PROCEEDINGS —

Twenty-fourth Annual Meeting

Volume XXIV • Number 1 1983

T R F

TRANSPORTATION RESEARCH FORUM

PROCEEDINGS —
Twenty-fourth Annual Meeting

Theme:

"Transportation Management, Policy and Technology"

November 2-5, 1983
Marriott Crystal City Hotel
Marriott Crystal Gateway Hotel
Arlington, VA

Volume XXIV • Number 1 1983

TRANSPORTATION RESEARCH FORUM

Quantified Opportunities for Centralized Nationwide Management of Empty Freight Cars

*by Alain L. Kornhauser**

Transportation Program, Princeton University — An Interdisciplinary Program Sponsored by: School of Architecture & Urban Planning; School of Engineering & Applied Sciences; Woodrow Wilson School of Public & International Affairs.

ABSTRACT

QUANTIFIED are opportunities for fuel and financial saving through optimal centralized nationwide empty freight car management practices. Presented are detailed and summary data and graphics which suggest that there exists a potential for significant savings. The perspective is nationwide, irrespective of ownership. The optimization algorithm—a car-mile minimization transhipment problem formulated over the U.S. railway system—insured that the supply and demand for specific car types were satisfied using a weighted carmile minimization car distribution process. This analysis simulates an efficient utilization of a nationwide pool of each car type. Perfect information in a time-invarient setting is assumed. Supply-demand data were obtained from the 1981 one-percent waybill sample. Presented are data for loaded car miles (L), minimum empty car miles (E), and E/L ratios. The data are complemented by computer graphic renderings of the nationwide distribution of the supply and demand for each car type and directionally specific actual loaded and simulated optimal empty car flows. Analyzed were tri-level auto carriers (AAR car type V4, V6, V8), 50 foot gondolas (G2), refrigerated box cars (R), open-top hoppers (H3), covered hoppers (L 53, L 54), and unequipped 50 foot box cars (B209). Summary data on dollar and fuel savings are presented for each of these car-types on a nationwide basis. Some railroad specific savings are also presented. Results conclude that up to 250 million gallons of fuel and $1 billion dollars of direct operating expenses could be saved annually for these five car types.

INTRODUCTION

Over the past decade the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA) have been conducting a thorough research program aimed at improving the utilization of railroad freight cars. The Freight Car Management Program, as it is called, has made many advances and in recent years has expanded to include the investigation of nationwide car management patterns using Princeton University's Railroad Network Model and Graphic Information System (PRNM/GIS). Utilizing the optimization and other network manipulation algorithm of PTNM/GIS it has been possible to simulate the centralized nationwide management of railroad freight cars under the simplifying assumption of deterministic, steady-state supply and demand. By taking the objective of minimizing empty service-weighted car miles, it has been possible to generate empty car assignment patterns which significantly reduce empty car miles. This reduction in empty car miles has consequences which yield savings in fuel consumption and direct operating expenses. There are also broader implications in terms oof fleet size, long term capital expenses and improvement in service and market share which are not covered in this paper.

Since there exists a fundamental skewness in the supply and demand for various freight cars, repositioning of empty freight cars is a necessary aspect of rail transportation. However, the current corporate structure of the U.S. rail system has tended to "Balkanize" the utilization of equipment. There is relatively little sharing of equipment among railroads. Interlined equipment too often returned home empty. Much equipment is maintained in pools which are operated under a reverse-route-home empty car management directive. In other cases the management of per diem (daily rental) charges encourages originating railroads to utilize their own equipment and send foreign equipment home empty.

With boxcar deregulation and other shifts to a more competitive and flex-

---

**Professor, Civil Engineering, Director, Transportation Program, Princeton University.*

Research sponsored by Association of American Railroads, Research and Test Department, Freight Car Management Program

ible railroad industry the efforts to reduce unnecessary costs will be intensified. Current operating practices which generate the largest unnecessary costs are those associated with the unnecessary movement of empty cars. These unnecessary costs are in the form of excess consumption of fuel, track and car maintenance and labor, since the amount of excess empty car movements extends beyond the elimination of marginal cars from trains to the elimination of entire trains. This paper attempts to uncover opportunities to reduce empty car miles by taking a centralized nationwide car management perspective.

PROBLEM FORMULATION

The fundamental question is: what is the magnitude of fuel and operating cost saving opportunities associated with a car management practice which focuses heavily on the minimization of empty car miles?

To answer this question one needs to know the empty car-miles associated with a car management strategy focused primarily on saving empty car miles. A comparison of the empty car miles generated by this strategy with current actual empty car miles yields the fundamental data for quantifying the opportunity. If little difference exists between the optimum and actual, then let "well-enough-alone." However, if a significant difference exists, then further investigation focused on the feasibility of implementation is warranted.

To calculate the empty car management strategy which tends to minimize empty car miles, the following optimization problem can be posed:

GIVEN: the supply of empty cars of a specific type k, S_i^k i = 1, . . . n, where S_i^k is the number of k-type cars supplied at locations i around the nation, i = 1, . . . n.

n = the number of specific locations on the U.S. railway system (there are 19,000 nodes in the U.S. portion of the Princeton Railroad Network Model).

D_j^k = the demand for number of cars needed to load of type k at location i around the country.

N_{mn} = the network geometry of the U.S. railway system including distances $DIST_{mn}$ and line code, LC_{mn}

FIND: the allocation of the supply to the demand over the network such that the summed weighted empty car distances $\sum\sum_{mn} \nabla_{mn} DISC_{mn} LC_{mn}$ is minimized

where V_{mn} is the volume of empty cars on network link from node m to node n

The above problem is a classical transhipment-type data D_j^k and network data $DIST_{mn}$ and LC_{mn}, where the objective is to minimize weighted empty car miles. A weighted car mile objective is used to reflect realistic car routings which tend to minimize movement costs between fixed locations. It reflects the fact that it is cheaper to route cars over mainlines than over branchlines.

There exists many computer-based solution procedures to the transhipment problem. One developed by Mulvey [1] called LPNET is particularly efficient and is structured to handle networks with a large number of nodes and links, a necessity, because the U.S. railway system as defined in the Princeton Railroad Network Model and Graphics Information System (PRNM/GIS) [2] consists of 19,000 nodes and 20,000 links. PRNM utilizes LPNET to solve the transhipment problem in the empty car miles minimization program called MTOPT.

MTOPT structures the supply-demand data from the traffic source, e.g., one-percent waybill data [3], forms the transhipment network, solves the transhipment problem (LPNET), and produces directional volumes of optimal empty movements. The empty car movements are plotted using the graphic functions of PRNM (see Table 1). MTOPT also extracts the loaded car movements, flows these cars on the U.S. railway system using ALKFLOW and displays the loaded car flows using the same graphic utilities as were used to display the empty car flows. Summary statistics of loaded and empty carmiles and ratios are also computed.

QUANTITATIVE FINDINGS

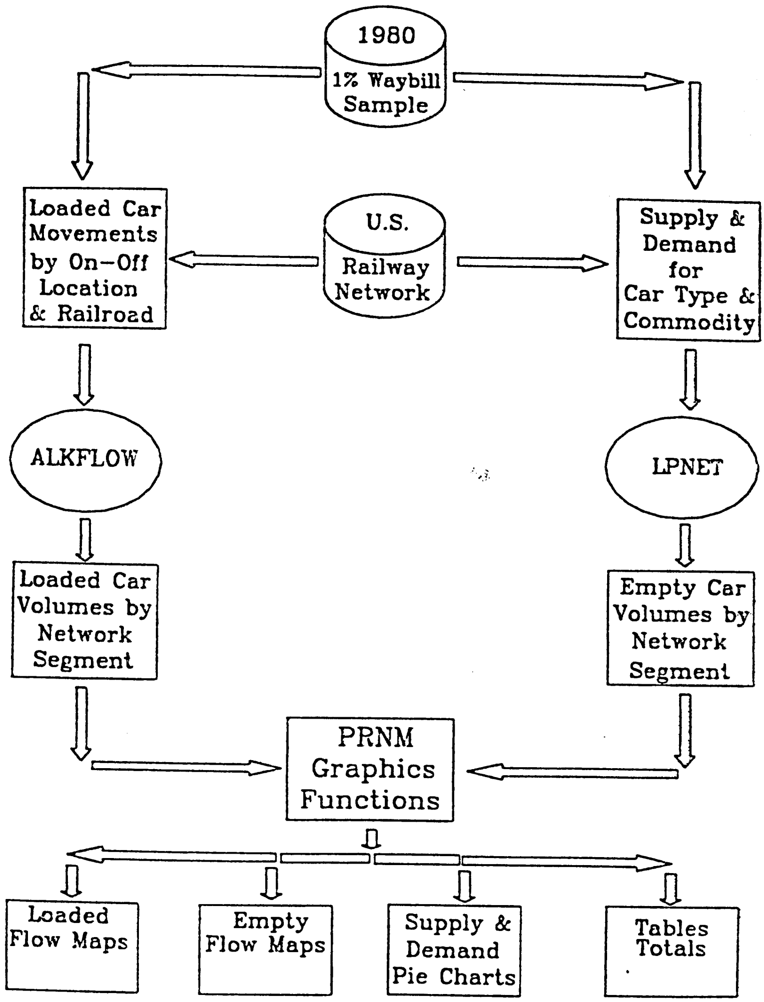
The MTOPT program was executed on six specific car types:

50 ft. XM boxcars
tri-level auto carriers
unequipped gondolas
unequipped hoppers
refrigerated cars, and
covered hopper cars.

The supply (termination of loaded movement) and demand (origination of loaded movement) for empty equipment for each car type was obtained from the

TABLE 1

COMPUTATIONAL PROCEDURES OF MTOPT



1981 Enhanced One Percent Waybill Sample [3]. These traffic data are convenient because the sample size is manageable (about 200,0000 observations), they are geo-coded with the PRNM node numbers for originations, interline junctions and terminations and the sample has been annualized based on 1981 Freight Commodity Statistics (FCS).

Loaded car miles and optimum empty car miles were computed utilizing the MTOPT procedure described in Table 1. The summary quantitative findings are presented in Table 2 below. Note that the Optimum Empty/Loaded (E/L opt) ratio was found to be highest for 50 ft. gondolas (.901) and lowest for 50 ft. boxcars (.214).

These loaded and optimal empty car flows are presented visually using computer graphics. Figure 1 shows the supply (unloading volumes) and demand (loading volumes) for tri-levels for the year 1981. Pie charts are used to depict the volume of supply and demand aggregated to the 2-digit Standard Point Lo-

TABLE 2

MINIMUM EMPTY CAR MILES AND LOADED CAR MILES FOR VARIOUS CAR TYPES IN 1981

Car Types	Load Car Miles (1981 Millions)	Minimum Empty Car Miles (1981 Millions)	E/L Optimum
50-ft. Unequipped Box Cars	1,551	328	.214
Tri-Levels	488	198	.408
52-ft. Gondolas	142	128	.901
Open Top Hoppers	1,920	1,274	.663
Covered Hoppers	2,389	1,080	.451
Refrigerated Box Cars	895	357	.399

cation Code (SPLC) level. The area of each pie is proportional to the sum of supply plus demand of tri-levels at that location. The supply is proportional to the shaded slice while the demand is proportional to the unshaded slice. Note that Washington State is relatively well balanced between supply and demand but Michigan is heavily imbalanced on the demand side while Florida, South East Texas and Arizona for example, are highly imbalanced on the supply side.

The loaded flow of tri-level freight cars in 1981 is shown in Figure 2. Shown are only the major corridors of flow of this car type. The graphic treatment utilizes bar graphs drawn perpendicular to the track segment. The height of the bar to the right of the line segment is proportional to the volume of flow in the facing direction. Thus both density and directional imbalance are depicted. Note that the Union Pacific mainline in Wyoming has balanced and heavy flow in both East- and West-bound directions. However, the Burlington-Northern flow is primarily eastbound and the flow on the Santa Fe in Arizona/New Mexico is primarily West-bound.

Figure 3 shows the flow of empty tri-levels if an empty car mile minimization objective were utilized to guide the assignment of empty cars to their next load. Also displayed on this figure is the supply/demand at the major (top 150) locations that load and/or unload tri-level cars. Note that all flows are one directional (a consequence of the optimality procedure). The empties flow from the locations of net supply to locations of net demand. This is highlighted by the flow of empties from Salt Lake City, Los Angeles and San Francisco to Portland, Oregon and Seattle. Also from Denver, Minneapolis, Memphis, Atlanta, Nashville to Detroit. Note that there is no major flow of empties across the "Continental Divide."

Appendix A contains the supply-demand pie charts and optimal empty flow charts for each of the other car types discussed in the paper.

COMPARISON WITH ACTUAL EMPTY CARMILES

While a comparison of optimal empty carmiles with loaded carmiles is interesting, it does not address the question: can the rail industry save fuel and operating expenses by changing its empty car management practice? This can only be answered by comparing the optimal empty flows with actual empty flow. A difficulty; however, is that detailed data on empty car flows does not exist in the public sector. Even many railroad companies' own data on empty car movements tend to be very "dirty." This is probably a reflection of a general lack of interest in the movement of empty cars since they were generally perceived to be relatively "free," at least until very recently. (In fact empty carmiles kept gross ton miles and yard activities at high levels.)

One public data source does exist for total annual empty carmiles, by railroad, by car type. This is the OS-A statistics compiled by the Interstate Commerce Commission. Further, one can simulate the actual movement of empty 50 ft. unequipped boxcars because they move empty under precise industry rules known as SCO-90 [4]. A computer model which reconstructs the movement of empty 50 ft. boxcars has been developed by the Author and B. P. Markowicz [5]. This model was used to simulate the

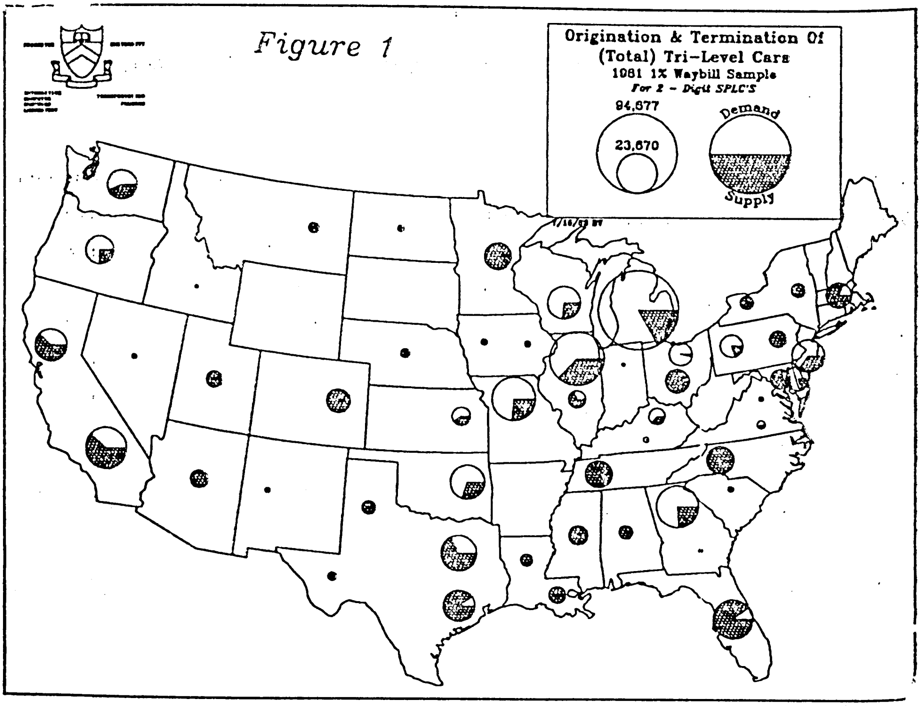


Figure 1
Origination & Termination Of
(Total) Tri-Level Cars
1981 1% Waybill Sample
For 2 - Digit SPLC'S
84,677
23,670
Demand
Supply

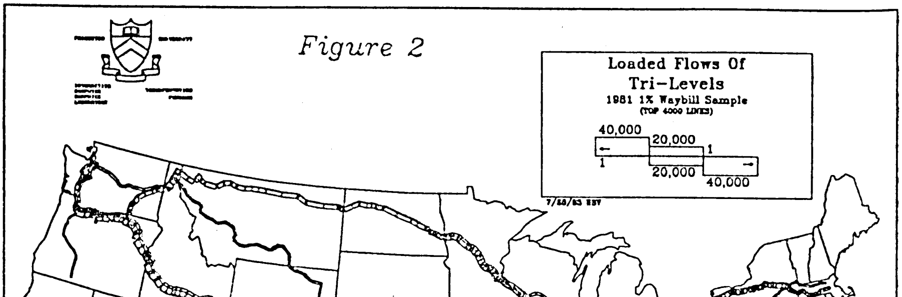


Figure 2
Loaded Flows Of
Tri-Levels
1981 1% Waybill Sample
(TOP 4000 LINES)
40,000
20,000
1
1
20,000
40,000

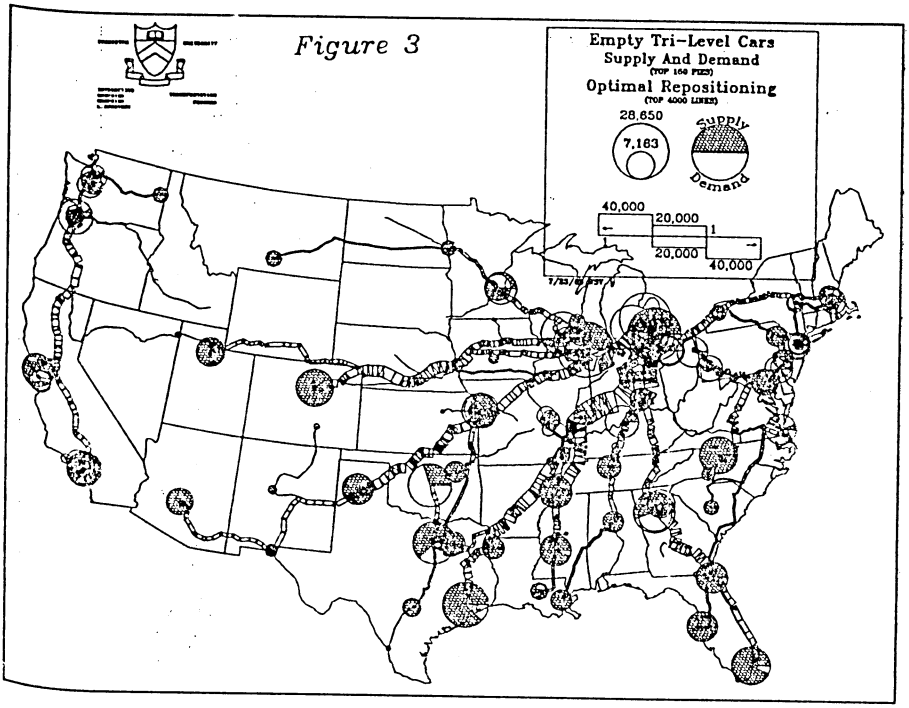


Figure 3

empty movement of these cars in 1981. The simulated actual empty flows are shown in Figure 4. The corresponding optimal empty flows are shown at the same scale in Figure 5. The difference is stunning. Note the propensity of two-way (simulated) flow especially on the Union Pacific. Also the simulated actual flow of empties through Arizona and New Mexico is Eastbound on the Santa Fe and Westbound on Southern Pacific. Similarly in the east near Lake Erie, the flow is eastbound on Canadian National and westbound on Conrail. Optimal car management focused on minimizing carmiles can neutralize these flows.

On a nationwide basis, Table 3 compares the optimal empty to loaded ratios (E/L) with the E/L ratios, as obtained from OS-A statistics. Notice that only 52′ Gondolas cartype (used mostly in coal unit train service) has an optimal E/L that is only slightly lower than the actual E/L.

FUEL OPERATING COST SAVING POTENTIAL

Table 4 takes the results of Table 3 and computes the difference in car miles and estimates the fuel conservation and operating cost implications of the optimal nationwide car management strategy for each car type studied. Note that the largest car mile and fuel saving can be gained from covered hoppers. Almost 1.5 billion carmiles can be saved on this cartype alone. At .075 gallons per carmile, a rough estimate of fuel consumption suggested by Don Wooden [6], over 100 million gallons could be saved annually. At a $ .35 average operating cost per empty car mile, this represents a potential operating cost saving of $500 million per year! After covered hoppers comes 50-foot unequipped boxcars in the hierarchy of potential fuel savers. About 800 million empty carmiles could be saved yielding slightly over sixty (60) million gallons of fuel per year.

In total for the six car types studied, over 3 billion carmiles could be saved yielding a savings of 250 million gallons of fuel per year. This is not a small amount. Using $ .35 per empty car mile as variable operating costs, then this analysis suggests that current car utilization practices incur roughly $1 billion in excess costs for only the six car types studied herein.

It must be emphasized that several simplifications were made for purposes of the analysis. These simplifications

Figure 4

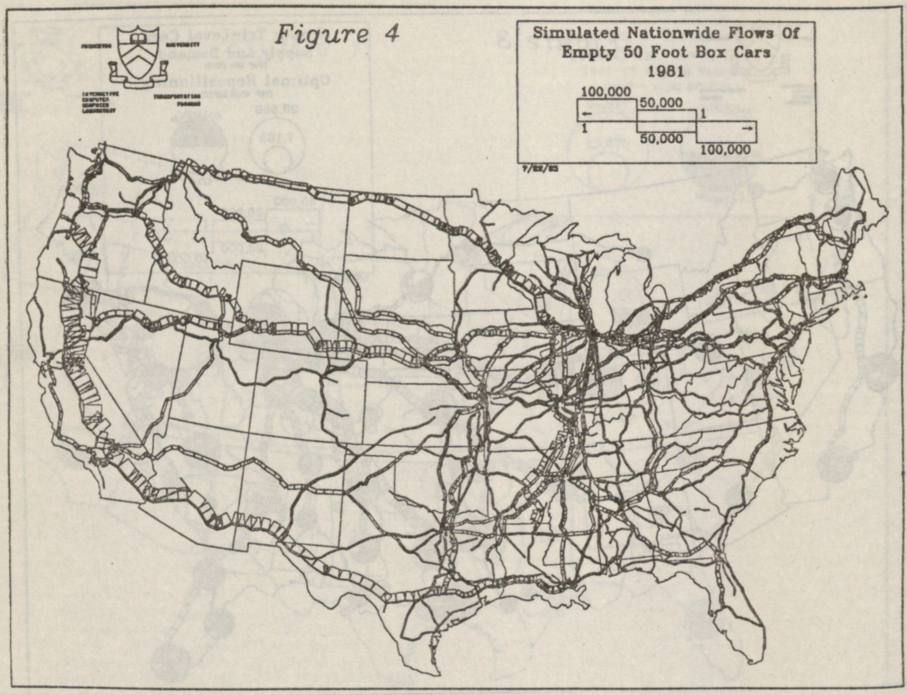


Figure 5

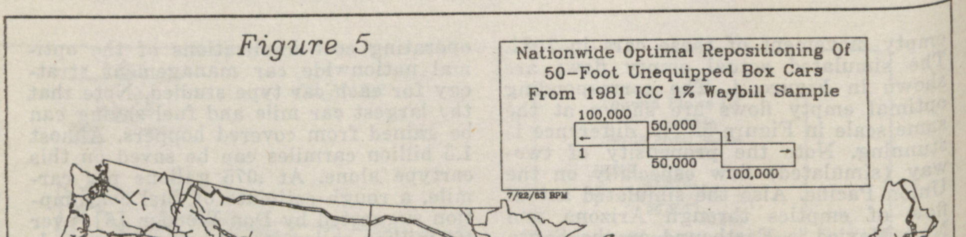


TABLE 3

1981 COMPARISON OF E/L RATIO FOR VARIOUS CAR TYPES

Car Type	Optimal E/L	Actual E/L
50′ Unequipped Box Car	0.214	0.769
52′ Gondolas	0.901	0.906
Refrigerated Box Car	0.399	0.842
Covered Hoppers	0.451	1.107
Unequipped Hoppers	0.663	0.919
Tri-Levels	0.408	0.916

TABLE 4

POTENTIAL BENEFITS OF NATIONWIDE CENTRALIZED FREIGHT CAR MANAGEMENT (Based on 1981 Demand Data For Several Car Types) (IN MILLIONS OF CAR MILES)

Car Type	Millions of Optimal Empty (1)	Car Miles Actual Empty (2)	Empty Car Mile Diff. (2) - (1)	Potential Fuel Saving (Million Gal./Yr.) .075 g/ Car Mile	Potential Operating Cost Saving $0.35/ Car Mile (Millions of Dollars)
50′ Unequipped Box Car	328	1,202	874	66	306
50′ Gondolas	128	175	47	4	16
Refrigerated Box Car	357	738	381	29	133
Covered Hoppers	1,080	2,172	1,092	82	382
Open-Top Hoppers	1,274	1,905	631	47	220
Tri-Levels	198	445	247	19	86
TOTAL	3,365	6,637	3,272	247	1,143

APPENDIX A

This oppendix presents figures depicting 2-digit SPLC aggregated supply demand patterns and optimal (min weighted distance) depositioning flows for various car types.

tend to over-estimate the potential savings. The primary assumptions were steady state supply and demand perfect information, and the substitutability of equipment within each car type. The steady state assumptions are only valid if there exists enough of an inventory of equipment so that fluctuations in supply and demand can be "evened out." The current glut in equipment suggests that the steady state assumption is quite justifiable. The improvement in railroad information systems also suggests that accurate real time supply demand data is almost a reality. The substitutability assumption may be the most serious. Certainly a tank car is not a tank car . . . etc. The implication may be that more car cleaning facilities (which would incur new costs) are needed. With boxcars shippers may need to be induced to use "off-spec." equipment through reduced rates, thus reducing revenues.

Nonetheless, the potential savings are staggering and much more research focused on the practicality of the implementation of nationwide car management strategies should be undertaken.

CONCLUSION

The paper has presented an analysis of the theoretical opportunities for fuel savings from a nationwide centralized freight car management strategy which focuses on minimizing empty carmiles and thus fuel and operating costs. The analysis focuses on six different car types. It analyzed these on a national basis rather than a corporate basis. The analysis can be restricted to a corporate basis and can be done for other car types.

For these car types it was found that significant empty car mile saving opportunities are theoretically available, especially for covered hoppers, boxcars and tri-level auto carriers. In total, a theoretical annual savings of 250 million gallons of fuel and over $1 billion in operating costs are identified.

The analysis did make several assumptions which can limit the extent to which these savings can be achieved. These include the disregard of temporal variations, the perfect substitution of cars within a car type and the nationwide car management and optimization perspective. These assumptions were necessary to allow the undertaking of a general analysis. However, the savings are of such a large magnitude that further analyses oriented toward implementation of more centralized car management strategies should be undertaken.

REFERENCES

1. Interstate Commerce Commission, *Exemption From Regulation-Boxcar Traffic, Ex Parte No. 346 (Sub. No. 8)*, Reply Comments of Consolidated Rail Corp. Verified Statement by Professor Alain L. Kornhauser, April 30, 1982.

2. Mulvey, J. M., "Pivot Strategies for Primal-Simplex Network Codes," *Journal of the Association for Computing Machinery,* Vol. 25, No. 2, April 1978, pp. 266-270.

3. Kornhauser, A. L., "Railroad Traffic Analysis Using Interactive Computer Graphics: An Update," presented at 1981 National Computer Graphics Conference, Baltimore, Md., June 1981.

4. Antush, R., "Enhanced One-Percent Waybill Sample," ALK Associates, Inc. Report 81-3, Princeton, N.J., November 1981.

5. Kornhauser, A. L. and Markowicz, B. P., "Car Management Opportunities: Actual Return Mileage vs. Optimal Return Mileage," presented at 1983 Transportation Research Board Meeting, Washington, D.C., January 1983.

6. Wooden, D., Remarks made at "Railroad Energy Technology Conference," November 30, December 1, 2, 1982, Memphis, TN.

FOOTNOTES

1 ALKFLOW is an efficient traffic assignment algorithm of PRNM/GIS

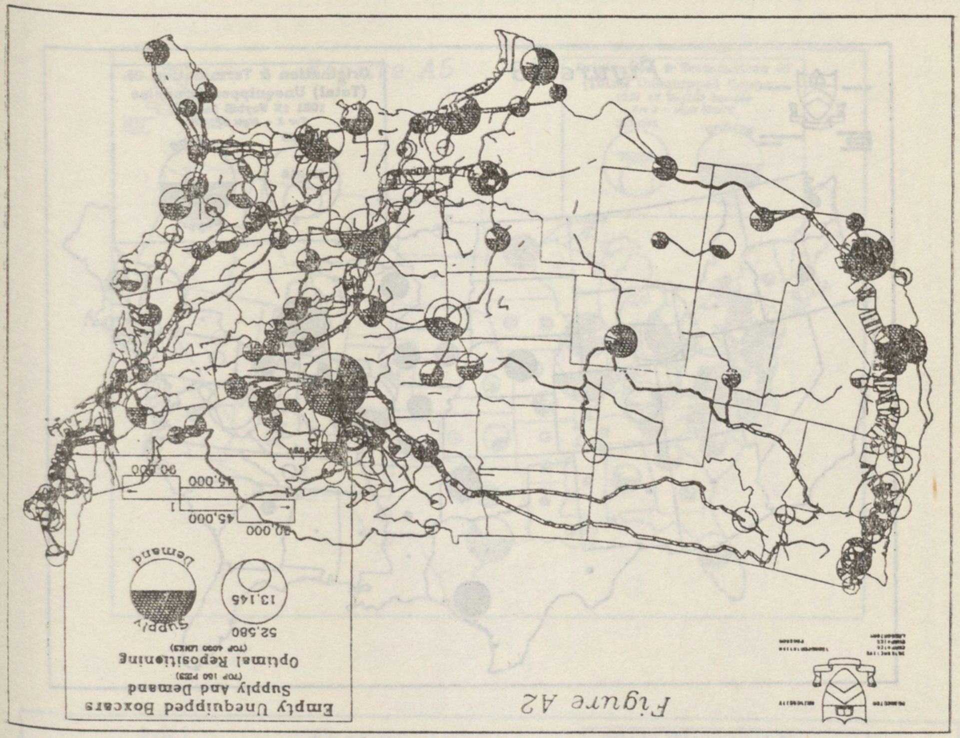


Figure A2

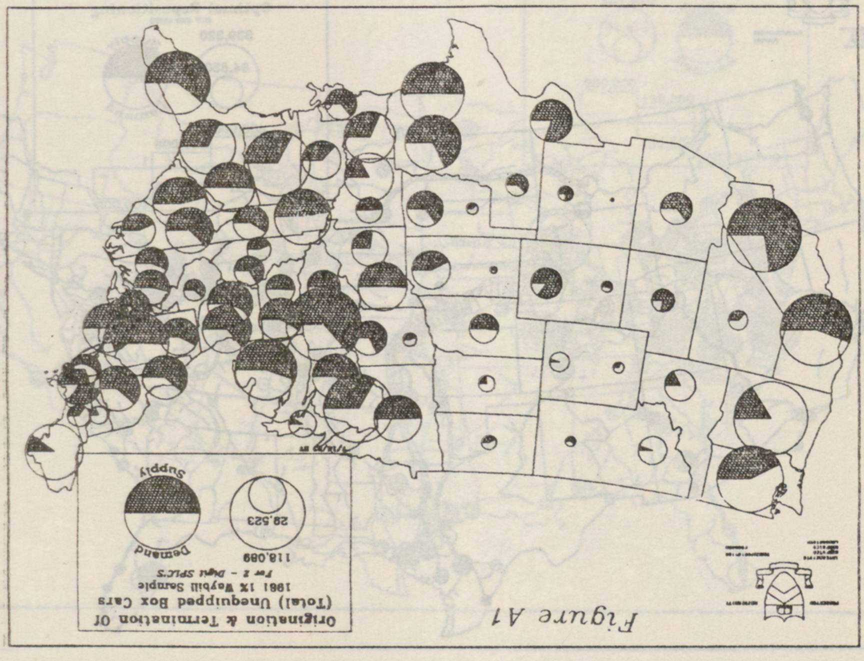


Figure A1

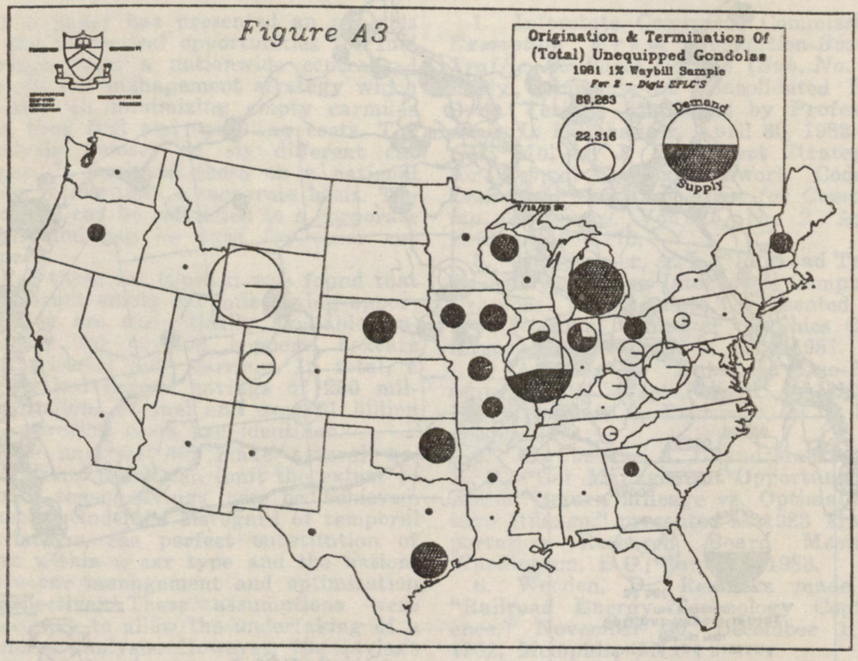


Figure A3

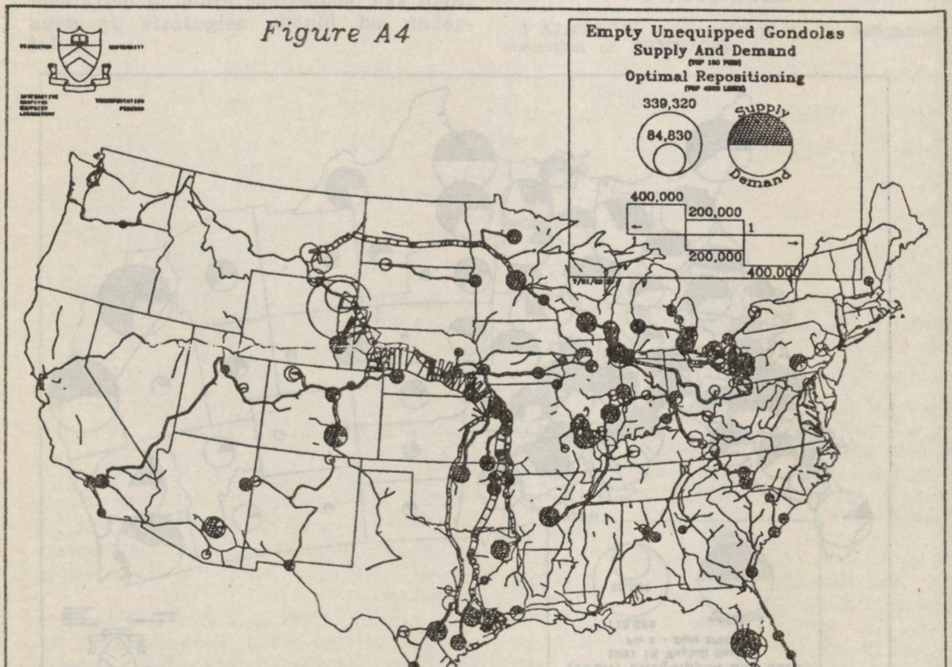


Figure A4

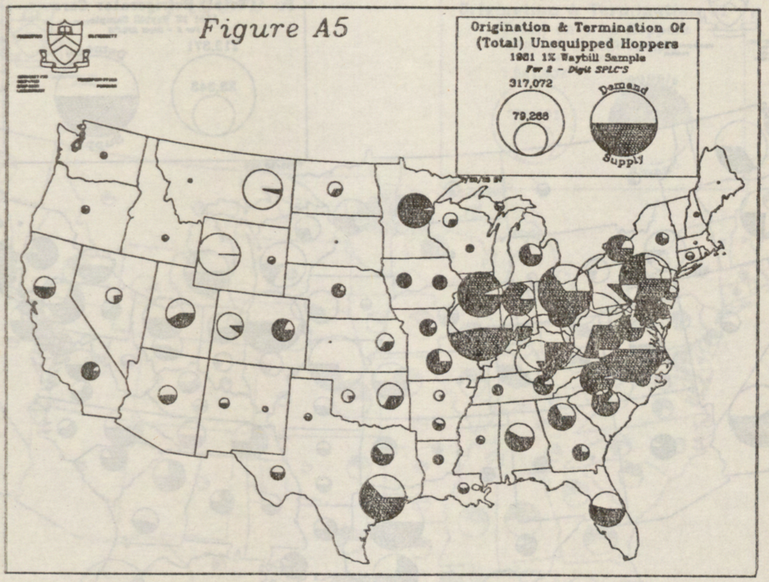


Figure A5

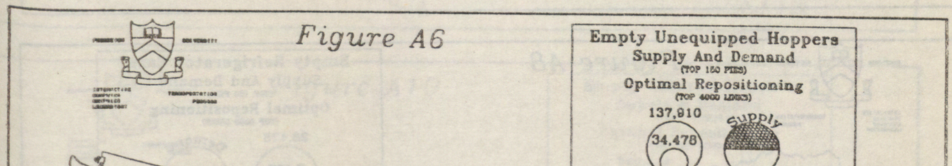


Figure A6

Figure A7

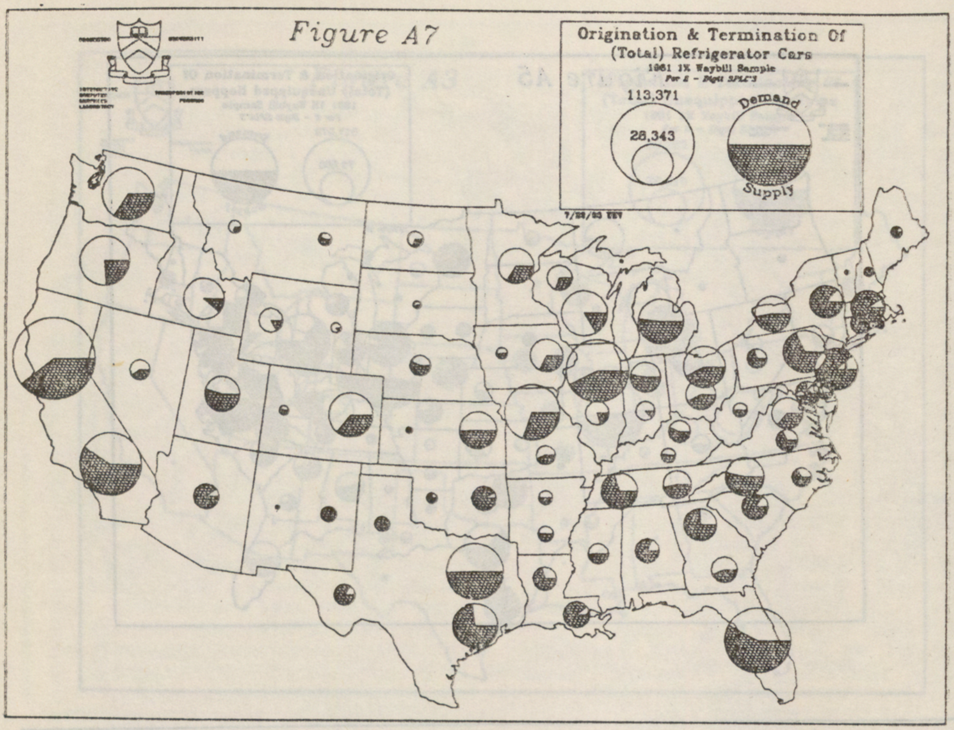
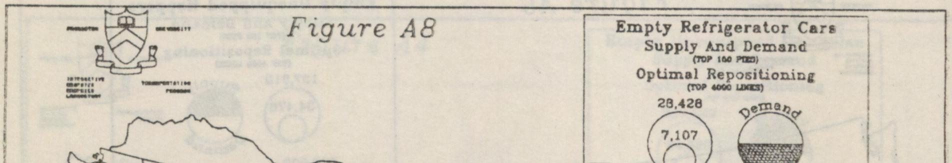


Figure A8



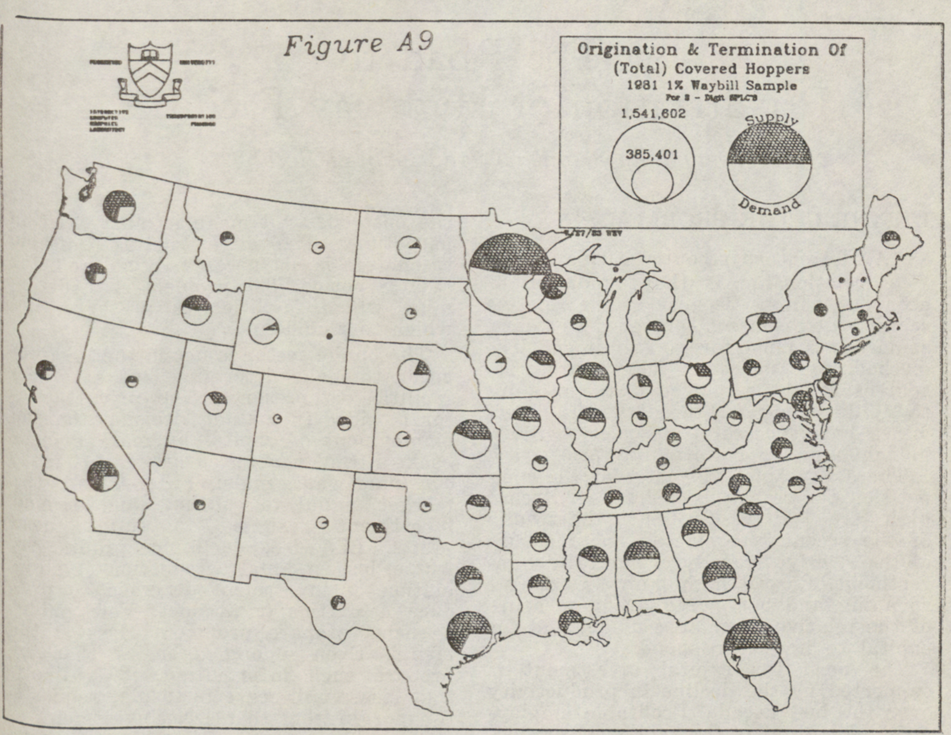


Figure A9
Origination & Termination Of
(Total) Covered Hoppers
1981 1% Waybill Sample
1,541,602
385,401
Supply
Demand

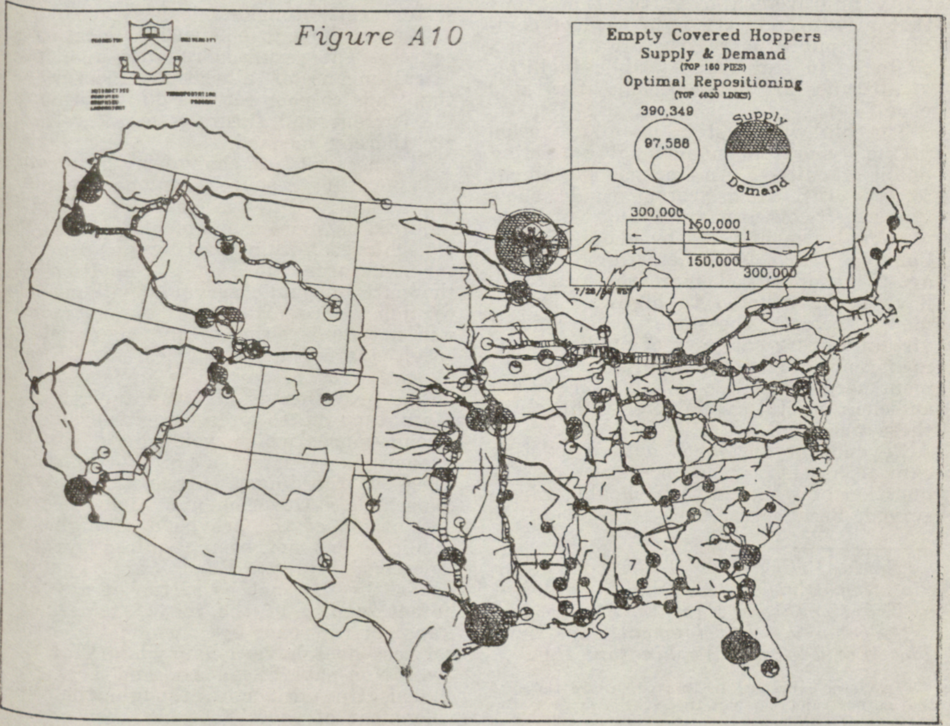


Figure A10
Empty Covered Hoppers
Supply & Demand
Optimal Repositioning
390,349
97,586
Supply
Demand
300,000
150,000
1
150,000
300,000