resistance is unimportant), then reduced aerodynamic resistance will not allow a reduction in power units. The problem here is the efficiency of power unit utilization. Nevertheless, for present purposes, it is reasonable to assume that the utilization, on the average, would be the same for trains of different aerodynamic resistances.

The energy saved by a specified change in aerodynamic resistance can be expressed by the relation

$$\Delta E = 0.002868\ \rho\ V^2\ \Delta C_d A$$

where ΔE is in hp-hrs per mile, ρ in slugs, V in mph, and $\Delta C_d A$ (the change in drag area) in ft^2. If sea level air density is used, the relation becomes

$$\Delta E = 6.817(10^{-6})\ V^2\ \Delta C_d A$$

In order to determine the cost of the additional energy, it is necessary to know the cost of the fuel and the maintenance and capital costs of the locomotives. The fuel consumption of a railroad locomotive is on the order of 0.056 gallon of fuel per hp-hr. This number is consistent with the basic information on diesel engines and with the information obtained from References 20 and 21. Reference 20 used 0.0606 and Reference 21 gives 0.056. The cost of the fuel has changed considerably during the past few years, and it is difficult to fix a lasting value. Reference 20, written in 1969, used $0.10 per gallon, and Reference 21 gives $0.269 per gallon as a current price in May 1975. Using the current figures from Reference 21, the fuel cost is $0.015 per hp-hr. Maintenance and capital cost are given in Reference 20 as $0.0034 per hp-hr, and in Reference 21 as $0.006 per hp-hr. Using the later and more current figure, the total cost of both fuel and equipment is $0.021 per hp-hr. It is interesting

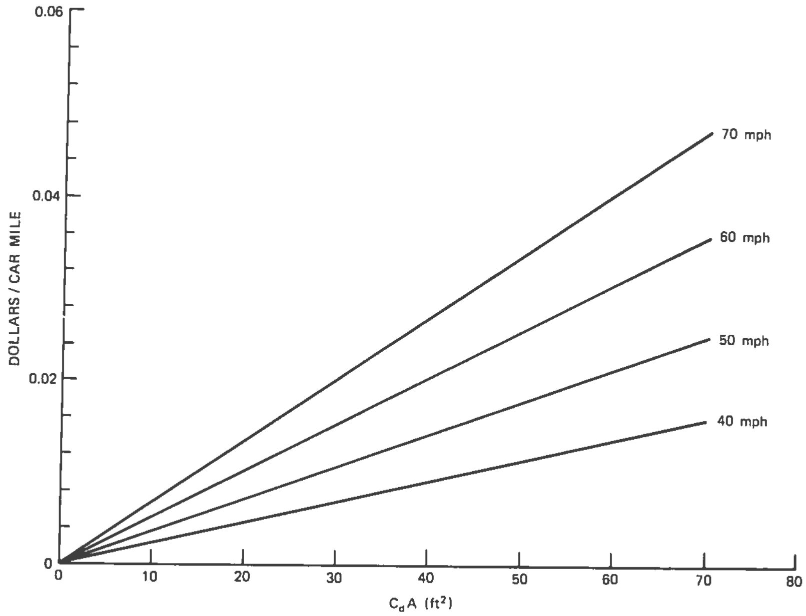


Figure 10-2. Cost per car mile required to overcome aerodynamic resistance as a function of drag area.

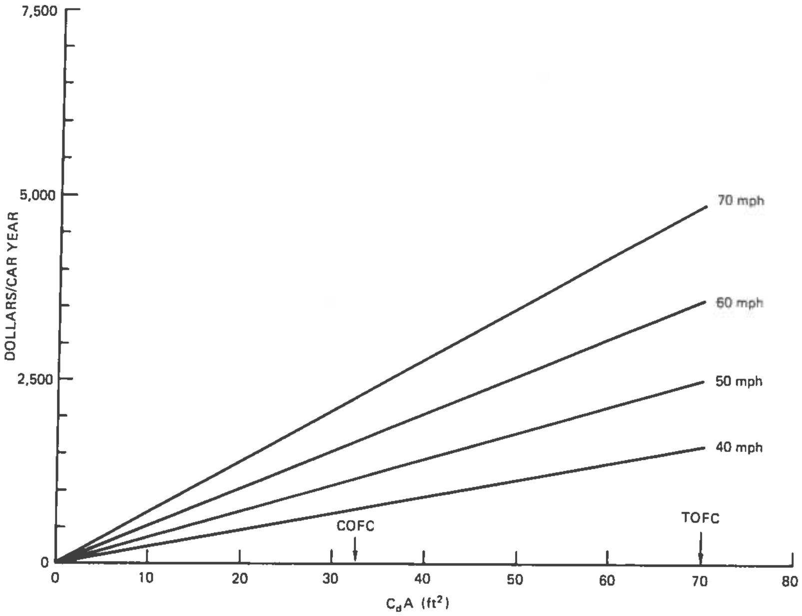


Figure 10-3. Cost per car year, based on usage of 200,000 miles per year, of oversoming aerodynamic resistance for different speeds as a function of drag area. Typical values of drag area for TOFC and COFC are shown.

to note that the proportion of the total cost attributable to fuel has not changed appreciably since 1969, that fuel costs are now 71 percent of the total, and were 64 percent in 1969.

Figure 10-2 shows the cost per car mile caused by aerodynamic drag as a function of CdA and speed, and Figure 10-3 the cost per year based on a heavy car usage of 200,000 miles per year. (Average national usage is about 100,000 mi./yr.)

Based on the available data on the aerodynamic resistance of TOFC and COFC operations, reasonable values of C_dA are 70 ft^2 (6.50 m^2) fpr TOFC and 37 ft^2 (3.43m^2) for COFC. As an example, it can be determined from Figure 10-3 that the use of containers instead of trailers in 60-mph service would result in an annual savings per car of $1,700.

RESTRICTIONS IMPOSED BY OPERATING PRACTICE

A survey of railway operating practice was conducted in order to determine the conditions under which railroad piggyback operations were conducted. A short exposure to railway loading yard practice soon convinces one that the equipment must be rugged and designed for rapid handling. Any changes that would increase the difficulty of handling the equipment in the loading and unloading process is not likely to be economically viable.

The relative merits of container and trailers are worth discussing. Containers seem to have all of the advantages from the point of view of line hauling. They are lighter in weight, give a lower center of gravtiy, and have considerably less aerodynamic resistance. Their disadvantages are that they require a trailer bed on which to be loaded that must be stored and available when the container is to be unloaded. They also are not suitable for circus style (drive on) loading and unloading, but require relatively expensive side or overhead loading equipment. At present their use seems to be pretty much restricted to maritime cargoes, for which trailers are unsuitable, and the land connections for these cargoes.

The main disadvantages of containers over the standard boxcar are the reduced loading per unit length caused by the reduced height and width, and the aerodynamic losses caused by the increased gaps between the containers on successive cars. The Southern Pacific has suggested a container well car design in which two containers are stacked on top of each other in a well between the wheels of the car. This design increases the weight per unit length of the train.

The great advantage of trailers is that they can be circus loaded when side loading equipment is not available, and that a side loader can set them directly on the ground without waiting for a trailer bed to be brought. Circus loading is particularly important in small freight terminals where side loading equipment is not available. The importance of circus loading seems to be decreasing as piggyback traffic increases and more yards obtain side loading equipment. If it is satisfactory to design equipment not suitable for circus loading, then better solutions for trailers become obvious. A well car, in which the wheels are located in wells between the trucks, is one solution. Such an arrangement requires the trailers to be loaded facing in opposite directions and the wheels submerged in a well. These conditions require side loading. It also lowers the center of gravity and decreases the frontal area of the loaded car. Other streamlining suggestions include fairing pieces to go under and/or between trailers. It seems necessary to add such fairing pieces after trailers have been loaded, and the cost of this additional loading operation is likely to prove prohibitive. Changes may restrict the flexibility of a car so that it is only suitable for trailers or containers. This restriction complicates the railway operation, but must be evaluated in individual situations.

WIND TUNNEL TESTS

Model scale tests were conducted at the California Institute of Technology GALCIT wind tunnel, which has a 12-foot ground plane, a 5-foot diameter yaw table, and a six-component strain gauge balance mounted in the yaw table. Since the models used in this experiment were longer than the yaw table, a 10-foot-long auxiliary mounting plate or track was provided and bolted to the yaw table. This overhung the ground plane, but turned with the yaw table and allowed the entire model system to be moved with the yaw table. In all tests, the only forces measured were those on the center car of the consist, herein called the metric car. The scale selected was 1/43. The train in each case consisted of a locomotive, three flatcars, and a boxcar. Figures 10-4 and 10-5 show the consist used for standard trailers. Figures 10-6 and 10-7 show two of the modified configurations which were tested.

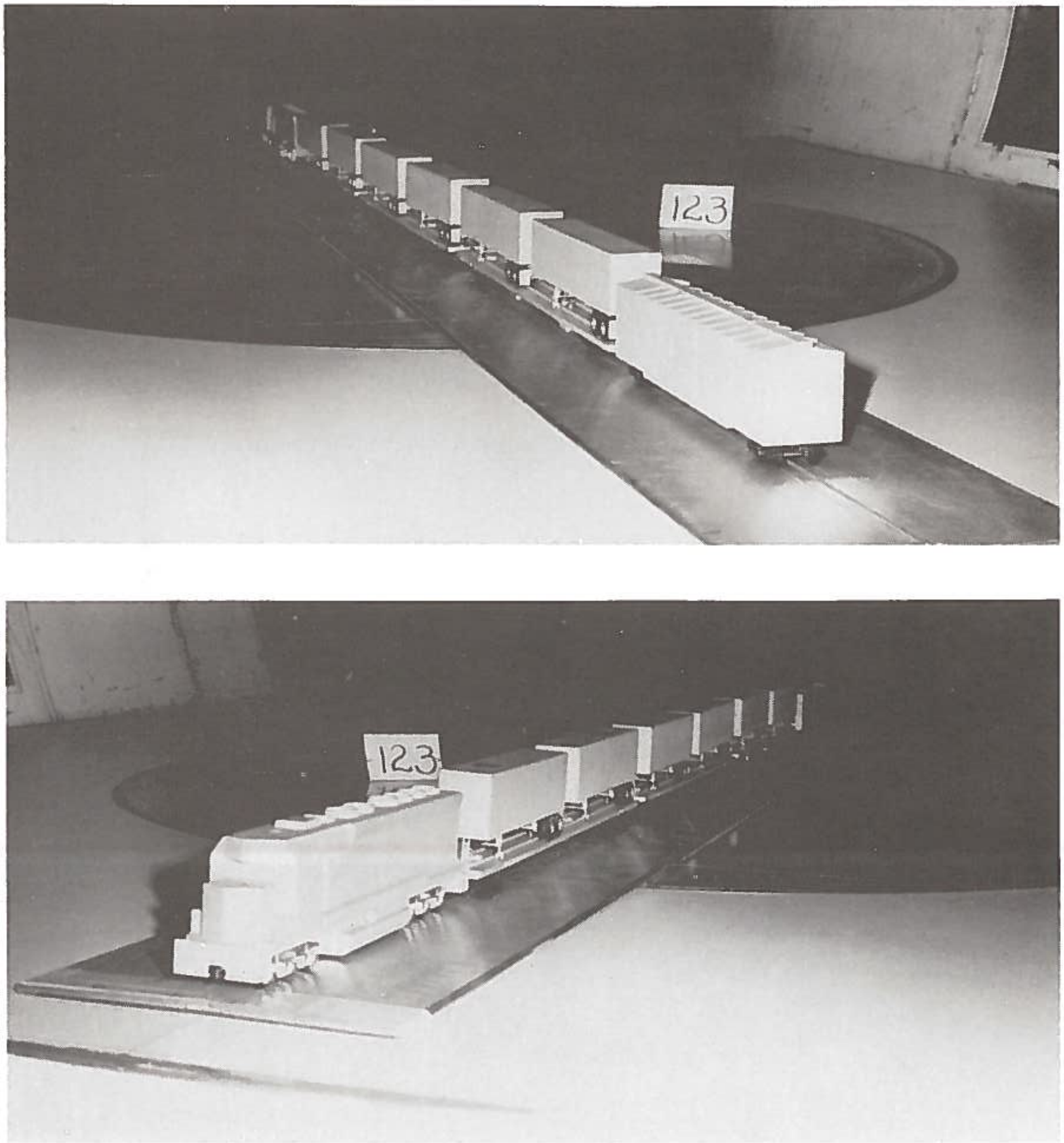
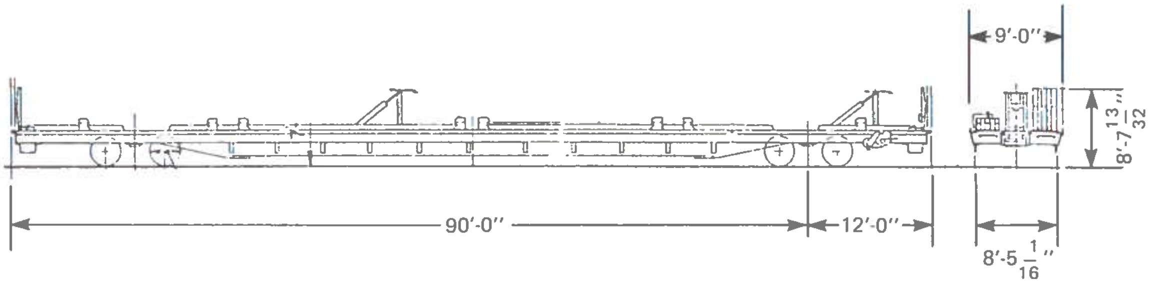


Figure 10-4. Photographs of model train mounted in wind tunnel.



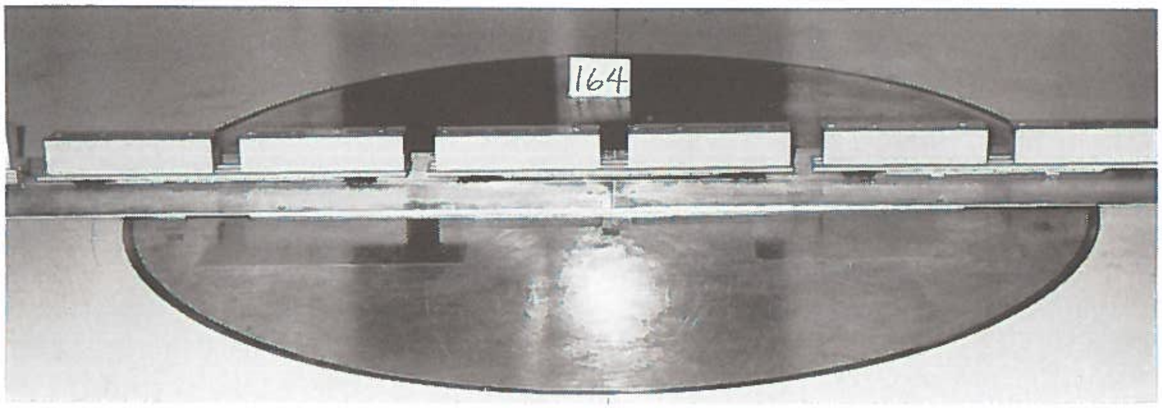


Figure 10-5. Photograph of TTX car with containers in wind tunnel.

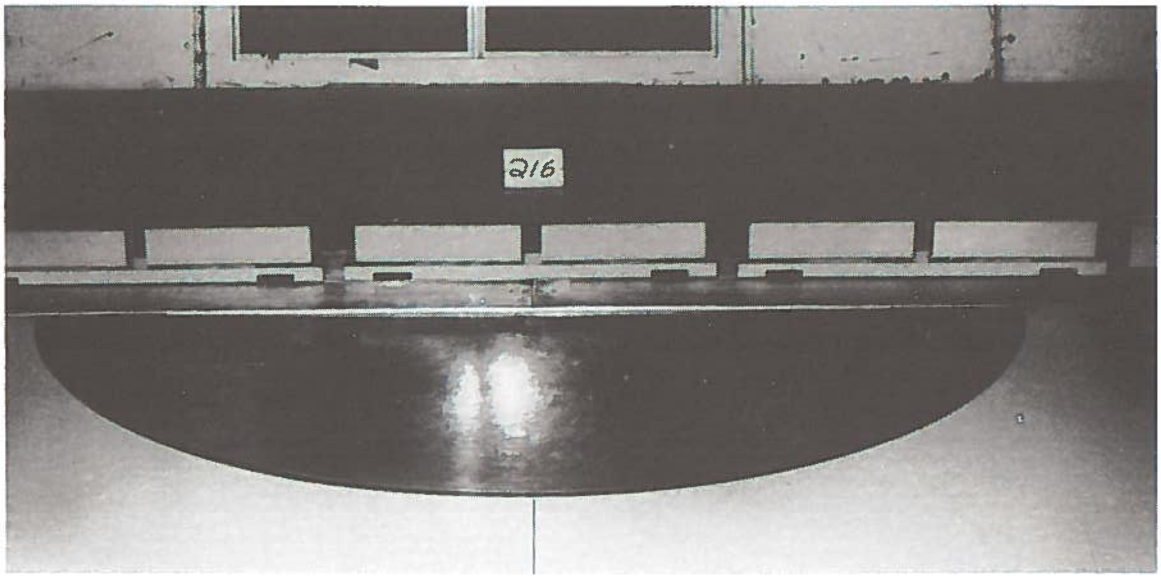


Figure 10-6. Photograph of TWC car with trailers in wind tunnel.

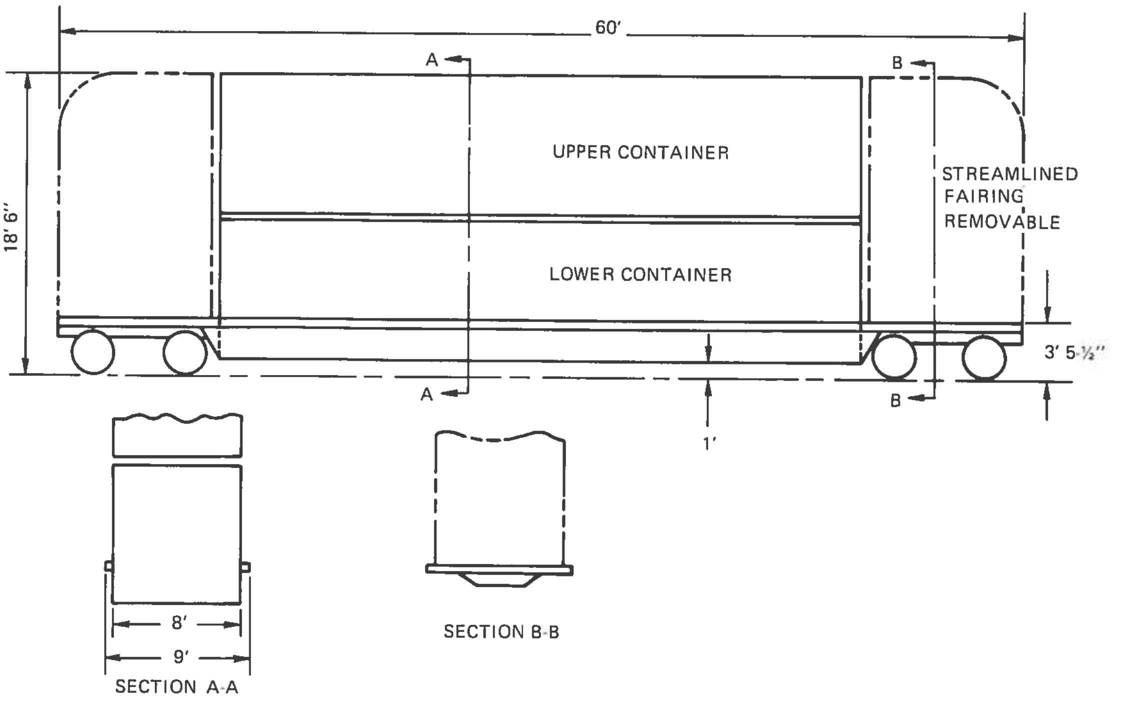
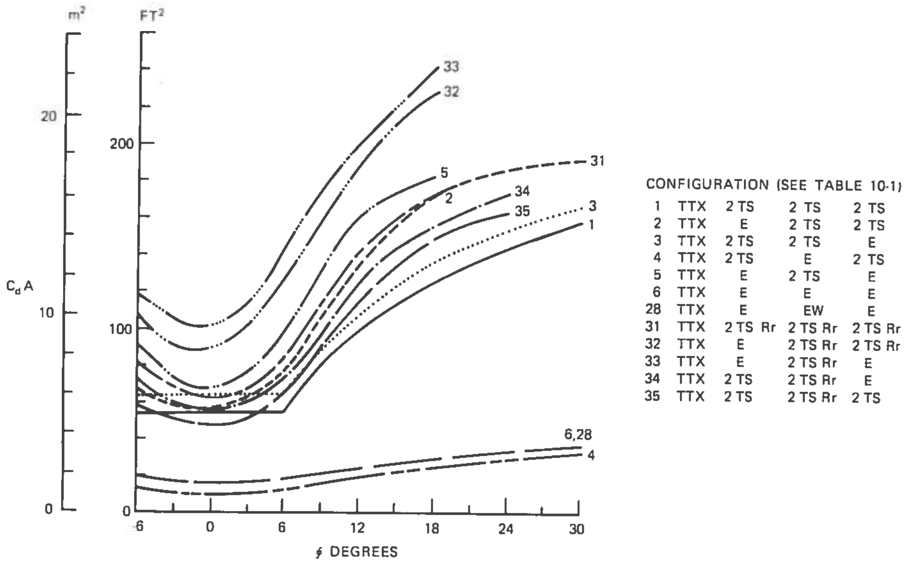


Figure 10-7. Container Well Car—CWC.



CONFIGURATION (SEE TABLE 10-1)

1	TTX	2 TS	2 TS	2 TS
2	TTX	E	2 TS	2 TS
3	TTX	2 TS	2 TS	E
4	TTX	2 TS	E	2 TS
5	TTX	E	2 TS	E
6	TTX	E	E	E
28	TTX	E	EW	E
31	TTX	2 TS Rr	2 TS Rr	2 TS Rr
32	TTX	E	2 TS Rr	2 TS Rr
33	TTX	E	2 TS Rr	E
34	TTX	2 TS	2 TS Rr	E
35	TTX	2 TS	2 TS Rr	2 TS

Figure 10-8. Drag area of TTX cars either fully loaded with two TS trailers or empty as a function of yaw angle. Re = 10^6.

Trailers

Drag on the TTX car fully loaded with two trailers and different loadings on the preceding and trailing cars is shown in Figure 10-8, which includes symbols shown in Table 10-1. In this figure the drag area is plotted against the angle of yaw ϕ. It is seen that the drag is minimal when ϕ is zero and increases as ϕ increases. The shape of the curve for different conditions of loading on the leading and trailing cars is basically the same. An empty car behind the metric car increases the drag of the metric car by a small amount and an empty car ahead of the metric car increases the drag by a larger amount. The drag of an empty car among other empty cars and with loaded cars on each side of it is also shown. It can be seen that a loaded car shields the next car from considerable aerodynamic load. If the drags for an empty car between loaded cars and a loaded car between empty cars are averaged, an average drag area of 39 ft^2 is obtained. This is not much lower than the value of 53 ft^2, which is obtained for a loaded car in a train of loaded cars. The conclusion is that a train of alternately loaded and unloaded cars has a drag comparable to a fully loaded train even though it is only carrying half as many trailers.

Table 10-1. Symbols Used on Graphs

Flat Cars	
TTX	Standard without bridge plate
TTXR	Standard with bridge plate
TTXA	TTX aero fairing
TWC	Trailer well car
CWC	Container well car
CWCA	CWC with aero fairing
Trailers	
TS	AMT* refrigerator van
Tr	AMT* exterior post van
TM	TS modified to moving van
TSA	TS with full aero fairing
TH	TS with height increase to 14 ft.
Containers	
CS	Smooth container with sharp edge
CSA	Smooth container with front edge rounded to r = 0.1 (width)
Location On Railroad Car	
F	Front
R	Rear
Other	
E	Empty
W	Wheel trucks removed
Rr	Rearward facing

The amount of drag caused by the wheels and trucks was assessed by removing the trucks from the metric car when the three TTX cars were empty. There was no measurable change in the drag. The effect of spacing between cars was also investigated. The coupling spacing was changed from the normal value of 60 inches to 30 and 15 inches. The results showed that there was no measurable difference between these two configurations.

The tests on a variety of modified car and trailer configurations are shown in Figure 10-9. Two trailer designs were investigated which seemed to have possibilities in reducing the drag by blocking all or part of the passage underneath the trailer. The first was the moving van with a lower floor, and the second was an idealized arrangement with a skirt extending down to the deck of the TTX. The moving van provided some reduction in drag, but not a very substantial amount. The trailer with the full aerodynamic skirt gave a much larger reduction in drag, especially at the larger angles of yaw.

Another configuration tested was that of the trailer well car (Figure 10-6). In this car, the wheels of the trailer were located in a well which was set down between the trucks of the rail car. The trailers were also placed in a back-to-back arrangement, with the fronts of the trailers at the ends of the car. The drag of this car was a little higher than for the standard TTX car with the trailers with full aerodynamic fairings. This result is somewhat surprising, since the total height of this car is less than the loaded TTX car, and the passage under the trailer is blocked. One other difference was that the trailers are facing in opposite directions, but this should not account for the higher drag.

A streamlined version of the TTX was also tested. The underbody of this car was faired to remove the protuberances which existed in the normal car. However, the test showed no improvement over the standard TTX car design. Apparently there is not much to be gained by changes of this type. However, it should be remembered that the wind tunnel tests may be less sensitive to such changes than in the actual case, because of the inexact simulation of the ground plane.

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* Plastic model kit manufactured by AMT, Troy, Michigan.

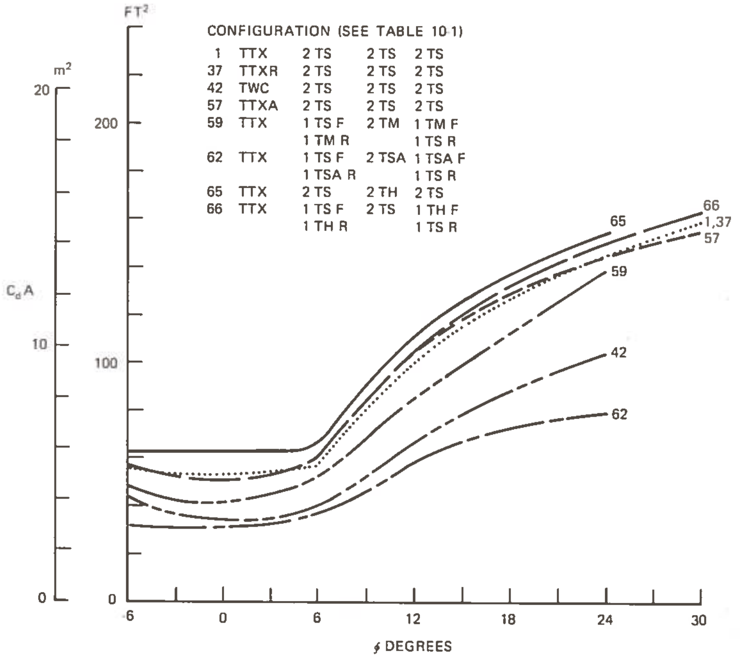

Figure 10-9. Drag area for a variety of different flat car and trailer combinations as a function of angle of yaw. Re = 10^6.

Another effect that was considered was that of the bridge plates on the drag. These are plates which are used to provide a bridge between the cars when loading, and are normally carried in a vertical position when the train is underway. All of the tests were carried out with these bridge plates removed, except for . few tests designed to show the effects of the bridge plates. Figure 10-9 shows that the effects are quite small. Evidently the flow between the cars was sufficiently retarded so that the presence of the vertical bridge plates did not have an appreciable effect on the trailer drag.

Containers

A similar set of tests has been run using containers. Tests were run using the TTX car and a container well car. Figure 10-10 shows test results for fully loaded TTX cars with different mixes of full and empty cars. The most important result is that the drag forces on containers are considerably less than on trailers. The vertical scale used in this figure is twice as large as that used in Figures 10-8 and 10-9 for trailers. The reduced drag of containers has been well known and had previously been measured by full-scale tests on railroads. The effect of using the component of the wind velocity in the direction of motion of the trailer to calculate the dynamic pressure is also shown on this figure. (Normally, the total velocity of the wind tunnel is used.) The flattening of the curves at the higher yaw angle is removed by this way of plotting. The results for containers are similar to those found for trailers in that the removal of containers from the car following the metric car does not cause as large an increase in drag as the removal of the containers from the preceding car. The curve for the fully loaded train has the same flattened shape at low angles of yaw. The results for only one container on the metric car and different loadings on the other cars are generally similar to those found for trailers.

The container well car which has been suggested by the Southern Pacific was also tested (see Figure 10-7). This is a shorter car, with two containers stacked vertically in the well between the two wheel trucks. The drag of the fully loaded car, Figure 10-11, was considerably higher than the fully loaded TTX car shown in Figure 10-10; however, the drag of

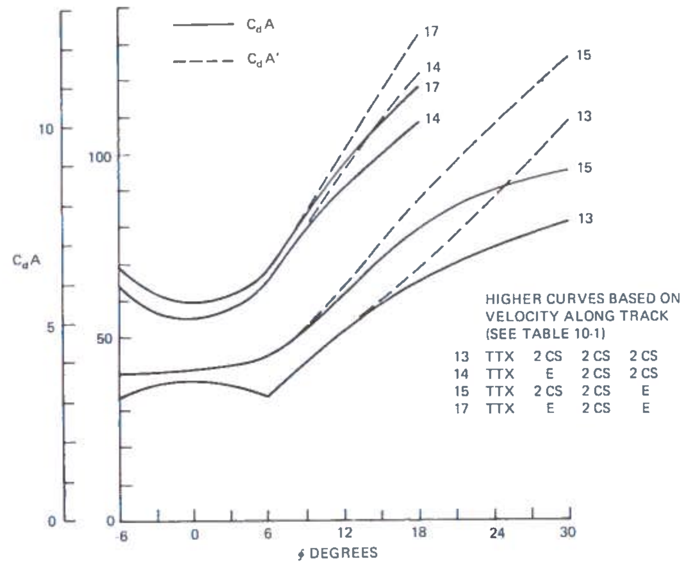

Figure 10-10. Drag area of TTX cars loaded with containers as a function of yaw angle. Dynamic pressure based on both full velocity and velocity component along track. Re = 10^6.

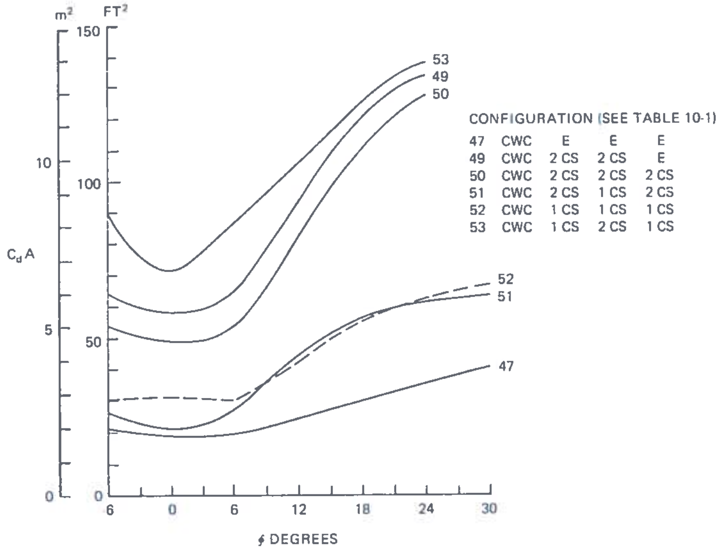

Figure 10-11. Drag area of container well car with different loadings of containers as a function of angle of yaw. Re = 10^6.

the empty car was less than the empty TTX car, Figure 10-8. Both of these results could have been anticipated because of the greater height of the loaded car and the reduced length, which is important in reducing the drag of the empty car. The increase in drag caused by partial loadings was less with this car than the TTX car. If a partially loaded train can consist of one container per car, the drag will be considerably reduced. It might be anticipated that the high drag of this car is caused both by the height and the large open spaces between the containers on successive cars. Two methods of reducing this drag were considered. First, a set of containers with rounded leading edges was used. This caused a

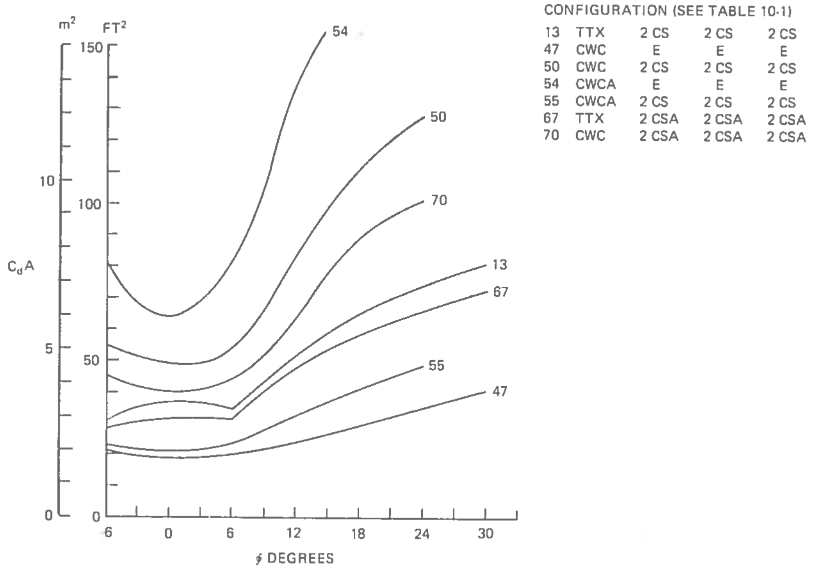

Figure 10-12. Drag area of TTX and container well car with various containers and loadings. Re = 10^6.

small reduction in the drag, Figure 10-12. The second method tested was to provide blocks on each end of the car to fill part of the space between the cars and to provide a rounded leading edge. This change cut the drag dramatically, almost down to the empty car drag of the container well car. These fairings seem to provide a very aerodynamically efficient train in the loaded condition. However, if the car with the aerodynamic fairing in place was operated unloaded, the aerodynamic drag was very high, higher than any other container configuration tested. From an aerodynamic drag point of view the container well car offers very interesting possibilities. If the aerodynamic fairings can be used, and if either empty operation can be avoided or the fairing removed during empty operation, a very low drag system would be obtained.

Full Scale Comparisons

The tests on the standard TOFC and COFC car configurations showed reasonable agreement with values in the literature that was discussed in the introduction. The following table shows the comparison.

	C_dA	
	Ft²	m²
TOFC (C and O tests)	63	5.85
TOFC (EL tests)	78	7.25
TOFC (wind tunnel test 0° yaw)	53	4.92
COFC (NYC tests)	37	3.44
COFC (wind tunnel test 0° yaw)	35	3.25

The wind tunnel tests showed a major increase in drag caused by angle of yaw. It is hard to know what the yaw angle was for the railroad tests. It seems reasonable that they contain some effect of yaw angle and, therefore, might be expected to show higher drag than the wind tunnel 0° yaw angle results. Considering the uncertainties, the comparison is surprisingly good.

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BIOGRAPHY

Dr. Andrew G. Hammitt has been extensively involved with the aerodynamics of ground transportation since the founding of the Department of Transportation and initiation of research and development in these areas. He has been involved with such studies first at TRW Systems from 1967 to 1972, and from 1972 to the present at Andrew G. Hammitt Associates, 30813 Marne Drive, Palos Verdes, California. He has also been involved with air cushion aerodynamics and other aspects of the transportation problem. He has recently published a book entitled, "The Aerodynamics of High Speed Ground Transportation," which contains a chapter on the drag of trains.

BIOGRAPHY

Dr. Timothy M. Barrows works for the U.S. Department of Transportation at the Transportation Systems Center in Cambridge, Massachusetts, where he has concentrated on various aspects of aerodynamic drag applied to freight containers and trailers mounted on rail flat cars. Dr. Barrows received his B.S.E. Degree in Aeronautical Engineering from Princeton University in 1966, and went on to graduate work at MIT. (S.M. 1968, Ph.D. 1970) His doctoral thesis was entitled, "The Use of Aerodynamic Lift for Application to High Speed Ground Transportation." In addition to the present work on aerodynamic drag, Dr. Barrows has conducted work on tunnel entry air pressure transients.

U.S. Department of Transportation *Freight Transportation Digest, October 1976*

RAILROAD CLASSIFICATION YARD TECHNOLOGY PRESENT AND FUTURE NEEDS

by

DR. JOHN B. HOPKINS

INTRODUCTION

The classification yard has long been recognized as a crucial element in the rail freight transportation system. Typically, freight cars pass through numerous yards in moving from shipper to consignee, and that passage is often quite lengthy. It has frequently been noted that these delays, nominally associated with the terminal areas, in fact often arise from causes other than the basic classification process: network constraints, scheduling, interchange, operating policies, etc. Further, the service level and efficiency of yard operations are functions not only of the physical plant, but also of network demands, operating procedures, labor agreements, industry and Government rules, and other activities such as car and locomotive maintenance. Nonetheless, yard technology, here broadly defined to include all relevant equipment and components, as well as more general elements such as basic yard design and information/control systems, remains a highly important factor in determining the degree to which functional demands are met. This is illustrated by the fact that in recent years, even with limited availability of investment capital, several railroads have found it appropriate to carry out major yard improvement or construction projects at individual costs approaching or exceeding $50 million.

The significance of the classification yard in both service and economic terms has made it the focus of major industry and Government research projects. The work to be presented here has been conducted by the Transportation Research Center as part of the Improved Rail Freight Service Program of the Freight Service Division, Office of Research and Development, of the Federal Railroad Administration. The objective of this study has been to provide a firm foundation on which to develop a sound reseach program in the area of classification yard technology. (Numerous other non-technology facets of improved yard performance are being addressed by those other elements of FRA which have appropriate responsibilities.) An effective attack on this problem area requires that one not only identify possible areas of improvement, but also that the actual costs and impacts of such changes be quantified, if only in an approximate fashion. Expenditures of limited Government research resources in this area must be based upon anticipated significant effect upon the efficiency and level of service of the rail freight transportation system. They must not be based merely on a desire to achieve amelioration of problems which may be endemic and irritating, but which do not actually have a serious effect upon operations, or which are serious now but may no longer exist when the research and development have been brought to fruition.

It is within this framework that TSC initiated, in 1974, a five-part project intended to provide both the information and understanding necessary to structure a long-term research and development program in classification yard technology. The first, most basic element was clear definition of the number, type, and function of the yards which now exist in the United States. Surprisingly, this information previously existed only in scattered and incomplete form, possibly because none of the many parties interested in such information has had both the resources and the need to warrant the necessary effort.

Given the lengthy time scale which characterizes development, acceptance, and widespread utilization of new railroad equipment or technical innovations, it was next deemed necessary to estimate the degree to which U.S.

classification yards will be affected, and must respond, to shifts in transportation demand and future changes in railroad operations and equipment. Ten and twenty-five year time frames were chosen for this analysis.

In parallel with these macroscopic yard characterizations was a survey of the technology and practices now prevalent in yards, with the objective of establishing a baseline for costs and performance and for identifying areas in which problems clearly exist or alternative technology offers marked potential benefits.

In the fourth task the impact of network operating practices upon terminal-area performance was considered. The objective of examination of this area was not a full study of the entire subject, which is a very large one, but rather an analysis of the degree to which network-terminal interactions affect or constrain the relevance and potential benefits of technology in general, and innovative equipment in particular.

The study concluded with an analysis of potential means of improvement and development of research recommendations. These were to arise from all preceding tasks in such a way that potential effects could be ranked in an objective and quantitative manner, with potential constraints, uncertainties, and disadvantages identified. This will allow formulation of research plans of maximum impact.

This study was implemented through a competitive procurement process which resulted in award of a contract (DOT-TSC-968) to Stanford Research Institute, a firm well qualified for such work. SRI began in early 1975, and devoted approximately 2-1/2 man-years of effort to the total project. The study is now complete, and the final report* is in publication; it will be available early in 1977. It is the purpose of this paper to summarize that project and its conclusions; what follows is drawn predominantly from the SRI report.

THE YARD SURVEY

The most direct approach to establishment of a reliable national yard inventory would consist of direct inquiries to all railroads. However, this procedure obviously would require resources and efforts, on the part of Government and railroads alike, far beyond the value of the information, and was immediately recognized to be impractical. A far more satisfactory procedure was devised which drew upon existing information associated with the safety inspection responsibilities of the FRA. Regional lists of yard inspection points were combined with interviews and questionnaires involving appropriate safety inspectors. Through this process, which received full cooperation from the FRA Office of Safety, it was possible to compile a truly comprehensive list of 4161 yards of all types within the coterminus United States, including 1229 at which significant classification activity occurred. Each yard was characterized by ownership, function (classification, classification/industrial, industrial, or small industrial); hump or flat switching; adjacent land use (industrial, commercial, residential, agricultural, or undeveloped); and role in the network (interchange, junction point, part of yard complex, etc). Table 11-1 categorizes the results of this survey. The remainder of the project dealt only with the 1269 classification yards thus identified. This entire listing is now stored at TSC on magnetic tape, and can readily be computer-sorted by state, railroad, type, function, etc.

In order to obtain a more precise characterization of "typical" yards in various categories, a detailed survey of a selected sample of classification yards was undertaken in cooperation with a number of Class 1 railroads. SRI obtained detailed information describing 61 hump yards (52 percent of the national total) and 153 flat yards (14 percent of the total); these were chosen to represent a variety of locations, railroads, functions, ages, and types. Results from this survey were extrapolated to the national yard population to permit an overall categorization in terms of volume and type. Some results of this analysis are shown in Tables 11-2 and 11-3.

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Table 11-1. Summary of Yard-Inventory

Inventory	Class./ Indus. Yards		Classification Yards		Industrial Yards		Small Indus. Yards		All Yards	
	#	%	#	%	#	%	#	%	#	%
Yard Design										
Flat Yards	930	90	183	91	138	99	1551	100	4025	97
Hump Yards	98	10	18	9	8	1	0	0	124	3
Adjacent Land Use										
Industrial area	424	41	40	20	602	43	419	27	1485	36
Commercial area	245	24	41	20	339	24	353	23	978	23
Residential area	216	21	57	28	318	23	516	33	1107	27
Agricultural area	42	4	25	13	45	3	160	10	272	7
Undeveloped area	101	10	38	19	85	6	103	7	327	8
Other	0	0	0	0	0	0	0	0	0	0
Population										
Less than 5,000	150	15	59	29	296	21	623	40	1128	27
5,001 to 50,000	375	37	93	47	557	40	639	41	1664	40
50,001 to 100,000	249	14	8	4	136	10	85	6	378	9
100,001 to 250,000	127	12	10	5	105	8	48	3	290	7
250,001 to 500,000	86	8	6	3	106	8	58	4	254	6
More than 500,000	141	14	25	12	189	14	100	6	455	11
Other Inventory Information										
Interchanges	534	51	81	41	505	37	452	29	1574	38
Junctions	276	27	41	20	177	14	159	10	653	16
End-of-lines	117	11	21	10	154	11	190	12	482	12
Total Number of Yards in Category	1028		201		1389		1551		4169	

Table 11-2. Samples of Characterization Descriptions for Hump Yards

Descriptors	Less than 1000 Cars/Day	1001 to 2000 Cars/day	More than 2000 Cars/Day
Number of classification tracks	26	43	57
Receiving tracks	11	11	13
Departure tracks	9	12	14
Standing capacity of classification yard	1447	1519	2443
Standing capacity of receiving yard	977	1111	1545
Standing capacity of departure yard	862	969	1594
Cars classified/day	689	1468	2386
Local cars dispatched/day	86	250	315
Industrial cars dispatched/day	74	86	220
Road-haul cars dispatched/day	632	1050	2297
Cars reclassified/day	94	195	275
Cars weighed/day	74	42	149
Cars repaired/day	38	43	153
Trailers and containers loaded or unloaded/day	36	30	39
Average time in yard (hours)	21	22	22
Inbound road-haul trains/day	8	14	27
Outbound road-haul trains/day	8	14	25
Local trains dispatched/day	2	3	5
Hump-engine tricks/day	3	5	6
Makeup-engine tricks/day	3	6	11
Industrial-engine tricks/day	2	2	10
Roustabout-engine tricks/day	2	1	4

Table 11-3. SRI Estimates of Yard-classification Volumes

Yard Category	Number of Yards	Average Daily Volume/ Yard	Daily Volume	Annual Volume	Percentage of Total Volume	Percentage of Classification Volume
Classification Yards						
Flat Yards						
Low Volume	364	288	162,432	58,475,520	15.03	19.32
Medium Volume	361	711	156,671	59,401,560	23.76	30.54
High Volume	188	1344	151,671	90,961,920	23.29	30.06
Subtotal			671,775	241,839,000	62.18	72.92
Hump Yards						
Low Volume	42	689	28,938	10,417,680	2.68	3.44
Medium Volume	40	1468	58,720	21,139,200	5.43	6.99
High Volume	34	2386	81,124	29,204,640	7.51	9.65
Subtotal			168,782	60,761,520	15.62	20.08
			840,557	302,600,520	77.80	100
Volume (all Classification Yards)						
Industrial Yards	1381	140	193,340	69,602,400	17.89	
Small Industrial Yards	1551	30	46,530	16,750,800	4.31	
Total Volume (all yards)			1,080,427	388,953,720	100	

FUTURE CLASSIFICATION YARD REQUIREMENTS

Obviously, many factors can affect the future demands which the nation's transportation system will place upon the capacity, location, and function of rail classification yards. Some elements are basically internal to the railroad industry: use of unit trains, corporate and network consolidations, purchase of larger freight cars, and a variety of operational matters. However, many of the most important constraints and forces will be external; the state of the economy, the cost and availability of fuel, demographic and other factors determining total transportation demands, and governmental actions affecting both operations and the trend toward network rationalization and yard consolidation. The complexity of this situation is suggested by the relationships shown in Figure 11-1. It would clearly be fruitless to attempt to predict accurately these and many other necessary types of information for a 25-year projection. However, one can establish bounds on the problem through consideration of several alternative scenarios based upon widely different assumptions concerning certain of the major critical variables. This is the approach which SRI followed. Three such scenarios were developed. The first, referred to as "Present Trends," assumes a relatively direct extrapolation of current levels and rates of change. This assumption is applied to such fundamental parameters as gross national product, freight demand, tons per carload, and railroad mergers. Corrections are then introduced to eliminate consideration of freight moving by unit train, etc. In the second case considered, "super-rationalization," economic and demand trends are as for the first scenario, but extreme network rationalization is envisioned, leaving a total of only 5 to 12 major railroads and a greatly reduced network. The final set of assumptions, characterized as "Energy Crisis," assumes shortages which have sufficient impact to virtually foreclose general economic growth. At the same

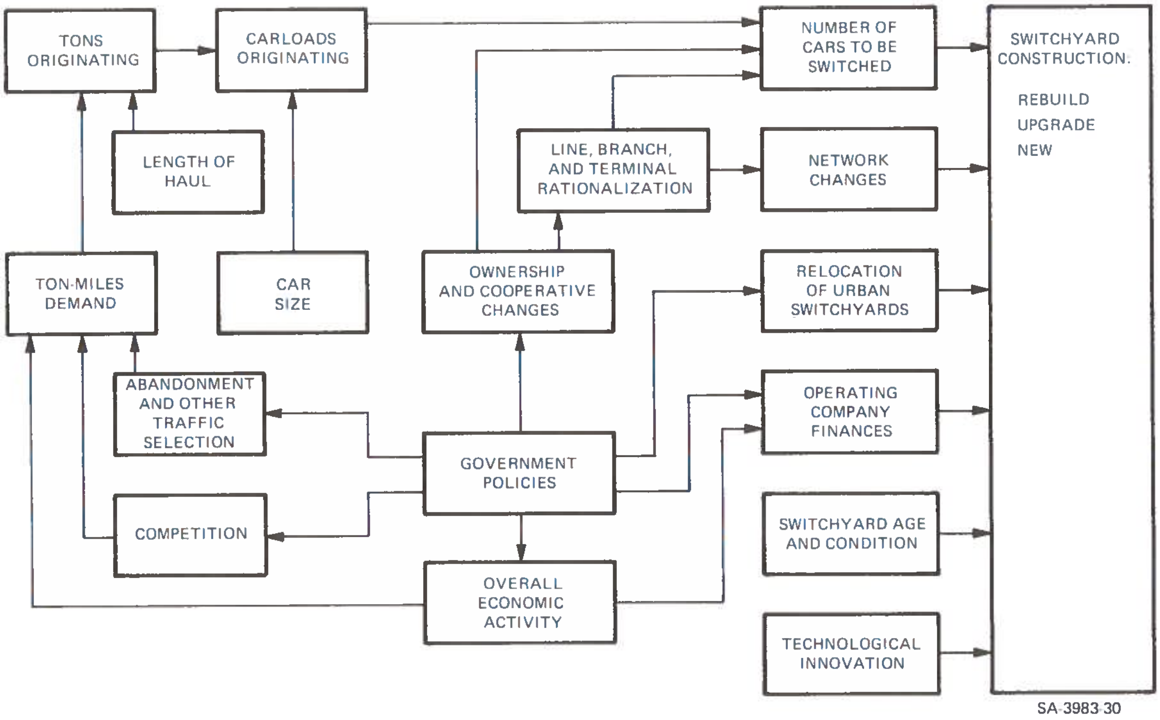


Figure 11-1. Simplified diagram showing interrelationships of factors affecting switchyard construction.

time, this scenario anticipates that fuel-conservation considerations would force all shipments for distances of greater than 200 miles to travel by rail. (The previous cases do not assume significant changes in modal split.) For each scenario, additional basic factors are considered, such as replacement of worn-out or obsolescent facilities, estimated from the current yard age distribution.

The analysis included a projection of traffic that showed an increase in ton-miles of approximately 50 percent by the year 2000 for both the Present Trends and Super-Rationalization scenarios, while trends toward longer hauls and larger freight cars resulted in an increase in carloading of about 20 percent over that period. However, improvements in system operation were projected, resulting in a net increase of only 5 percent in the number of cars switched for the Present Trends scenario (see Table 11-4) and a reduction of about 30 percent for the Super Rationalization case. Reduction of total demand, accompanied by a shift of highway freight traffic to railroads, implies a 10 percent increase in number of cars switched for the Energy Crisis case. Thus, overall switching capacity requirements will not require substantial new yard construction. On the other hand, projected consolidations of networks, relocation of urban yards, and normal replacement will contribute to the retirement of some yards, and expansion of capacity or modernization in other situations. The net result is a potential for as many as 200 major construction projects between now and the year 2000, though only a handful would be totally new high-capacity hump yards. A summary of this analysis is shown in Table 11-5.

CURRENT CLASSIFICATION YARD TECHNOLOGY

In this study the term "classification yard technology" was defined quite broadly, and includes five principal categories: yard facilities, equipment, and hardware; computer, communications, and control technology; rolling stock technology; operational processes and procedures relating to facilities and

Table 11-4. Projected Number of Cars to Be Switched for the Present-trends Scenario

	1974	1985	2000
Freight carloads originated (000) annually	26,727	(1%) 29,063	30,729
Projected daily switching operations	909,867	(1%) 989,392	1,046,107
Less:			
Light-density line abandonments	—	(1%) 9,894	(2%) 20,932
Reduction of interchange	—	(2%) 19,788	(4%) 41,844
Improved blocking	—	(2%) 19,788	(4%) 41,844
Total improvements	—	49,470	104,610
Number of daily switching operations	909,867	939,922	941,497

Table 11-5. Estimated Number of Classification Yards to be Expanded, Reconfigured, Re-equipped, or Newly Constructed

		1975 to 1985		1986 to 2000	
SCENARIO	CAUSE	Flat	Hump	Flat	Hump
Present Trends	Switching Requirements	9	1	0	0
	Wearout and Obsolescence	0	27	0	25
	Network Changes and Urban Relocation	30	20	40	20
	Total	39	48	40	45
Super Rationalization	Switching Requirements	0	0	0	0
	Wearout and Obsolescence	0	27	0	25
	Network Changes and Urban Relocation	40	35	35	40
	Total	40	62	35	65
Energy Crisis	Switching Requirements	5	2	3	1
	Wearout and Obsolescence	0	27	0	25
	Network Changes and Urban Relocation	0	0	0	0
	Total	5	28	3	26

equipment; and yard design. Information concerning the performance and operational characteristics of yard technology was obtained from railroad personnel, equipment suppliers, and published literature, and a comprehensive description is provided in the full SRI report. Information concerning equipment cost and current extent of usage was included to the degree that it was available. This survey was complemented by an examination of the general process of technological change within the railroad industry, and the factors that influence this process.

The survey and analysis indicated that, with a few exceptions, the state-of-the-art in classification yard technology in the United States is fairly stable. The recent trend has been to implement technological improvements, such as computer control, at a small number of yards, while the majority of terminals have remained relatively unchanged. Some of the major factors contributing to this situation are the basic structure of the industry, the nature of the transportation service market, the impact of government regulation, the relationship between railroads and their suppliers, labor agreements, and the availability of capital. The last two elements have had the most substantial influence on the implementation of new technology during this time period, a condition unlikely to change markedly in the foreseeable future.

IMPACT OF NETWORK/TERMINAL INTERACTIONS

This complex subject was examined by means of a case-study approach utilizing the SRI network simulation model and car movement information from a portion of a rail system operated by a U.S. Class 1 railroad. The impacts of three alternative system operating policies upon yard operation were compared. The results of this study and other related SRI work confirm that changes in railroad system-wide operating policies can significantly affect yard operations. Scheduling of trains, train-length policies, and other factors can have strong impact upon the efficiency of the yard and car detention time. However, this work indicates that it is probably not possible to establish simple, universally-applicable guidelines for blocking and train-operating policies. The specifics of origins and destinations, network geometry, and yard capacities associated with each policy must be compared on an individual basis. The particular rail network topology, demand patterns, individual yard capacities and other characteristics, and other factors can generate substantial variations from one system to another that must be accounted for when developing system-wide operating policies.

MEANS OF IMPROVEMENT

Performance of this task first required determination of the magnitude and impact of possible problem areas associated with classification yard operations. Available ICC and AAR data were used to estimate that the cost of operations for all types of yards during 1973 was nearly four billion dollars. Information collected in the course of the yard survey work indicated that the cost associated with classification yards alone was about three-quarters of that, and therefore amounted to approximately one-quarter of total railroad industry operating expenses during that year. By similar reasoning, it can be estimated that total national costs associated with classification yard operations during the period from 1980 to the year 2000 will be greater than 75 billion dollars.

A breakdown of this cost analysis shows that the major part of expenses of yard operations—approximately two-thirds of the total—is labor related. The next highest cost item is associated with car detention time, amounting to about 12 billion dollars over the twenty-year period, or nearly 16 percent of total classification yard costs. The remaining 18 percent of the yard costs are related to items such as materials, property taxes, lading loss and damage, and others.

A detailed breakdown of the elements of the yard cost projections was used to identify approximately those yard operational areas in which technological change might offer reduced operating costs. Engineering analysis was used to define these areas more precisely and to examine their sensitivity to change. Selected elements of existing proposed yard technology were then evaluated to estimate the potential savings that would accrue over the 1980–2000 time period if that technology element were developed and implemented by 1980. The derivation of these cost estimates was based upon judgmental assumptions regarding operational and technical characteristics and feasibility of the postulated items of technology. These estimates were then used as first-order indicators of the relative cost savings impact of the various alternatives. Although the 1980 implementation date is not likely to be realistic in some cases, it is used to place all candidates on equal footing. This process would be achieved through the application of less labor-intensive technology, which would typically reduce the size or number of switch-engine crews, inspection crews, or clerical personnel. Although a number of the particular technologies examined did appear to reduce manpower requirements, the most significant savings tended to occur in the area of switch engine technology, yard hardware, and the technology of yard computers, communications, and control. The second major area of cost savings resulted from reduction of car time in yards. In many cases the labor reduction technologies also reduced car-time expenses. However, these benefits can also be obtained through the implementation of new yard and network operating procedures. The cost reductions associated with less consumption of materials (such as switch engine fuel) and other savings were found to be less significant than these two areas, although in some cases they may be more readily attainable.

Another incentive for the introduction of new technology is improvement of the quality of transportation service offered the shipper. Seven elements of service quality were defined to explore this question. These areas were origin-destination transit time, transit time reliability, equipment availability, schedule adaptability, correct delivery of cars, lading loss and damage, and availability of car and load status information. It was not possible, within the scope of this project, to associate quantitative economic benefits with improvements in these areas. Instead, a relative rating procedure was developed and used to suggest those alternatives for which service improvement characteristics would be important.

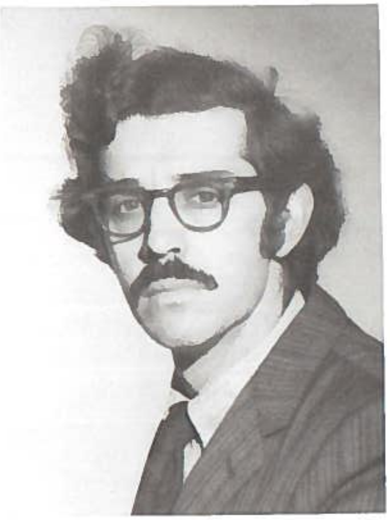
CONCLUSIONS AND RECOMMENDATIONS

In a brief summary such as this, it is not possible to address the many specific technology areas examined by SRI, or the numerous detailed recommendations which resulted. These findings are now being subjected to further analysis, and will be incorporated into future research efforts as appropriate. However, it is possible to present some of the general conclusions resulting from the study. Within the understanding that Federally-sponsored research programs must be partially based upon policies established at higher levels, this research finds that development of research and development plans related to classification yard technology should incorporate the basic considerations described in the following.

> R&D efforts in the near future should be applications-oriented. Much basic technological information is available; however, it must be developed or transformed to the point at which it can successfully be adopted by the railroads.
>
> If impact is to be truly significant, future rail-oriented R&D programs should extend beyond the actual stages of research, invention, and development. The major benefits of such efforts are generally realized only after the use of the newly developed technology has diffused throughout the industry. An important stage of the process of technological change is the introduction of new technology into operational use. This stage of innovation often requires large financial equipment, relatively high risk of failure, and special expertise in fields which may not previously have been relevant to railroads; all of these factors, as well as other structural and psychological factors, can be effective barriers to change. Government involvement in testing and evaluation of

new technology in an operational environment may significantly improve the effectiveness and impact of the original research efforts devoted to development of the technology.

The relatively high proportion of railroad expenses attributed to classification yard operations suggests that development and implementation of cost-reducing yard technology should be highly emphasized. Technology designed to reduce the labor intensiveness of yard operations would have the greatest impact on yard costs, although non-technical constraints may significantly reduce the practicality, or delay the time scale, of some potential advances in such topics. There is little doubt, however, as to the value of conducting appropriate feasibility analysis in this area, pending the resolution or relaxation of factors which would constrain their implementation.



BIOGRAPHY

John B. Hopkins received an A.B. degree from Amherst College in 1958, having majored in physics. He subsequently attended Harvard University, from which he received an A.M. degree in 1959 and a Ph.D. in 1966, both in Applied Physics. He was then employed at the NASA Electronics Research Center from 1966 to 1970, with responsibility for experimental and analytical feasibility studies concerning solid state microwave devices. Since 1970 he has been a member of the Mechanical Engineering Division of the Transportation Systems Center, where he has had managerial and technical responsibilities in a number of projects relating to ground transportation systems. These have dealt primarily with safety and efficiency in rail freight transportation.

He is a member of Phi Beta Kappa, Sigma Xi, IEEE, AAAS, and the Transportation Research Board. He has authored four patents and numerous technical papers and Government reports.

U.S. Department of Transportation *Freight Transportation Digest, October 1976*

AN ANALYSIS OF FREIGHT CAR INVESTMENT

by

JAMES F. OIESEN

INTRODUCTION

The Problem and an Approach

The problem of freight car shortages has plagued the railroad industry for literally decades. The periodic inability of railroads to supply shippers with sufficient cars has been a dependable source of complaints and ill-feeling. Railroads, therefore, have attempted to devise policies that would deal with this problem, as has Congress, which has held numerous hearings on this topic over the years [e.g., U.S. Senate, 1971].* However, this search for policies has not been entirely successful. The Interstate Commerce Commission recently described the present policies as "ineffective," and went on to say that the freight car shortage is ". . . impeding both the domestic and export movements of agricultural, mineral, forest, and manufactured products and other commodities [Traffic World, 1975, p. 46]."

This paper proposes a new approach to searching for appropriate policies. The new approach consists first of modeling the railroad system with the techniques of modern economics and operations research, and then of using that model to predict the effects of alternative policies. It should be stressed at the outset that the present paper represents no more than a first step on the road to realization of this approach. Nevertheless, it is an initial attempt at using systematic, explicit analysis to solve the problem. Other work that carries this approach further will be mentioned at the end of the paper.

This paper is a condensation of a much longer study [Oiesen, 1975]. The reader is referred to that longer study for a more comprehensive discussion of the issues raised in this paper.

Framework for Discussing Freight Car Shortages

In analyzing the effect of a policy on freight car shortages, it is convenient to divide that effect into two areas.

1. What is the effect of the policy on the number of freight cars in the national fleet?
2. Given the number of cars in the national fleet, what is the effect of the policy on the efficiency with which these cars are utilized?

Once these two questions are answered, then one has also answered the question of how the policy being considered affects car shortages.

The purpose of this paper is to describe a model that gives a partial answer to the first question. Technically, this model characterizes the freight car investment decision as a stochastic non-linear programming problem. The output of the model is used to draw qualitative, comparative statistical conclusions about the effect of a policy change. That is, given a change in policy, the model predicts whether the fleets of individual railroads and of the nation as a whole will increase or decrease as a result of that policy change.

As the model is explained, the reader will see that it incorporates assumptions that are possibly inaccurate. It cannot be denied that these possibly inaccurate assumptions might damage the model's reliability. However, the point to stress is that this model does provide a unified framework for thinking about freight car investment. It explicitly states what variables are important and the mechanisms

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*Square brackets refer to entries in the bibliography at the end of the paper.

through which these variables work to determine the size of the national fleet. This explicitness gives the reader full scope to criticize the model and perhaps to suggest more accurate assumptions.

Organization of this Paper

In addition to the introduction, this paper presents three more sections. The first concentrates on how a *single* railroad decides how many cars to own. This section describes the model's assumptions, defines the relevant variables, and states some of the main properties of the model. The next section applies the model to several potential policies in order to predict whether that policy would increase or decrease the national stock of cars and the stocks of individual railroads. The final section describes how this investment model fits together with another railroad model to form a comprehensive research program directed at predicting the effects of various policies on railroad performance.

THE MODEL: THE FREIGHT CAR INVESTMENT DECISION FOR A SINGLE RAILROAD

The Setting of the Freight Car Investment Decision

A railroad's decision on how many cars to own is complicated by the fact that about half of all shipments are interlined, i.e., they start out on one railroad and end up on another. To see the issues that arise, consider a hypothetical interlined shipment. Suppose a railroad loads a shipment of freight into a car on its own lines, and then sends the car on its way. While the car is on that railroad's home lines, the railroad receives revenue for shipping this load; this does not depend on whether the car belongs to the railroad or not. If the car does not belong to the railroad, it must pay a rental fee called a per diem charge to the owner of the car. Once the car moves off-line, if the railroad that originated the shipment does not own the car, then it is finished with this shipment. Suppose that it does own the car; then it will receive a per diem fee from the railroad that controls the car. When the car has reached its destination and has been unloaded, the railroad that unloads it is not free to treat this foreign car as its whims dictate. There exist car service rules that specify minimum standards for how railroads must handle foreign cars. Eventually this car will work its way back to its home lines.

Therefore, when a railroad is thinking of investing in additional freight cars, it must consider questions such as the following: How much will these cars be off-line? How much will they earn while off-line? How many foreign cars will be on-line? How often will cars on-line have loads to carry? How much will be earned by carrying a load? How much does a car cost? This paper fits all these questions together in order to model a railroad's freight car investment decision.

The main assumption of the model is that a railroad maximizes expected profit. That is, a railroad adjusts the number of cars it owns by purchasing more or by failing to replace those that wear out, so that it owns the number of cars that maximize expected profit. It should be admitted that there is no completely convincing argument that maximization of expected profits is the best assumption. However, since profit seeking must be a central concern for the financially pressed railroads, many of the forces that bear most strongly on railroad decisions can presumably be modeled by assuming that railroads maximize expected profit. Thus, while this assumption does not capture all the factors that influence railroad investment decisions, it does seem to capture the most important ones.

Input and Output Variables

The relevant variables are discussed below.

The number of cars owned by an individual firm (n): This is an individual railroad's decision variable. That is, the railroad can decide how many cars it will own; no other variables can be controlled by the individual railroad.

Demand (D): This is a random variable that indicates the level of demand for the railroad system as a whole.

Number of cars in the national fleet (N): This includes the cars owned by railroads, by other private firms, and by the government.

Cost to a railroad of owning a car for one year (C): It is assumed that there is a constant annual cost C that is incurred if a new car is purchased. This cost is the payment that, if made every year over the expected life of the car, would be expected to cover the original cost of the car, maintenance costs, and a normal profit. For details on how C is calculated, see Grunfeld [1959, pp. 58-66].

Expected revenue earned by carrying a load for one day, net of non-car costs (R): When a car carries a load, the railroad expects that car to be occupied with that load for some number of days, to receive some payment for carrying that load, and to incur costs while carrying the load. Let "non-car cost" be all the marginal costs incurred in carrying a load except for the cost of the car itself; thus, non-car marginal cost includes costs such as labor and fuel costs, but excludes the per diem fee or the cost of owning a car. Then

$$R = \frac{\text{expected payment} - \text{non-car cost}}{\text{number of days the car is occupied}}$$

The expected profit per day earned by carrying a load is R minus the daily car cost, which is the per diem charge if the car is a foreign car and C/365 if the car is a home car.

Per diem charge (PD): The per diem charge is the rent that a road pays per day when using a car belonging to another road. In fact, the per diem charge consists of a flat daily rate plus a mileage charge. Since the model assumes a constant per diem charge, PD should be interpreted as an expected value. For a more detailed discussion of per diem rates, see Reebie Associates [1972, pp. 195-203].

Car Service Rules (CSR): The car service rules specify how a railroad must treat foreign cars on its lines. For example, a road is not allowed to load a foreign empty car and send it away from its home lines. Therefore, the speed with which a car off-line returns to its home lines depends on the car service rules. In this paper the relevant car service rules are not the temporary ones imposed in extraordinary circumstances, but the expected long-term rules, since the latter are relevant to investment decisions. For a more detailed discussion of car service rules, see the U.S. Senate Hearings [1971, pp. 350 ff.].

The model of an individual firm's freight car investment decision has as output, n, the number of cars that the firm would own. All of the other variables defined in this subsection are inputs to the model. The only other input is the expected marginal revenue function, which will now be discussed.

The Expected Marginal Revenue Function

It is assumed that the added revenue that a railroad would earn if it purchased one more car, i.e. marginal revenue, depends on how many cars it owns when it purchases that car, how many cars are in the national fleet, the car service rules, the per diem rate, the net revenue earned per day while loaded, and the level of demand. Therefore, one can write the marginal revenue function as

$$MR(n; N, CSR, PD, R, D).$$

The number of cars, n, owned by this railroad is placed to the left of the semicolon, since the railroad can choose a value for this variable. N, CSR, PD, R, and D are placed to the right of the semicolon, since it is assumed that these are variables over which the single railroad has no influence. Since demand D is an exogenous random variable, the expectation is taken with respect to D to get

$$E[MR(n; N, CSR, PD, R)].$$

This is the expected marginal revenue function. Given values for the variables to the right of the semicolon, this function tells how much added revenue the railroad expects to earn by purchasing one more car when it already owns n cars.

Model Logic: The Equilibrium Condition

The assumption that a railroad maximizes expected profit is represented mathematically by assuming that n is chosen so that the following equation, which is called the equilibrium condition, is satisfied:

$$E[MR(n; N, CSR, PD, R)] = C.$$

This equation represents the model logic since, when the inputs N, CSR, PD, R, C, D, and E[MR(.)] are specified, this equation determines the value taken on by the output, n. The interpretation of this equation is that a railroad owns the number of cars such that the increase in annual net expected revenue that would be earned by purchasing one more car equals the annual cost of a car. In this context, this equilibrium condition is a necessary and sufficient condition for a railroad to be maximizing expected profit.

In order to reach conclusions about the effect of a policy change on the number of cars that a railroad will own, it is necessary to analyze this equilibrium condition. However, in order for the analysis of the equilibrium condition to yield any results, it is necessary to make assumptions about the properties of the expected marginal revenue function. At the same time, the expected marginal revenue function incorporates so many factors and complicated interactions that it is difficult to arrive at assumptions about it that have a high degree of intuitive plausibility.

The next section decomposes this expected marginal revenue function into simpler components. Since these components are simpler, it will be easier to formulate attractive assumptions about their properties. These assumptions about the components will then be analyzed to deduce properties of the expected marginal revenue function. In short, the role of mathematics generally is to take a set of assumptions, and then to deduce the implications of those assumptions. The usefulness of mathematics lies in its ability to uncover implications that would otherwise remain hidden. So, after the marginal revenue function is simplified to permit assumptions about its components to be made, a mathematical analysis will be carried out to deduce from those assumptions their implications about the properties of the expected marginal revenue function.

The Four States A Car Can Be In

In order to add scope to the analysis, the expected marginal revenue function will be written in a more detailed form. To do this, consider the four possible states that a car can be in on one particular day, and what that car would earn on that day.

First, the car might be on foreign lines, i.e., on the tracks of a road that does not own it. In this case, the car earns the per diem payment PD for the owning road.

Second, the car might be on-line and carrying an extra load. That is, the car is on home lines; it is carrying a load or committed to a load; and this load would not have been carried if this car had not been available. It should be stressed that this car is not in this state just because it is carrying a load; in particular, it is not in this state if it is carrying a load that, in the absence of this car, would have been carried by another home car or by a foreign car. When the car is in this state, it earns R per day.

Third, the car can be on-line and replacing a foreign car. The car is in this state if it carries a load that, in the absence of this car, would have been carried by a foreign car. Thus, the foreign car can be sent home. It is assumed that the road can immediately and without cost send the foreign car home. If the car is in this state, its marginal daily earnings is PD, since the road earns the same revenue regardless of whether the load is carried in a foreign or home car, but it is relieved of paying the per diem charge on the foreign car that is sent home.

Fourth, the car can be on-line and idle. It is in this state either because there is no demand for it, or because it is being repaired. If the car is in this state, it earns nothing.

Let v, w, x, and y represent respectively the number of days that the marginal car will be in each state. These variables depend on n, N, CSR, PD, R, and D. Since D is an exogenous random variable, the expectation can be taken with respect to D. Thus, E(v; n, N, CSR, PD, R) stands for the expected number of days the marginal car will be off-line if the road owns n cars. Similarly, E(x; n, N, CSR, PD, R) stands for the expected number of days the marginal car is on-line and carrying an extra load, E(y; n, N, CSR, PD, R) for the expected number of days it is on-line and replacing a foreign car, and E(z; n, N, CSR, PD, R) for the expected number of days it is on-line and idle.

The expected marginal revenue can now be written as

$$
\begin{aligned}
E[MR(n; N, CSR, PD, R)] &= PD \cdot E\ (v; n, N, CSR, PD, R)\\
&\quad + R \cdot E\ (x; n, N, CSR, PD, R)\\
&\quad + PD \cdot E\ (y; n, N, CST, PD, R).
\end{aligned}
$$

This equation breaks expected marginal revenue down into three components. The interpretation is as follows. The expected revenue derived from purchasing one more car equals the amount that a car earns by being off-line for a day (i.e., PD) times the expected number of days that the marginal car will be off-line, plus the amount that a car earns by being on-line and carrying an extra load (i.e., R) times the expected number of days that the marginal car will be on-line and carrying an extra load, plus the amount that a car earns by being on-line and replacing a foreign car (i.e., PD) times the expected number of days that the marginal car will be on-line and replacing a foreign car. There could be another term representing the amount that a car earns by being on-line and idle (i.e., zero) times the expected number of days that the marginal car will be on-line and idle, but this term is dropped, since it is zero.

Declining Expected Marginal Revenue

An important feature of the model is that, as the number of cars a railroad owns increases, the expected marginal revenue falls. This feature is represented graphically by the downward sloping curve in Figure 12-1. Since the cost of a car is assumed constant, a horizontal line at C represents the cost of purchasing a car. The intersection of the downward-sloping curve and the horizontal line gives n*, which is the number of cars that satisfies the equilibrium condition. That is, n* is the number of cars that the railroad would own in order to maximize expected profit.

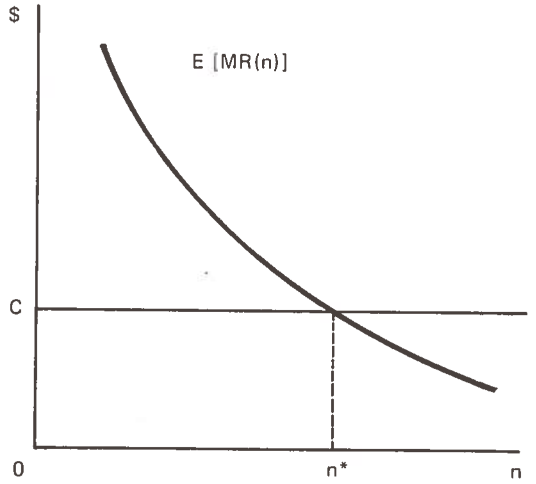

Figure 12-1. Graphical depiction of the equilibrium stock of cars.

The fact that the expected marginal revenue function has a negative slope is important for the following reason. If a railroad holds *more* than n* cars, then the expected marginal revenue of a car is less than its cost, so the road will decrease the number of cars it holds; in order to increase profit, it will continue to decrease its stock of cars until the stock reaches n*. In contrast, if a road holds *less* than n* cars, then the expected marginal revenue of adding a car is greater than its cost, and the road will buy cars until its stock reaches n*. This means that if a policy is changed and if it is known whether, under the new policy, the expected marginal revenue when holding n* cars is less than or greater than the cost of a car, then it is also evident whether the policy change will induce the railroad to decrease or increase its stock of cars. For example, if the expected marginal revenue of a road with n* cars is less than the cost of a car, then that road will decrease the size of its fleet (since that will increase its expected profit). In this way, one can analyze the effects of a policy in order to determine its effect on fleet size.

It has been asserted that expected marginal revenue is declining, but this needs to be proved. This one result will be stated and proved to show how theorems can be established, but first, the intuitive basis of the result will be explained. As the number of cars n owned by a road increases, there tend to be more home cars on line. Hence, there is a greater chance that demand will be insufficient to employ all the home cars and, thus, a greater chance that the marginal car will be idle. Since there are more cars on-line, there is a smaller chance that the marginal car will get to carry an extra load. These two factors cause expected marginal revenue to decrease as n increases. It turns out that this decrease cannot be offset, even if there is an increase both in the expected number of days the marginal car is off-line earning the per diem charge and also in the expected number of days that it replaces foreign cars.

Before the result is proven, the assumptions to be used will be written out. The previous paragraph has reasoned that as a road owns more cars, the number of days that the marginal car will be on-line and idle is likely to increase. If $n_1 < n_2$, this assumption is written as

$$\begin{aligned} &E\ (z; n_1, N, CSR, PD, R) \\ &\quad < E\ (z; n_2, N, CSR, PD, R). \end{aligned} \tag{1}$$

The previous paragraph has also reasoned that as a road buys more cars, the number of days that the marginal car is online and carrying an extra load is likely to decrease. If $n_1 < n_2$, this assumption is written as

$$\begin{aligned} &E\ (x; n_1, N, CSR, PD, R) \\ &\quad > E\ (x; n_2, N, CSR, PD, R). \end{aligned} \tag{2}$$

An assumption must now be made about the relative magnitude of R and PD. It is natural to assume that the revenue earned by carrying a load for a day is greater than the per diem rate, i.e., a road makes money by carrying a load in a foreign car. In this case

$$0 < PD < R. \tag{3}$$

Finally, the four states are defined so that a car must be in exactly one of them every day. Given that there are 365 days in a year, the following expression is

$$\begin{aligned} 365 = {} & E\ (v; n, N, CSR, PD, R) \\ & + E\ (x; n, N, CSR, PD, R) \\ & + E\ (y; n, N, CSR, PD, R) \\ & + E\ (x; n, N, CSR, PD, R) \end{aligned} \tag{4}$$

for all values of all the variables to the right of the semicolon. The result can now be stated and proved.

THEOREM: If assumptions (1)—(4) hold and if $n_1 < n_2$, then

$$\begin{aligned} &E\ [MR(n_1; N, CSR, PD, R)] \\ &\quad > E\ [MR(n_2; N, CSR, PD, R)]. \end{aligned}$$

To cut down on notation, N, CSR, PD, and R are suppressed, since these variables are held constant.

PROOF: From (4),

$$365 = E\ (v; n) + E\ (x; n) + E\ (y; n) + E\ (z; n)$$

for all n. From (1),

$$E\ (z; n_1) > E\ (z; n_2)$$

These last two expressions imply

$$\begin{aligned} &E\ (v; n_1) + E\ (x; n_1) + E\ (y; n_1) > E\ (v; n_2) \\ &+ E\ (x; n_2) + E\ (y; n_2) \end{aligned}$$

which can be rewritten as

$$\begin{aligned} &E\ (v; n_1) - E\ (v; n_2) + E\ (x; n_1) - E\ (x; n_2) \\ &+ E\ (y; n_1) - E\ (y; n_2) > 0 \end{aligned} \tag{5}$$

From the definition of expected marginal revenue,

$$\begin{aligned} & E\ [MR\ (n_1)] - E\ [MR\ (n_2)] \\ &\quad = PD \cdot E\ (v; n_1) + R \cdot E\ (x; n_1) + PD \cdot E\ (y; n_1) \\ &\qquad - PD \cdot E\ (v; n_2) - R \cdot E\ (x; n_2) \\ &\qquad - PD \cdot E\ (y; n_2) \\ &\quad = PD\ [E\ (v; n_1) - E\ (v; n_2)] + R\ [E\ (x; n_1) \\ &\qquad - E\ (x; n_2)] + PD\ [E\ (v; n_1) - E\ (v; n_2)] \\ &\quad > PD\ [E\ (v; n_1) - E\ (v; n_2)] + PD\ [E\ (x; n_1) \\ &\qquad - E\ (x; n_2)] + PD\ [E\ (y; n_1) - E\ (y; n_2)] \\ &\quad = PD\ [E\ (v; n_1) - E\ (v; n_2) + E\ (x; n_1) \\ &\qquad - E\ (x; n_2) + E\ (y; n_1) - E\ (y; n_2)] \\ &\quad > 0 \end{aligned}$$

where the first inequality is justified by (2), which says

$$E(x; n_1) > E(x; n_2)$$

and by $PD < R$. The second inequality is justified by (5). Collecting the results from this string of equalities and inequalities gives

$$E[MR(n_1)] - E[MR(n_2)] > 0.$$

This completes the proof.

Note that no assumption is made about whether the number of days that the marginal car is expected to be off-line or on-line and replacing a foreign car. The result holds no matter what is true for these values. This shows how assumptions might at first glance appear inadequate to establish a conclusion, but they are shown by mathematical analysis to be sufficient to reach that conclusion.

APPLICATIONS

Introduction

The machinery that has been developed will now be applied to analyze the effects of a number of policy changes. The format for these explanations will be as follows. First, the policy change being considered is described. Second, the assumptions about how that policy change will affect the components of expected marginal revenue or cost are stated verbally. Third, the resulting effect on the size of the fleets of individual roads and of the entire railroad system is discussed. The policies analyzed are:

- a government purchase of cars
- government load guarantees
- a change in the car service rules.

The detailed mathematical statements and proofs of the theorems are omitted; the reader interested in these or in an application to a change in per diem rates can consult Oiesen [1975, pp. 41-65].

Government Purchase of Cars

One policy that has been proposed [U.S. Senate, 1971, p. 4] is for the government to buy cars and rent them to the railroads. The claim is that this policy would mitigate the freight car shortage problem by increasing the number of cars in the national fleet. If the government purchased cars, this would initially mean there were more cars spread around the national system. This would have two effects on an individual railroad. First, since there would be more cars on-line, there would be a decrease in the expected number of days that the marginal car would be carrying an extra load. Second, other roads, because of the increase in cars, would be more likely to return this railroad's cars; with more home cars on-line, there is a greater chance that demand will be inadequate to employ them. Thus, the number of days that the marginal car would be expected to be idle would increase. From these two premises the conclusion is that the number of cars owned by this railroad would decline. The graphical interpretation is that this government policy would decrease the equilibrium stock of cars for a road by shifting down the expected marginal revenue curve.

Hence, the increase in the national fleet caused by the government purchase is followed by a decrease as individual railroads reduce their fleets. Can this decrease be so large as to offset the government purchase and to cause the government action to result in a decline in the size of the national fleet? The answer is, "No," but the details of the reasoning will not be given here. The extent to which the government purchase is offset by decreases in the private stocks cannot be determined from the qualitative assumptions made here. To summarize:

THEOREM: If the government purchases cars and rents them to railroads, then the size of the national fleet will increase, but by less than the size of the government purchase.

Government Loan Guarantees

Another suggested policy has the government guaranteeing loans that railroads take out to purchase cars [U.S. Senate, 1971, p. 4]. There are several ways this loan guarantee might increase the supply of freight cars. First, the guarantee might allow railroads with low credit ratings to secure loans that they could not otherwise get. Second, the guarantee could attract new lenders. Third, the guarantee could lower the interest rate that is charged. We will concentrate here on the third possibility.

If a lower interest rate is charged, then a railroad pays less in interest than if the higher interest rate were charged. Thus, the loan guarantee has the effect of lowering the annual cost C of a car. With a lower cost for the same number of cars the expected marginal revenue will be greater than marginal cost, so the railroad will purchase more cars. Graphically, this policy causes a downward shift of the horizontal line in Figure 1; this increases the equilibrium stock of cars. To summarize:

THEOREM: If the government guarantees car loans, then the size of the national fleet will increase.

Car Service Rules

Car service rules are an important policy that can affect freight car investment. If car service rules are tightened and foreign cars are sent home more rapidly, then the marginal car has a smaller chance of earning the per diem charge by being off-line, and it has a smaller chance of replacing a foreign car on-line. So the marginal car's contribution to marginal revenue from being in these two states declines for both net exporting and net importing roads.

For net exporting roads, the number of cars on line will be larger after car service rules are tightened, since the number of home cars returned from off-line is expected to exceed the number of foreign cars that are returned to their home lines. Thus, for a net exporting road, the chance of the marginal car carrying an extra load declines. Putting this all together, it is evident that for a net exporting road, expected marginal revenue declines as the car service rules tighten. Consequently, as car service rules tighten, net exporting roads decrease the number of cars that they own.

The analysis is not so straightforward for net importing roads. When the car service rules are tightened, the number of cars on-line is expected to go down, since the foreign cars sent home outnumber the repatriated home cars. Therefore, the marginal car is expected to carry more extra loads, and this component of expected marginal revenue increases. Since the other two components of expected marginal revenue decrease, one cannot say which way expected marginal revenue changes when car service rules are tightened. Therefore, it cannot be said for sure whether net importing roads buy more cars or not when car service rules are tightened. However, in the extreme case where a net importing railroad has no cars off-line, a tightening of car service rules causes this railroad to purchase more cars. This follows, since the only change is that foreign cars are sent home, so the marginal car carries an extra load where previously it only replaced a foreign car.

The qualitative assumptions do not permit one to infer whether a tightening of car service rules will cause the size of the national fleet to increase or decrease. To summarize:

THEOREM: As car service rules are tightened, there is a decrease in the number of cars owned by a railroad that is a net exporter of cars.

THEOREM: As car service rules are tightened, there is an increase in the number of cars owned by a railroad with no cars off-line.

CONCLUSION

A policy designed to deal with the problem of freight car shortages can have an impact by affecting the number of cars in the national fleet and by affecting the efficiency with which cars are utilized. This paper has described an investment model that predicts the qualitative effect that various policies would have on the size of the national fleet. A prototype of a companion performance model that predicts the effect that various policies would have on the efficiency with which cars are utilized is described in Oiesen [1976]. Moreover, this latter model, when fully developed, will be capable of calculating the expected profit for an individual railroad as a function of the number of cars it owns and of the policies that are adopted. Since this is precisely the input needed by the investment model, this performance model would extend the investment model in two ways. First, the investment model would be able to make not just qualitative predictions but also quantitative ones, e.g., it could predict not just whether the size of the national fleet would increase or decrease if a particular policy were adopted, but also by how much. Second, since this other model can handle a wide range of policies, it would allow the investment model to be applied to many more policies than just those described in this paper.

An improved version of these two models will provide a method for predicting the effect of various policies not only on freight car shortages but also on other aspects of railroad operation.

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BIOGRAPHY

James F. Oiesen has worked at the Transportation Systems Center for two years. His work has centered around modeling various aspects of the transportation sector. In addition to modeling railroad investment and operations, he has modeled airports and competition within modes, and he has written on the general characteristics of transportation models.

He received a B.A. in economics from the University of Texas in 1970 and did graduate work in economics at MIT, where he specialized in microeconomics and decision-making under uncertainty.

RAIL TERMINAL INFORMATION AND CONTROL SYSTEM

by

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ROBERT D. REYMOND

INTRODUCTION

Major rail terminals act as gateways and points of car exchange for a number of railroads. While these terminals are the focus for interline railroad operations, they are also an important impediment to efficient railroad operations. For example, the average freight car spends about 61 percent of its time in railroad yards and this same car visits at least two yards during a trip.(1,2) As the size of the terminal increases, these problems are compounded. Much research has and is being focused on railroad operational improvements which either speed trains through terminals or avoid terminal bottlenecks. The improvement of inter-railroad operations in major terminals is the focus of this paper.

Railroads have made significant progress in the last ten years in embracing computers for use in providing management information used to control intraline operations. Railroads have implemented scheduling systems for trains and cars, have developed sophisticated computer programs to distribute and control the movement of empty cars, and have achieved a high degree of automation in the transmission of car movement data among the various stations on the individual railroad.

Recent years have seen the railroads initiate cooperative efforts aimed at improving operations throughout the industry. A national car information system, TRAIN II, has been implemented by the Association of American Railroads (AAR). The system is used primarily by the Car Service Division in supporting its car distribution function through national Car Service Orders and Directives. The system also provides message switching facilities and national car location information to appropriate users. Plans are currently being implemented for TRAIN II to automatically provide the verification documents associated with interchanging a car from one railroad to another.

The Freight Car Utilization Research and Demonstration Program was implemented in 1974 as a joint industry-government project to study and experiment with various improvements to railroad operations and to recommend modifications to regulations governing those operations. For example, in the Clearing House Experiment, railroads are cooperatively sharing freight cars in pools without regard to existing car service rules. In addition, some railroads are automatically exchanging information on cars to be interchanged among themselves. The various efforts of the Car Utilization Program, as well as the other industry efforts including TRAIN II, will do much to improve rail operations and profits in the future.

While the individual railroad efforts and industry-wide efforts do improve operations, there remains a major opportunity to improve the process of interchanging cars and managing the major terminal gateways in the railroad systems. As such, terminals and systems to improve their management and control are a key area of research at the Transportation Systems Center.

TYPICAL RAILROAD TERMINAL OPERATIONS

In the context of this paper, a rail terminal is defined to be a geographical area in which several railroads interchange cars and conduct switching and industrial service operations. Using this definition, a terminal may contain as many as 100 classification and support yards as in the case of Chicago, along with all the trackage interconnecting the various yards. Many of the line haul railroads which operate in a major rail terminal gateway terminate their operations there. The Burlington Northern, Santa Fe, Conrail, and Chessie, for example all terminate in Chicago. For such roads, the traffic they bring to the terminal is either to be delivered to a local industry or to be interchanged to another railroad. For roads which operate into and through a terminal, their traffic system involves their own line haul operations, services to industry, and interchanges with other railroads.

One of the most important terminal activities in which any railroad participates is the process of interchanging cars. Interchanges can be empty cars being returned to or through the receiving road to the cars' owners' or loaded cars intended for destination on or beyond the receiving railroad. Four basic types of interchanges are involved: (1) regular interchanges, (2) joint facility interchanges, (3) set outs, and (4) industry pulls. Joint facility interchanges occur; for example, when the Kansas City Southern classifies a car on the appropriate track in the joint yard, it operates with the Milwaukee road in Kansas City. Another type of joint interchange involves a placement at an industry of an empty car by one road and the pull from industry of the same loaded car by a second road, the latter road usually being the outbound carrier. The interchange in this case occurs at the industry location. Interchanges can also occur when the delivering road simply sets a cut of cars on a siding for the receiving road to pick up at its convenience.

Another important facet of the interchange process is the reciprocal agreement. These are interchange agreements between two roads whereby one road provides locomotive power and crew for both the delivery of cars to the other road and the return of cars from that road. The agreements often last for a set period of time, such as ninety days, at which time the other railroad provides the service. Reciprocals conserve locomotive power by eliminating "light moves" or the practice of engines and cabooses moving without cars. For example, in Chicago, the Santa Fe conducts daily interchange deliveries to the Belt Railway of Chicago (BRC) at Clearing Yard. The engine, caboose, and crew remain at Clearing from two to four hours and then return with a group of cars for interchange from the BRC to the Santa Fe at Corwith Yard. In Kansas City, about a third of the roads practice similar reciprocal interchanges

Most current terminal interchange operations in major rail gateways are unstructured, often informal, and a function of operating procedures developed between the railroads involved, including such practices as the reciprocal agreements described above. Interchange operations are at least nominally scheduled in most terminals on a once per day or even once per shift basis, depending on the level of activity in the terminal. These schedules are not rigidly adhered to. The railroads make the scheduled moves if they have sufficient volumes of cars to justify a train. If business is light, a scheduled interchange train might well be cancelled. Conversely, if business is unexpectedly heavy or there is a high-priority traffic situation, an extra train may make an unscheduled interchange move.

Offering and acceptance management for interchanges ranges in most terminals from little or none to reasonably formal procedures between certain railroads. Notification of an impending delivery may be accomplished by a telephone call between yards, the transmission of waybills or switch lists by facsimile machine, or through the use of messengers to pick up the waybills from the delivering yard. Often, however, the only advance notification is the appearance at the throat of the yard of the delivering switch engine with its cut of cars.

There are a number of interchange practices which complicate the orderly movement and scheduling of cars through terminals. One situation is an interchange move involving a switching road pulling a car from industry to the billing road. The switching road receives a charge of about $60 per car but does not participate in the division of revenues for the shipment. The billing road is the orginating road even though the shipper's siding is serviced by the switching road. The car is frequently pulled without the benefit of waybill or similar documentation. The only information that exists on the car is the shipper's name and the interchange yard to which it is to be delivered. After arrival at the yard, because information is missing, the car is in a "no bill" situation and is assigned to the hold track until waybill information becomes available. This type of situation frequently occurs at night and on weekends when the shipper's traffic office has closed and no personnel are available to prepare the bills. By ordering the car moved in this manner, the shipper avoids demurrage charges or the expense of a delayed shipment while the road is forced to hold the car for the start of the week while awaiting the bill. Although this type of transfer move tends to be fairly common, it is repetitive and certain patterns become established. This repetitive nature permits railroads to anticipate most of these interchanges, plan for them, and even send some of them on outbound trains without waybills (slip billing).

Other movement situations which affect interchange operations are dual deliveries. This type of interchange frequently occurs where one road has a relatively small amount of traffic for several different railroads. It involves multiple interchanges within one delivery move with cuts of cars comprising several offerings from the delivering road. Dual deliveries reduce the number of train originations required, but can create congestion and confusion, particularly at a small crowded yard because of additional handling and possible track blockage.

To reduce the number of interchanges in road haul operations, run-through agreements are being initiated between two or more carriers. These agreements permit the run of a single, jointly operated train between major rail terminals without the necessity of intermediate car interchanges. This type of operation is becoming more frequent among major rail carriers and is setting the pattern for future through-train operations. Run-through operations permit the participating roads to extend rail service beyond their normal operating networks and offer fast freight service between distant points. Run-through trains seldom stop except for inspection and refueling, and crew changes are often conducted on the fly while the train is slowly moving through the terminal or yard. Power is supplied by one or both parties to the agreement and trains are often made up with locomotives from two or more roads. Power is not changed during the run of the train, and as a result, crews frequently operate other railroads' locomotives. The trains do not stop and are not detained in interchange terminals. This speeds the movement of the cars actually involved in the run-through and reduces the volume of cars that must be processed in interchange through major rail terminals.

Run-through trains, however, do impose some constraints on the operations of railroads, particularly in the information transfer and processing area. These impacts are centered principally on the difficulties in transferring waybill and consist information in a timely manner between the parties to the agreement. These difficulties are particularly pronounced at the point when control of the train passes between the participating roads. There does not appear to be in most cases an automated information transfer system for accommodating run-through train data. Clearly, a timely, formal interface is necessary to link the roads' information systems for data exchange on these operations.

TERMINAL CONTROL FUNCTION

A degree of interchange control, which is at present unique to major rail terminals, is exercised in Kansas City by the Kansas City Terminal Railway Company (KCT). All movements over the KCT trackage, which constitute 81 percent of the interchanges in Kansas City, are monitored and controlled by a centralized traffic control facility. The movements controlled include through trains, locals, and interchanges. While individual train movements are controlled by the system, there is no structured offering and acceptance management for interchanges.

The traffic control facility is designed around two WABCO train control consoles, Figure 13-1. A control board displays the status of all switches and signals on the KCT trackage. Each control console is manned by a train director. The center is manned on a twenty-four-hour basis throughout the year.

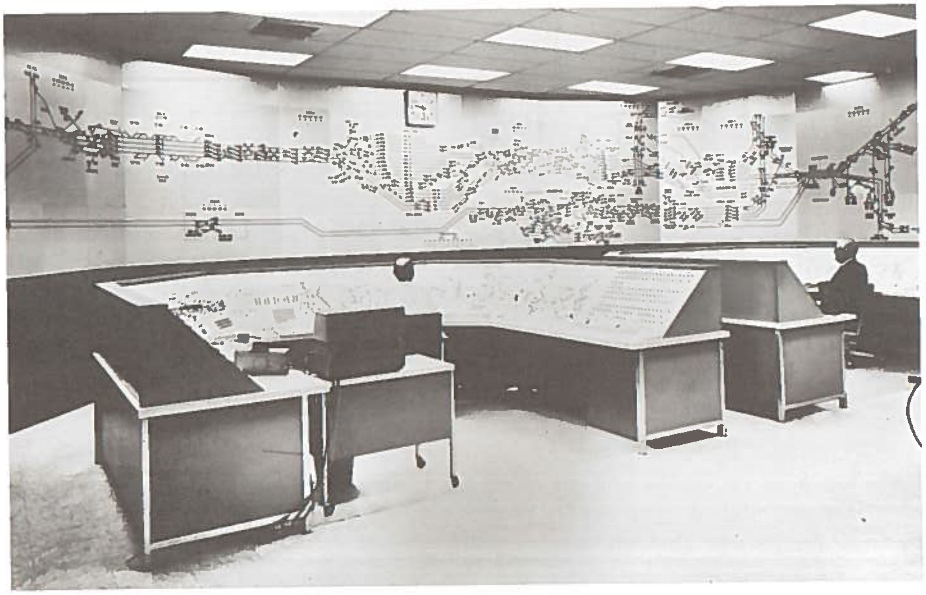


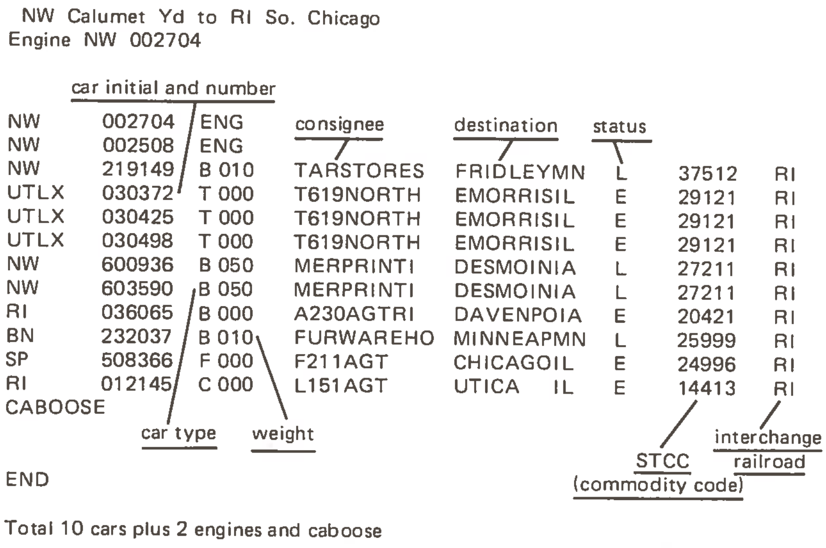
Figure 13-1. Traffic control center.

Train routes are set up automatically for each move by pressing control buttons at the points representing positions where the train enters or leaves the KCT tracks. As a train is cleared to enter the system, its route is lighted on the board, thus highlighting its moves through the terminal. As a train passes a switch or signal point, the indicator lights turn from white to red thus indicating its progress and locations. Communications are maintained directly with the trains via on-board two-way radios or through remote wayside transceivers located at strategic points on the KCT trackage. The central traffic facility accomplishes partial interchange control by clearing interchange movements with the receiving yard. Thus, if there is congestion in the yard or the route is in use, the delivering road is denied permission to enter the KCT tracks.

Lacking in this type of central traffic control system is the information about the cars being offered in interchange. Even though the movement of the individual trains is closely monitored and controlled, the information essential to the receiving road in its subsequent classification and movement of the car is not transmitted routinely or automatically from one road to the other. It is this lack of information about these cars that is the basis for the concept of terminal information systems being advanced in this paper. The premise is that timely receipt of the information about such cars will allow the receiving road to better plan its operations and will also allow for improved operating efficiency of the entire rail terminal.

INTERCHANGE INFORMATION FLOWS

Information on train moves can be categorized into two areas: information about inbound trains—both through trains and locals; and information on cars being delivered and received in interchange. Most of the railroads at major terminals receive advance consists on their own inbound trains. These are reports which identify the car initial and number of the cars in the train in approximate train order with information on the contents, origin, destination, consignor, consignee, and load or empty status. Subsequent railroads to which the car will be interchanged are often included in the advance consists. Figure 13-2 is an example of a typical advance consist. The advance consist is usually received in advance of the arrival of the train so that the yard can plan for the receipt,



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NW Calumet Yd to RI So. Chicago
Engine NW 002704

NW       002704  ENG
NW       002508  ENG
NW       219149  B 010   TARSTORES    FRIDLEYMN    L    37512   RI
UTLX     030372  T 000   T619NORTH    EMORRISIL    E    29121   RI
UTLX     030425  T 000   T619NORTH    EMORRISIL    E    29121   RI
UTLX     030498  T 000   T619NORTH    EMORRISIL    E    29121   RI
NW       600936  B 050   MERPRINTI    DESMOINIA    L    27211   RI
NW       603590  B 050   MERPRINTI    DESMOINIA    L    27211   RI
RI       036065  B 000   A230AGTRI    DAVENPOIA    E    20421   RI
BN       232037  B 010   FURWAREHO    MINNEAPMN    L    25999   RI
SP       508366  F 000   F211AGT      CHICAGOIL    E    24996   RI
RI       012145  C 000   L151AGT      UTICA    IL  E    14413   RI
CABOOSE

END

Total 10 cars plus 2 engines and caboose
```

Explanation:

NW 219149—loaded box car weighing 10 tons loaded with bicycles going to Tara Stores via the Rock Island

UTLX three empty tank cars which normally carry liquified gas. Being delivered to East Morris, Illinois to station T619North for loading.

NW600936 and 603590—loaded box cars weighing 50 tons each. Loaded with magazines going to a printing company in Des Moines, Iowa via the Rock Island.

BN 232037—Loaded box car weighing 10 tons filled with restaurant furniture for a furniture warehouse in Minneapolis.

SP 508366—Empty flat car which carries particle board. To be delivered to freight agent F211 in Chicago on the Rock Island.

RI 012145—empty covered hopper which last carried sand. Being delivered to agent in Utica, Illinois.

Figure 13-2. Typical advance consist.

breakup, classification, delivery, and subsequent interchanges of the cars in the train. In the absence of an advance consist, yard operations cannot be planned until all waybills accompanying the train have been sorted and switch lists have been prepared. This advance consist information is the key input to a terminal information system.

Advance consists on inbound local trains are often non-existent principally because the local station does not have the means of transmitting this information to the receiving yard. The local trains usually service a number of shippers and/or small unmechanized stations along a route. The facilities often do not provide input to the railroad's information system. Under these circumstances, the waybills carried on the train are the only source of information for subsequent operations planning.

Information quality on advance consists is a function of the sophistication of the information systems of the various individual railroads. Most railroads prepare the consists at the central computer of the railroads' headquarters and transmit the consist over the communications systems of the road. The accuracy of the consists is usually quite high, although this varies by railroads. For example, the 12 railroads which serve Kansas City are in the order of 97 percent accurate.(3)

On the other hand, advance consist information is seldom provided to other railroads on interchange movements. The receipt of advance consists by inbound yards in a rail terminal does not assure that the same information will be passed on to the next railroad. Information flows on interchange moves are usually informal and unstructured, vary not only from road to road, but also from shift to shift within the roads themselves. Often, no advance information at all is given to the interchange road.

Clearly in major rail gateways, a void exists between the advance consists which are received on inbound trains and the transmission of information about cars being delivered in interchange. This void is a function of the lack of both a formal information exchange structure and a system to assure that such information is developed and exchanged. The basis for such information transfer exists. Each railroad receives information about its own inbound trains. Each railroad prepares switch lists from waybill information, and provides outbound interchange information to its own system. However, seldom is this information transmitted to others who need it.

RAIL TERMINAL INFORMATION SYSTEMS

A central computer-based communications system at major rail terminals holds promise for providing the information exchange involved in the interchange process, and for improving the operational efficiency of the terminals. Rail terminal information systems would formalize and automate the exchange of information between railroads at the terminal. Such systems would receive advance information (advance consists) on inbound road trains at the same time individual railroads at the terminal would receive that information. Inbound trains would be identified by a remote car identification system such as Automatic Car Identification (ACI) prior to the trains' arrival at the terminal. The information system would then provide a corrected train list to the railroad involved and update the inventory maintained by the terminal system. Railroads would enter train list information on interchange movements into the system at the same time they would normally provide such information to their own central computers. Cars moving in interchange would be scanned again and corrected train lists would be provided automatically to the receiving railroad in advance of the arrival of the interchange train. The amount of advance notice would depend on the physical configuration of the terminal and the particular interchange move. Outbound road trains would similarly be scanned as they depart the terminal area and the terminal inventory record would be adjusted accordingly.

Besides serving the information exchange function for the interchange of cars between railroads, terminal information systems can serve several management functions which allow overview, monitoring, and if desired, control over the operations in a major rail terminal. For example, all consist records could be merged by the system to form an inventory of the entire terminal. A railroad, for example, could inquire of the information system about all cars in the terminal expected to be delivered to that railroad. Origin, destination, and contents could be listed for each car involved. Such information released only to the railroad concerned would be of benefit to yard operators in planning their locomotive, crew, and clerical activities. The inventory capability and the ability to use the system to examine aggregated train movements in the terminal would offer a management overview of terminal activities for the railroad managers involved whether they be in a terminal railroad such as in Kansas City or Houston, or a General Managers Association such as in Chicago or New York.

INFORMATION FLOW— TERMINAL INFORMATION SYSTEMS

The key input to a terminal information system is advance consist and car waybill information on all trains enroute to the terminal. Figure 13-3 represents the flow of in-

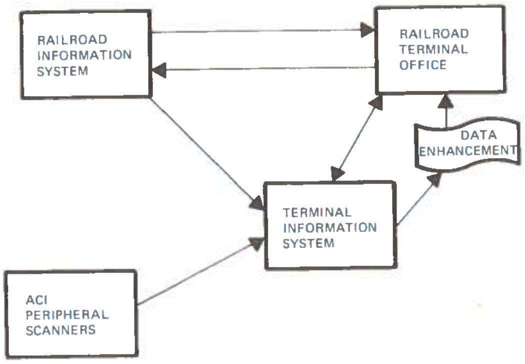

Figure 13-3. Terminal information system—advance consist information flow.

formation to provide the input to the information system. The advance consist information would be automatically sent to the terminal information system at the same time consists would normally be created in the railroad's main computer. ACI or other automated detection data would be fed directly to the terminal information system as trains pass scanners, and the data would be merged with the appropriate advance consist data, resulting in a final train list more accurate than either the scan list or the advance consist. The respective railroads at the terminal could use the enhanced consist data to update their own central information systems.

Figure 13-4 shows the information flow which would be involved in the interchange of cars between any two railroads. It is this flow of information that is the primary purpose of the terminal information sytem. When a railroad originates an interchange train, it would provide the consist both to its main railroad computer system and to the terminal information system. After an interchange train departs its yard, it would be scanned and an enhanced train list would also be returned to the delivering road for updating of its information. The receiving railroad would provide the information on the train to its headquarters computer to update the railroad's inventory. The receiving yard would have information about a train before its arrival and thus would have the ability to plan the switching and classification operations, train scheduling, etc., in order to reduce delays, improve yard efficiency, and speed cars to their destinations.

Information exchanges would take place in the format of each of the railroads in the given terminal. All of the format conversion takes place within the terminal information system. Data security would be maintained in the information system such that no railroad would be able to access data of a proprietary nature about the shipments of another railroad.

CHICAGO RAIL TERMINAL INFORMATION SYSTEM (CRTIS)

In 1973, the railroads in Chicago undertook development of the Chicago Rail Terminal Information System (CRTIS) to demonstrate some of the features and capabilities described previously. This pilot system is sponsored in part by the Federal Railroad Administration and in part by the major railroads operating in the Chicago Terminal. The system, consisting of a central computer, communications circuits to each railroad, and 109 ACI scanners, was implemented during 1974. Since then, it has provided advance consists on many of the interchange trains moving in Chicago, and has provided the General Managers Association with reports of ter-

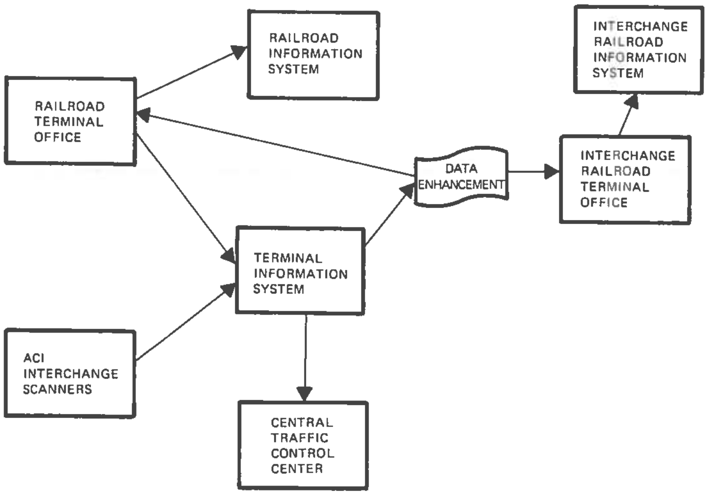

Figure 13-4. Terminal information system—car interchange information flow.

minal inventory, and levels of activity within the terminal. The system has been plagued with problems of input data quality which has reduced the system's effectiveness in the eyes of many of the railroads. The appropriate railroad inputs are often not made in a timely manner. As a result, the interchange information is often not transmitted to the receiving road. The Transportation Systems Center (TSC) during 1975–76 has conducted a major study of the effectiveness of CRTIS and of rail operations in Chicago. A report on this evaluation will be published during December 1976. Despite the input problems experienced in CRTIS to date, TSC believes that CRTIS is aiding in improvements in information flow in Chicago and has significant potential for continued support to the management of rail operations in Chicago.

KANSAS CITY TERMINAL INFORMATION AND MESSAGE EXCHANGE SYSTEM

Building on the experiences and lessons learned in Chicago, the Federal Railroad Administration (FRA) and the railroads in Kansas City have embarked on a design feasibility study for a terminal information system to be operated by the Kansas City Terminal Railway Company. In support of this effort, TSC has completed a requirements and benefits analysis of such a system.(3) The system, if implemented, would formalize and automate the exchange of information between railroads on cars involved in interchange. The system would automatically receive and send advance consists on inbound, outbound, and interchange trains. An important facet of the design feasibility study is the participation of a Railroad Advisory Committee to coordinate the railroad input requirements and the function and outputs of the terminal information system. The role of the FRA in the project is to support the design study and stimulate the railroads in undertaking this type of improvement project. The benefits to be derived from the system will be projected by the railroads, and evaluated by FRA through measurement of the improvement in operations in Kansas City.

TERMINAL INFORMATION SYSTEMS IN THE FUTURE

The two terminal information system projects co-sponsored by the Department of Transportation are important first steps toward achievement of the objectives of terminal information systems as described in this paper. The design concepts demonstrated in Kansas City and Chicago and the lessons learned in those projects will be applicable to other major rail terminals in the United States. Figure 13-5 shows the 26 major terminals based on interchange volumes. Some of these would appear to be likely candidates for future terminal information system developments. In particular, St. Louis and Pittsburgh hold promise for future investigation for such system applications.

As more terminal information systems are implemented and the operations in the various terminals improve, one would expect the movement time and reliability of the movement of freight cars to improve. The average car cycle and the percentage of time spent in terminals would be expected to decrease. The terminal systems would foster increased data exchange within the railroad industry. At present, data exchange is in pilot use on several railroads with compatible information systems. System interfaces at the terminal level would allow automated data exchange at more locations and with greater use than single railroad-to-railroad data exchange.

The process of automatically verifying the time of interchange of cars will become increasingly important as the industry adopts hourly per diem. The terminal information systems offer to the railroads an objective, indisputable record of the exact time of interchange as reported by automatic car sensing systems. The TRAIN II system is designed to provide the certified documents to railroads and resolve disputes among railroads on time of interchange. The terminal systems have the capability to automatically issue the verification documents, and could also be tied directly to TRAIN II in providing the time of interchange.

Figure 13-5. Major rail terminals.

The terminal information systems offer potential for improving the quality of data needed for freight car movements. The systems can significantly reduce the number of "no bill" cars, those cars traveling without the proper waybill information. The pilot system in Chicago, for example, has seen a reduction in daily "no bill" cars from more than 800 in 1969 to fewer than 100 in September 1976. At least part of this dramatic reduction is due to CRTIS. Terminal information systems provide an important additional source of data to be used by the railroads in closing open records about the waybill information on a car. Not only does this improved information reduce clerical workload, but it also can help move the freight cars through the terminals more quickly.

An important potential use of terminal information systems lies in their ability to communicate large amounts of car movement information to other terminal systems. Such interconnection of terminal information systems, shown diagrammatically in Figure 13-6,

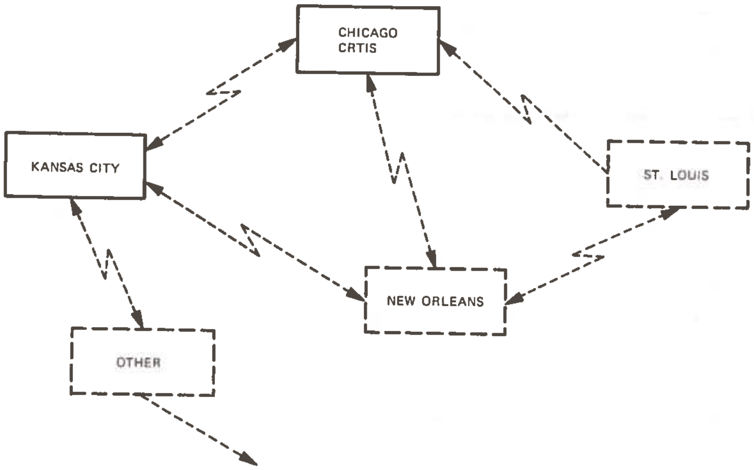

Figure 13-6. Terminal information systems—possible future directions.

could significantly improve the data quality of each terminal system by eliminating some of the input requirements which would be placed on individual railroads operating at the various terminals. One could envision the Chicago Rail Terminal Information and Message Exchange system automatically transmitting to the Kansas City Terminal Information and Message Exchange system the consist data for trains originating in or going through Chicago bound for Kansas City. The communications requirements of the individual railroads would be reduced and the dependence of the terminal system for separate input would be consolidated and thereby decreased. These terminal systems could also communicate and provide data to TRAIN II concerning the interchange activities in the various terminals. The interconnection of the terminal systems and TRAIN II would greatly facilitate the collection and exchange of interchange data. The information system burden of individual railroads would be lessened with respect to interline traffic, and the railroad could concentrate its information efforts on movement of the cars on its lines.

The concept of interline car scheduling, as advocated by the Department of Transportation in its co-sponsorship of the Missouri Pacific car scheduling project, would also be facilitated through the existence of interconnected terminal information systems. To be effective, interline scheduling needs efficient exchange of information about the origin, destination, routing, and scheduling of a car on delivering and connecting carriers. The terminal systems would have the capability to provide the information transfer in a timely enough manner to allow such scheduling to take place.

Terminal information systems, whether in existence as in Chicago or planned as in Kansas City, have unrealized potential for improving railroad operations in major terminals. The concept of data exchange has been slow to develop in the railroad industry because of the traditional competitive relationship which exist among railroads. These traditional relationships act as constraints on cooperative computer efforts. More detailed evaluation of the influence of these relationships, and the potential functions of terminal information systems is needed. More explicit definition and quantification of benefits of such systems is required. The potential for terminal information systems seems to be great. Careful study of the functions, issues, and constraints associated with the systems is an appropriate area for cooperative research between the Department of Transportation and the railroad industry.

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Mr. Troup has been involved in research at the Transportation Systems Center related to freight transportation for the past five years. His emphasis has been on the use of information systems in freight transportation, and on railroad operations. He has been responsible for the planning, management, and conduct of a variety of freight and railroad oriented projects including analysis of agricultural commodities transportation during the 1973 grain crisis, terminal information and control systems in freight transportation, railroad freight car operations, and institutional aspects of the rail/highway grade crossing safety program. Before joining TSC in 1971, he was with the U.S. Air Force involved in the development of meterological data collection systems. He has a BS degree in Engineering from Purdue and an MS degree in Engineering Management from Northeastern University.

BIOGRAPHY

Mr. Reymond graduated from Wesleyan University with a BA in mathematics and economics. For the past twenty years he has held analytical and advisory positions of increasing responsibility with the AVCO Corporation, Westinghouse Electric Corporation and the U.S. Government. These assignments focussed on such diverse areas as information system applications, requirements, benefits and cost analysis in the fields of surface and marine transportation, military logistics and freight and commodity movements. His work has also been concerned with the development of advanced system concepts in marketing and product development. During the Korean War, Mr. Reymond served for three years as Operations Officer aboard an Atlantic Fleet Destroyer.

EVALUATING RETURNS ON INVESTMENT IN TODAY'S REGULATED MOTOR CARRIER INDUSTRY

by

DR. ROBERT F. CHURCH

INTRODUCTION

The material presented in this paper is the result of a 1974 request by the Office of the Secretary of Transportation to TSC to investigate and report on returns on investment in the U.S. regulated motor carrier industry. The paper discusses the level and pattern of returns to equity investment in motor carriers; how the ICC has attempted to take these returns into consideration when granting general rate increases; how the returns are affected by profits of carrier affiliates; how to judge the significance of the amounts of debt financing undertaken by carriers; and how the investment community views the performance and prospects of the large carriers whose stock has been sold to the public.

SOME BASIC FINANCIAL CHARACTERISTICS OF THE REGULATED MOTOR CARRIER INDUSTRY

Although less stable from year to year, regulated motor carriers' net income as a percentage of stockholders' equity was not greatly above that of other industries in the years 1960-1972. This can be shown by comparing the Federal Trade Commission's composite return-on-equity series for manufacturing corporations (4) with a comparable series for Class I Motor Freight Carriers. (See Table 14-1.)

Table 14-1. A Comparison of the Return on Equity for Class I Motor Carriers and All Manufacturing Corporations

	Class I Motor[a] Freight Carriers	All Manufacturing Corporations[b]
1972	15.4%	10.6%
1971	16.2	9.7
1970	6.7	9.3
1969	9.8	11.5
1968	12.9	12.1
1967	9.2	11.7
1966	14.5	13.4
1965	15.7	13.0
1964	13.6	11.6
1963	12.1	10.3
1962	12.4	9.8
1961	10.2	8.9
1960	4.9	9.2
Aver.	11.8	10.9
Std. dev.	3.5	1.5

[a] **Source:** ICC *Annual Reports*

[b] **Source:** Federal Trade Commission, as reported in *Economic Report of the President*. See Table 14-12 for breakdown into 21 different industry groups.

The nature and significance of these returns to equity investment in the motor carriage industry has been the subject of considerable discussion by various observers. Craig Kloner, a motor carrier securities analyst with Goldman Sachs,(6) has characterized the return as "erratic," and pointed out that:

> "growth in physical volume . . . does not assure profit growth in any particular year . . . . Over the short term the most important factor in motor carrier profitability is the amount and timing of rate relief ICC grants to offset rising costs . . . . Since the first national contract was signed in 1964, the teamsters have been very successful in their negotiations with the trucking industry; national agreements were ratified in 1967; 1970 and 1973 . . . (However) the ICC granted rate increases in 1967, 1968, 1970, and 1971 which more than offset the higher costs experienced by motor carriers."(6)

Figure 14-1 shows how overall operating ratios changed during these years. Kloner noted that "the Commission has tended to be more generous with rate relief when the operating ratio of all Class I and II carriers approaches or exceeds 96 percent," and that the Commission did not grant general rate relief during 1973 in excess of amounts needed to cover operating cost increases, because, at least during the first part of the year, the overall operating ratio had not reached the 96 precent "danger area."

Although in general, over 60 percent of motor carrier expense goes to wages and related fringe benefits, and although teamster wage increases have generally exceeded those gained by other manufacturing workers, the industry has avoided restrictive work rules in its union contracts. This has helped trucking company managements maintain profitability from year to year. Paul Schlesinger, of L. F. Rothschild & Co.,(19) has pointed out that:

> "Management enjoys labor flexibility when merging companies (without

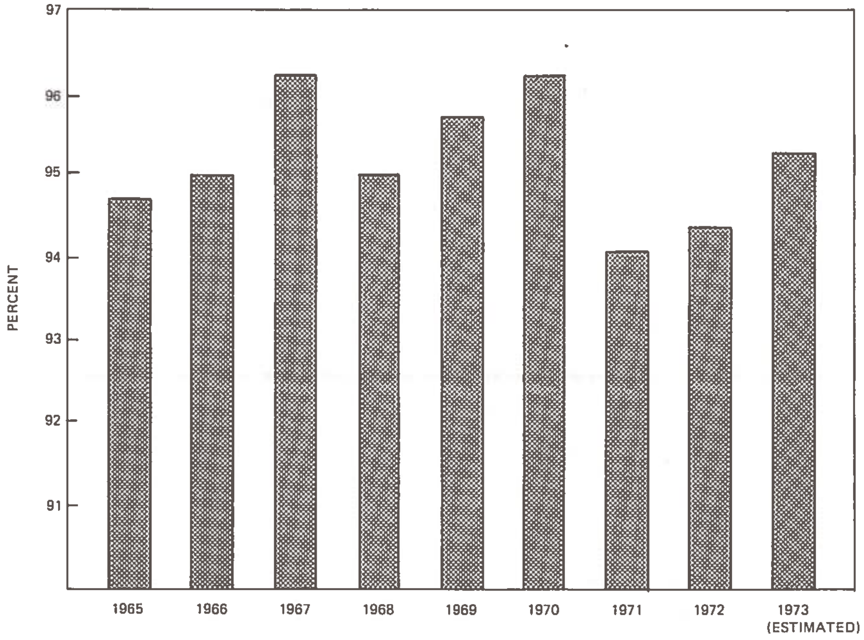

Figure 14-1. Operating ratios of all Class I and II motor carriers, 1965-1973.

Source:(6)

> seniority or jurisdictional disputes) and can quickly adjust overall employment levels to current business conditions. Only seven days' notice is required for pay-off of full-time workers, and up to 10% part-time workers are permitted . . . (Also), many non-labor costs are closely related to traffic levels . . . Furthermore, the companies' capital investment requirements are not great. Incremental units of capacity (either in revenue equipment or in terminals) are not costly, with delivery terms usually less than six months and good financing terms usually available. Management can generally readily adjust capital spending plans when business or internal financial circumstances require."

It is also important to keep in mind that motor carrier tractors and trailers are depreciated much more rapidly than other types of capital equipment, and that, despite the significant amount of leasing that goes on, and the increasing proportion of investment going into terminal properties, vehicles constitute a high percentage of operating property on motor carriers' books. For example, at the end of 1972, Class I common carriers of general freight owned "revenue equipment" with an original book value of $2.6 billion, compared to an original book value of $3.8 billion for all their operating property; $461 million of the revenue equipment had been acquired during that year and $282 million of depreciation taken on equipment. The general freight carriers *operating cash flow,* i.e., their net income after taxes plus depreciation, has been much more stable over time than their net income alone. Table 14-2 illustrates this phenomenon for the years 1967-1973.*

CARRIER PROFITABILITY MEASUREMENT AND ICC REGULATION OF RATE LEVELS

The problem of selecting an appropriate profitability measure of the need for general

Table 14-2. Operating Cash Flows of Class I & II General Freight Carriers and All U.S. Corporations.

Class I and II Common Carriers of General Freight

	1967	1968	1969	1970	1971	1972	1973
Net income AT	$ 99.1m	165.6	134.3	100.0	313.3	333.5	305.2
Depreciation	251.7m	270.2	296.4	318.9	338.7	363.8	388.9
Total	350.8	435.8	430.7	418.9	652.0	697.2	694.1

Percentage Changes Year-to-Year, Class I and II G. F. Common Carriers

	1967-68	1968-69	1968-70	1970-71	1971-72	1972-73
Net income AT	67.1%	-18.9%	-25.5%	+213.3%	+6.4%	-9.3%
Depreciation	7.4%	+ 9.7%	+ 7.6%	+ 6.2%	=7.4%	+6.8%
Total	24.2%	- 1.2%	- 2.7%	+ 55.6%	+6.9%	- .5%

Percentage Changes Year-to-Year, All U.S. Corporation

Net Income AT	+2.6%	- 6.3%	-10.3%	+ 14.6%	+13.7%	+25.2%
Depreciation	+8.8%	+10.9%	+6.4%	+ 9.2%	+12.3%	+ 7.4%
Total	+5.6%	+ 2.3%	- 1.5%	+ 11.4%	+12.9%	15.2%

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* These calculations appear in Prof. James Nelson's article "Motor Carrier Regulation and the Financing of the Industry," *ICC Practitioners' Journal,* May/June 1974. (9)

motor carrier rate adjustment seems to be somewhat an unresolved matter at the ICC. Harvey A. Levine has reviewed this controversy in his 1972 (unpublished) doctoral thesis for American University.(7) From World War II until the mid-1960's, the Commission used operating ratio (OR) as a criterion for judging carrier revenue need. The carriers themselves had generally recommended this measure on the grounds that although railroads had been subjected to return-on-investment criteria, trucking was an industry where the value of operating property was much less significant compared to gross revenues, and in which the principal risk was more related to the level of operating costs than to investment. According to Levine, "no economically sound basis was given for arriving at a desired ratio." However, in 1943, the *Increased Common Carrier Truck Rates in the East* (42 MCC 633), the Commission had adopted an OR of 93 percent as "appearing to be reasonable," and there was reliance on this 93 percent standard in numerous cases. In 1962, in *General Increases—Eastern Central Territory* (316 ICC 467), the Commission noted that, although it had just approved increases which would produce OR's in the 93-95 percent range, it did not regard such percentages as an "immutable standard," and that in the future more cost detail, especially on transactions between carriers and their affiliates or subsidiaries, would be required. Then, in a series of orders in 1964, the Commission instructed carrier groups in general rate cases to provide supporting data for "representative" companies which would include the ratios of:

- Net income, before and after taxes, to net worth;
- Operating income to revenues;
- Net income before and after taxes to revenues;
- Operating income to book value of operating property plus working capital;
- Net income before and after taxes to book value of operating property.

For the next few years there was considerable controversy between the carriers and the Commission about what constituted a representative sample, and many rate increase applications were turned down for lack of adequate data. Finally, in 1967, the Transcontinental Lines obtained a District Court Order instructing the Commission to explain "what standards are being applied" and "what type of data it is requiring." As a response, the Commission issued a series of orders in 1967-1968 explaining its requirements for traffic and cost studies, data concerning affiliates, and justification for the desired profit level. *Statement of Policy, Motor Carrier General Rate Increase Proceedings,* April 28, 1967, as amended August 10, 1967.) The explanation of revenue need standards consisted of a statement that "respondents shall produce evidence of a sum of money, in addition to operating expenses, needed to attract debt and equity capital which they require to ensure financial stability and the capacity to render service. This evidence should include, without limiting the evidence that may be presented, particularized reference to the respondents' reasonable interest, dividend and surplus requirements; and experienced, projected, and needed rate of return on depreciated investment in transportation."

In a subsequent 1969 case *(Increased Rates and Minimum Charges Within, From and To the South,* 332 ICC 820, 838), the Commission made some calculations of "revenue need" on its own, using three alternative rates of return on shareholders' equity less intangibles (ROE)—10 percent, 12 percent, 14 percent—without specifying which, if any, should be used as a standard. However, the carriers' present net revenues in this case fell below by over 7 percent what would have been necessary for a 10 percent ROE, and the Commission did conclude that "need for a reasonable increase in revenue" had been shown, given "statutory requirements, including requirements for growth and replacement." It rejected, however, the respondents' claim that a 20 percent ROE (and an OR below 90 percent) should be allowed. In another case in that same year *(Increased Rates and Charges, From, To, and Between Middlewest Territory,* 335 ICC 142), the Commission rejected requested increases which would have produced an annual net operating income before interest and taxes equal to over 25 percent of net transportation investment plus net working capital (ROI).

Thus, while never specifying a desirable ROE or ROI, the Commission kept hinting at the boundaries of what it considered acceptable. In approving New England Territory rate increases in 1969 (335 ICC 185), it noted that these carriers "ranked behind the average carriers in the country," and that their net worth had only grown at an average of approximately 2 percent during the past eleven years. When the Southwestern carriers applied for increases that same year (355 ICC 361), the Commission determined that rate relief was necessary because of the ROE and ROI of these lines had fallen below "the ratios produced in more stable and lower risk industries" and even the proposed increases would allegedly produce an average ROI of only 10.2 percent, below that of all manufacturing companies taken as a whole.

In August 1970, the Commission initiated Ex Parte No. MC-82, *Proposed New Procedures in Motor Carrier Revenue Proceedings.* Many interest groups responded, including the ten principal rate bureaus, various shippers' associations, and the DOT. In the original ICC proposal, there was to be required a showing of ROE (less intangibles), ROI, OR and a capital turnover ratio. Although respondent Arthur Anderson and Co. (a major public accounting firm which does motor carrier and motor rate bureau work)(15) suggested that rate-of-return ratios would not be relied upon in "short-run" rate level comparisons because the industry was "under capitalized," the Commission held to its original proposal and, at the suggestion of DOT and the Central and Southern Motor Freight Tariff Association, added the debt/equity, "cash throwoff"-to-debt, and current ratios. There was no inter-relation of these ratios so as to suggest at what levels they should be set, and there was still no desirable level prescribed for the "sum of money" which revenue should provide above operating costs. This sum was merely defined as net income, plus income taxes, plus net "miscellaneous deductions," for the traffic study carriers in the projected or constructed year, reduced by the carriers' affiliate profits, increased by any leases of operating units, and proportionately reduced by the percentage of the carriers' property not devoted to transportation.

A Funds Flow Approach Suggested by DOT

DOT, in its response to MC-82, had urged that the Commission adopt a "funds flow" approach for determining motor carrier revenue need. Byron Nupp, who wrote the Departmental "reply statement,"(15) pointed out that in the 1966-68 period, ICC account summaries showed Class I Intercity General Freight Common Carriers put 32 percent of their available funds (net of depreciation allowances) into current assets, 42 percent into tangible" property and 14 percent into "investments and advances." The sources of funds had been 29 percent through increase in current liabilities, 23 percent increase in long-term debt, and 46 percent from increase in shareholders equity. Less than 1 percent came from the sale of bonds and less than 3 percent from the sale of capital stock, whereas unappropriated retained earnings accounted for 37 percent. During this three-year period the group of carriers had financed revenue growth of approximately 7-1/2 percent per year. DOT objected to the Commission's "revenue need" methodology, especially the practice of automatically including interest payments (part of "miscellaneous deductions") in computation of this need—DOT urged examination of all fund requirements and all fund sources, along with their different costs, when considering desirable revenue levels. The Commission agreed that such an analysis would "supplement the other analytical tools prescribed . . . in our order," but declined to include any new formal requirement for motor carriers to submit Source and Application of Funds Statements without "further investigation and consideration."

An Example of Profitability Measurement in an ICC General Rate Increase Case

As an example of how the Commision has been regulating general rate levels since MC-82, we might take *General Increase, East-South Territory* (341 ICC 735), decided in November of 1972 and relating to LTL tariff schedules filed to become effective January 21, 1972 which had been suspended to the extent they exceeded 3 percent. The Southern Motor Carriers Rate Conference, which is the major tariff publishing bureau in the South, in conjunction with one other Southern rate association and one individual Southern motor carrier, submitted all the required data in the MC-82 format to justify increases of 1 to 5 percent on LTL traffic according to weight bracket. Studies of the traffic which would be carried under these rates by over seventy carriers operating in Southern Territory showed a projected ratio of operating expenses to revenues of 95 percent on the subject traffic within the South and 91.3 percent between the East and the South, without any increases over 3 percent included and without reflecting future productivity gains. The overall financial position of the study carriers for the past four calendar years could be expressed in the following financial ratios (Table 14-3):

Table 14-3. Financial Ratios for the Study Carriers—Southern Territory

	1968	1969	1970	1971
Return on net property plus net working capital (before interest and taxes)	20.33%	17.10%	12.66%	30.23%
Return on equity (after taxes)	15.54	12.46	7.55	23.37
Net income to revenue (before interest and taxes)	2.93	2.18	1.32	3.70
Long-term debt to LT debt plus equity	45.00	45.73	47.85	45.39
Net income plus depreciation to LT debt	43.28	40.66	32.77	54.07
Operating Ratio	94.03	95.26	96.33	92.41

The Commission stated in its decision that these ratios indicated no need for immediate relief in the form of a rate increase. "Greater expenses resulting from union contracts, . . . and other inflation-induced increases . . . would appear to have been offset to a great extent by previously-permitted rate increases, changes in traffic, and other factors . . .". They noted that some of these "other factors" may have been a 1.7 percent increase in average load, an 11.2 percent increase in average haul, and a 17.2 percent increase in average weight per shipment for the study carriers in the period 1968-71. It was concluded that the adequacy of the 3 percent rate adjustment (already incorporated in 1971 results) to absorb past cost changes, and the obviously satisfactory financial condition of the carriers during the past year, precluded any further rate increases. Such increases would be unnecessary to provide "good service or expansion," and to "attract capital and maintain credit," would not be "cost-justified" and would "anticipate inflation."

Effect of Carriers' Equipment—Leasing Affiliates

It has in the past been alleged that the use of non-capitalized equipment leases by motor carriers distorts any comparisons of their returns on investment with those in other industries. Some carriers have leased from outside companies in order to obtain a new source of funds at a slightly higher cost of money than direct credit. Also, some carriers have set up leasing affiliates, perhaps—for small companies—to take advantage of the $25 thousand corporate tax rate break, while that was in force.

In 1973, the Regular Common Carrier Conference of the ATA published a study of the accounts of Class I and II intercity common carriers of general freight, expanded, through use of a sample survey, to include motor carrier-related affiliates.(10) Table 14-4 shows the results of this study at the end of 1970.

HOW THE MOTOR CARRIER INDUSTRY FINANCES ITS OPERATIONS

The ATA study referred to above made much of the high leverage in the financing of motor carriers compared to industry in general, which it said justified comparatively higher returns due to the increased risk involved. The proportion of long-term debt in the capital structure (consolidated) of the study carriers was compared to the proportion for those unregulated industrial corporations described in Standard and Poor's "Compustat" data series.(12) (See Table 14-5.)

Table 14-5. Ratio of Funded Debt[a] to Funded Debt Plus Equity-Motor Carriers and Industrial Corporations

Year	Motor Carriers and Affiliates	Unregulated Industrial Corporations
1968	36.6%	23.7%
1969	37.9	24.4
1970	38.9	26.3

[a] Same basis as previous table.

That motor carriers have made substantial use of debt financing is not questioned by anyone. In past years a total funded debt/equity ratio of .5 to 1 has been the norm for general freight carriers. (See Table 14-6.)

Table 14-4. Results of ATA Study of Motor Carriers and Their Affiliates

	Carriers	Affiliates	Total
Net carrier operating property plus net working capital	$1,653 m	$462	$2,115
Funded debt[a] (due after 1 yr.)	$ 744 m	224	968
Stockholders equity	$1,354 m	165	1,519

	Carriers	Carriers Consolidated w/Affiliates
Operating revenues	$6,396	$6,432
Operating ratio	95.9%	96.7%
Net income AT	$ 70 m	$ 88 m
Return on net carrier operating property plus net working capital	19.9%	18.0%
Return on equity	8.4%	8.8%
Dividends paid	$ 36.6 m	$ 44.0 m
Capital turnover (Operating revenues: net operating property plus net working capital)	3.9	3.0

[a] In this table all "advances," plus funded debt due within one year, are counted as current liabilities. (Advances amounted to 28 percent of total funded debt in 1970.)

Table 14-6. Motor Carrier Funded Debt to Equity Ratios, 1968–73

Class I and II Common G. F. Carriers		
Year	Total Funded Debt[b] to Equity	Total Funded Debt[b] less Net Working Capital to Equity
1968	51%	43%
1969	58	51
1970	57	51
1971	46	37
1972	40	31
1973	44	34

[b] Includes portion due within one year.

However, bankers serving the motor carrier industry will apparently accept a ratio of total funded debt less net working capital to equity of up to 100 percent without considering that financial condition unsatisfactory.

Banks usually finance carriers' revenue equipment by straight secured term loans, with amortization beginning shortly after disbursement, but to some carriers they also offer unsecured revolving credit arrangements. Tractors are normally financed over a four-to-five-year period and trailers over five-to-seven years. Wm. H. Joyner, in a 1972 thesis for the Stonier Graduate School of Banking(5), points out that "secured revenue equipment financing is typically granted to the strong small carriers or to weaker large carriers. Although it is difficult to define a small carrier (for this purpose), one may say that, in general, a small carrier has annual revenues less than $10 million." According to Joyner, required down payments range between 10 percent and 20 percent and interest rates run from a low of 1/2 percent over prime to a high of 3 percent over prime, depending on loan quality and deposit balances. Term loans are usually evidenced by notes and secured by chattel mortgages. For "marginal" carriers, bankers may also require personal guarantees or assignments of operating rights. (However, such carriers may also be able to obtain conditional sale or mortgage financing through equipment manufacturers, at higher rates.) Unsecured revolving lines of credit for revenue equipment have become more common now that the motor carrier industry has "matured" and "gained stature in the financial community." Under these arrangements, a carrier may borrow at any time as long as outstanding loans don't go above a specified percentage (usually 85-90 percent) of the net book value of equipment. There are normally provisions for funding in cases where all the requirements of the credit line are not being met by the borrower.

Terminal facilities are financed either by conventional mortgages or sale-leaseback arrangements. Naturally, due to the maturities involved, terminal financing is handled more often by long-term lenders than by commercial banks. As Joyner explains, "the motor carrier industry has an excellent record of repayment of terminal loans secured by real estate. Financial institutions now look with favor on (these loans), and borrowing conditions more nearly coincide with those affecting other types of real estate."

Maturities of mortgage loans on terminal properties typically run 15-25 years, and the "knowledge mortgage lender" will usually cover about 65 percent of the net book or appraised value of the property. Life insurance companies are common sources of such financing. In recent years, there have developed arrangements available to carriers with strong credit standings under which (1) several terminals can be covered by a blanket mortgage with right of substitution, or (2) both terminal and vehicle financing needs can be filled on an unsecured basis by a joint coordinated loan between a bank and an unsecured basis by a joint coordinated loan between a bank and an insurance company, by which each would share pro-rata in the collateral if it were necessary for a security interest to be taken.

Motor carriers clearly have proportionately greater debt than many other industrial corporations; on the other hand, their cash flow appears ample to service this debt. (See Table 14-7.)

Professor Nelson, in his above-mentioned article, quotes Henry Livingston (then) of Clark, Dodge & Co., who authored the ATA's 1972 Financial Analysis of the Motor Carrier Industry,(1) to the effect that "a ratio of about 30 percent (to total debt) for truckers indicates ample debt servicing abilty."

Table 14-7. Comparison of Cash Throw-off to Debt for Motor Carriers and All Industrial Corporations.

	1968	1969	1970	1971	1972	1973
Class I and II Common G. F. Carriers						
Cash throw-off* to:						
Funded debt due after one year	86%	67%	61%	97%	101%	88%
Total funded debt	63%	52%	48%	74%	81%	69%
Depreciation to funded debt due in one year	149%	155%	164%	165%	210%	185%
Cash-throw-off* to funded debt due in one year	240%	225%	216%	318%	403%	330%
All Industrial Corporations[a]						
Cash throw-off* to:						
Funded debt due after one year	32%	28%	24%	25%	27%P	NA

*Cash throw-off = net income after taxes plus depreciation.
P = Preliminary
[a] U.S. Internal Revenue Service, "Statistics on Income," Corporation Income Tax Returns," Annual.

Joyner's thesis(5) states that, from a banker's standpoint, 40 percent is considered to be the minimum satisfactory level for the motor carrier. He also indicates that lenders like to see cash throw-off covering the current portion of LT debt by at least 150 percent and depreciation allowances running at least 100 percent of this current portion in any given year.

Starting in 1968, the closing year of Byron Nupp's "funds flow" statement to the ICC in MC-82,(15) and running through 1973, ICC accounts for Class I and II Common G. F. Carriers show that in six years:

Gross Revenues	grew 66 percent
Net Carrier Operating Property	grew 51 percent
Net Working Capital	grew 105 percent
Other Assets	grew 78 percent
Long-term Debt	grew 44 percent
Shareholders' Equity	grew 67 percent

Motor carriers have financed this growth by drawing on the credit sources we have just described and by retaining their income from operations. "New equity" money coming into the industry recently has generally not been thought to be very significant, but dividend payout is not too high, either (24 percent of net income for Class I Intercity Common G. F. Carriers in 1972, as opposed to approximately 50 percent for all U.S. corporations). There appears to be little incentive to pay out more earnings. The owners of smaller family-held carriers have opportunities to pay themselves salaries and are presumably interested in building up a saleable company for capital gain purposes. Carriers who have sold shares to the general public have attracted buyers more by the promise of earnings growth than by dividends, and they often have substantial holdings by insiders and/or employees.

LARGE PUBLICLY HELD MOTOR CARRIERS AS VIEWED BY THE INVESTMENT COMMUNITY

Up to this point, we have been considering the motor carrier industry (actually its *general freight* segment) in the aggregate. It is interesting to look at some comparable information for large publicly held companies in the industry. Securities analysts generally seem to agree that "well-managed" truckers can outperform the averages, and that large investor-owned companies, which usually fall in this category, have prospered and should continue to prosper in the 1970's. Thomas Trantum, of Wainwright and Co., commented at a recent Wall Street Transcript roundtable discussion of motor carrier stocks that "well-managed carriers with good route authority are capable of consistently earning over 20 percent on equity."(19)

It may be that in the past some investors feared the effect of the Teamsters and of the ICC on motor carrier profitability. (Teamster wages have been, on the average, 40 percent higher than those in all U.S. manufacturing.) However, as has been noted before, the ICC has been reasonably prompt in allowing cost charges to be passed on, and apparently some efficient carriers have found that their individual cost changes have been more than offset by general rate increases. In the early 1970's a substantial proportion of these increases came down to net income for many firms. Paul Schlesinger of L. F. Rothschild, also speaking at the 1974 WST roundtable made the observation that "incremental profits go to the treasuries of the efficient carriers and don't have a depressant affect on rates."(19)

There are roughly 65-70 motor carriers with publicly held and traded shares, of which the major ones are:

Arkansas-Best Freight System
Associated Transport*
(controlled by Eastern Freight Ways
and de-listed from NYSE in 1974)
Carolina Freight Carriers*
Consolidated Freightways*
Cooper-Jarrett, Inc.*
Lee-way Motor Freight
McLean Trucking*
National City Lines (Time-D.C.)
Overnight Transportation
Roadway Express*
Smith's Transfer
Spector Industries*
Transcon Lines*
Yellow Freight*

Standard and Poor maintains an index of 10 trucking stocks;(12) the starred companies above are included in it. Figure 14-2 shows a chart comparison of this index with S&P's 425-stock industrial series for the years 1961 to 1974. We can note a sharp increase in trucking stock prices in the early 1970's.

Large, sales-oriented companies with extensive route systems to bring in LTL freight look particularly attractive to the investment

Figure 14-2. Market performance of the Standard & Poor 425 industrial and the Standard & Poor Trucking Indexes, 1969-1973.

Source: Goldman-Sachs.(6)

analysts. They have been generally recommending Roadway, Yellow, Smith's, C.F. and McLean for buying and/or holding. They do not seem to feel that the ICC's growing interest in ROE/ROI (as opposed to OR) will harm the industry; on the contrary some believe that it will ensure future financial health, especially as basic revenue equipment, tractors and trailers, has increased sharply in price with recent inflation.

The analysts note that trucking operators, with their high cash flow, good growth prospects and (in many cases) low price-earnings ratios, have been tempting acquisition prospects for some diversified corporations. Some companies who have purchased motor carriers in the recent past are:

Del Monte
International Utilities
U.S. Industries
Walter Kidde
Allegheny Corp.
Fugua Industries
Texas Gas Transmission
American Export.

Analysts always seem concerned, however, about the relatively small volume of motor carrier securities outstanding, which tends to make it difficult to attract interest from large securities houses and institutional buyers. They are reluctant to spend time studying an issue unless there is opportunity for substantial purchases at current prices. Motor carrier financial consultant Andrew Davlin(2) gives as an example the policy of Kidder, Peabody, which limits analysis to companies whose common stock "float" (non-insider-held shares times price) is above $200 million. Only Roadway* and Yellow would meet this test. Paradoxically, the very success of some large publicly held carriers has contributed to this situation; their cash flows have been so ample compared to re-investment requirements that they have never had to go back to the market and only stock dividends and splits have increased the number of shares outstanding. Also, according to Davlin, the "second-tier" trucking issues will probably be affected by the declining number of retail brokerage firms available and willing to make over-the-counter markets for them. OTC is the normal way small and medium sized issues are traded. (In fact, Roadway and Yellow are still OTC, having never listed on NYSE like McLean and C. F.)

Most trucking stocks have been selling for three to eight times earning in the post - 1972 depressed market. Firms going public would probably want seven to ten times earnings to avoid unacceptable dilution in a new issue. Only Roadway and Yellow were selling over 10 as of late 1974. (Roadway had actually reached *over 25* times trailing earnings during 1974, which led analysts to counsel not buying at such a high price on the grounds it would be very vulnerable to any profit softening.)

Table 14-8 shows some key financial data taken from the latest Value Line survey (Oct. 18, 1974) for the 10 common stocks which are included in the Standard and Poor's (S&P) Trucking Index. Table 14-9 shows the Price/Earnings (P/E) ratios of these stocks, compared to S&P's Composite Index, for the ten years 1964-1973. We can see from this latter table that for the "favorite four" carriers—C.F., McLean, Roadway, Yellow—P/E's were generally higher at the end of the ten-year period than they were at the beginning. Many observers feel that in the late 60's and early 70's investors first began to understand the motor carrier industry and appreciate the potential of selected companies for high and substantial earnings growth. However, Table 14-8 indicates how P/E's had fallen drastically by the date of the survey.

McLean, Roadway and Yellow all had Return on Earnings (ROE) of over 20 percent in the five years preceding the Value Line Survey. CF had not done as well, but it must be noted that this company had been engaged in various transportation activities in addition to trucking and truck manufacturing. Their well-known expansion into the steamship business ended in failure, and other smaller enterprises have been sold or discontinued.

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*Even in the case of Roadway, the acknowledged market leader, over half of the stock is held by insiders and employees.

Table 14-8. Key Data for Companies in the S&P Trucking Index—From Value Line Survey of the Truck and Bus Industry, October 18, 1974.

	Year 1973	As of Survey Date		Past Five Full Yrs. - Average Annual Rate of:			Over Past Seven Yrs.	Year 1973	
	Revenues	P/E Ratio	Dividend Yield on Stock	Earnings Growth Per Share	Dividend Yield on Stock	Earnings as a % of Equity	"Beta Coefficient"*	Debt*** Ratio	Cash Flow to Debt Ratio
Associated Transport	$147.6 mil.	(1)	Nil	(2)	.7%(a)	1.2%**	.65	41%	Neg
Carolina Freight Carriers	$ 88.9 mil.	3.9	7.8%	19.5%	4.6%	16.1%	.85	55%	41%
Consolidated Freightways	$ 706.1 m.(3)	4.3	5.8%	6.5%(6)	3.0%	16.5%	1.15	34%	76%
Cooper-Jarrett	$ 56.9 m.	2.8	4.3%	-14.0%	1.8%(b)	10.3%**	.95	70%	21%
McLean Trucking	$ 234.1 m.(4)	5.5	3.3%	17.0%	2.2%	26.8%	.90	43%	57%
National City Lines	$332.7 m.	3.9	11.5%	2.5%	4.8%	16.5%	.95	69%	27%
Roadway Express	$447.6 m.	16.3	1.0%	26.5%	1.1%	21.3%	1.05	0%	(5)
Spector Industries	$136.3 m.	1.9	Nil	-11.0%	.4%(c)	15.2%**	.80	89%	21%
Transcon Lines	$130.8 m.	4.0	8.8%	2.0%	2.4%	10.0%	.95	36%	69%
Yellow Freight	$336.4 m.	11.7	1.9%	22.0%	1.8%	30.3%	1.10	49%	57%

* As calculated by Value Line; NYSE Average = 1.0.

** Defecits not deducted. Non deficit years total averaged over 5 years.

*** Funded debt to Funded debt plus equity.

(1) Delisted from New York Stock Exchange.

(2) No meaningful figure; deficits in three of last five years, including last two.

(3) Motor carrier operations accounted for 59%. CF also manufactures trucks and trailers.

(4) Time—D.C. accounted for 56%, specialized motor carriers 27%, vehicle parts mfg. 12%, urban passenger transit mgt services 5%. Operating results of Time—D.C. (67% owned) are consolidated.

(5) Roadway has no funded debt.

(6) CF's write-down in 1973 of its ownership interest in Pacific Far East (Steamship) Line more than halved earnings in that year.

(a) No dividends in three of the years, including last two.

(b) No dividends in 1971.

(c) No dividends in last four years.

Table 14-9. Price-Earnings Ratios:
Companies in the Standard and Poor Trucking Index
Vs. Market Composite.

	Standard & Poor Composite Index	Associated Transport	Carolina Freight Carriers	Consolidated Freightways	Cooper Jarrett	McLean Trucking	National City Lines	Roadway Express	Spector Industries	Transcon Lines	Yellow Freight
1964	18.8	8.0	14.4	7.4	6.0	7.2	12.7	15.0	5.5	9.0	8.7
65	17.9	8.9	11.8	9.8	8.7	7.7	10.0	15.7	8.1	9.9	10.6
66	15.2	8.4	8.3	9.3	9.3	8.6	9.1	15.1	5.2	12.2	9.8
67	17.5	30.0	76.3	13.9	23.3	7.3	15.3	14.2	12.8	12.9	11.7
68	17.7	31.4	10.3	14.7	14.3	9.4	27.6	17.3	(deficit)	12.5	10.4
69	16.5	25.3	10.3	12.2	15.1	14.2	18.3	16.5	(deficit)	17.1	13.3
70	15.7	(deficit)	5.8	18.6	(deficit)	16.1	61.4	12.5	(deficit)	34.5	12.6
71	18.5	62.2	9.0	11.6	13.3	11.5	10.9	14.7	51.7	12.6	12.6
72	18.2	(deficit)	11.9	13.0	15.7	11.1	10.1	18.8	29.1	15.2	17.3
73	15.9	(deficit)	8.8	21.1	(deficit)	11.3	6.6	25.4	4.6	9.3	17.7

Their earnings-per-share growth rate for 1968-73 was less than a third of what they enjoyed for the full ten years 1963-73. However, observers have since come to feel that the company is pulling back from "over-extension of management resources" and is well positioned to re-establish an uptrend in the financial performance of their basic businesses.

We can also see from Table 14-8 that none of the favorite four companies had long-term debt outstanding beyond the rule-of-thumb safety percentages which have been previously identified. Roadway, in fact, had no debt at all and was extraordinarily "cash-rich," having cash-and-marketable securities equal to 86 percent of current liabilities at the end of 1973, as contrasted with 31% for all Class I and II—G.F. Common Carriers. In Addition, Table 14-8 includes for each carrier a measure which is often used in the investment community to indicate the "riskiness" of a stock. This is the "Beta Coefficient," or the slope of a regression line relating changes in the stock price to changes in the market. In this case, Value Line uses the New York Stock Exchange Index as the Market and calculates over the past seven years. A reasonable rule-of-thumb might be to classify stocks with Betas below .90 and above 1.15 as being somewhat risky in terms of their not moving with general changes in the market. A large numbe of stocks would fall within this range, as do the favorite four trucking stocks.

The Cost of Equity Capital to Four Prominent Publicly Held Carriers

Given the long-standing controversy before the ICC as to what is a desirable level of ROE for motor carriers in general, we might ask how one could try to estimate the "cost of equity capital" for carriers whose stocks are publicly traded. A common way to express this cost—that is, the rate of return which stockholders require from the enterprise—is to add the normal divided yield to the normal expectation of growth per year.* As has been noted, dividends in the motor carrier industry have generally been kept low, although growth, at least in some companies, has been quite high, perhaps even greater than expectations: Value Line made the predictions shown in Table 14-10 for annual dividend yield and annual earnings-per-share growth rate for 1977-79 compared to 1971-73.

Table 14-10. Value Line Predictions for Annual Dividend Yield and Growth.

	Predicted Dividend Yield	Predicted Growth
CF	2.3%	15.0%
McLean	1.9	9.0%
Roadway	1.1	13.0%
Yellow	1.7	12.5%

We have adjusted the growth percentages downward to reflect Value Line's concurrent predictions of the P/E ratios which stockholders shoud expect to enjoy in 1977 through 1979 as opposed to those which had prevailed in 1971 through 1973 (Table 14-11). This probably results in figures that are too low, but we have used them as examples, in lieu of actual stock price growth predictions for new issues.

Table 14-11. Prediction of Annual Dividend Yield Plus Growth.

	Predicted P/E Ratio	Reduction from 71-73 P/E Aver.	Predicted Growth Adjusted	Total Dividend + Growth
CF	10.0	34%/6 yrs = 5.6%	9.4%	11.7%
McLean	11.5	2%/6 yrs = .3%	8.7%	10.6%
Roadway	16.0	19%/6 yrs = 3.2%	9.4%	10.5%
Yellow	13.0	22%/6 yrs = 3.7%	8.3%	10.0%

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*This figure may also be used to represent the "opportunity cost" of capital from retained earnings.

It is important to keep in mind, however, that many of these large companies have been growing faster than, and probably at the expense of, smaller carriers. They have exploited existing routes more intensively and added revenues through acquisitions. We have already noted that revenues of Class I and II G.F. Common Carriers were 66% greater in 1973 than in 1968. By contrast:

CF revenues (total) increased 82%
(carrier revenues only-61%)
McLean revenues (total) increased 122%
Roadway revenues (total) increased 143%
Yellow revenues (total) increased 154%

Clearly not every carrier could be expected to procure outside equity capital with the lure of past growth rates like those of Roadway and Yellow. Also, we can see from the data in Table 14-8 for companies other than the "favorite four" that it is certainly possible for a relatively large, publicly held carrier *not* to meet the optimistic growth and return expectations of some of the securities analysts, and even to find itself in an over-expanded debt position.

TENTATIVE CONCLUSIONS: RETURNS TO INVESTMENT IN THE MOTOR CARRIER INDUSTRY

In his thesis referred to above, Harvey Levine states(7), "the carriers attempt to convince the ICC that returns are too low, while at the same time convince the financial community that returns are relatively high." The material we have seen seems to indicate that aggregate returns have not been too low to sustain adequate growth by carriers which operate at or above today's standards of efficiency. The ICC has, in effect, made sure that these standards do not become too restrictive by minimizing regulatory resistance to cost-price adjustments, while at the same time preserving the general framework of "controlled competition" provided by the Interstate Commerce Act. We have also seen information which suggests that there may be no great substance to allegations either that (1) the use of motor carrier-affiliated corporations to hold equipment results in significant under reporting of carrier profitability, or that (2) the carriers use of debt financing makes them very risky enterprises which "deserve" higher returns. In fact, certain well-managed carriers have been able to attain

Table 14-12. Net Income After Taxes As A Percentage of Stockholders' Equity and Mfg. Industries, 1960-1972

		Manufacturing Industries									
	All Class I Motor Freight Carriers	Motor Vehicles	Air-Craft	Elect. Equip.	Other Mach'y.	Fabr'd Metal	Iron & Steel	Non Fer. Metals	Stone, Clay, Glass	Furni-ture	Lumber & Wood Prod's.
Aver. Annual Rate	11.8%	14.1	10.9	11.0	10.9	9.9	7.1	9.1	9.2	10.2	9.3
Standard Error of Linear Regression Estimate for the 13-Year Period	3.4%	3.3	3.1	1.9	2.4	2.6	1.8	2.6	.9	2.5	2.8

	Instru-ments	Food	Tobacco	Textiles	Apparel	Paper	Printing & Publishing	Chemicals	Petro-leum Refining	Rubber & Plastics Prod's.	Leather
Aver. Annual Rate	14.8	10.2	14.2	7.4	10.7	8.6	11.8	13.0	11.1	10.2	9.2
Standard Error of Linear Regression Estimate for the 13-Year Period	2.8	.5	.4	1.9	1.9	1.5	1.9	1.3	1.2	1.5	2.6

profitability levels well above that of motor carriage in general or industry in general, and certain larger carriers have been able to grow through expansion and acquisition at rates which have, at least in the past, provided the opportunity to sell stock at attractive prices. The question remains, however, whether the performance of these industry leaders can be taken as a good indication of what "standard" industry performance would be if the present system of rate and entry control were substantially dismantled.

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BIOGRAPHY

Mr. Church obtained his undergraduate education at Brown University and also studied at Harvard Business School, where he received the M.B.A. and D.B.A degrees and specialized in transportation and logistics management. He has been employed by thg Southern Railway System in Washington, D.C. and by the Pennsylvania Railroad in Philadelphia; in both cases he was involved in freigtt service pricing and market planning. For the past three years he has been at TSC where his work principally involves problems of understanding the management and behavior of commercial freight carrier enterprises, particularly from the financial standpoint.

A PRELIMINARY ESTIMATE OF THE IMPACT OF THE IMPLEMENTATION OF FIVE PROPOSED COAL SLURRY PIPELINES

by

JOSEPH MERGEL AND DR. LAWRENCE VANCE

INTRODUCTION

Background

A number of coal slurry pipelines have been recently proposed (coal slurry is a mixture of water and ground coal). This increase in the number of proposals for coal slurry pipelines, coupled with the inability of their sponsors to amicably secure the required right-of-way has resulted in the introduction of federal eminent domain legislation for coal slurry pipelines. The proposed legislation would require the issuance of a certificate of public convenience and necessity to the pipeline carrier prior to its receipt of the right of eminent domain. The Department of Transportation (DOT) may have a role, either directly or indirectly in the review of applications for certification.

For this reason DOT has considered the need for the development of a methodology for evaluating the impacts of the proposed coal slurry pipelines on the total transportation system and for determining the role of coal slurry pipelines in the overall transportation system. The potential impacts of coal slurry pipeline systems and the available information on their technical, environmental and economic feasibilty have been described previously.(14) While that paper described the data needed to conduct a fairly elaborate impact assessment, with special emphasis on rail system impacts, this paper presents the results of a somewhat simplistic analysis of the potential impacts of coal slurry pipelines.

Problem Statement

The purpose of this exercise was to determine the aggregate impact of the implementations of five proposed coal slurry pipelines in the western United States (see Figure 15-1). Impacts were to be determined for these pipelines, in terms of water and steel requirements, energy use, construction costs and user costs, railroad employment and revenue losses, and effects on required railroad fleet size.

A basic premise of the analysis was that the pipelines would be built, as proposed. The question of whether or not they should be built or if an alternative mode, would provide a more cost-effective, resource-efficient solution in a particular application was not addressed here.

The analysis is based on readily available published information, and is intended to provide only a first order estimate of the individual impacts studied. As such the analysis is subject to the deficiencies of the published data set. No attempt has been made to rigorously evaluate the deficiencies of the available data or to develop an independent data set. Elaborate modeling techniques have not been utilized. The impacts studied have been limited to those that can be readily estimated with simple operations on the available data set.

Summary

This paper presents the results of a preliminary analysis of selected impacts of the implementation of five proposed coal slurry pipelines. This impact assessment is not intended to be comprehensive, nor is it to be construed as a comparison of the effectiveness of coal slurry pipelines and other coal transportation modes.

As estimated in the analysis the five coal slurry pipelines together would:

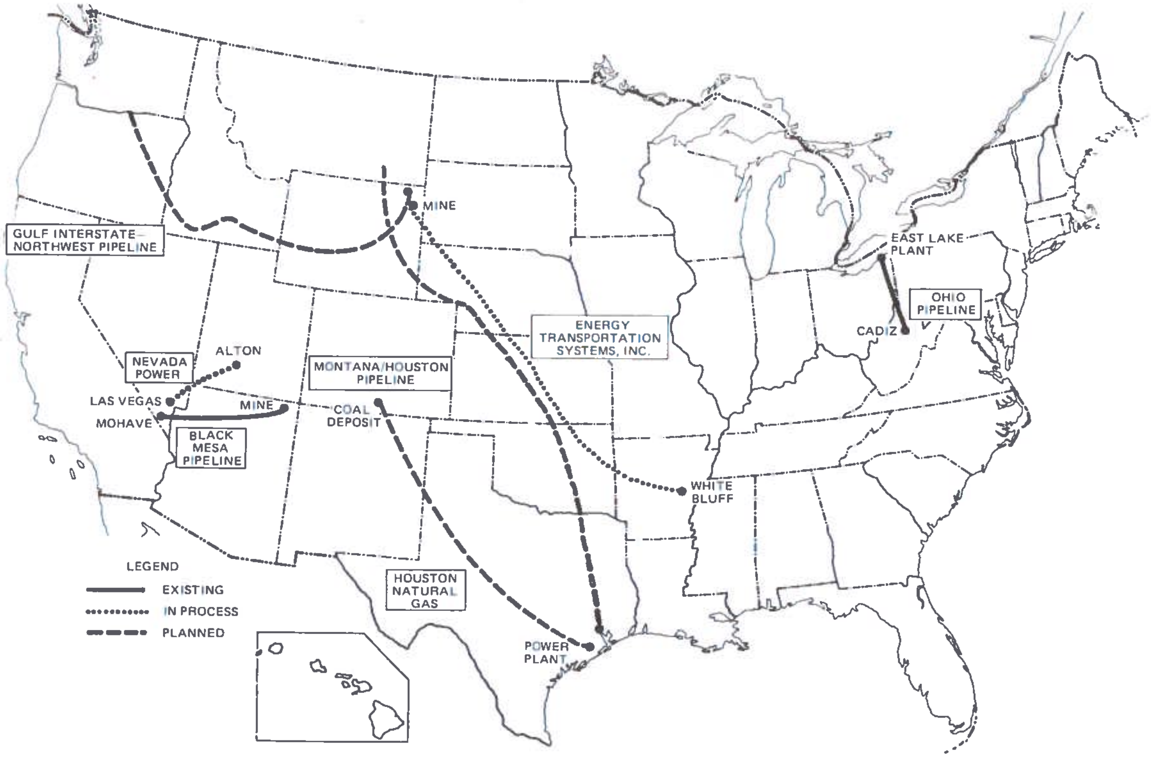

Figure 15-1. Existing and proposed coal slurry pipelines.

- use 56,000 to 62,000 acre-feet of water per year (50 to 55 million gallons per day) for coal transportation only;
- use 4.1 to 5.6 million tons of steel pipe;
- use 2.5% to 2.9% of the energy content of the coal shipped in transporting that coal;
- require a capital investment of $2.6 to $3.5 billion (preliminary estimates, in part from the industry);
- charge coal shippers $434 to 742 million per year (preliminary estimates, in part from the industry).

Furthermore, if the slurry pipelines were built, the railroads would not gain a substantial portion of the projected increase in western coal traffic. Note that it was assumed that the railroads would retain their current coal traffic. Thus, it was estimated that the railroads would:

- not gain $795 to $929 million per year in revenues (based on current rates);
- not hire 2850 to 3300 additional employees with an annual payroll of $43 to $49 million;
- not acquire 15,350 to 17,670 hopper cars and 670 to 760 locomotives at an estimated cost of $700 to $800 million.

PROPOSED COAL SLURRY PIPELINE SYSTEMS

System Descriptions

Existing and planned coal slurry pipeline systems are indicated in Figure 15-1. The proposed pipelines' major parameters are summarized in Table 15-1.

Only two coal slurry pipelines exist in the U.S. today, and only one of these is currently operational. This is the 18 inch Black Mesa line which carries coal a distance of 273 miles from the Black Mesa coal fileds of Arizona to the Mohave power plant in Nevada. This line has an annual capacity of 5 million tons. It began operations in 1970.

Table 15-1. Proposed Coal Slurry Pipeline System Characteristics

System	Location	Length (Miles)	Diameter (Inches)	Annual Throughput Capacity (Million Tons)
Texas Eastern/ Brown & Root	Montana to Texas	1260	42	22-30
Northwest Pipeline/ Gulf Interstate	Wyoming to Oregon	1100	22	10
Energy Transportation Systems, Inc.	Wyoming to Arkansas	1030	38	25
Houston Natural Gas Co.	Colorado to Texas	750	22	9
Nevada Power Co.	Utah to Nevada	180	24	10

Sources: Kiefner, J. F.; "Review of Slurry System Projects in the U.S.", paper presented at an International Technical Conference on Solid-Liquid Slurry Transportation; Columbus, Ohio; February 3-4, 1976.

Pipeline Transportation to 1990; prepared for the U.S. Department of Transportation; the Pace Company; January, 1976.

Table 15-2. Projected Coal Slurry Pipeline Market Shares

System	Origin	Destination	System Capacity (Million Tons/Year)	Increase in 1990 Shipments Over 1973 (Million Tons/Year)	Pipeline's Share of Increased Shipment
Texas Eastern/ Brown & Root	Montana	Texas	22 to 30	44	100%
Energy Transportation Systems Inc.	Wyoming	Arkansas	25		
Northwest Pipeline/ Gulf Interstate	Wyoming	Oregon	10	20	50%
Houston Natural Gas Co.	Colorado	Texas	9	20	45%
Nevada Power Co.	Utah	Nevada	10	10	100%
TOTAL			76 to 84	94	81% to 89%

Increase in total PADD4 coal shipments 1973 to 1990 equals 124.9 million tons.

Source: *Pipeline Transportation to 1990;* prepared for the U.S. Department of Transportation; The Pace Company; January, 1976.

The 10-inch Ohio pipeline ran 108 miles from Cadiz to Cleveland, and was capable of carrying 1.3 million tons of coal per year. This line began operations in 1957, but was shut down 6 years later because of a reduction in rail freight rates resulting from the introduction of unit-train operations.

The other lines are in the planning or proposal stage. These include the 1,260 mile, 42-inch diameter Texas Eastern/Brown & Root line with a proposed annual capacity of 30 million tons; the 1,100 mile Northwest Pipeline/Gulf Interstate line, which would have a diameter of 22 inches and an annual capacity of 10 million tons; the Energy Transportation System, Inc. line with a 38-inch diameter, 1,030 mile length and 25 million ton per year capacity; the 750 mile, 22-inch diameter Houston Natural Gas Co. pipeline with a 9 million ton annual capacity; and the 24-inch Nevada Power Co. line having an annual throughput of 10 million tons per year

Table 15-3. Estimates of Selected Impacts of the Proposed Coal Slurry Pipelines

Water Requirements[1]	56,000-62,000 Acre Feet/Year[12] (50-55 million gallons/day)
Steel Pipe Required[2]	4.1-5.6 million tons[3]
Percent of Energy Carried[4] Used in Transportation	2.5%-2.9%
Capital Investment Required[5,11]	\$2.6-\$3.4 billion
Annual User Tariffs[6,11]	\$434-\$742 million
Annual Revenues Not Gained by Railroads[7]	\$795-\$929 million[12]
Railroad Employees Not Hired[8]	2850-3300[12]
Annual Payroll Associated with These Jobs[9]	\$43-49 million[12]
Additional Rail Equipment Not Needed[10,11]	
—Hopper Cars	15,350-17,670[12]
—Locomotives	670-760[12]
—Capital Cost of Equipment	\$700-\$800 million[12]

Notes to Table 15-3

1. Does not include the water that may be required for coal processing prior to shipment.
2. Does not include equipment associated with slurry preparation or dewatering, nor pumps and associated equipment.
3. The upper end of the range assumes a uniform pipe thickness throughout, while the lower end assumes a variation in pipe-wall thickness with fluid pressure.
4. Includes slurry preparation, transportation and dewatering.
5. Includes all facilities associated with a slurry pipeline system, i.e., pipe, pump stations, water supply, slurry preparation and dewatering equipment.
6. Includes operating costs, debt service, taxes, depreciation and profit.
7. Based on 1973 rates for trainload movements in carrier equipment inflated to 1975 dollars (2), (5), (11), (20).
8. Based on a figure of 30.9 coal-related employees/billion ton-miles of unit train traffic (13).
9. Based on an average salary of \$15,000/job (8), (18).
10. Based on a unit train of 4 locomotives at a cost of \$450,000 each and 100 hopper cars of 100 ton capacity at \$26,000 each (6).
11. 1975 dollars
12. Variation due only to the range in the estimated throughput of the Texas Eastern/Brown & Root Pipeline.

and a length of 180 miles. All of these proposed pipelines connect large coal fields with power plants.

The Market-Share Potential of Coal Slurry Pipelines

A large portion of the projected increase in the nation's coal production is likely to come from an increase in the production of low-sulfur Western coal. Much of the increase in Western coal production will come from the states that make up Petroleum Administration for Defense District 4 (PAD District 4). These states are Colorado, Idaho, Montana and Wyoming. Annual shipments of coal from PAD District 4 are projected to increase from 20.1 million tons in 1973 to 145 million tons in 1990.(16)

The projected increase in coal-flows over this same time period for the general origin-destination pairs served by the proposed coal slurry pipelines is indicated in Table 15-2.

This table also indicates the potential market share of coal slurry pipelines within these particular markets. As shown in Table 16-2 the proposed coal slurry pipelines would carry, on the average, 81 percent to 89 percent of the projected increase in coal traffic in the corridors indicated. Moreover, the set of proposed coal slurry pipelines (total annual throughput capacity is 76 to 84 million tons) would carry between 61 percent and 67 percent of the total projected increase in annual PAD District 4 coal shipments and 52 percent to 58 percent of the total yearly shipment in 1990. The market share of the pipelines could be even greater in the years before 1990 depending on the actual rate of increase in Western coal production in the years between 1975 and 1990 and the implementation dates of the pipelines.

IMPACTS OF COAL SLURRY PIPELINE IMPLEMENTATION

Water Requirements

Coal slurry is a mixture of pulverized coal and water. In general the optimum mixture has been found to be one of roughly equal proportions of coal and water by weight. Thus one ton of water is required to ship one ton of coal in the form of a slurry. The water requirements of the proposed coal slurry pipelines, for transportation only, are indicated in Table 15-3 along with other selected pipeline impacts. The water needed to ship coal via the proposed pipelines amounts to 56,000 to 62,000 acre-feet per year (49.9 to 55.2 million gallons per day). No water is needed to ship coal by unit train.

Additional water could be required to clean the coal prior to shipment. This would range from 1 to 2.5 tons of make-up water per ton of coal, depending on the process used.(15) (Considerably more water per ton of coal is required in the cleaning process, however this water is recirculated.) Thus cleaning would add an additional 56,000 to 155,000 acre-feet per year (49.9 to 138 million gallons per day) to the water required for coal transportation, bringing total requirements to 112,000 to 217,000 acre-feet per year (99.8 to 193.2 million gallons per day).

The need for cleaning would depend on the physical and chemical properties of the raw coal in question and on the requirements of the ultimate user of that coal. Cleaning might be required in order to remove sulfur from the coal in order to meet the coal user's requirements. In this case cleaning would be necessary whether the coal was shipped by pipelines or by rail.

On the other hand cleaning might be required in order to improve the chemical and physical properties of the slurry. Excessive amounts of extraneous sand, slate, oxidized material, etc. could have an adverse effect on the hydraulic properties of the slurry, and the operation of the pipeline and dewatering portions of the coal slurry system. The final decision on cleaning, in this case, would be dependent on the cleanliness of the raw coal available, and an economic trade off between the cost of coal cleaning and increased pumping power costs, pipe wear and dewatering system costs. A rail alternative would not be sensitive to the properties of the coal.

Studies have been conducted on the availability of water for energy related uses in the Western coal regions.(23),(24) However, the results of these studies are inconclusive. They indicate that more data has to be gathered on both ground and surface water supplies and potential uses before definite conclusions can be reached on the availability of water for future energy resource development.

Steel Requirements

A total of 4.1 to 5.6 million tons of steel pipe would be required in order to construct the proposed coal slurry pipelines. It should be noted that these estimates are for pipe only and do not include the steel required for pumping equipment, slurry preparation plants or dewatering facilities. However, these latter requirements would be small in comparison to the steel tonnage needed for the pipeline itself. This is almost an order of magnitude larger than the estimated steel requirements for rail cars and locomotives (600,000 to 690,000 tons) needed to provide an equivalent coal hauling capability.

Total U.S. production of large-diameter steel pipe of the type required for these lines was only 1.7 million tons in 1975, down from a 1968 figure of 3.8 million tons.(1) Furthermore, it should be noted that up to 3800 miles of large diameter natural gas pipeline might be required in the U.S. within the same time frame in connection with the Alaskan Natural Gas Pipeline.(10) Temporary shortages of pipe, pipeline construction crews and equipment could be a problem if all pipelines were scheduled for construction at the same time.

The upper end of the range for steel requirements is based on the assumption of a uniform wall thickness throughout the pipeline length. The lower range estimate is based on the assumption that pipe-wall thickness would be varied to coincide with the pressure encountered in different sections of the pipe. Pressure is increased at each pump station and decreases with distance away from the pump station. This method of varying wall thickness along the length of the pipeline is known as telescoping.

Energy Requirements

A total of 48.7 to 62.7 trillion BTU's will be required to transport 1938 to 2134 trillion

BTU's via the proposed slurry lines. The average energy use of all lines would be between 2.5 percent and 2.9 percent of the energy transported, which is comparable to the unit train alternative. Note that the energy use figures also include the slurry preparation and dewatering phases of the coal slurry transportation process.

Energy flows for each pipeline were determined as a function of the projected annual tonnage shipped and the mean BTU value of coal produced in each of the origin states. These values range from 12,220 BTU/lb. for Montana coal to 13,370 BTU/lb. for coal from Nevada.(22)

The energy utilized by the slurry system in transporting this coal was calculated as follows: 200 to 300 BTU/ton-mile(3), (13), (16), (19) would be required for the pipeline transportation of the slurry; and 450,000 BTU/ton would be required for the preparation and dewatering process.(16) This is equivalent to an energy requirement of 650 to 750 BTU/ton-mile for a 1,000 mile pipeline. This compares well with the results of other studies for a pipeline of this length which give energy requirements of 600 BTU/ton-mile(6) and 750 BTU/ton-mile.(25)

Cost Considerations

Pipeline Capital Investment. The total capital cost of all pipelines is estimated as $2.6 to $3.5 billion. These figures include all facilities associated with the preparation, pipeline transmission and dewatering portions of a coal slurry pipeline system. These estimates are preliminary and are presented in terms of 1975 dollars. Inflation and more detailed system design at later stages of project planning would work to increase these cost figures.

These capital requirements were based on projected costs for the ETSI (Energy Transportation System Inc.) pipeline, which range from $750 million(6),(16) to $1 billion.(18) These estimates resulted in a cost per inch-mile of $19,200 to $25,500 for the ETSI System. The projected cost/inch-mile of the ETSI system was then applied to the other proposed systems to determine their respective capital costs.

Pipeline User Charges. The total estimated annual cost to shippers using the slurry pipelines was estimated as $434 to $458 million. These user charges are based on preliminary estimates of pipeline tariffs by slurry proponents(3) and are in 1975 dollars. The estimates include all costs associated with the preparation, transportation and dewatering portions of the slurry transport system. In addition to operating costs the estimates include a provision for debt service, taxes depreciation and profit. Having been based on preliminary capital cost estimates, these tariffs would be revised upward to reflect inflation and a more detailed system design at later stages of the planning process.

Furthermore, it should be noted that these estimates appear to be on the low side, all other things being equal. The only point of comparison is the ETSI pipeline. The estimated tariff for this pipeline by its proponents is 0.5¢/ton-mile. Alternative estimates of the tariff for this pipeline range from 0.69¢/ton-mile(18) to .81¢/ton-mile.(6) If it were assumed that estimated tariffs on the remaining pipelines varied proportionately, then the total annual user charges would be between $599 million and $632 million for the case with ETSI's tariff set at .69¢/ton-mile and would range from $704 million to $742 million for the case with ETSI's tariff set at .81¢/ton-mile.

Rail System Impacts

Revenue Loss. Estimated annual revenues that would accrue to rail carriers serving the PAD District 4 area in the absence of coal slurry pipeline construction have also been estimated. The projected revenue loss in terms of estimated 1975 rates is between $794 and $929 million per year. The magnitude of this revenue loss can be placed in perspective by noting that in 1974 the total coal revenues received by all U.S. railroads was $1.8 billion, while that of Western District Railroads was $338 million.(7) While rail revenues would increase over time, due to inflation and increased coal production, implementation of all the proposed coal slurry pipelines would at the minimum severely restrict the potential future growth of the railroads' coal revenues.

In contrast to the projected coal slurry pipeline tariffs, the rail rates used in the study are based on historical data, i.e., actual tariffs (escalated to current dollars). However, the results are still subject to a few caveats. First, these rates are for distances comparable to the short-line rail distances indicated, while the actual rail routes utilized by the carriers(s) serving the movement could be somewhat longer, thus tending to increase the rates indicated.

Unit train rates are, in a sense, subject to volume discounts. The rates indicated are for annual volumes which are an order of magnitude less than the projected pipeline flows. This factor would tend to lower the indicated rates.

Rail Employment. A total of 2855 to 3290 railroad jobs having an annual payroll of $42.8 to $49.4 million would not be added as a result of the construction of the slurry pipelines.

It should be noted that as common carriers the railroads might be required to service the coal traffic in question depending on the scheduled completion of the pipelines and the needs of the coal users. Thus the railroads could be forced to increase their employment levels by the amounts indicated for a period of one to two years and then be forced to reduce employment levels once the pipeline was operational. In this sense, at least some of the jobs and payroll indicated could represent an actual loss.

The number of employees associated with a rail alternative to each pipeline was determined from data on the number of employees directly involved in or directly allocated to coal traffic operations of the Burlington Northern Railroad.(13) The figure used was 30.9 employees per billion ton-miles of coal unit-train traffic. This figure can be further broken down as follows: enginemen, conductors and trainmen—13.8/billion ton-miles; car and locomotive maintenance personnel allocated to unit train operations—12.4/billion ton-miles; maintenance of way crews allocated to coal traffic—3.0/billion ton-miles; and dispatchers, clerks, agents, signalmen and supervisors allocated to this traffic—1.7/billion ton-miles.

Note that these figures do not include employment associated with the construction of new rail lines or the up-grading of existing rail lines. Data on the amount of track up-grading required to serve this potential traffic was not readily available. Moreover, only about 60 miles of new rail mainline would have to be constructed (exclusive of sidings to mines) in order to provide rail alternatives to the pipeline routes. The 60 mile link would provide a rail alternative to the Nevada Power Co. pipeline. All other pipeline links could be served by existing rail routes.

The annual payroll for these rail employees was computed on the basis of an average salary of $15,000/year/job.(8),(18)

Rolling Stock Requirements. The number of unit trains required to provide a coal hauling capability equivalent to that provided by the proposed coal slurry pipelines was estimated as a function of the coal volume moved, the capacity of a unit train, and the average round trip time. Round trip time was estimated on the basis of a speed of 25 mph, and included allowances for loading, unloading, inspections, and contingencies.

A total of 152 to 172 unit trains would be needed to provide the required coal hauling capability. This translates into a requirement for 15,350 to 17,670 hopper cars and 670 to 760 locomotives. These figures are based on a train consisting of 4 locomotives and 100 hopper cars of 100 ton capacity, and includes a provision for 10% spares for both cars and locomotives.(6) If all equipment had to be purchased, it would require a capital investment of $700 to $800 million in terms of 1975 dollars (based on a cost of $26,000/car and $450,000/locomotive(6)). In terms of steel requirements, these figures indicate a need for 601,200 to 689,700 tons of steel. This is based on an assumed requirement of 30 tons of steel per car and 210 tons of steel per locomotive.(20) The equipment requirements indicated here may be underestimated since the actual routing utilized by the carrier(s) could be longer than the short-line rail distance.

The estimate of railroad investment requirements, in terms of locomotives and cars, is especially important since the railroads may be required to make at least part of this investment to service the projected increase in coal traffic in the interim period between the coal users' first requirements for delivery and the start-up date of the pipelines.

The above investment requirements do not include any estimate of the capital or steel required for the construction or up-grading of rail lines. Existing rail lines could be used to provide alternative rail service to all pipelines without new construction in all cases but one. About 60 miles of new line would have to be built to provide a rail alternative to the Nevada Power Co. line.

Up-grading may be required on certain exsiting route segments in order to improve the quality of the roadbed, or to increase the capacity of the line so as to serve the new coal traffic. An analysis of these requirements for up-grading is beyond the scope of this study.

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BIOGRAPHY

Mr. Mergel received a Bachelor of Science in Civil Engineering from Drexel University in 1972 and a Master of Science in Civil Engineering (Transportation Systems Division) from M.I.T. in 1974.

Since joining TSC in 1974 as an Operations Research Analyst, Mr. Mergel has performed a variety of tasks. For the past year he has been engaged in a study of coal slurry pipelines and more recently natural gas pipelines. His current assignments include an analysis of the cost-effectiveness and resource efficiency of coal slurry pipelines versus alternative coal transportation modes in various applications, and an evaluation of alternative Alaskan natural gas transportation systems.

BIOGRAPHY

Dr. Vance is Manager of the TSC Transportation Energy Policies Project. The purpose of this project is to maintain an overview of transportation-energy issues and to prepare background analyses related to energy conservation programs. This project also provides the department with projections of future requirements for the movement of energy commodities.

Dr. Vance received his Doctor of Engineering (Transportation Engineering) from the University of California (Berkeley) in 1970. He has been employed by the Bay Area Transportation Study Commission as a staff assistant to the Commission for analysis of new transportation concepts. While at the University he supervised a study of the transportation needs of developing countries for DOT (TPI). Dr. Vance joined TSC in 1971.

PIPELINE SYSTEM MODELING AND THE PROBLEM OF ALASKA

by

DAVID B. HIATT

INTRODUCTION

Since the onslaught of the "energy crisis," beginning with the oil embargo of October, 1973, increasing attention has been focused on the nation's energy industries. One of the major subjects of this scrutiny has been the petroleum industry, the world's third largest industry behind only agriculture and public utilities. The attention focused on the petroleum industry has brought to light the tremendous size, complexity, and importance of a transport mode previously disregarded by much of the public—the oil and gas pipeline systems. The role these systems play in the economics of the industry and the volumes they carry guarantee that they will continue to be the dominant mode of transport for petroleum and natural gas.

In spite of the immensity of the oil and gas pipeline systems and their complete dominance of energy transportation, their operation and characteristics remain little understood outside the petroleum and pipeline industries. Although the continuing energy problem has helped to illuminate their importance, the pipeline systems remain in a kind of jurisdictional limbo with no single organization possessing the authority and interest to effectively analyze them. This void has left transportation planners and policy analysts without the range of analytical tools necessary to investigate the impacts of important policy propositions—such as the construction of deepwater ports or development of Alaskan North Slope gas fields. The menu of analytical tools available reflects the historical importance placed on other spheres of the energy market; a wide variety of energy demand models, inter-fuel substitution models, electrical-generating plant models, refinery models, and national energy-system models are available.(1) But few models that deal explicitly and in detail with the pipeline networks can be found outside the petroleum industry itself.

This paper first delineates the size of the U.S. pipeline systems and their dominance in energy transportation to indicate their national importance. Two modeling systems that typify extant analytical tools are then briefly described. A section is devoted to an analysis of alternate delivery systems proposed for Alaskan North Slope natural gas; the analysis was performed as part of a larger study of the nation's energy transportation system performed for the Federal Energy Administration.(2) The results of the analysis evidence the need for thorough investigation of proposed major pipeline projects and their potential economic impacts. The final section discusses appropriate tools and focus for such investigations.

BACKGROUND

The United States got an early start in the use of pipelines for oil transport as producers outside the Rockefeller cartel tried to by-pass his control of the railroads. The subsequent development of the nation's pipeline systems, due to our extensive production and consumption and to our geographical size, has exceeded that of any other country and has produced a transport mode whose relative importance in freight movement is generally underestimated. Table 16-1 shows the 1973 freight movements of the four principal modes; surprisingly, oil pipeline (including both crude oil and petroleum products, but not including natural gas) ranked third behind the combined total of waterway, lake, and coastal ship movements. Table 16-2 shows the line mileage for all line-haul railroads versus that for oil pipelines and natural-gas pipelines. The extent of the nation's pipeline system is truly remarkable, with over 222,000 miles of oil pipelines and almost one million miles of natural gas pipelines.

Table 16-1. U.S. Freight Transport 1973 Ton Miles-Intercity.

• Rail (Class I):	851 Billion
• Waterway & Coastal:	585 Billion
• Oil Pipeline:	507 Billion
• Truck (Regulated):	505 Billion

Source: *Summary of National Transportation Statistics,* U.S. Department of Transportation, Office of the Secretary, Washington, D.C. Report No. DOT-TSC-OST-75-18, June 1975, PP. 27, 31, 34, and 37.

Table 16-2. U.S. Pipeline System (1973)—The Most Extensive Pipeline System in the World

- 69,000 Miles of crude oil gathering lines
- 76,000 Miles of crude oil trunk lines
- 77,000 Miles of refined oil trunk lines
- 968,000 Miles of natural gas pipelines and utility mains.

Source: *Energy Statistics,* U.S. Department of Transportation, Office of the Secretary, Washington, D.C., Report No. DOT-TSC-OST-75-33, August 1975, Tables 1-4 and 1-5.

Pipelines appear as an even more important transport mode when one examines their role in transporting oil and gas—the two fuels that together provide 76% of our total energy needs.(3) Pipelines dominate the transport of crude oil in the U.S. with 77% of the total crude tonnage carried in 1973.(4) The importance of pipelines for movement of petroleum products is difficult to determine since most product movements are multi-modal trips. For example, the product may be carried from the refinery to a regional terminal by pipeline and then be distributed by truck. We do know, however, that 55% of all petroleum products consumed in the U.S. in 1975 were transported by pipeline for some part of their total trip.(5) If we eliminate products that cannot be moved by pipeline (residual oil, wax, coke, asphalt, and the like), we find that 75% of all "pipeable" products (gasoline, jet fuel, kerosine, distillate fuel oil, and natural-gas liquids) were transported by pipeline in 1975(5) Finally, natural gas, which provides over 30% of total U.S. energy needs, is transported almost entirely by natural gas pipelines.

PIPELINE MODELING

Two models that include explicit pipeline network representations are Gezen's Superport Model(6) and Debanné's Energy Supply-Distribution Model.(7) The Superport Model, in particular, typifies the treatment of pipeline system capacity, tariffs, and expansion costs that is generally used in energy distribution models.

The Superport Model was originally developed at the U.S. Department of Transportation, Office of the Secretary, in conjunction with its analysis of deepwater port and refinery siting implications. It models the petroleum industry's distribution and refining system by minimizing estimated crude oil transportation costs, refining costs, and oil product transportation costs. Both crude oil supply and final product demand are specified exogenously by region. Existing pipeline capacities between supply zones and refinery zones and between refinery zones and demand zones are modeled. However, the flow-allocation scheme used in the model treats transport tariffs on both existing lines and new lines as a simple function of volume and distance. This average cost curve technique is used merely to compare pipeline tariffs to those for other transport modes, such as truck; it cannot be used to examine alternate pipeline system expansion proposals because it does not include cost differences that will occur due to terrain differences, labor cost differentials, the construction of new lines (as opposed to expansion of existing lines), and other regional cost variations. This technique is similar to that used by the Pace Company in its study,(8) in which the cost of new gas pipeline capacity, for example, is simply modeled as 3¢/Mcf/100 miles for all sizes in all regions.

Debanné's model for North American oil supply and distribution comprises two major components. The first of these is an exploration and production investment model that forecasts development of production activities for crude oil and natural gas, based on data describing existing fields and reserves, and as a function of market price and exploration costs. The second component is a network model of the complete North American oil and natural gas pipeline systems and the principal tanker route system. This component contains: 1) a somewhat aggregated representation of the existing liquid and gas pipeline systems, including length, climatic, and capacity data; (2) a demand driven, least-cost network flow alogrithm for allocating oil and gas supplies through the network to demand centers; and (3) a pipeline construction algorithm that designs and prices optimal pipeline capacity additions based on extensive detail.

The network model uses some sixty supply and demand modes to model natural gas and oil flows—crude oil and product flows are not differentiated—in the entire U.S. and Canada. Each supply node is characterized by current oil production, natural gas production, and field prices. Each demand node is characterized by a demand level and an expected growth coefficient for both petroleum liquids and natural gas. A linear optimization model allocates flows through the pipeline system by minimizing the cost of supplying expanding oil and gas demands. Capacity additions are permitted when the incremental capacity would lower the overall cost of transport.

The characteristics of the pipeline systems are modeled in substantial detail. Major pipeline routes are represented as series of pipeline segments or links. The tariff or cost per unit throughput for any pipeline segment is estimated to be equal to the annual "cost of service" for the segment, divided by the annual flow. The "cost of service" is set equal to 20 percent of total investment. Thus, the tariff per barrel (or mcf) is set such that annual revenues will equal 20 percent of total investment. Note that this is not equivalent to a 20 percent rate of return on investment, since operating and other expenses have not been deducted from total revenue.

It is this third component—a pipeline construction and investment alogorithm sensitive to regional cost differences—that is central to pipeline system analysis.

ALTERNATIVE ALASKAN NATURAL GAS DELIVERY SYSTEMS

As part of its support to the Federal Energy Administration during its Project Independent program, the U.S. Department of Transportation, Transportation Systems Center provided basic cost, capacity, and expansion requirements data for the major energy transportation modes connecting FEA-designated supply, processing, and demand regions.(9) For the projected incremental energy flow increases developed by the FEA,(10) we estimated the total investment requirements for expanding pipeline capacity between regions by determining the requirements for capacity expansion between each set of regional nodes, where each region's principal node (or city center) was also designated by the FEA. During the evaluation of alternative delivery systems for Alaskan North Slope natural gas, we discovered that the simple comparison of the investment costs of the Alaskan systems does not fully and accurately represent the costs of the alternatives due to implied distributional requirements within the continental U.S.

The investment requirements for expanding the United States' natural gas pipeline capacity were developed by us with the use of the investment algorithms and data base of Debanné's simulation of the North American pipeline system.(7) The investment requirements for expanding pipeline capacities between regions of the U.S. were approximated by determining the requirements per unit of capacity added between specific city pairs. The route between each city pair was broken down into segments; the investment required for capacity expansion along an existing pipeline segment or for addition of a new pipeline segment comprises three elements: the cost, C_s, of the pipe (steel); the cost, C_p, of pumping power (horsepower); and the cost of laying pipe, C_c, (construction). In the model, these costs are expressed as:

$$I = C_s + C_p + C_c$$

with

$$\left.\begin{array}{l} C_s = 28.2 \cdot A \cdot (D+t) \cdot t \\ C_c = B \cdot (D+t) \\ C_p = \dfrac{23.63 \cdot S \;\; Q^{2.75} \cdot V^{0.25}}{D^{4.75}} \end{array}\right. \qquad \text{(for oil)}$$

$$\begin{array}{l} C_p = \left[\dfrac{S \cdot Q^3 \cdot T \cdot G}{(3.16 \times 10^{-7}) \cdot D^5 \cdot H} \right] \\ \qquad \left[2 \cdot \log(924 \cdot OD)^2 \right] \end{array} \qquad \text{(for gas)}$$

Where:

C_s = cost of steel in dollars per mile
C_c = construction cost in dollars per mile
C_p = cost of pumping power in dollars per mile
Q = new capacity in thousands of barrels per day (oil) or trillion BTU per year (gas)
D = Internal diameter of the line in inches
t = Pipe wall thickness in inches
V = Average oil viscosity in centistokes
A = dollars per ton of steel—varies by geographic region
B = dollars per inch diameter per mile—varies with the difficulty of the terrain crossed
S = dollars per horsepower
T = mean flowing temperature
G = a function of the ratio of maximum to minimum line pressure, minimum pressure, and T
H = A function of pressure and temperature
OD = outside diameter of the line

The expressions for the separate cost elements indicate that pipeline cost is a function of two types of variables: regional variables—terrain, steel cost, and mean winter temperature (used to estimate flowing temperature and viscosity); and pipeline dimension variables—flow capacity, pipe diameter, and pressure. For a given pipeline segment, the regional variables are exogenous data while the pipeline variables will be determined so as to minimize cost while providing the specific capacity required. Regional data are contained in the model data base. One of eight terrain categories, each having an estimate for pipeline construction cost, is encoded for every point on a grid of North America composed of latitude and longitude lines spaced 1/2° apart. Pipe cost and mean winter temperature are encoded by state or province.

The costs per unit of additional capacity for pipelines with specific routing(11)but unspecified pipeline dimensions were determined by taking investment costs for several pipeline segment expansions and additions in each region, dividing the cost by the change in capacity and length of the segment, and selecting a near-median value. This process produced investment rates—\$/(bbl/day)/mile or \$/(mmcf/day)/mile that vary only as a function of the regional variables—terrain, pipe cost, and mean winter temperature.

The investment rates were then used to determine the investment required per unit of capacity added between each pair of cities. For each city pair, a pipeline route was specified—pipeline segment by pipeline segment; where practical, existing pipeline routes were followed. The investment requirement per unit of capacity (e.g., \$/bbl/day) was then computed separately for each segment by selecting an investment rate appropriate to the location of the segment and multiplying by the length. The segment investment requirements were then summed to produce the total required investment per unit of capacity added (\$/bbl/day or \$/mmcf/day) between the two cities.

The total national requirements for gas pipeline capacity expansion were then estimated by multiplying the FEA specified, incremental region-to-region flows(10) (mmcf/day) by their appropriate investment rates.

Table 16-3 indicates that the major increase in natural gas transport capacity is that required to move natural gas from Alaska to the continental U.S.; sixty-three percent of the incremental daily volume originates in Supply Regions 1 and 1a. This importance is not surprising since the continental U.S. has a projected net decline in natural gas production between 1972 and 1985. The Alaskan production is widely distributed through the U.S.: to the Atlantic Coast (Demand Regions 2 and 5), the Midwest (Demand Region 3), the Gulf Coast and East South Central area (Demand Region 6), the Rocky Mountains (Demand Region 8), and the Pacific Coast (Demand Region 9).

We have analyzed three routings for major pipeline systems for transporting natural gas from Alaska's northern shore (Prudhoe Bay) to the continental U.S. The first route is from Prudhoe Bay to Valdez, Alaska; from Valdez, gas would be carried by LNG tanker to the west coast. The second route is from Prudhoe bay to Portland through Canada. The third route is from Prudhoe Bay to Emerson, Manitoba (directly above the Minnesota/North Dakota border) through Canada. The results are shown in Table 16-4. As described above, we computed requirements for individual pipeline segments along a route, based on regional information; the various requirements for an entire route are then the sums of the requirements for the segments. (The route from Prudhoe Bay to Valdez comprises a single segment). Columns one through three in the table contain the information used to

Table 16-3. Incremental Natural Gas Flows (1972–1985) Via Pipeline Supply Regions to Demand Regions— MMCF/DAY

Census Demand Region Supply Region	1 NE (BOSTON)	2 MA (NYC)	3 ENC (CHICAGO)	4 WNC (KC)	5 SA (ATLANTA)	6 ESC (BIRM-INGHAM)	7 WSC (HOUSTON)	8 M (DENVER)	9 P (LA)
1 A/H Valdez			1844						1329
1a NS Prudhoe Bay		2178			1307	88		2638	2458
2 PS Los Angeles									151
2a PO Los Angeles									
3 WRM Farmington									
4 ERM Cheyenne								41	
5 WTENM Midland									
6 WGB Beaumont	1090						2784		
6a GULF New Orleans					260				
7 MC Wichita		2115		52					
8, 9, 10 EC&NE Robinson	378	189							
11 AS Tampa									
11a AO Newport News									

Table 16-4. Alaskan Gas Pipeline Analysis: Investment and Resource Requirements for Alternate Pipeline Routes

FROM	TO	Distance Miles	Assumed Pipe Diameter—Inches	Mean Temp. °F	Investment $/MCF/Day	Tons Steel Per MCF/Day	HP Per MCF/Day	Man Hours Per MFC/Day[1]
Prudhoe Bay	—Valdez	790	36	3	469	.13	.31	3.33
Prudhoe Bay	—Portland							
Prudhoe Bay	—Canadian Arctic	337	34	10	172	.06	.12	1.20
Canadian Arctic	—Ft. Simpson	568	48	10	248	.10	.15	1.21
Ft. Simpson	—Edmonton	655	48	18	243	.12	.15	1.07
Edmonton	—Kamloops	362	36	35	145	.08	.10	1.22
Kamloops	—Vancouver	152	36	42	55	.03	.04	0.39
Vancouver	—Portland	275	36	45	83	.06	.08	0.73
TOTAL: Prudhoe Bay	—Portland	2,349	—	—	945	.45	.65	5.81
Prudhoe Bay	—Emerson:							
Prudhoe Bay	—Canadian Arctic	337	34	10	172	.06	.12	1.20
Canadian Arctic	—Ft. Simpson	568	48	10	248	.10	.15	1.21
Ft. Simpson	—Edmonton	655	48	18	243	.12	.15	1.07
Edmonton	—Calgary	173	42	31	33	.04	.03	0.27
Calgary	—Regina	394	42	25	79	.09	.08	0.57
Regina	—Near Virden	190	42	19	37	.04	.04	0.26
Near Virden	—Winnipeg	181	42	17	37	.04	.03	0.26
Winnipeg	—Emerson	69	42	17	16	.02	.01	0.12
TOTAL: Prudhoe Bay	—Emerson	2,567	—	—	863	.52	.62	4.94

[1] Man hours are estimated as one-half the construction cost divided by $10/hour

Table 16-5. Tanker Requirements For Transporting Natural Gas from Valdez to Los Angeles

Loading Time	37 hrs/trip
Transit Time (one way)	90 hrs/trip
Unloading Time	36 hrs/trip
Weather Delay	12 hrs/trip
Out-of-Service Time (each ship)	480 hours/year
Capacity (each ship)	125,000 cubic meters/trip 2,750 mmcf/trip 83 bcf/year 228 mmcf/day
Requirements Per Ship:	$106 million 26×10^3 tons steel and steel products

compute each segment's requirements. Columns four through seven contain the estimates.

The tanker requirements for shipment of LNG from Valdez to Los Angeles were also estimated. These estimates are based on time requirements for tanker service and are summarized in Table 16-5.

The projected Alaskan natural-gas system will deliver 11.8 bcf/day to the continental U.S. In alternative one, the natural gas is assumed to be transported by pipeline across Canada to the U.S. Natural gas produced on the North Slope is piped 905 miles from Prudhoe Bay to Ft. Stimson, NWT, where it is joined by natural gas produced in Southern Alaska and piped 950 miles from Valdez to Ft. Simpson. From Ft. Simpson, the natural-gas pipeline goes 655 miles to Edmonton, Alberta where it branches to Portland, 790 miles away, for delivery of 3.8 bcf/day to the Pacific Coast; and to Emerson, Manitoba, 1007 miles away, for delivery of 8.1 bcf/day to demand regions 2, 3, 5, 6, and 8. In all, the trip from Prudhoe Bay to Portland is 2350 miles and from Prudhoe Bay to Emerson is

2565 miles. The total cost of the Trans-Canada system was estimated to be $10.5 billion. The major route segments are described in Table 16-6.

In alternative two, 8.7 bcf/day of North Slope natural gas is transported via pipeline to Valdez, Alaska. There, it and 3.1 bcf/day of Southern Alaska gas are liquified and two LNG tanker routes are used to transport 7.8 bcf/day to Los Angeles and 4.0 bcf/day to Portland, Oregon. The investment requirements are shown in Table 16-7.

Based on the cost projections for the two systems, the trans-Alaskan/LNG tanker alternative is considerably less expensive. However, since the point-of-entry into the continental U.S. will determine continental pipeline requirements to reach the various demand regions, we went on to include pipeline capacity expansion required in the U.S. for delivery of the Alaskan gas in the total cost of each alternative. Assuming, as the FEA projections did, that the Alaskan gas would be distributed to the same markets, we

Table 16-6. Alternative One: Trans-Canadian Natural Gas Pipeline System

PIPELINE SEGMENT		DISTANCE	PROJECTED: CAPACITY	COST	STEEL	HP	LABOR
From	To	Miles	MMCF/Day	$ 10^6	10^3 Tons	10^3	10^3 Man-Hours
Prudhoe Bay	Ft. Simpson	905	8,669	3,638	1,474	2,427	20,892
Valdez	Ft. Simpson	950	3,173	1,332	539	888	7,647
Ft. Simpson	Edmonton	655	11,842	2,874	1,421	1,776	12,671
Edmonton	Emerson	1,007	8,055	1,617	1,853	1,530	11,921
Edmonton	Portland	789	3,787	1,069	606	833	8,862
TOTAL:			11,842	10,531	5,893	7,456	61,993

Table 16–7. Alternative Two: Alaskan Natural-Gas Delivery System

PIPELINE ROUTE	Distance Miles	Capacity mmcf/day	Cost 10^6	Steel 10^3 tons	HP 10^3	Labor 10^3 man-hrs
Prudhoe Bay-Valdez	790	8669	4066	1103	2647	28,783

TANKERS ROUTE	Distance Miles	Number of ships	Capacity mmcf/day	Cost* 10^6	Steel 10^3 tons
Valdez-Portland	1400	14 (125,000 cubic meters each)	4022	1484	358
Valdez-Los Angeles	2050	34 (126,000 cubic meters each)	7820	3604	870
Subtotal (tankers)		48	11,842	5088	1228

TOTAL PIPELINE AND TANKERS	Capacity mmcf/day	Cost $ 10^6	Steel 10^5 tons
	11,842	9154	2331

* $106 million each

estimated continental requirements for each alternative as shown in Table 16–8. As the table shows, the Trans-Canadian system now appears to be the less expensive.

Table 16–8. Total Requirements for Natural Gas Pipelines

Alternative 1: Trans-Canadian Pipeline System		
Alaskan-Canadian Segments:		
	Pipeline:	$\$10{,}531 \times 10^6$
Continental US Segments:		
	Pipeline:	$\$3146 \times 10^6$
TOTAL:		$\$13{,}676 \times 10^6$
Alternative 2: Trans-Alaska Pipeline and LNG Tanker System		
Trans-Alaska Pipeline and Tanker Segment		
	Pipeline:	$\$4066 \times 10^6$
	Tankers:	$\$5088 \times 10^6$
	Sub total:	$\$9154 \times 10^6$
Continental U.S. Segments		
	Pipeline:	$\$5175 \times 10^6$
TOTAL:		$\$14{,}329 \times 10^6$

The assumption that the Alaskan natural gas would be distributed to the same end markets for both alternatives may not be entirely accurate and may overstate the cost of the Trans-Alaska/LNG tanker alternative. But, we have not included investment costs for liquification and gasification facilities either, and these should more than offset any decrease in continental distribution requirements. In addition, these cost estimates are meant to be indicative rather than substantive since they are based on 1972 cost estimates and do not include recent construction cost inflation or the rising costs of environmental safeguards. They do indicate, however, that the massive pipeline system projects planned for the next decade can have substantial impacts beyond their own costs and must be evaluated carefully in a full system context.

CONCLUSIONS

The reduced continental production of both crude oil and natural gas coupled with the development of offshore and Alaskan North Slope fields guarantee that we will see construction of major new delivery systems for oil and gas in the next decade. The economics of pipeline transport will continue to dominate for these two energy sources. These two factors will almost certainly engender the construction of new pipeline systems as large as, and perhaps several times larger than, the Alaskan oil pipeline system now under construction. Projects of this magnitude require enormous amounts of men, material, and capital. But in addition to their own requirements, these mammoth pipeline projects will to a large extent also determine the continental transportation system requirements.

The magnitude of these systems and the pervasive influence they will have on the energy transportation systems of the next quarter century argue for a comprehensive public capability to investigate both the characteristics of major individual pipelines and the impacts they will have on the national transportation systems. At present, there are no analytical tools available that can examine individual proposed pipeline projects accurately and in detail. The investment requirements technique we developed is certainly a step in that direction, but the assumptions and procedures we were forced to adopt make it useful for projecting indicative results only. Debanné's investment model is more precise in its estimation of pipeline requirements, but it is embedded in a complex modeling system driven by an endogenous supply estimation and a network distribution model. As a result, it cannot be used for repetitive and comprehensive evaluations of individual pipeline proposals.

The second area in which the public capability is deficient is that of policy-sensitive, energy distribution-system analysis. Several major issues created by the Alaskan North Slope gas reserves will illustrate this need. The problem with these reserves is not how to deliver them to the U.S. so much as what to do with them. North Slope natural gas is associated gas; i.e., it is a by-product of crude oil production. In the past, associated gas has generally been flared, or burned at the well, but natural gas has become too valuable a fuel to be wasted. One of the major arguments favoring the Trans-Alaska/LGN tanker delivery system is its ability to deliver surplus gas to other markets, especially energy-starved countries such as Japan. On the other hand, the trans-Canada pipeline could initially be built only as far as Edmonton, Alberta, and the gas be used to supply the currently under-utilized Canadian natural gas system—The Trans Canada Pipeline (TCPL) and the Great Lakes Pipeline (GLP). The gas could be supplied to the Canadians in exchange for current oil supplies or future gas supplies, and thus be used as the basis for a mutually advantageous energy-exchange agreement. Or, it could still be earmarked for the U.S. and use portions of the under-utilized Canadian system simply to reduce the extent of new pipeline facilities required.

The problem we face is in analyzing these extremely complex issues. Should Alaskan crude oil and natural gas be reserved for use solely by the American people, or are the costs of the required transportation systems excessive? If exchange agreements are negotiated with the Canadians, would there be a net savings for the U.S.? Or, could we use the existing western Canada pipeline system as part of the delivery system to the U.S. thereby improving their capacity utilization and reducing the need for our new system? If LNG tankers were diverted from the west coast to Japan, would we benefit as a nation, or would other areas of the country be forced to develop even more expensive energy sources as a result of a compensating distributional shift to the west?

These are just a few of the issues we will face in the next decade. Without a sophisticated representation of our energy distribution system, which for oil and gas means pipeline system, we will continue to be unable to effectively represent the public sector.

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7. J. G. Debanné, *A Regional Techno-Economic Energy Supply-Distribution Model for North America,* University of Ottawa, Faculty of Management Sciences, July 1975.
8. *Energy and Hydrocarbons in the United States to 1985,* The Pace Company, Houston, Texas, January 1974.
9. D. Anderson and D. Hiatt, op. cit., Volume II, Appendix A.
10. The FEA provided projected 1985 region to region flows for all energy commodities. The flows used in this analysis were from the "High Trial Scenario." We subtracted 1972 estimated flows to get "incremental" flows.
11. For all expansion requirements, specific routing refers to city-center connections among regions. Each FEA region was assigned a city center which was the origin and destination for all flows to and from that region.

HIATT

BIOGRAPHY

Mr. Hiatt received his Master of Science and Bachelor of Science in Engineering from the Massachusetts Institute of Technology in 1970, and his Master of Science in Management from MIT's Sloan School of Management in 1973. Since then, he has worked as a program manager and senior analyst for the Transportation Systems Center in a variety of areas, including Transportation Energy Policy Project, airport operations and investment modeling, and financial modeling and forecasting for transportation industries. He recently returned from a five month assignment as a special consultant in Geneva, Switzerland where he was responsible for the coordination and technical direction of a United Nations' professional group assembled to develop an international transportation data system proposal for the Economic Commission for Europe.

U.S. Department of Transportation *Freight Transportation Digest, October 1976*

SIMULATION AS A BASE FOR SEAWAY NAVIGATION AND CONTROL

by

ROBERT D. REYMOND, DANIEL E. BRAYTON, AND WILLIAM S. SPRIGGS

The thesis presented in this paper is that an interactive on-line simulation forms an ideal base for the development of a marine traffic control and data management system. This thesis is supported by two detailed descriptions of operational data requirements in the United States section of the St. Lawrence Seaway. The first description is presented in terms of requirements and desired solutions as seen by the operational personnel of the St. Lawrence Seaway Development Corporation (SLSDC). The second is a highly structured description of these same requirements.

In March 1972, the Transportation Systems Center of the U.S. Department of Transportation conducted a systems analysis of current and projected operations on the St. Lawrence Seaway.(1) The study was undertaken at the joint request of the Undersecretary and the Administrator of the St. Lawrence Seaway Development Corporation to determine the need, benefits and costs of a marine traffic control and information system. The study indicated that the St. Lawrence Seaway cannot meet current demand under conditions of sustained peak loading and that under such peak conditions, safety is degraded. Projections are for Seaway demand to grow in the future, both for cargo transportation and other traffic. If such growth is to continue, and the Seaway is not to become the bottleneck for waterborne commerce in mid-America, then the assured throughput capacity (measured in vessels and tonnage) must be increased with no decrease in safety margins. Of the options open for increasing throughput, it appears that more optimal use of the present facilities through the incorporation of centralized vessel flow control would result in the most return for the least investment.

Prior to the St. Lawrence Seaway systems analysis completion in March 1972, an attempt to introduce vessel flow control was made by a joint U.S.-Canadian controller team at Cornwall, Ontario during the shipping congestion crisis in the fall of 1971. The vessel control system introduced consisted of teletype links and terminals with a manually maintained Seaway status board. Although the system results were encouraging, the attempt revealed that such a system could not sustain the data update rate necessary for effective flow control.

Concurrent with efforts at Cornwall, the St. Lawrence Seaway Authority developed and operated two computer-based systems for use in Seaway management: the locks and facilities usage system at St. Lamberts; and the Computerized Information Lakes System CILS) for Lake Ontario traffic control at St. Catharines. The next step planned was to develop a computer-based system for overall Seaway traffic control. The Canadians proceeded with the specification for such a system in the spring of 1972 and by summer had initiated procurement procedures of the necessary software and hardware.

These developments mentioned above, as well as a TSC study in March 1972, highlighted a need for an in-depth analysis of data utilization and information requirements of the management and operations users in the SLSDC.(1) A second TSC study was initiated in the fall of 1972.(2) Previous studies had identified the data which are processed by traffic controllers at Massena and had showed how the data are communicated. The lastest study not only considered data processing and communication, but also provided analyses of data structure, data update and access frequency. In addition, the study considered the impact of introducing a computer into the existing manual information and control system. At first, it appeared that use of a computer would merely reduce elements of manual work from the job, but upon closer study it became evident that it would introduce additional benefits. These benefits are discussed in this paper.

The basic processes of control involved can be likened to a driver controlling the speed of his car. Although there are many factors about the moving auto which must be known, the main or most sensitive variable is its speed as displayed by the speedometer. The speed requirement of a particular section of highway is displayed on speed limit signs. The driver continually accelerates or decelerates his car in order to attempt to match his speed at the moment (status) to his desired speed (requirement). The control function is introduced when the driver accelerates or decelerates his vehicle thereby changing the vehicle speed or status. This concept is shown diagrammatically in Figure 17-1.

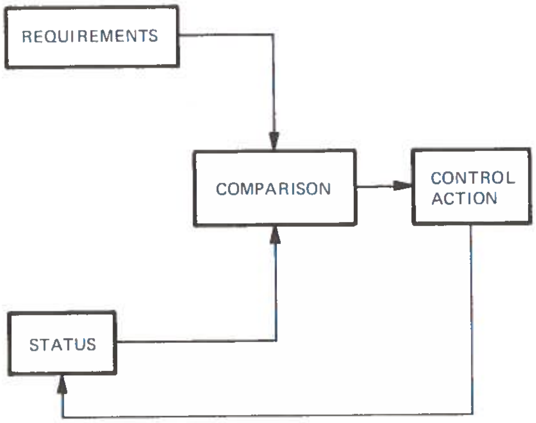

Figure 17-1. Basic control process.

Many factors affect the auto's speed such as wind velocity, road grade, etc., yet the driver generally does not sense these factors directly but relies mainly on his speedometer. This can be in the form of a specific numeric difference between his speed and his desired or required speed or as an effect upon the rate at which his control action causes his actual speed to approach his desired speed.

Seaway vessel traffic control is similar to the driver-vehicle control example. However, in vessel control, the principal variable is not speed, but rather vessel location in space and time. In the vehicle control example, the differential between speed limits (requirements) and the actual speed (current status) is the control to be ordered. In the Seaway, the control order is the difference between actual vessel position and the desired vessel position at a given time. The space-time location desired of the vessel is translated by the master or pilot into a requirement for action. He may cause the vessel to speed up, slow down, or maintain a "status quo." Thus, the process of traffic control on the Seaway is not control of the vessel itself, but rather control of the desired vessel positions.

It is the function of the vessel traffic controller to determine the desired vessel position. This desired position is a dynamic vessel space/time location, continually moving through the Seaway and subject to operational and environmental constraints. It is the function of the master to attempt to match his actual vessel position to the desired, dynamic vessel position as determined by the controller.

Seaway vessel control and automotive vehicle control are both focussed on monitoring or control of variables, time-location variables in the seaway case and a speed variable in the automotive case. In times of stress, however, other parameters may become involved. For example, when a car overheats, this fact is displayed to the driver by a gauge or warning light. Engine temperature may then become more important for control than the driver's original speed objective. Similarly, in Seaway vessel control, other parameters can become more important than time-location. Such events could include hazards to navigation, loss of steering, breakdown, or limitations on visibility. Although the Seaway controller must monitor and provide direction for vessel position, under any given stress situation other factors may become dominant.

In the absence of Seaway Vessel control, the time-location requirements of a vessel are generated on-board by the navigator. The navigator's job is to break down the overall mission into a series of sub-goals or requirements, based on the vessel's status. For example:

1. To follow an optimal wind pattern;
2. To avoid areas of adverse currents;
3. To follow a route of minimum fuel requirements;
4. To minimize the possibility of running aground;
5. To follow the route that minimizes the possibility of collision.

The helmsman and crew operate the vessel in the Seaway to meet requirements established by the navigator.

Figure 17-1 may be expanded to include actions of the navigator and helmsman as shown in Figure 17-2.

Before proceeding, it will prove worthwhile to expand the model of vessel navigation and control through inclusion of two other data management functions. These additional functions are the collection of data and formatting of data and are shown in Figure 17-3. Both the navigator-master team and traffic controller-master team perform the same basic functions. These functions include collecting data, formatting it so as to describe both status and requirements, comparing the existing status with that desired, and if warranted, executing a control action that will bring vessel status in line with requirements. The navigator-master and controller-master functions differ only in level of control. These differences are in the frequency of access to data, quality of data and extensiveness of data available.

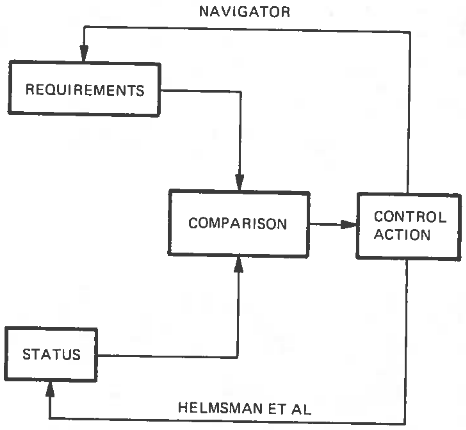

Figure 17-2. Marine vessel control process.

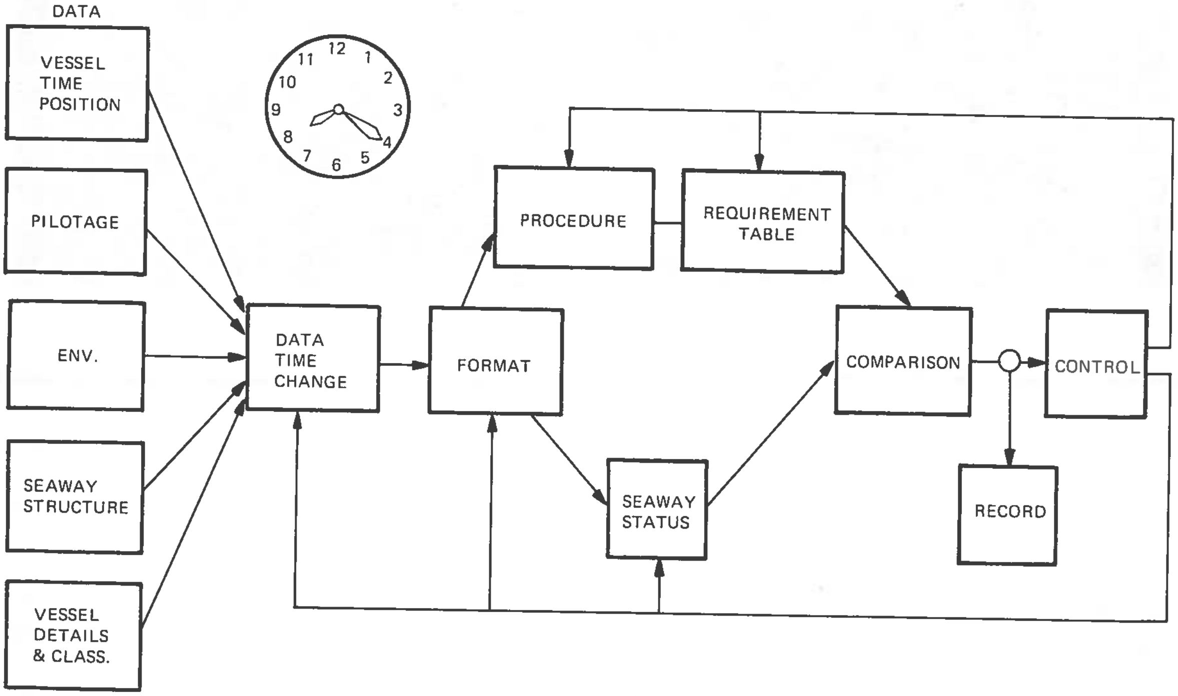

Figure 17-3. Generalized vessel control model.

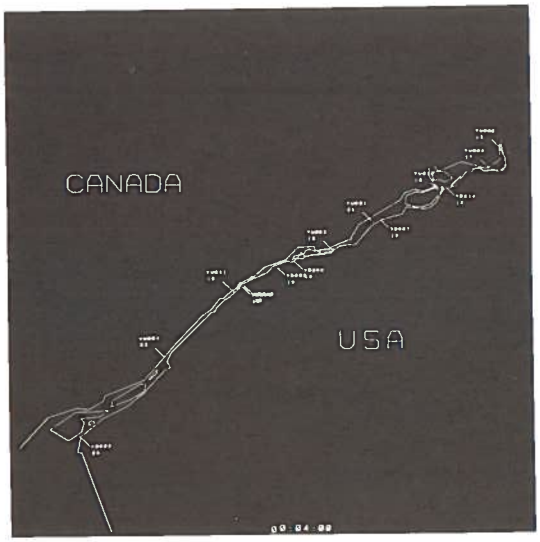

Figure 17-4. Seaway navigation structure file—Seaway display.

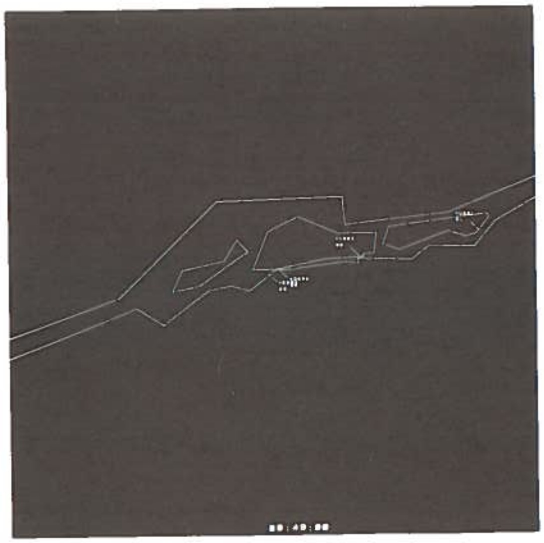

Figure 17-5. Seaway navigation structure file—Eisenhower-Snell display.

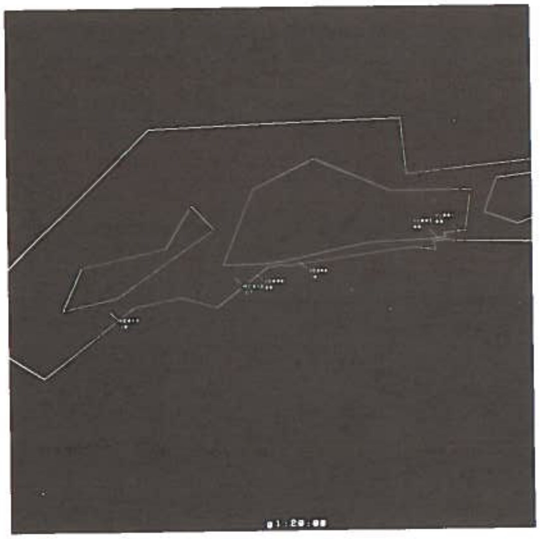

Figure 17-6. Seaway navigation structure file—Eisenhower-Snell display with zoom feature.

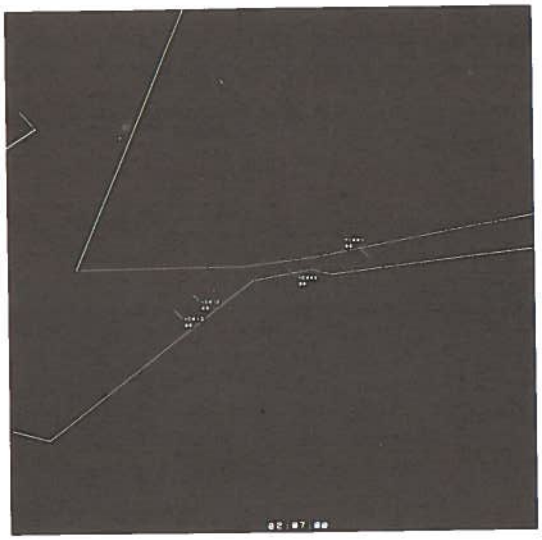

Figure 17-7. Seaway navigation structure file—Eisenhower-Snell display with zoom feature.

Consider data for the model of a seaway, for example, displayed as a large map with vessels moving across it. Portrayed on this map along with vessel positions are data blocks of amplifying text as shown in Figures 17-4 through 17-7. Also projected is a similar picture with desired vessel position and overall seaway status.(1) Using this information, action can be taken to make the actual position of a vessel coincide with its desired position.

Figures 17-4 through 17-7 show how a Seaway Navigational Structure File might appear on a CRT. A zoom feature is included, which would be analogous to changing from a regional chart to a harbor chart. Figures 17-4 through 17-7 show how this zoom feature is used to examine vessel traffic in the Snell-Eisenhower Locks section of the St. Lawrence Seaway. Each succeeding figure magnifies the Snell-Eisenhower Locks more showing greater detail.

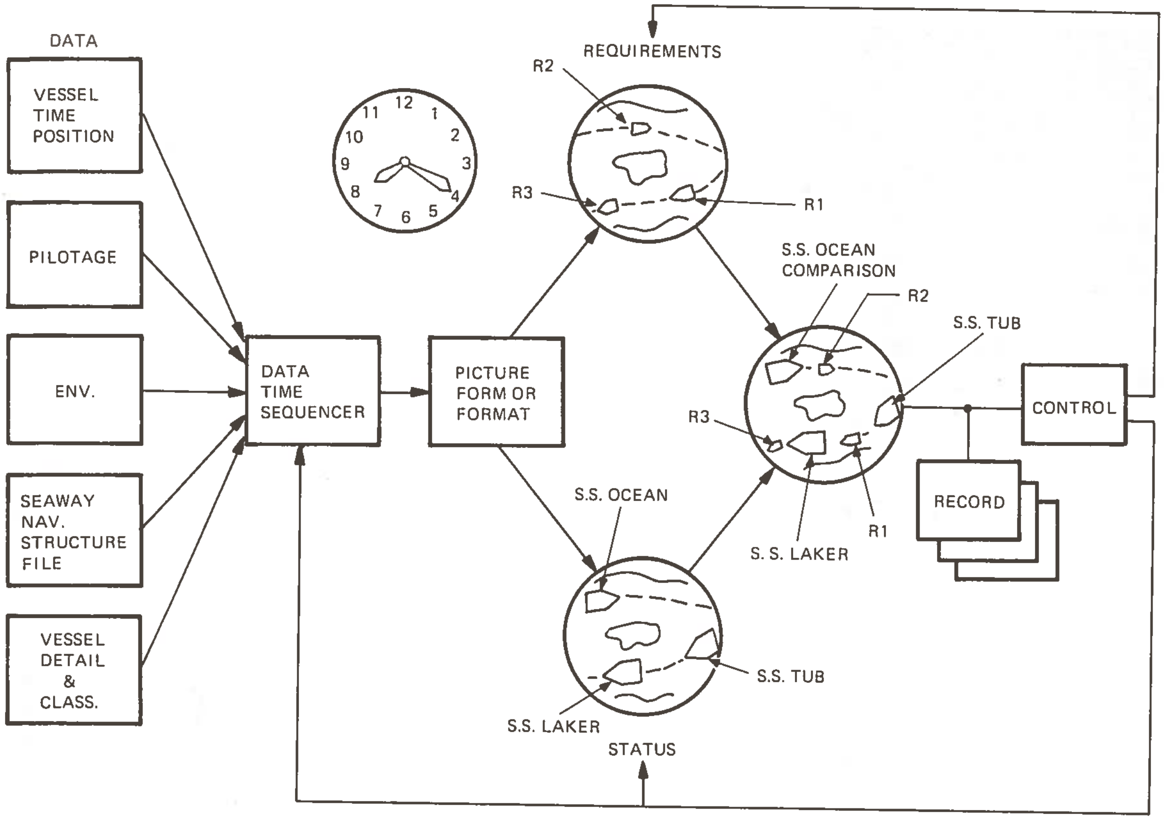

Figure 17-8. Idealized dynamic control model.

A moving-position-requirements-blip is used to indicate where the vessel is required to be. This feature is similar to a dynamic update of the Position and Intended Movement (PIM) familiar to Navy operating personnel. However, the major difference between traditional navigation and control and the system discussed here is that the data display is dynamic or animated. That is, the desired vessel position blip and the actual vessel position blip on the display are in continuous motion.

The model discussed above describes a navigation and control system concept and this concept is implemented as a computer-based simulation of the seaway and vessels using it. Figure 17-8 illustrates an idealized vessel control model with a dynamic display that shows the relative position between a vessel and the position it should be trying to reach. Both the vessel and the position it is trying to assume are in continuous motion (e.g., S.S. tub in Figure 17-8 is trying to reach position R1).

And now, consider the entire system suggested. The simulation, if coupled with real world inputs of current, wind conditions and lock status, becomes a primary navigator capable of setting requirements for a vessel in anticipation of the events it will encounter on the waterway. The vessel's master-pilot-navigator team is free to concentrate on meeting those requirements. The result will be a safer and more expeditious flow of vessel traffic through the waterway.

REFERENCES

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BIOGRAPHY

Mr. Reymond graduated from Wesleyan University with a BA in mathematics and economics. For the past twenty years he has held analytical and advisory positions of increasing responsibility with the AVCO Corporation, Westinghouse Electric Corporation and the U.S. Government. These assignments focussed on such diverse areas as information system applications, requirements, benefits and cost analysis in the fields of surface and marine transportation, military logistics, freight and commodity movements. His work has also been concerned with the development of advanced system concepts and product development. During the Korean War, Mr. Reymond served for three years as Operations Officer aboard an Atlantic Fleet Destroyer.

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