14. R.K. Abbott and others. Locomotive Data Acquisition Package, Phase 2, System Development--Volume 2: LDR Operations and Maintenance. Lawrence Berkeley Laboratory, Univ. of California, Berkeley, March 1980.
15. W.G. Ambrose, S.M. Kiger, and S.H. Patel. Enhancing Train Operations Through On-Board Processing: The Advanced Locomotive Cab Instrumentation System. Presented at AAR Track-Train Dynamics Conference, Chicago, IL, Nov. 27-29, 1979.

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

Car Management Opportunities: Actual Return Mileage Versus Optimal Return Mileage

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Recent developments in the research on car management currently undertaken by Princeton University under the sponsorship of the Association of American Railroads are described. The research makes extensive use of the Princeton Railroad Network Model and Information System. Car management opportunities are examined by comparing simulated actual empty return mileage (ARM) with optimal empty return mileage (ORM). ARM is the mileage obtained when empty cars that terminate on foreign roads are returned home under New Car Service Rule 2 (Rule 2) or Special Car Order 90 (SCO90) or both. ORM is the mileage obtained when empty cars that terminate on foreign roads are returned according to a cost (mileage-based) minimization criterion. The concept of ARM versus ORM is presented for the Southern Pacific Railroad by using 1980 1 percent waybill data for unequipped 50-ft boxcar traffic.

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PROBLEM DEFINITION

Empty cars on a foreign road (not the owner's or not part of the owner's system) can be either reloaded by the terminating road or sent back to the owner (it is assumed here that cars will not be reloaded en route to the owner). If sent back to the owner, the car will travel over foreign roads. Once on the owner's road or system, the car will be repositioned in order to meet the next load.

The current return of empty railroad cars to their owners is achieved mainly through a set of commonly accepted industry rules. The industry rules (chiefly SCO90 and Rules 2 and 6) provide member roads with instructions as to where cars for each owner should be received and forwarded. By a chaining process, in which they proceed from their unloading points back toward their home road, the cars eventually reach the owner's gateway.

SCO90 and Rule 2 have been designed to assure the direct return of empty cars to their owners, but under the current system, car hire penalizes the roads carrying empty foreign cars. Therefore, SCO90 and Rule 2 have also been designed to distribute the empty-car-mile obligations among roads for the sake of fairness. Carriers of empty rail cars, because of car hire, will forward the cars to the closest SCO90 third-party or owner junction (Rule 2) in order to minimize car-mile obligations. The car owner then has little power over where the empty cars are returned.

Once the cars have reached the owner's system, they may appear at junctions where reload opportunities are low. The owner then has to reposition the empty cars within the system, sometimes over considerable distance, in order to meet demand. The sum mileage of the SCO90/Rule 2 return and the system repositioning is referred to as ARM.

The owner can specify, however, through an incentive system, the best return path that would minimize repositioning efforts. The junction with foreign roads where empty cars are to be returned would be indicated. To minimize the incentive payoff, the owner would specify the optimal path over foreign roads from the unloading point to the specified owner junction.

In this paper, the ORM concept is introduced and its effectiveness in the case of the SP system is evaluated. [The system includes SP, the Cotton Belt Route (SSW), and the Northwestern Pacific (NWP).]

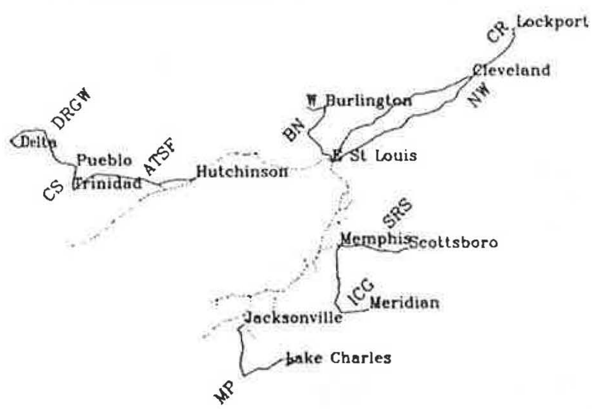
SIMULATION OF ARM

Data on the movement of SP 50-ft unequipped boxcars are obtained from the 1980 1 percent waybill sample (Interstate Commerce Commission). From all SP and Cotton Belt marked cars, the following data are selected from the sample: originating railroad, terminating railroad, terminating station, and number of cars.

Assessing Reload Behavior and Percentage of Return

From the selected waybill records, a percentage of reload has been computed for each railroad. The percentage of reload is defined on each road as the ratio of terminating SP cars to originating SP cars. The percentage of cars to be returned is defined on each railroad as (1 - percentage of reload). The location and number of cars to be returned are derived by uniformly factoring termination records by the return percentage on each road.

Figure 1. Return of SSW cars from sample termination points.



Simulating Return of Empty Cars to SP

Cars are returned railroad by railroad. At each program pass, records are moved from one railroad to the next by using delivery-junction tables (Figure 1). The iterative process is halted when all SP records have reached either an SP or a Cotton Belt gateway. The delivery-junction tables are

1. The junction table used for AAR Rule-2-type return (list of active railroad-to-railroad junctions from the enhanced waybill sample), and
2. The SCO90 table used for AAR SCO90-type return (comprehensive table of AAR directives concerning owner, railroad car is on, railroad to which car goes, and stations).

Four main routing-decision types form the return simulation process:

1. If the car terminated on SP or Cotton Belt, it is "frozen" and ready for repositioning.
2. If the car is on a road with junctions to SP, it is returned to the best possible junction (Rule 2).
3. If the car is on another road and SCO90 directives can be found for that road, the car is moved to the best SCO90 outlet. The record of that car will be processed until it has been returned to the owner under steps 1 or 2.
4. If no SCO90 outlets are found for the ownership or road that they are currently on, the cars are reverse routed.

The best junction or SCO90 outlet is defined as the point that minimizes mileage on service routes for the road currently holding the empty cars. [Specifically, it is an impedance metric of distance times line class (line class is a function of traffic and line quality: class 1, tracks with expedited train service; class 2, best through-train service; class 3, regular local service; class 4, irregular local traffic); the metric takes advantage of the shortest distances on the better tracks.] The closest point is determined by using a minimum-path algorithm and computing the best service route among all possible network combinations.

Repositioning Cars Within SP System

Once the appropriate cars have been returned to the owning road or system gateway, the cars are repositioned within that system to satisfy the demand for loads. Supply of and demand for cars are defined as follows. Cars are supplied from foreign cars reloaded on SP, private fleet terminated on SP, SP cars terminated on SP, and delta SP cars returned and currently at gateways.

Delta is defined as the percentage (close to 1) that ensures absolute equality between supply and demand. The supply and demand are fed into a linear program (transshipment problem), which computes the optimal repositioning flows over SP and Cotton Belt to minimize car miles on service routes. Demand points are 50-ft unequipped SP and Cotton Belt car origination points, and supply points are the termination points.

ORM

ORM is defined as the nationwide empty mileage to reposition SP empty cars that minimizes the fleetwide cost. The supply of empty railroad cars is defined as the set of SP cars terminated on foreign roads and not reloaded, SP cars terminated on the SP system, foreign cars terminated on SP and reloaded by SP, and private cars terminated on SP. The demand for cars is defined as the set of 1980 SP originations of boxcars.

The solution to the ORM problem is obtained by submitting the nationwide supply of and demand for SP cars to a linear program transshipment algorithm (OPTRAIL) over the entire North American rail network. The program will assign each empty car to a load and return it over the entire U.S. network so as to minimize the total cost.

In the incentive-based system, foreign roads charge SP for carriage of their empty cars. The fleetwide cost is the sum of off-line payments and on-line estimated empty-carriage costs.

In a first step, the mileage charge is assumed the same for all foreign roads but could be different for each road without damage to the methodology. The owner's perceived empty-mile cost is realistically less than the mileage rate charged by third roads. This is introduced in the ORM scheme by specifying a discounted mileage cost on the SP system. ORMn is defined as the mileage obtained when the owner's repositioning cost is n percent that to the owner on a foreign road. In this case study we will look at ORM100, ORM80, and ORM0. ORM80, for instance, means that the owner (the SP system), in specifying the best return paths, must consider that the cost of moving an empty SP car on the SP system is $0.40 mile when other roads are charging SP $0.50/mile. ORM0 reflects the fact that the owner's real or perceived cost is $0.00/mile when the cost on a foreign road is $0.50/mile.

SP EMPTY-CAR MILEAGE: ARM VERSUS ORM

Figure 2 shows the termination volumes of SP marked 50-ft unequipped boxcars in the United States from the 1980 1 percent waybill sample. Figure 3 shows the empty SCO90/Rule 2 return flows over the U.S. network of those cars not reloaded by foreign roads. The SCO90/Rule 2 return is computed from each termination point as described in the section on ARM. The flows are displayed by using rectangles proportional to the yearly volume of empties on each link. Figure 4 shows the supply of empty SP/SSW cars at the SP system gateways and at internal termination points. Figure 5 shows the demand for boxcar loads on SP and Cotton Belt for 1980. Although some of the boxcars are returned from Burlington Northern to SP in Oregon and close to the major loading points, the majority of the boxcars returned from the East are returned to SP at New Orleans (Figure 3). From the graphics (Figures 5 and 6), it is clear that the return of many empty cars at New Orleans forces SP

Figure 2. Nationwide 1980 terminations of SP/SSW-owned 50-ft unequipped boxcars sent home before SCO90/Rule 2 return.

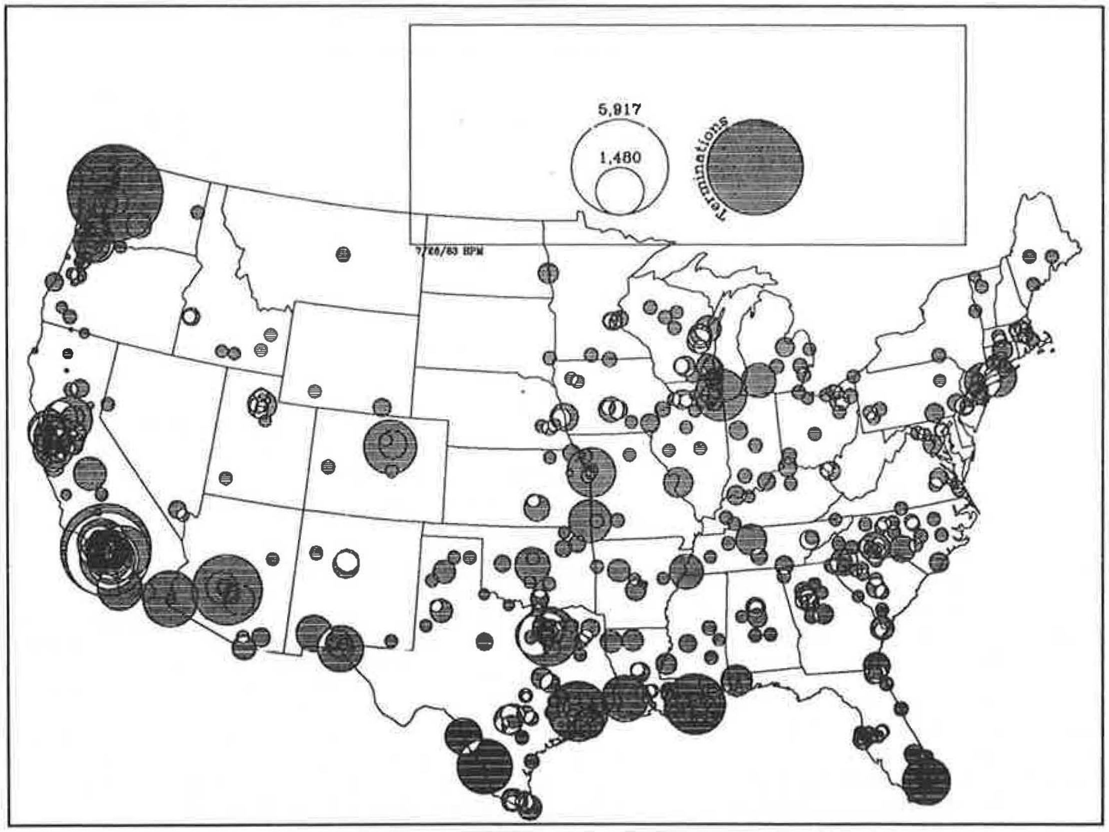


Figure 3. Simulated 1980 SCO90/Rule 2 return of SP/SSW-owned 50-ft unequipped boxcars.

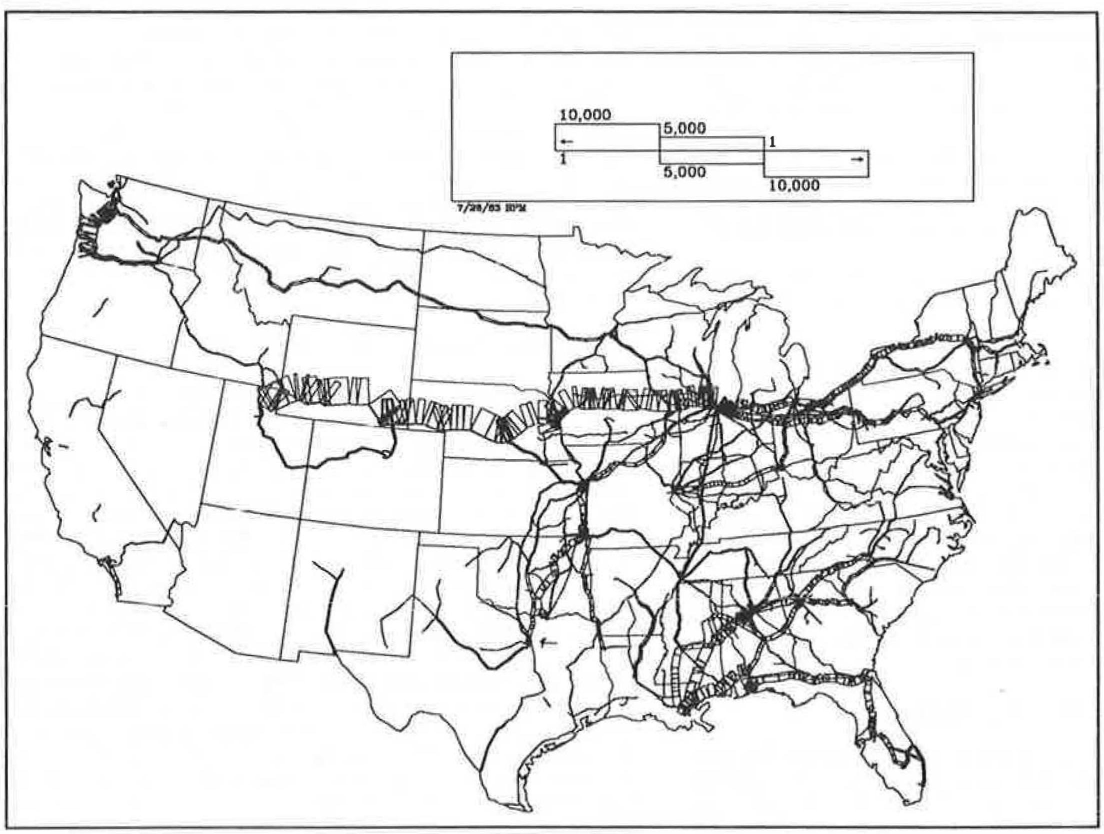


Figure 4. Supply of 1980 SP/SSW-owned 50-ft unequipped boxcars after SCO90/Rule 2 return.

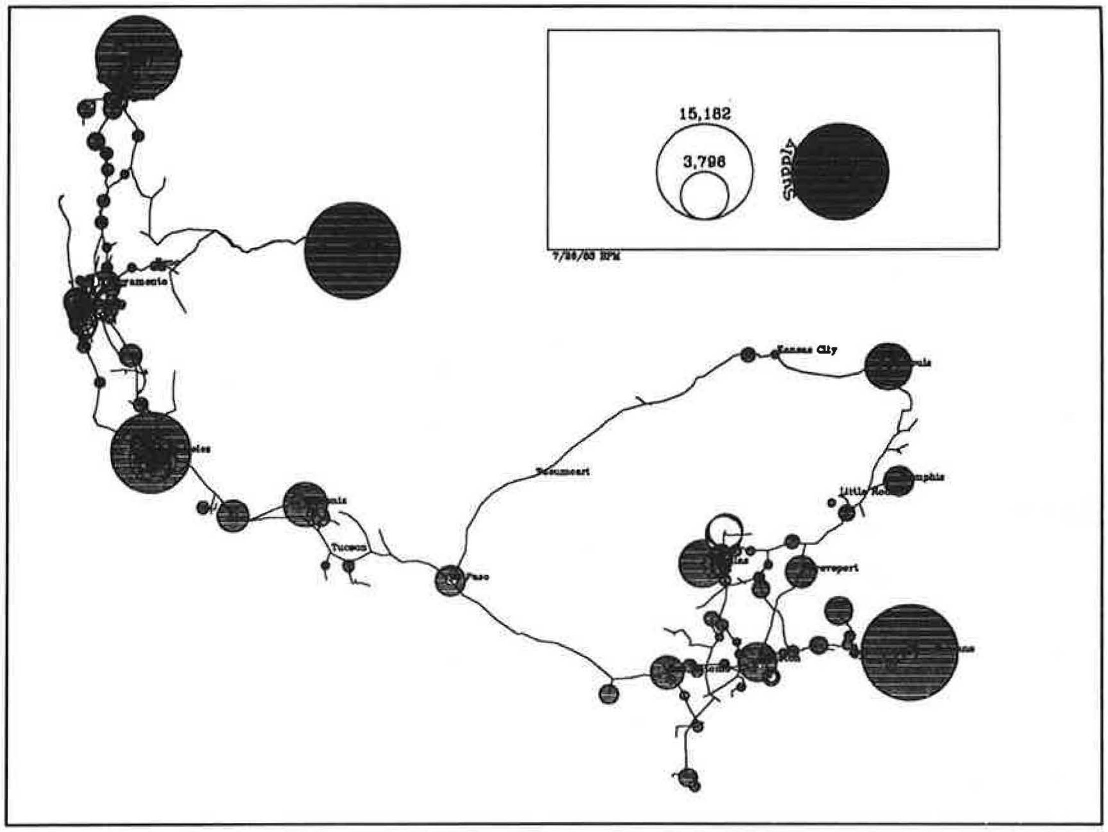


Figure 5. Home demand for 1980 SP/SSW-owned 50-ft unequipped boxcars.

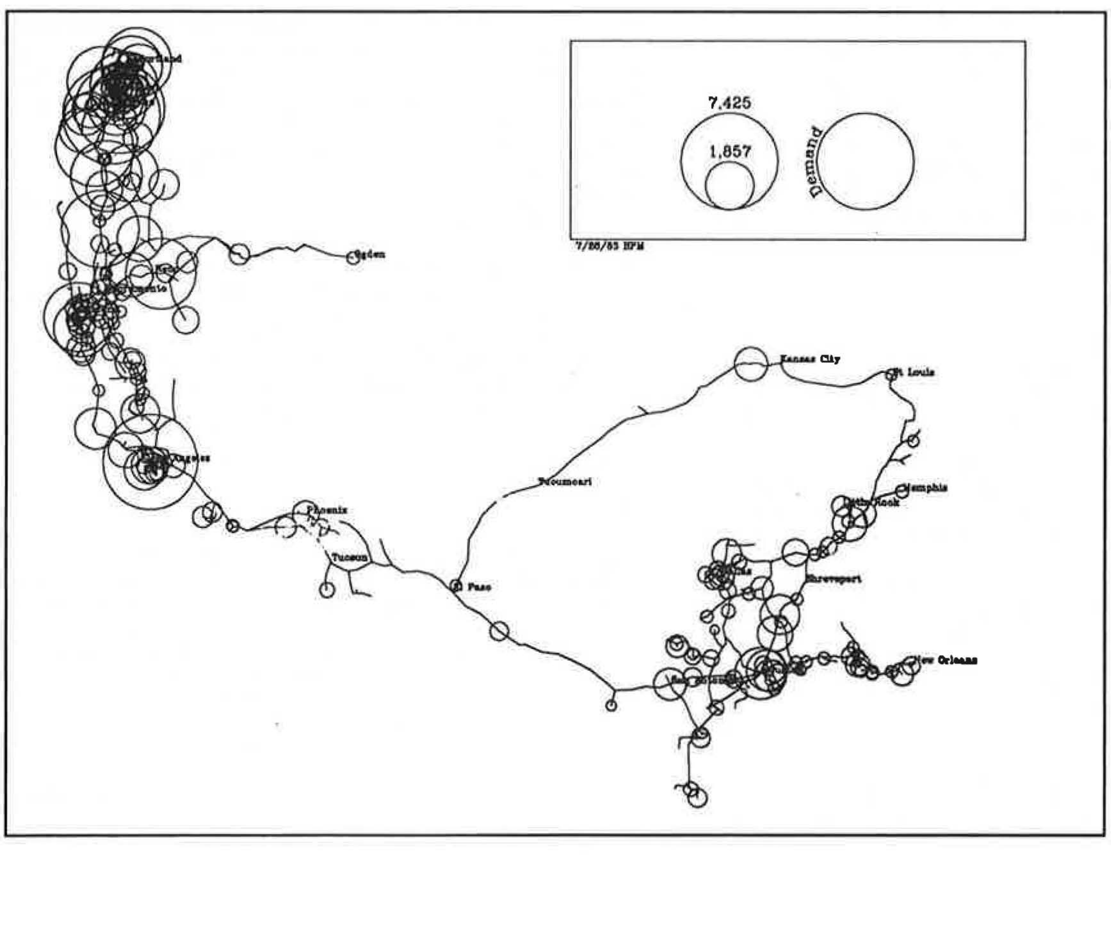
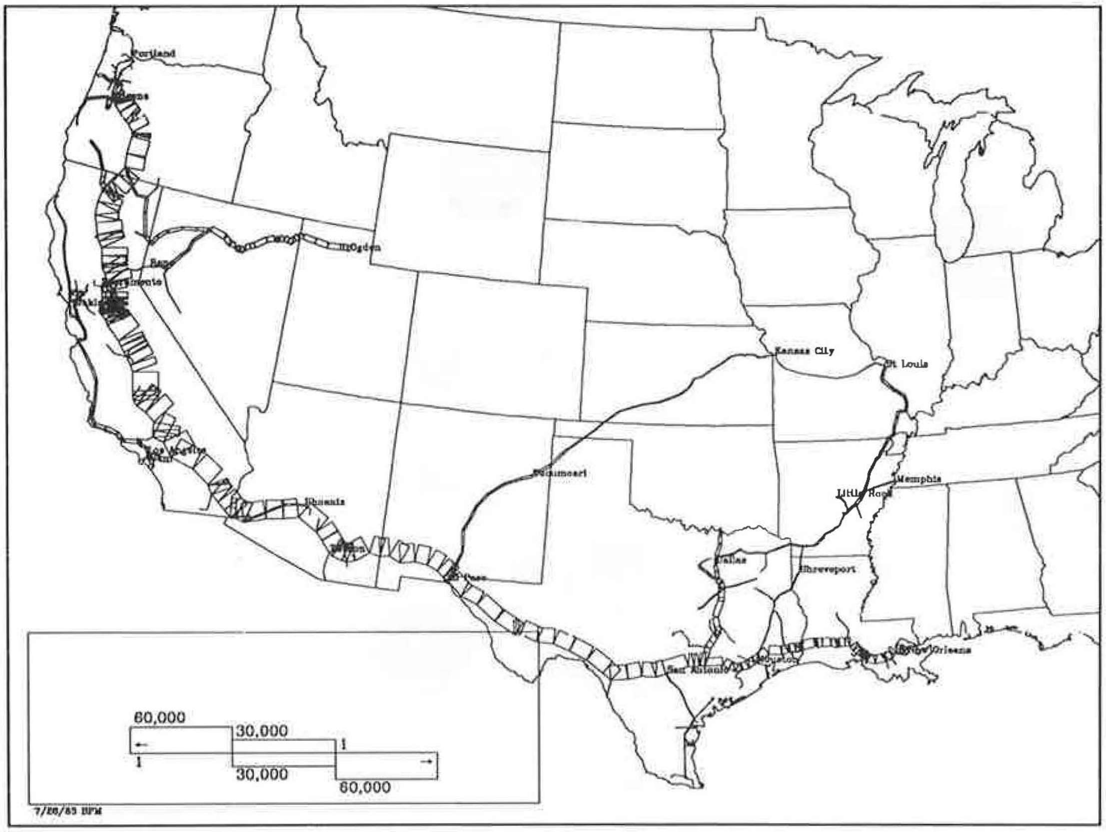


Figure 6. System repositioning of 1980 SP/SSW-owned unequipped boxcars after SCO90/Rule 2 return.



to haul them for a considerable distance to meet loads in Oregon. Figure 6 shows the optimal repositioning flow on SP given supply and demand. The majority of the empty traffic originates in Louisiana and Texas and is bound for Oregon.

Figure 7 shows the total ARM flow over the U.S. network. Figures 8, 9, and 10 show drastically different patterns for ORM100, ORM80, and ORM0, respectively. Table 1 compares ARM (SCO90/Rule 2) with the three ORM cases.

ORM100

Figure 7 clearly shows that a large portion of the cars returned from the Northeast are hauled across the continent from Chicago, Illinois, to Bieber, Oregon, on the Burlington Northern. Burlington Northern is the shortest way to get empty cars from the eastern states to the major demand points of northern Oregon and Washington. Traffic from the South accumulates at Memphis, Tennessee, where it is reloaded by Cotton Belt. A substantial volume of traffic still runs on SP's West Coast line between major consumption and production centers. The scale of Figure 7 indicates, however, that the top volumes are much less than those of Figure 5. It is important to note that under ORM100 there is no traffic of empty cars between northern California and Oregon. This is because the optimal solution indicates that cars returned from the eastern states satisfy the demand in the northwestern states and that cars made empty in Los Angeles and the South can all be reloaded between Los Angeles and southern Oregon.

Table 1 compares the simulated actual and optimal empty return mileages by carrier. Major differences are seen between SCO90 and ORM100 on Burlington Northern, Union Pacific (UP), and the Atchison, Topeka, and Santa Fe (ATSF). UP becomes the second largest carrier of empty SP/SSW 50-ft unequipped boxcars; under ORM100, UP carries more than 16 million car miles as opposed to 6 million under SCO90/Rule 2. ATSF follows; it carries 11 million car miles under ORM100 as opposed to 5 million under SCO90/Rule 2. Missouri Pacific, Louisville and Nashville Railroad Company, Consolidated Rail Corporation (Conrail), and Southern Railway Company all show a major car-mile decline. The largest shift in car-mile obligation, however, occurs on SP itself, where empty-car miles under ORM100 are four times less than they are under SCO90. Therefore, although the overall empty-car miles to return SP cars drops by 16 percent, from 233 million to 200 million car miles, SP itself has a mileage drop by a factor of 4.

ORM80

Major changes are graphically noticeable between ORM100 and ORM80. Because the cost of a system empty mile is only 80 percent that of a mile on a foreign road, SP will want to take control of its cars earlier than in the ORM100 solution. This is why the main stream of empty westbound SP cars now flows over UP. This change from ORM100 to ORM80 is noticeable in Table 1, where UP's empty-car mileage more than doubled. Although some cars returned from the southern states traveled on ATSF under ORM100, the discounted cost on SP-Cotton Belt drives those cars on SP to the East earlier.

Figure 7. Simulated 1980 nationwide return of 50-ft unequipped boxcars under SCO90/Rule 2.

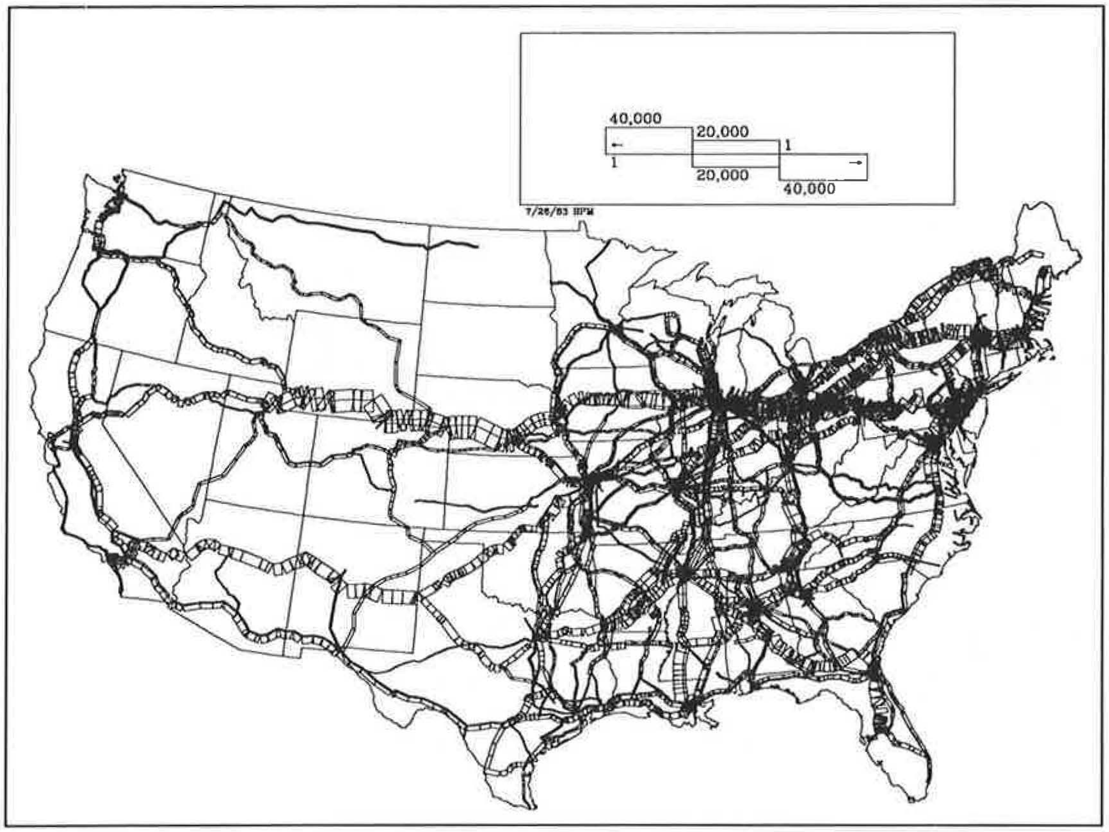


Figure 8. Optimal return of SP/SSW 50-ft unequipped boxcars under ORM100.

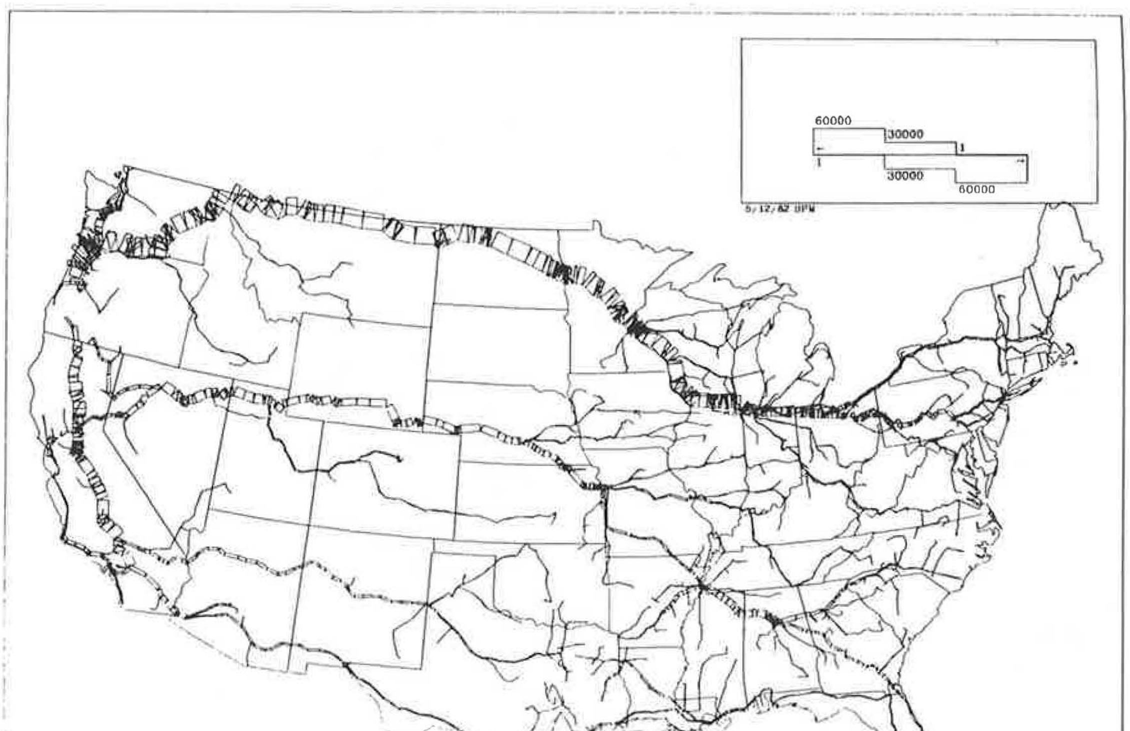


Figure 9. Optimal return of SP/SSW 50-ft unequipped boxcars under ORM80.

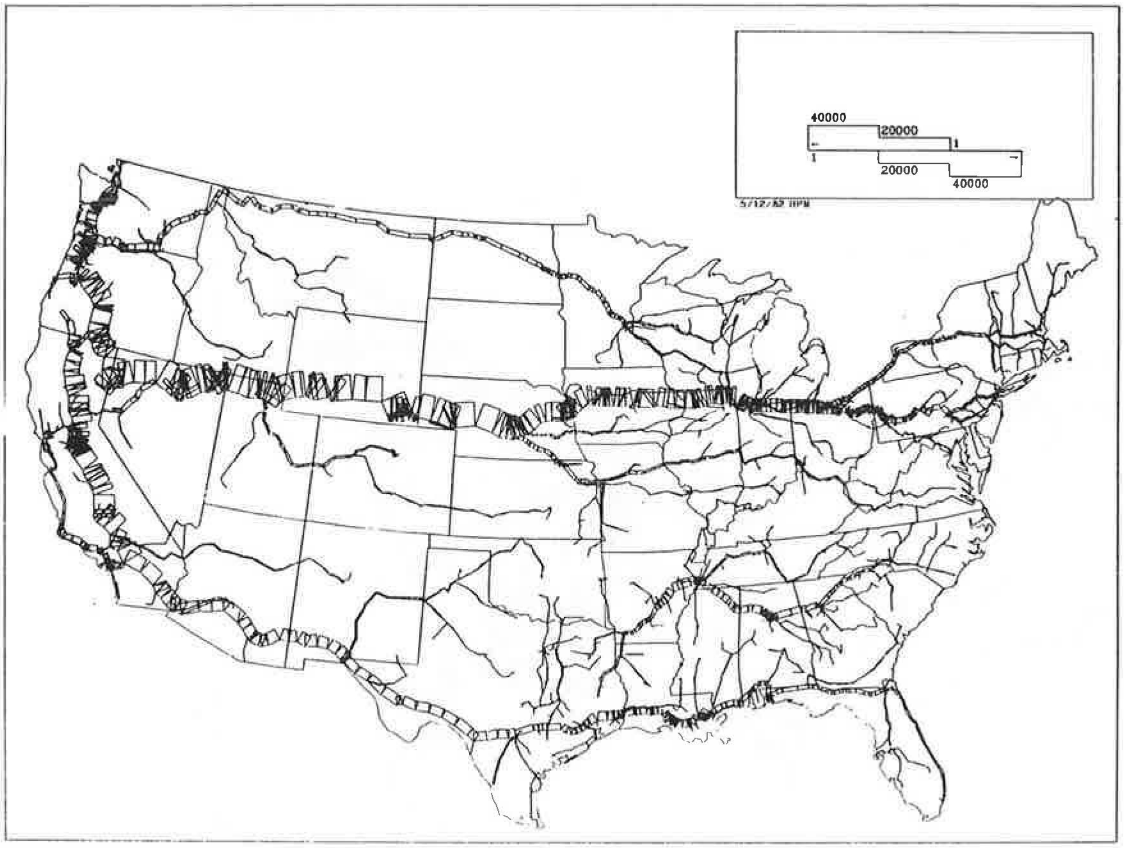


Figure 10. Optimal return of SP/SSW 50-ft unequipped boxcars under ORM0.

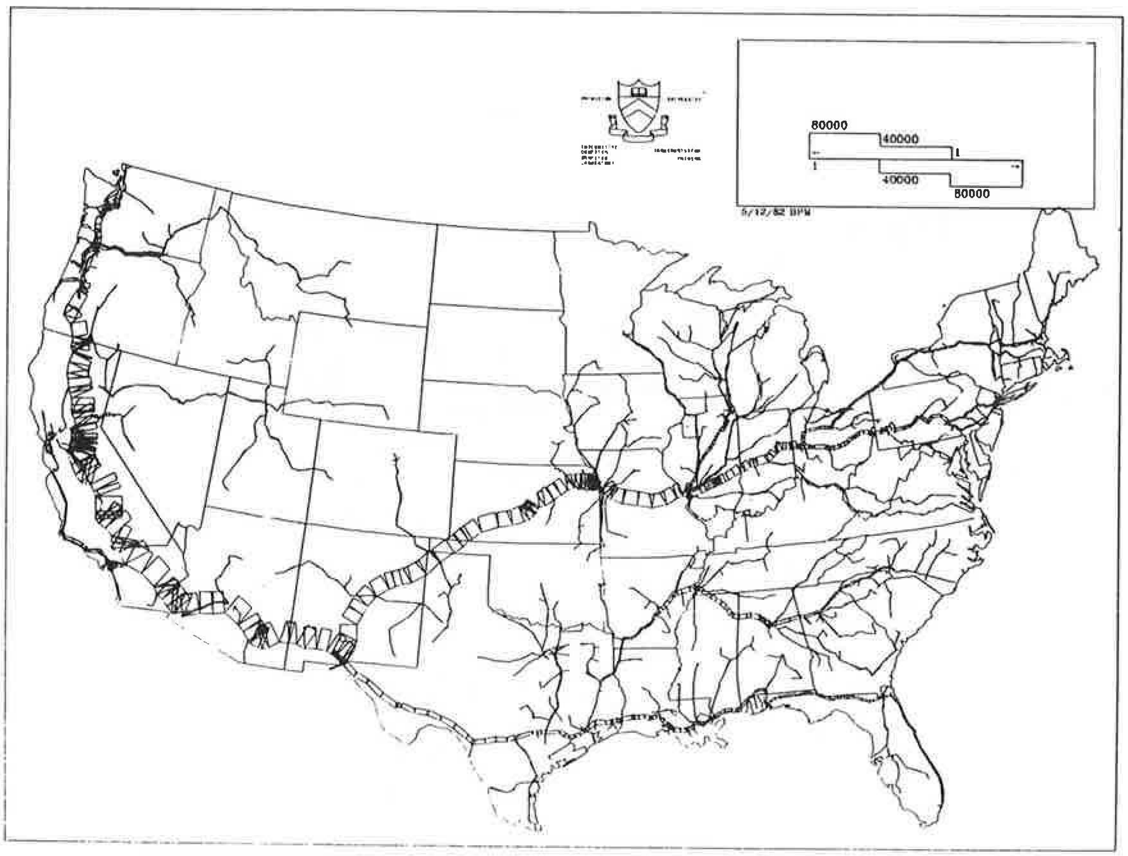


Table 1. Comparison of simulated actual and optimal empty return mileages by carrier for 50-ft unequipped boxcars.

Railroad	Total Empty Car Mileage by Major Carrier (000,000s)			
	SCO90/ Rule 2 (ARM)	ORM100	ORM80	ORM0
Missouri Pacific	7.400	3.286	2.201	1.980
Conrail	6.536	7.290	7.120	16.619
Southern	6.926	3.221	3.348	3.633
Louisville and Nashville	4.061	2.113	3.756	2.800
Burlington Northern	11.707	82.120	19.453	5.221
Union Pacific	5.790	16.084	36.531	0.539
Chicago and North Western	2.707	2.577	13.632	1.062
Milwaukee Road	2.454	0.526	0.579	0.209
Norfolk and Western	1.480	2.808	3.297	2.019
Seaboard Coast Line	2.856	2.939	2.173	2.264
Atchison, Topeka, and Santa Fe	4.416	11.984	6.554	9.056
Illinois Central Gulf	1.653	0.752	0.487	2.608
Chesapeake and Ohio	0.944	5.442	5.326	1.570
St. Louis-San Francisco	0.759	5.066	2.306	2.703
Denver and Rio Grande Western	0.602	1.680	1.689	0.265
Chicago, Rock Island and Pacific	0.375	1.566	1.632	43.485
Kansas City Southern	0.849	0.448	0.265	0.207
Baltimore and Ohio	0.256	0.732	0.555	0.580
Boston and Maine	0.113	0.394	0.394	0.394
Florida East Coast	0.249	0.892	0.859	0.859
Delaware and Hudson	0.377	0.043	0.043	0.043
Soo Line	0.175	0.734	0.734	0.587
Grand Trunk Western	0.288	1.231	1.134	0.074
Missouri-Kansas-Texas	0.158	0.175	0.111	0.018
Western Pacific	0.108	0.815	0.009	0.009
Ft. Worth and Denver	0.044	0.062	0.064	0.208
Maine Central	0.034	0.034	0.034	0.034
Southern Pacific	169.306	44.054	90.906	151.829
Total	238.838	200.505	205.771	251.873

Note: Data were obtained for all carriers in the analysis, including a number of carriers with minor volumes, which are not shown in this table.

As in ORM100, the traffic of empty SP unequipped 50-ft boxcars returning through Chicago is sufficient to satisfy the SP demand for that car type in the northwestern states. This is again shown in the graphics by the absence of traffic between northern California and northern Oregon. In Table 1, it is shown that the total mileage under ORM80 is greater than that under ORM100. Although ORM100 really minimized total car miles, ORM80 minimizes cost based on a different objective function, as shown in Table 2.

From Table 2 it can be verified that ORM80 is indeed a better solution than ORM100 when the discounted system mileage cost is $0.40/mile. With an actual system empty-mile cost of $0.40, the total cost for the ORM100 empty flows would be calculated as follows:

($0.50 x 156,451,000) + ($0.40 x 44,054,000) = $95,441,000.

This is more than the total cost of $93,794,000 obtained under ORM80. Empty mileage under ORM80 is slightly better distributed among railroads. Although SP's mileage is only cut by half over the ARM internal repositioning effort, the total return mileage is still decreased by 12 percent.

Table 2. Comparison of costs under ORM100, ORM80, and ORM0.

Item	ORM100	ORM80	ORM0
Mileage cost ($)			
Base	0.50	0.50	0.50
On foreign road	0.50	0.50	0.50
On SP/SSW	0.50	0.40	0.00
Mileage (000,000s)			
On foreign road	156.451	114.865	100.044
On SP/SSW	44.054	90.906	151.829
Total	200.505	205.771	251.873
Cost ($000,000s)			
On foreign road	78.225	57.432	50.022
On SP/SSW	22.027	36.362	0
Total	100.252	93.794	50.022

ORM0

ORM0 is closer to ARM than the other solutions, as seen from both the graphics and Tables 1 and 2. Cars are channeled from the East to St. Louis, south on the Cotton Belt to Kansas City, and west on the Tucumcari line. This solution is reached because empty mileage on the SP system is considered free (0 percent) as compared with mileage on foreign roads (100 percent).

CONCLUSION

The comparison between ARM and ORMn shows global reductions of 16 percent (ORM100) and 12 percent (ORM80) in the case of SP. This reduction in total mileage could have a major impact on car cycle, maintenance, and availability of equipment. Under a payment-based system in which the SP system would pay foreign roads for the return of its equipment, the savings to SP would amount to $19 million annually under ORM100 and $10.5 million under ORM80.

In addition, it has been shown that the specification of optimal return paths, in which the objective is to minimize total car miles, could have a drastic impact on the owner's own repositioning effort. SP's empty mileage is decreased by factors of 3 (ORM100) and 2 (ORM80).

Finally, it has been shown that relatively small changes in the objective function (20 percent perceived discount on system empty miles) lead to drastic changes in the corresponding optimal routing specifications. Although traffic would be routed primarily on Burlington Northern for ORM100, it is shown to travel mostly over UP under ORM80.

ACKNOWLEDGMENT

This research is part of an ongoing effort in the area of freight-car management supported by the Freight Car Management Program (FCMP), AAR. The research team wishes to thank Peter French, manager of the FCMP, and his staff for material and technical support. We are also grateful to Yehonathan Hazony, director of the Interactive Computer Graphics Laboratory, for his assistance.

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