Potential for Nationwide Pooling of Various Types of Railroad Cars

ALAIN L. KORNHAUSER AND YEN-SHWIN SHAN

All opportunities for triangularizing loaded-car movements in order to minimize empty-car miles are investigated. The minimum empty-car-mile repositioning requirements of various railroad car types are presented from the perspective of the entire United States, regardless of car ownership. The optimization algorithm (a car-mile minimization transshipment over the U.S. railway system) ensured that supply and demand for specific types of cars were satisfied. This analysis simulates an efficient utilization of a nationwide pool of each type of car. Supply-and-demand data were obtained from the 1980 1 percent waybill sample. Data on loaded-car miles (L), minimum empty-car miles (E), and E/L ratios are given. Also presented are computer-graphic renderings of the nationwide distribution of the supply and demand for each type of car and directionally specific actual loaded and simulated optimal empty-car flows. Cars analyzed were trilevel automobile carriers, 50-ft gondolas, refrigerated boxcars, open-top hoppers, open-top hoppers carrying coal, covered hoppers, and tanks carrying corn sweetener.

It is well recognized that a major opportunity for the U.S. railroad industry to increase productivity is through improved use of freight cars. Even though there currently exists a glut of equipment, significant operating-cost savings are thought to exist as a result of a better assignment of the supply of empty cars to the demand for loads so as to minimize the accumulation of empty-car miles. In a recent verified statement to the Interstate Commerce Commission (ICC), Kornhauser estimated that in 1980 there existed as much as a billion excess empty-car miles in 50-ft unequipped boxcars (ICC Ex Parte 346, Sub No. 8, April 30, 1982). At what is considered a low marginal cost of $0.30/car mile, this represented a net loss of $300 million to the railroad industry for this car type alone.

Excess empty-car miles are fundamentally unproductive. This is not even a good way to increase the ambient air temperature. But there are many good reasons why empty-car miles are accumulated over the U.S. railway system. One is that car owners want to load or have shippers on their railroad load their own cars because their own cars better meet shipper needs: They have the correct doors, are properly equipped, do not need to be cleaned, and so on. Second, the nature of the business is that raw materials are produced at one location and consumed at another; little material goes back. This skewness in supply and demand is considered to be the root cause of empty-car movements. What could possibly be backhauled in open-top hoppers that carried coal from West Virginia to Norfolk, Virginia? Qualitatively it is clear, but quantitatively the following fundamental question remains: What are the minimum empty-car miles that can be achieved given the current loaded-car movement patterns for various car types? The answer to this question is important in order to identify any missed opportunities that can reduce empty-car miles, and thus cost, that are imbedded in current empty-car management practices. In areas where significant deficiencies are identified, the minimum empty-car-mile solution can suggest where attention should be focused.

In this paper a solution to the minimum empty-car-mile problem is described, the results of applying the procedure to several car types are presented, and the implications of the analysis are discussed. The procedure, MTOPT, is based on the analytical capabilities of the Princeton Railroad Network Model (PRNM) and the 1980 1 percent waybill sample.

PROBLEM FORMULATION

The fundamental question is how big the productivity opportunities are that are associated with a car management philosophy that focuses heavily on the minimization of empty-car miles.

To answer this question, one needs to know the value of some idealistic, optimum empty-car-mile measure and compare it with actual empty-car-movement statistics. If little difference exists between the optimum and the actual figures, then no further investigation is necessary. If a significant difference exists, however, then further investigation is warranted.

One means of obtaining the idealistic optimum value is to pose the following problem:

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 type-k cars demanded at location i around the nation, i = 1,...,n; n is the number of specific locations on the U.S. railway system where traffic is assumed to originate or terminate (there are 17,000 nodes in the U.S. portion of the PRNM); D_j^k is the demand, i.e., number of type-k cars needed to load at location j around the country; and N_{mn} is the network geometry of the U.S. railway system, including distance (DIS_{mn}) and line code (LC_{mn}), and m and n are the end nodes of each segment of the U.S. railway network.

Find the empty-car volumes for each network link (V_{mn}) such that the supply satisfies the demand over the network and the summed and weighted carload distances:

$$\sum_{mn} DIS_{mn} \times LC_{mn} \times V_{mn} \text{ is minimized}$$

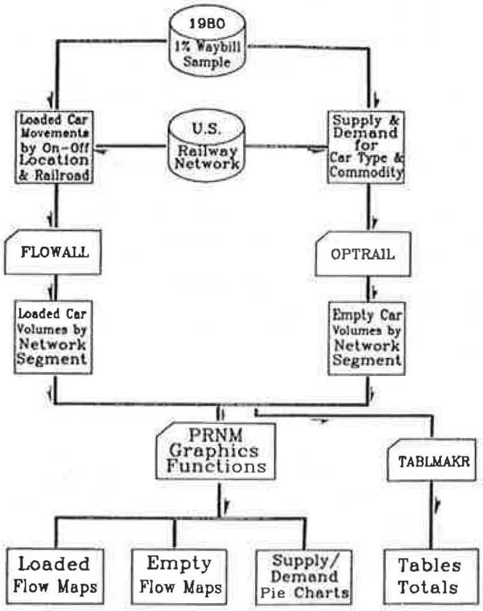
where V_{mn} is the volume of empty cars traveling from location m to n.

The above problem is a classical transshipment-type linear programming problem. Supply data (S_i^k), demand data (D_j^k), and network data (DIS_{mn} and LC_{mn}) are given. The objective is to minimize a weighted car-mile objective that tends to route cars on segments that have a smaller value of LC_{mn} (main lines) than those with a higher value (branch lines). This weighted minimization is necessary in order to add realism to the solution, because railroads tend to move empty cars on main lines rather than on branch lines.

Many solution procedures exist to the transshipment problem. One developed by Mulvey (1) and called LPNET is particularly efficient and is structured to handle networks with a large number of nodes and links, which is a necessity because the U.S. railway system as defined in PRNM (2) consists of 17,000 nodes and 18,000 links. PRNM uses LPNET to solve the transshipment problem in the empty-car-mile minimization program called MTOPT.

MTOPT structures the supply-and-demand data from the traffic source, e.g., 1 percent waybill data (3); forms the transshipment network; solves the

Figure 1. Computational procedures of MTOPT.



transshipment problem (LPNET); and produces directional volumes of optimal empty-car movements. The empty-car movements are plotted by using the graphic functions of PRNM (see Figure 1). MTOPT also extracts the loaded-car movements, plots the flow on the U.S. railway system by using ALKFLOW (efficient traffic-assignment algorithm of PRNM), and displays the loaded-car flow by using the same graphic utilities that display the empty-car flow. Summary statistics of loaded- and empty-car miles and ratios are also computed.

QUANTITATIVE FINDINGS

The MTOPT program was executed on seven specific combinations of car type and commodity [Standard Transportation Commodity Code (STCC)]:

Car Type	AAR Car-Type No.
Trilevel automobile carrier	V4, V6, V8
Gondola, 50-ft	G2
Open-top hopper	H3
Open-top hopper carrying coal	H3 (STCC = 11)
Covered hopper car	L 53, L 54
Refrigerated boxcar	R
Tank car carrying corn sweetener	T (STCC = 2046)

The supply of (termination of loaded movement) and demand for (origination of loaded movement) empty equipment for each car type were obtained from the 1980 enhanced 1 percent waybill sample (3). These traffic data are convenient because the sample is of reasonable size; they are coded with the PRNM network node numbers for originations, interline junctions, and terminations; and the sample has been annualized based on 1980 Freight Commodity Statistics (FCS).

Loaded-car miles and optimum empty-car miles were computed by using the MTOPT procedure described in Figure 1. The summary quantitative findings are given in Table 1. Note that the optimum empty/loaded (E/L_{opt}) ratio was found to be highest for 50-ft gondolas (0.904) and lowest for trilevels (0.314). Somewhat surprisingly, open-top hoppers carrying coal have some significant triangularization potential; the E/L_{opt} is 0.793, which annually could save as much as 120 million empty-car miles. Removing the commodity restriction from open-top hoppers suggests that E/L_{opt} could be as low as 0.697. Even tank cars carrying corn sweetener have some triangularization potential; E/L_{opt} is 0.759. Covered hopper cars and refrigerated cars gain the most in terms of optimum empty-car miles relative to loaded-car miles; for covered hopper cars, E/L_{opt} is 0.496, which yields 1.2 billion less empty miles than loaded miles, and for refrigerated cars, E/L_{opt} is 0.326, which yields 700,000 fewer empty miles than loaded miles.

Table 1. Minimum empty-car miles and loaded-car miles for various car types.

Car Type	1980 Car Miles (000,000s) Loaded	Minimum Empty	E/L_{opt}
Trilevel	357	112	0.314
Gondola, 50-ft	105	95	0.904
Open-top hopper	876	570	0.697
Open-top hopper carrying coal	639	507	0.793
Covered hopper	2,434	1,207	0.496
Refrigerated boxcar	1,035	338	0.326
Tank car carrying corn sweetener	59	45	0.759

DETAILED FINDINGS

Each of the combinations of car type and commodity is described further in this section. For each, the following data are given:

1. Pie charts show the volume of cars originated and terminated by location at the major origins and destinations in the United States. The pie charts have been drawn so as to be centered on the location and with an area proportional to the sum of originations plus terminations of that car type. Slices delineate the originations from the terminations.
2. Loaded-flow volumes show the directionally specific volume of loaded-car movements over the most densely traveled segments of the U.S. railway system (not all segments are shown, to avoid cluttering the maps). The flow volumes are depicted by using a right-hand rule: The height of the bar chart perpendicular and to the right of a line segment is proportional to the volume of flow in the facing direction.
3. Minimum empty-car-mile flow charts can be used to compare with the loaded volumes. These maps also have net supply minus demand superimposed. These graphs clearly show the flow of empty cars from points of net supply to points of net demand. Note that the nature of the optimal solution is such that empty cars flow in at most one direction on any track segment.

Specific findings by car type are as follows.

Trilevel Cars

Figure 2 shows the nationwide distribution of the supply and demand of trilevel equipment. Some locations such as Dallas, Los Angeles, Atlanta, and Kansas City are fairly balanced in their supply and demand. Major net supply points are Denver, Phoenix, Salt Lake City, Florida, Mississippi, Tennessee, Alabama, and North Carolina. A major net demand area is Michigan.

Figure 3 shows the loaded flow of trilevel cars. Note the westbound imbalances on the Atchison, Topeka, and Santa Fe (ATSF); Union Pacific (UP) to Ogden; and Southern Pacific (SP) on the central corridor and the eastbound imbalances on the Burlington Northern (BN), UP from Oregon to Ogden, and the old New York Central of Consolidated Rail Corporation (Conrail); the flow is exclusively southbound on the Family Lines, Florida East Coast Railway Company (FEC), and Cotton Belt Route (SSW).

Figure 2. Gross supply and demand of empty trilevel cars.

Figure 3. Loaded flow of trilevel cars.

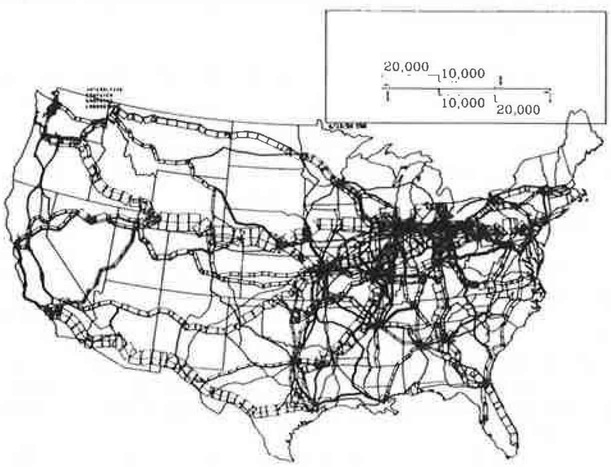


Figure 4. Net supply and demand of empty trilevel cars.

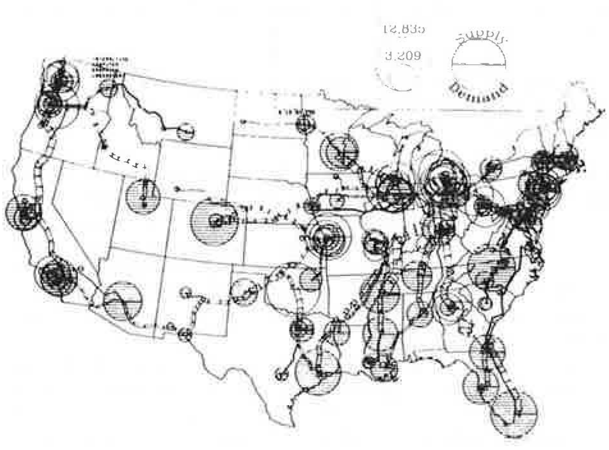


Figure 4 shows the optimum empty-car flow on the same scale as that in Figure 3. Note the stunning difference in the traffic flow densities. Because the total car miles in each chart is simply the summed area of all of the flow boxes, one immediately sees that the empty-car miles are much less than the loaded-car miles. In fact, almost no trilevels need to be shuttled empty across the Rockies. Empty trilevels need to be reallocated along the West Coast; from Houston to Oklahoma City; from Miami through Jacksonville, Atlanta, and Cincinnati to Detroit; from Mississippi and Memphis to Detroit; and from North Carolina through Virginia to western Pennsylvania. Other major empty flows are southward from Albany to northern New Jersey; eastward from Denver through Chicago to Detroit; and from Minneapolis to Milwaukee.

Gondolas

Figure 5 shows the supply-and-demand aspects of 50-ft gondolas. These cars exhibit a different spatial distribution of supply and demand from that of trilevels. There are a few major generation points and many minor ones. No region both originates and terminates this equipment. Major originations are in the coal areas of Wyoming and Colorado and steel-producing areas of western Pennsylvania. Consumption seems to be at major inland waterway

Figure 5. Gross supply and demand of empty 50-ft gondolas.

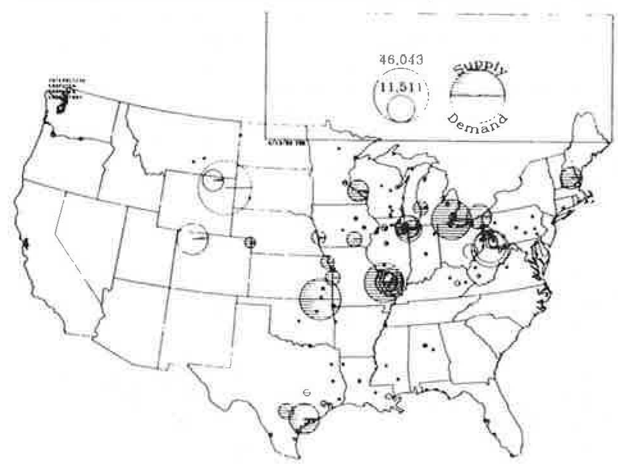
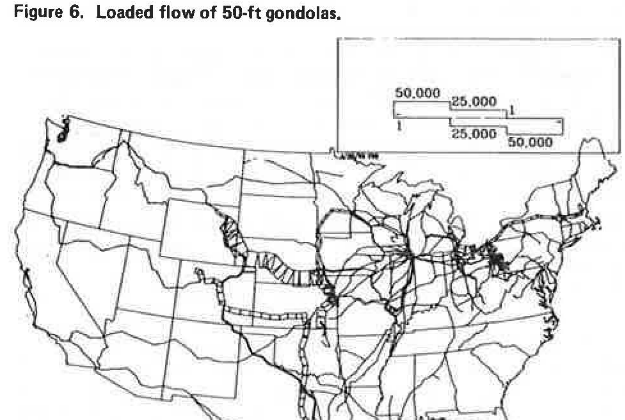


Figure 6. Loaded flow of 50-ft gondolas.



locations along the Missouri and Mississippi Rivers, the Gulf Coast, and the Great Lakes.

Figure 6 shows the loaded flow, which is primarily one-directional. It is not surprising that the E/L_{opt} for this car type is close to 1.0 (0.904).

Figure 7. Net supply and demand of empty-50-ft gondolas.

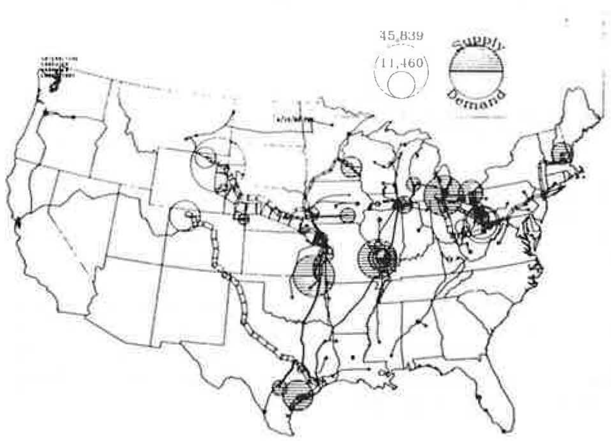


Figure 7 shows the optimal empty flow. This is the exact reverse of the loaded flow except that the empty cars are routed on the most direct service route (minimum impedance = DIS x MLC) to the demand point irrespective of rail ownership. The effect of the disregard of railroad ownership is discussed in the next section.

Open-Top Hoppers

Open-top hopper cars carry primarily coal; however, they also transport other bulk commodities such as sand and crushed stone. The nationwide distribution of the supply and demand for empty open-top hoppers is shown in Figure 8. The supply and demand for the hoppers used to move coal is easily recognized in Wyoming, Utah, Colorado, and the East. The Florida supply and demand is an example of sand and gravel movements.

Figure 9 shows the flow volume of loaded open-top hoppers. Note the propensity of one-way flows from the mining areas in Montana, Wyoming, and West Virginia to the unloading points of Minneapolis, Norfolk, and Toledo. Note also the one-way flow northbound on FEC.

The one-way loaded flow suggests that little triangularization may be available except in areas of Texas and Pennsylvania. Computation of the minimum empty-car-mile strategy did uncover some signif-

Figure 8. Gross supply and demand of empty open-hopper cars.

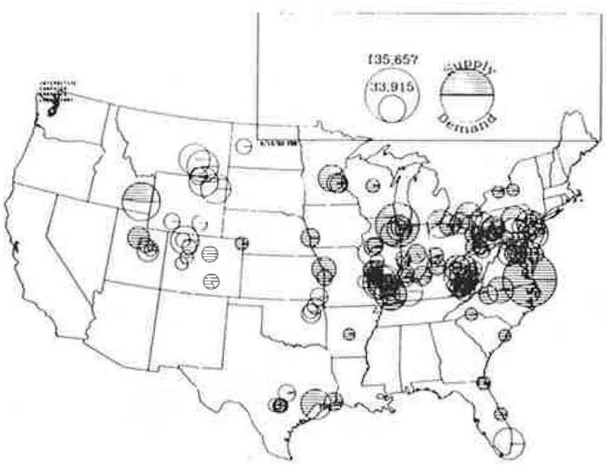


Figure 9. Loaded flow of open-hopper cars.

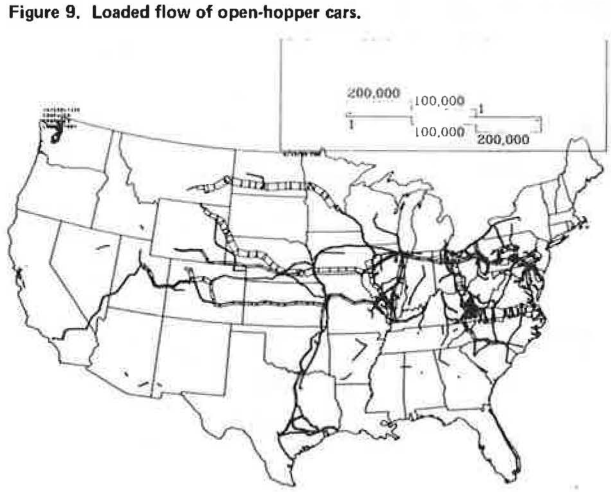


Figure 10. Optimal repositioning of empty open-hopper cars.

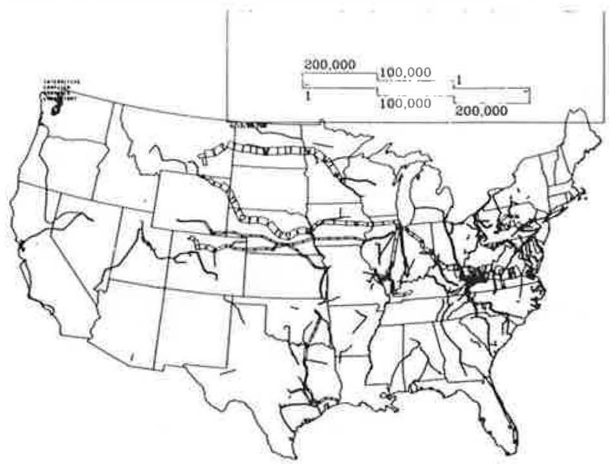
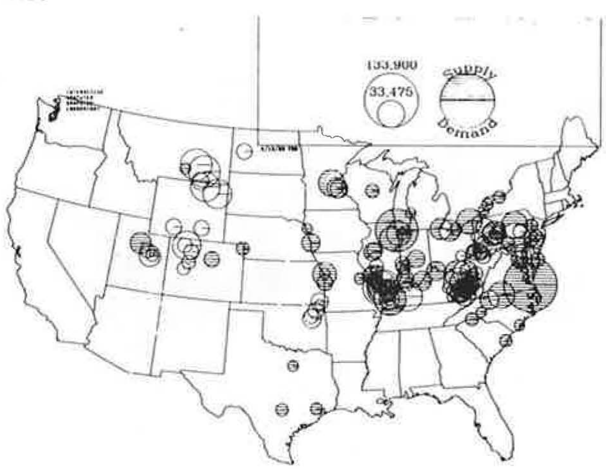


Figure 11. Gross supply and demand of empty open-hopper cars that carried coal.



icant reductions in car miles relative to the loaded-car miles. An E/L_{opt} of 0.697, which yielded 250 million less empty-car miles than loaded-car miles, resulted. Figure 10 shows the optimal empty-car flow. Note that no savings were found in Florida, West Virginia to Norfolk, or out of Wyoming and Montana. Significant opportunities exist, however, in Illinois, Indiana, Ohio, and Pennsylvania as well as in Texas and Colorado.

It is recognized that to achieve such savings would require extreme cooperation among competing railroads; however, the magnitude of the benefits that appear to exist may make desirable such cooperative undertakings.

Open-Top Hoppers Carrying Coal

A criticism of the previous section may be that the analysis failed to realize that hopper cars that carry coal are fundamentally different from those used to carry other bulk commodities. For this reason, traffic flow of open-top hoppers carrying coal was analyzed. Figure 11 shows the supply and demand for this case. Note that it is similar to the previous case except for the Florida traffic and some other minor changes. The loaded-car flow of Figure 12 is similar to that of Figure 9.

Given the restrictions on commodities, one would expect fewer opportunities to triangularize loaded movements. This was found to be the case. The E/L_{opt} increased 10 percentage points to 0.793. Figure 13 shows the optimal empty-car flow. This suggests that restricting open-top hoppers to coal traffic significantly reduces the opportunity to save empty-car miles. If the commodity restriction is more beneficial than the potential savings, then so be it; however, one can now quantify the opportunities and evaluate the trade-offs.

Covered Hoppers

The nationwide distribution of the supply and demand for covered hoppers is shown in Figure 14. This distribution is significantly different from that of the other car types in that there exist a few large supply points (Superior/Duluth, Houston, and Tampa) but many nearly equal medium-sized supply-and-demand points (Figure 14 shows only the largest 150 supply-and-demand points so as not to overly clutter the diagram).

Figure 15 shows the 2,500 segments with the highest loaded covered-hopper volume of the U.S. railway system. Note the uniformity of flow as well as the balanced two-way flow on many segments, particularly on UP's central corridor.

Figure 12. Loaded flow of open-hopper cars carrying coal.

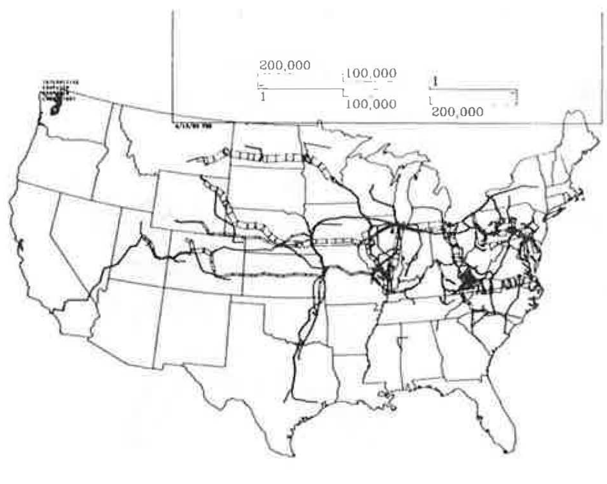


Figure 13. Net supply and demand of empty open-hopper cars that carried coal.

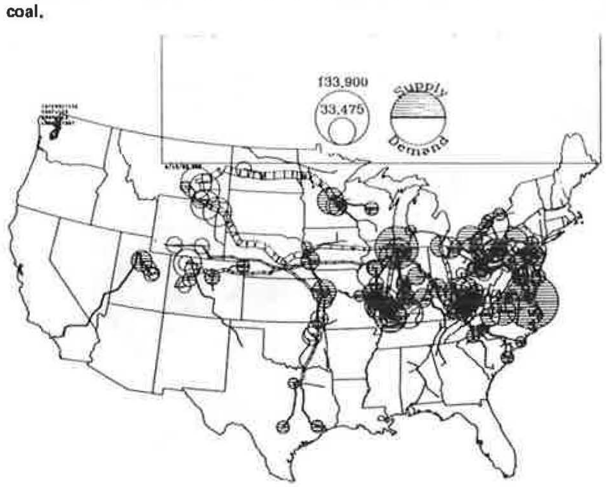


Figure 14. Gross supply and demand of empty covered-hopper cars.

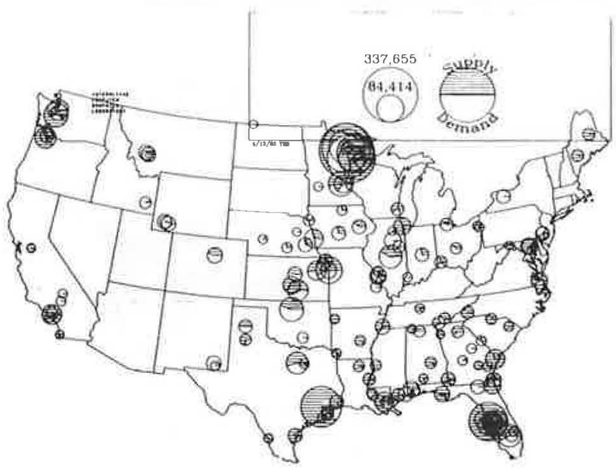
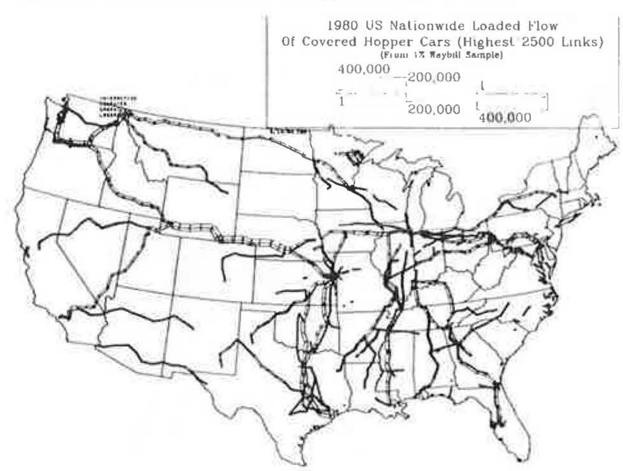


Figure 15. Loaded flow of covered-hopper cars.



The loaded flow of Figure 15 suggests the great opportunity for backhaul loading of covered hoppers. Optimal repositioning of the supply of empty cars to loaded cars led to an E/L_{opt} of 0.496, which suggested the movement of two loaded cars for each empty one. The empty-car flow is shown in Figure 16, which exhibits the following interesting aspects: (a) no empty covered-hopper movements on UP's central corridor, ATSF, or SP; (b) few westbound movements on BN; (c) significant westbound repositioning from eastern points of Conrail to Chicago and high volumes northbound out of Houston and New Orleans to the grain areas of Iowa and Nebraska; and (d) self-sufficiency of the Superior/Duluth and Tampa markets.

Refrigerated Cars

In Figure 17 the nationwide supply-and-demand distribution of refrigerated boxcars is shown. The distributions follow that of perishable commodities, as expected.

The loaded flow of refrigerated cars (Figure 18) shows good directional balance on the ATSF, SP, and parts of UP and Seaboard Coast Line; strong eastward imbalance exists on Conrail.

The loaded flow suggests good reload opportunities, which do in fact exist. The optimum repositioning of empties suggests an E/L_{opt} of 0.326--three loads for every empty movement. The empty flow, shown in Figure 19, is much smaller than the loaded flow. A predominantly transcontinental westward repositioning is shown. Although some cars are repositioned empty coast to coast, many more are reloaded nearby.

Tank Cars Carrying Corn Sweetener

In order to study an example of a specific combination of car type and commodity, tank cars carrying corn sweetener were chosen. It was thought that such specificity would eliminate all opportunity for reload. The supply and demand for this case are shown in Figure 20. Although the demand for such cars seems to be centered in Illinois, the supply is well distributed nationally.

The loaded flow, primarily Coastbound from Illinois, is shown in Figure 21. The computation of the optimum repositioning gave an E/L_{opt} of 0.759--three empty movements for every four loads. Surprisingly, there are some opportunities for reload short of return to shipper. As can be seen from the optimum empty-car flows in Figure 22, some of the empty-car miles are saved because of a more direct return of empty cars to the loading point as

Figure 16. Optimal repositioning of empty covered-hopper cars.

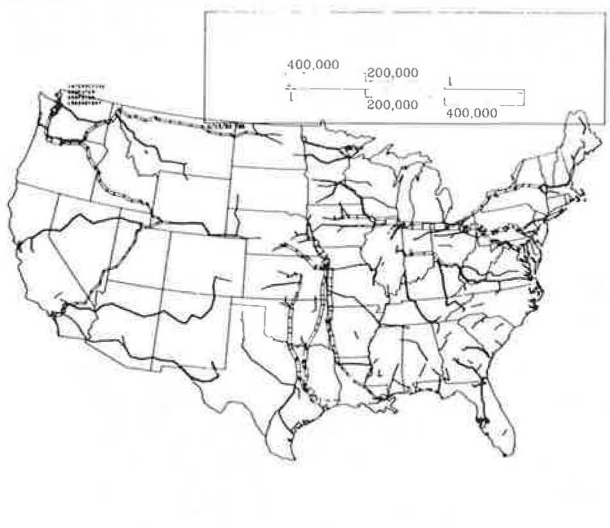


Figure 17. Gross supply and demand of empty refrigerated cars.

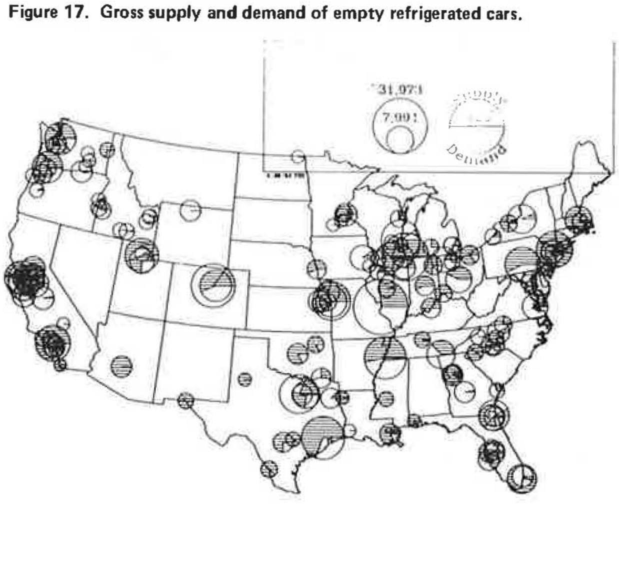


Figure 18. Loaded flow of refrigerated cars.

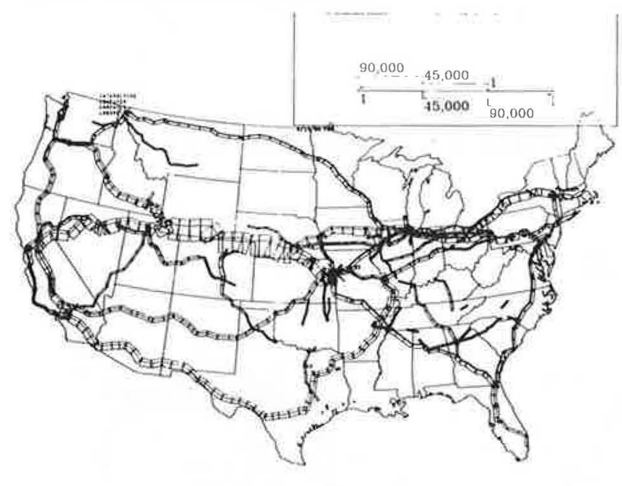
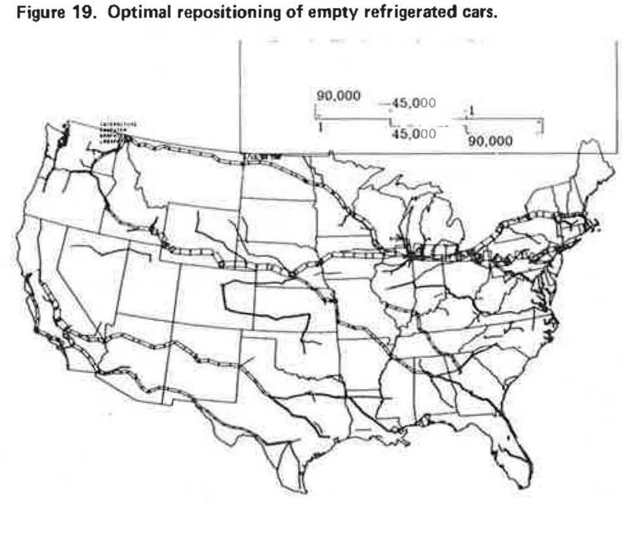


Figure 19. Optimal repositioning of empty refrigerated cars.



compared with their route when loaded. This difficulty is analyzed in the following section.

IMPACT OF NON-RAILROAD-SPECIFIC EMPTY RETURN

The algorithm that computed the minimum empty-car miles did so over a network representation of the U.S. railway system in which the distance and quality of service on each segment were considered but no attempt to enforce continuity of ownership was made. The optimization objective was a service-weighted distance minimization. Thus empty cars were repositioned over the shortest, best-served routes, and branch and corridor lines of the National Railroad Passenger Corporation (Amtrak), which may have been shorter, were generally circumvented. Nevertheless, a loaded single-carrier movement may occasionally have the car returned to the shipper via an unrealistic multicarrier route. Inspection of the empty-car flow suggests that this is generally a minor problem, because main lines tend to run parallel or orthogonally rather than in a close-weaving pattern. The only area in which this is not true is corridors radiating in and out of Chicago. What the optimal empty flows do point out is that in some cases there exists a routing back to the shipper that is less circuitous than that of the loaded movement.

The circuity effect is estimated by generating routes on a unified rail network. These routes are computed from origin to destination independent of track ownership and historical interline locations. This computation, in which loaded service-route car miles were minimized, when compared with the actual loaded-car miles provides a measure of the service-route circuity of loaded-car movements. Table 2 summarizes the computation for each car type and commodity. Presented are actual loaded-car miles, service-route minimum loaded-car miles, service-route minimum empty-car miles, and optimum ratios of empty- to loaded-car miles (E/L_{opt}) based on each loaded-car-mile computation. Note that from Table 2 there is relatively little circuity introduced by the actual loaded route as compared with a service-route optimization. The difference ranges from 5 to 10 percent. The effect on E/L_{opt} is roughly five percentage points. This suggests that there is some

Figure 20. Gross supply and demand of empty tank cars that carried corn sweetener.

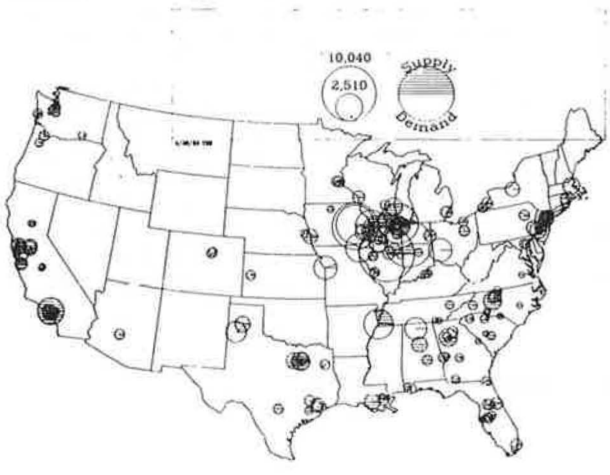


Figure 21. Loaded flow of tank cars carrying corn sweetener.

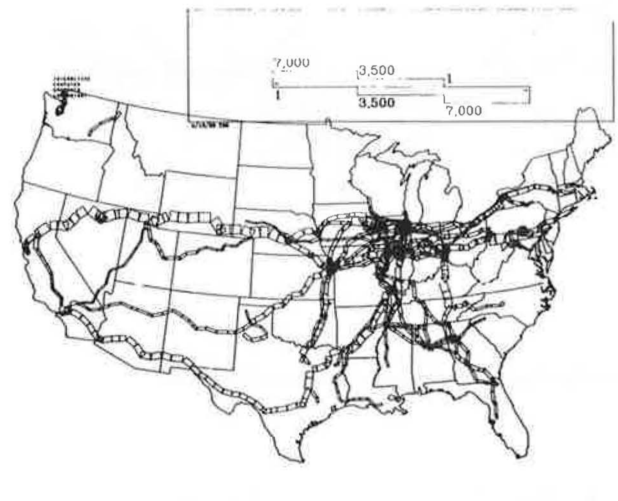


Figure 22. Optimal repositioning of empty tank cars that carried corn sweetener.

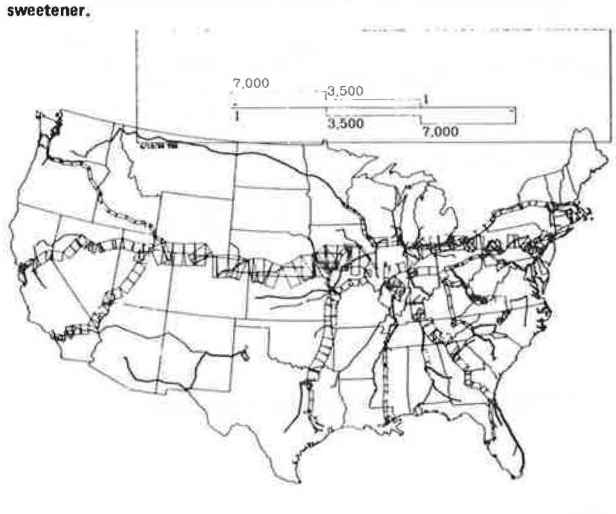


Table 2. Loaded- and empty-car miles by using service-route optimization.

	1980 Car Miles (000,000s)				
Car Type	Actual Loaded	Minimum Service-Route Loaded	Minimum Service-Route Empty	E/L^{a}_{opt}	E/L^{*b}
Trilevel	357	324	112	0.314	0.345
Gondola, 50-ft	105	100	95	0.904	0.954
Open-top hopper	816	753	570	0.697	0.756
Open-top hopper with coal	639	597	507	0.793	0.849
Covered hopper	2,434	2,231	1,207	0.496	0.541
Refrigerated boxcar	1,035	934	338	0.326	0.361
Tank cars with corn sweetener	59	52	45	0.759	0.853

[a]Column 3 divided by column 1. [b]Column 3 divided by column 2.

effect and opportunity associated with service-route minimization; however, the effect is small compared with the opportunities to minimize empty-car miles by repositioning cars so as to maximize reload opportunities.

CONCLUSION

A study has been presented of the loaded flow, empty-car supply and demand, and opportunities for car-mile minimization by empty-car repositioning for a variety of car type and commodity combinations. The analysis is entirely quantitative and suggests that although there is a sizeable skewness in the supply and demand for specific equipment types, the degree of skewness varies greatly. This suggests good opportunities for finding backhauls, thus reducing empty-car miles, which was unexpected for some equipment types. The analysis suffers only slightly from studying only spatial skewness without temporal effects. The temporal or seasonal effects can be minimized in a period of large surpluses in equipment by maintaining proper strategic inventories of the surplus cars so that temporal imbalances can be smoothed. Minimizing empty-car miles can add to the surplus, which should lead to further smoothing of any temporal imbalances.

Significant further research and analysis needs to be carried out. The optimal empty-car flow needs to be compared with the actual flow. The difficulty is that there exists no publicly accessible data source on empty-car movements. Nevertheless, railroad companies, shippers, and car owners do (or should) maintain proprietary data bases on these movements. Those companies that do have access to these data sources should utilize the MTOPT methodology to analyze opportunities for improved car management.

REFERENCES

1. J.M. Mulvey. Pivot Strategies for Primal-Simplex Network Codes. Journal of the Association for Computing Machinery, Vol. 25, No. 2, April 1978, pp. 266-270.
2. A.L. Kornhauser. Railroad Traffic Analysis Using Interactive Computer Graphics: An Update. Presented at 1981 National Computer Graphics Conference, Baltimore, MD, June 1981.
3. R. Antush. Enhanced One-Percent Waybill Sample. ALK Associates, Inc., Princeton, NJ, Rept. 81-3, Nov. 1981.

Publication of this paper sponsored by Committee on Railroad Operations Management.

Measuring the Quality of Freight Service: Analysis of Shipper Recording Practices with Emphasis on Railway Users

GARLAND CHOW AND RICHARD F. POIST

The purpose of the study was to determine the extent to which quality of freight service is measured and recorded by transportation buyers. To be specific, a mail questionnaire was sent to a sample of traffic managers to assess their recording behavior with respect to 22 quality-of-service attributes. Overall, the results indicate that although service measurement generally does take place, it tends to be accomplished on an informal basis rather than through formally recorded reports. Likewise the results indicate that recording practices do differ somewhat, depending on the degree of rail use by the shipper. Some managerial implications of these results for both buyers (i.e., shippers or users) and sellers (i.e., carriers) of freight service are presented.

In every industry, attention must be given to customer needs and preferences, or what is commonly referred to as the marketing concept (1, pp. 22-25). For the rail and trucking industries, this attention takes an increased significance as both industries move toward a more competitive environment spurred by regulatory relaxation and greater economic pressures.

The significance of researching the shipper's transport selection decision is great. In the long run, product and pricing strategy is based on knowledge of the mode and carrier characteristics rated highly by shippers. Over shorter time horizons, the carrier wants to identify shippers with similar needs or preferences. In this way sales resources can be allocated more efficiently and sales approaches or strategies can be planned more effectively.

Research regarding the transportation selection decision is important also to the buyer of transport services. The responsibility for so-called right and wrong transport selection decisions generally rests with the traffic manager, and the results of such decisions can mean the difference of hundreds of thousands of dollars to a company. Whatever traffic managers can do to make themselves better informed and educated consumers is obviously to their advantage.

Over the past decade, the transport selection decision has been the subject of numerous survey analyses. It is not our intention to review these surveys in detail, since this has been done previously (2, pp. 5-9). It is relevant, however, to note in passing that these studies vary in technique, objective, and, in many cases, conclusions (3-10). Generally, these studies are characterized as follows:

1. Some studies analyze the importance of various quality-of-service attributes or factors solely for the mode selection decision. Other studies analyze only the carrier selection decision. Others look solely at the private versus for-hire decision. Some studies analyze two or more of the