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CONTENTS

OPTIMAL CARGO VEHICLE FLOW PATTERNS FOR INLAND WATERWAY SYSTEMS

Michael S. Bronzini, Georgia Institute of Technology

In this paper is solved the following multicommodity, mixed fleet transportation problem: Given origin-destination matrices for two commodities, the first of which can be moved in both open hopper and covered hopper barges and the second of which must be moved in covered hoppers, find minimum cost origin-destination flows for loaded and empty hopper barges such that all commodities are moved and flow conservation conditions at each port are satisifed. A linear programming model of this problem is developed, and an efficient solution technique is presented. The model is then used to derive optimal barge flows for an inland waterway system. The effect of this flow optimization on system operations is then investigated, with the aid of an inland waterway simulation model.

•A PHENOMENON common to freight transport systems is that the prevailing commodity flow patterns often dictate the movement of empty cargo units. This, in turn, has important implications regarding the demands placed on the transportation system.

Consider, for example, an inland waterway system. The demand for freight transportation that the waterway must serve is most readily expressed as a matrix (X_{ijk}), the elements of which specify the tons (megagrams) of commodity k that will be shipped from port i to port j during some designated time period. To analyze the operation of this waterway requires that the port-to-port movements of barges, both loaded and empty, that must occur in order to provide for the indicated commodity tonnage flows be determined.

The realities of equipment movement impose an important constraint on the solution of this problem, which may be termed the balance principle: The numbers of barges of each type that depart from and arrive at each port must be equal. That is, a steady-state system cannot have equipment sources or sinks. Some common equipment usage phenomena readily visible on the waterways, such as the ingenuity of the carriers in their attempts to garner backhauls to avoid moving empty barges, pose further difficulties. As a case in point, consider covered hopper barges and open hopper barges. Grain must be protected from the elements and thus must be shipped in covered barges. Many other bulk commodities, such as coal or sand and gravel, are transported in open hoppers. However, these latter commodities can also be moved in covered hoppers if it is convenient to do so. A prime example of this double-duty use of covered hoppers occurs on the Mississippi River, where barges that move grain downstream are used to haul coal northward. The major difficulty involved in incorporating these considerations into the predicted vehicle flow pattern is in determining when such double-duty barge use is possible and convenient (i.e., economically attractive).

STATEMENT OF THE PROBLEM

The specific problem investigated in this paper may be defined as follows: Given origin-destination (O-D) matrices for two commodities, the first of which can be moved in both open hopper and covered hopper barges and the second of which must be moved in covered hoppers, find minimum cost O-D flows of loaded and empty hopper barges such that all commodities are moved and flow conservation conditions are satisfied at each port.

Similar transportation flow problems, usually in the context of fleet scheduling, have been investigated, and a fairly comprehensive literature review is available elsewhere (1). The linear programming (LP) model makes use of some of the ideas presented by Schwartz (2), Laderman et al. (3), Rao and Zionts (4), and Gould (5).

LINEAR PROGRAMMING MODEL

The following variables are used in the formulation of the LP problem:

N = number of ports in the system,
F_{ijk} = number of type k barge loads available for shipment from port i to port j, rounded to the nearest integer,
X_{ijk} = number of loaded type k barges that will move from i to j,
Y_{ijk} = number of empty type k barges that will move from i to j,
c_{ijk} = cost per barge of moving loaded type k barges from i to j,
d_{ijk} = cost per barge of moving empty type k barges from i to j, and
k = 1 for open hopper barges and 2 for covered hopper barges

where subscripts i and j have the range $1, \ldots, N$, $i \neq j$.

Then the linear programming problem may be stated as follows: Find nonnegative values of X_{ijk}, Y_{ijk} such that

$$\text{Min } Z = \sum_{i \neq j}^{N} \sum^{N} \sum_{k}^{2} c_{ijk}X_{ijk} + d_{ijk}Y_{ijk} \tag{1}$$

subject to

$$X_{ij2} \geq F_{ij2} \tag{2}$$

$$X_{ij1} + X_{ij2} = F_{ij1} + F_{ij2} \tag{3}$$

$$\sum_{j \neq i}^{N} (X_{ijk} + Y_{ijk}) - (X_{jik} + Y_{jik}) = 0 \tag{4}$$

X_{ijk} and Y_{ijk} are, of course, the decision variables, i.e., the loaded and empty O-D barge flows to be found. The condition that all covered hopper loads must move in covered hopper barges is expressed by equation 2, and equation 3 states that all O-D commodity flows must be satisfied. Note that, if $X_{ij1} < F_{ij1}$, the latter constraint requires that X_{ij2} exceed its lower bound. That is, some open hopper loads would then move in covered hopper barges. Equation 4 ensures that the number of barges of each type originating at each port is matched by an equal number of terminations. The objective, equation 1, is to minimize total transport costs.

At this point, the reader well versed in mathematical programming techniques might ask why the decision variables are not constrained to have integer values. Indeed, this would be a desirable outcome, for the existence of noninteger X- and Y-values might make the LP solution somewhat difficult to interpret. Further, the flow constraints, F_{ijk}, have been defined to be integers.

The major reason for not requiring that the variables have integral values is that, for most practical problems, the X- and Y-values will be so large that rounding of the

LP solution will be an acceptable procedure. In addition, it is advantageous to avoid the usually troublesome complexities of integer programming at this stage of model development.

SOLUTION TECHNIQUE

The LP problem presented in equations 1 to 4 can readily be solved by the simplex method. The special structure of the model, however, leads directly to an easily obtainable feasible solution and thus greatly reduces the number of simplex iterations required to achieve optimality.

The most obvious and intuitive starting point is to set $X_{ijk} = F_{ijk}$. That is, all type k barge loads should initially be assigned to barge type k. This immediately guarantees that equations 2 and 3 will be satisfied. Initial Y_{ijk} values can then be found by solving two linear programming transportation problems (LPTPs).

Define the demand for empty type k barges at port i as

$$B_{ik} = \sum_{j \neq i}^{N} (X_{ijk} - X_{jik})$$

for i = 1, . . ., N and k = 1, 2. The following demand and supply vectors can then be derived:

$$\begin{aligned} D_{ik} &= B_{ik}, \; B_{ik} > 0 \\ &= 0, \; B_{ik} \leq 0 \\ S_{ik} &= -B_{ik}, \; B_{ik} < 0 \\ &= 0, \; B_{ik} \geq 0 \end{aligned}$$

Hence, vectors D_k and S_k and matrices Y_k and d_k collectively define an LPTP, which can be stated as follows: Find Y_{ijk} subject to

$$\text{Min} \sum^{N} \sum^{N}_{i \neq j} d_{ijk} Y_{ijk}$$

$$\sum_{j \neq i}^{N} Y_{ijk} = S_{ik}$$

$$\sum_{i \neq j}^{N} Y_{ijk} = D_{jk}$$

$$Y_{ijk} \geq 0$$

for i, j = 1, . . ., N, i ≠ j and k = 1, 2.

After the two LPTPs stated above are solved by using any standard transportation algorithm, the initial basic feasible solution to the overall LP problem is complete. A relatively small number of simplex iterations, again based on any conveniently accessible LP package, will then produce the optimal solution.

APPLICATION: THE ILLINOIS-MISSISSIPPI WATERWAY SYSTEM

In this section, the LP model is applied to the problem of deriving optimal hopper barge flows for an inland waterway system. The results obtained with the model are examined in two stages. First, the optimality characteristics of the LP solution itself are explored. Second, an inland waterway simulation model is used to study the impact of barge flow optimization on the operation of the system. Before these topics are discussed, a brief description of the system characteristics is supplied.

Description of the System

The waterway system chosen for this application is a 10-lock subsystem composed of the Illinois Waterway and an adjacent portion of the Upper Mississippi River. This system has been the subject of several previous studies (6, 7, 8, 9, 10, 11, 12). Consequently, the data needed for the study were readily available.

The Illinois Waterway extends for approximately 326 miles (524 km) from Chicago to its confluence with the Upper Mississippi River near Alton, Illinois. Seven locks and dams (L&D) are located along the river at Lockport, Brandon Road, Dresden Island, Marseilles, Starved Rock, Peoria, and LaGrange, each of which is a single-chamber facility 600 ft (183 m) long and 110 ft (34 m) wide.

Also included in the system is a 56-mile (90-km) segment of the Upper Mississippi River, beginning just above L&D 25 and ending below L&D 27 near St. Louis. The former lock consists of a single 600- by 110-ft (183- by 34-m) chamber; L&D 27 has a 1,200- by 110-ft (366- by 34-m) main chamber and a 600- by 110-ft (183- by 34-m) auxiliary chamber. L&D 26, which is just below the mouth of the Illinois River, has one 600- by 110-ft (183- by 34-m) chamber and a second chamber that is 360 ft (110 m) long and 110 ft (34 m) wide. This lock is currently processing traffic at the rate of about 3,000,000 tons (2700 Gg) per month, making it one of the busiest facilities on the inland waterways. Long delays and queues are commonplace at L&D 26, and plans are under way to replace it with a larger facility (12).

Figure 1 shows a diagram of the system. As can be seen, 15 ports were included in the system: 12 internal ports and three end ports at the system boundaries. Commodity flows among these ports for the year 1968 were analyzed in this study. This was the base year used in the previous studies referenced above.

The commodity movements that were considered are summarized as follows (1 ton = 0.9 Mg):

Commodity	Total Tonnage
Grain	14,818,000
Coal	12,146,000
Petroleum	12,085,000
Cement, stone, sand, and gravel	5,863,000
Sulfur	381,000
Iron and steel	2,382,000
Industrial chemicals	2,380,000
Agricultural chemicals	1,989,000
Other selected	1,832,000
Miscellaneous	2,201,000
Total	56,077,000

Grain, which must move in covered hopper barges, is the principal southbound commodity; it originates at points along the Illinois and Upper Mississippi Rivers and is shipped to Lower Mississippi River ports. Coal and petroleum are the most significant northbound flows. Coal generally moves in open hopper barges, although it can be (and sometimes is) moved in covered hoppers. Petroleum is shipped in several types of tank barges.

Grain, coal, and petroleum collectively account for about 70 percent of the commodity movements in the system. Lesser amounts of sulfur, construction materials, iron and steel, industrial chemicals, and agricultural chemicals are also shipped, primarily in open hopper barges and tank barges.

Table 1 gives some characteristics of the barge and towboat fleet in use on the system. It was assumed throughout this study that all hopper barge commodities move in jumbo barges 195 ft (59.4 m) long by 35 ft (10.7 m) wide, at an average loading of 1,300 tons (1180 Mg).

Application of the LP Model

A period of analysis of 44,000 min (approximately 1 month) was selected for this study. The requisite barge flow inputs were obtained by dividing annual tonnage flows for 1968 by 12 and then by 1,300 (the assumed average barge load). The resulting flow matrices contained about 1,700 loaded open hopper barge movements and 1,000 covered hopper barge loads. (Tank barge flows were not included in this part of the study because they were assumed to be noninterchangeable.)

It was assumed in this study that barge movement costs are a linear function of interport distance. If m_{ij} is the mileage between ports i and j, the corresponding cost functions are as follows:

$$c_{ij1} = 20 + 3.6\ m_{ij} \tag{5a}$$

$$c_{ij2} = 25 + 4.0\ m_{ij} \tag{5b}$$

$$d_{ij1} = 4 + 0.9\ m_{ij} \tag{5c}$$

$$d_{ij2} = 5 + 1.0\ m_{ij} \tag{5d}$$

This means that the cost of shipping commodities in covered hopper barges is assumed to be on the order of 3 to $3\frac{1}{2}$ mils per ton-mile (0.2 cent per g-km), which is reasonably accurate.

It must be noted at this point that ports 14 and 15 were located approximately halfway between end points of the system (Figure 1) and New Orleans and Minneapolis respectively to reflect the fact that actual commodity origins and destinations are distributed along the Mississippi River and its tributaries. This approximation must be kept in mind when the study results are reviewed, and the transportation costs for various barge flow patterns must be interpreted in accordance with the limitations imposed by this assumption.

Based on the input data given above, the initial basic feasible solution contained about 1,000 empty barge movements for each barge type. The corresponding total cost was as follows:

Barges	Cost (dollars)
Loaded	11,312,100
Empty	2,294,479
Total	13,606,579

This initial solution provides a convenient standard against which to measure the LP results. This is so because the actual system operates somewhat less efficiently than this (i.e., empty barge flows actually exceed those included in this solution), but this standard of efficiency could feasibly be approximated by the operators, given certain economic inducements.

The LP problem remaining after the initial basic feasible solution contained 558 variables and 99 constraints. The optimal solution was achieved after 42 simplex iterations. The resulting total cost was $12,134,594, which corresponds to a cost savings of $1,471,985.

A dramatic reduction in the flow of open hopper barges and empty covered hopper barges was achieved by applying the LP model. This is demonstrated in Table 2, which gives total hopper barge flows for the initial basic feasible solution and the optimal solution. It must be noted that this solution is likely to be sensitive to the end port location assumption mentioned above. That is, it is assumed here that covered hopper destinations match open hopper origins beyond the system boundaries closely enough to allow the optimal solution to be implemented.

Cost savings were achieved in the LP solution by allocating open hopper loads to covered hopper barges that would otherwise move empty. As a result of this process, more than 1,000 hopper barge movements, which is about one-quarter of the initial total flow, were eliminated. This should produce a decrease in traffic congestion in the system. The significance of this effect is studied below.

EFFECTS OF FLOW OPTIMIZATION ON SYSTEM OPERATIONS

To determine whether the reduced barge traffic predicted by the LP model would effect a corresponding decrease in towboat delays, we observed the simulated operation of the system under the load patterns produced by the initial and optimal LP solutions respectively. The main reason for simulating the initial flows was to establish a datum against which the performance of the system in processing the LP flows could be measured. The waterway systems simulation model (WATSIM) developed at the Pennsylvania State University (13) was used for this experiment.

Simulation Runs

WATSIM was developed at the Pennsylvania State University during the period 1968-1971 as a general-purpose inland waterway system simulator. WATSIM accepts as input a chronologically ordered list of tows that are to be processed during the simulation. The other major inputs to WATSIM are a system description and a set of frequency distributions for the various components of the locking cycle for each lock chamber. The model outputs statistics on the traffic processed at each lock in the system, including the associated service and delay times. Printouts of selected tables at various intervals during one simulation run may be obtained if desired.

The simulation input data for this experiment were the same as those used for previous simulation studies of the Illinois-Mississippi system (8). Identical tank barge movements were input for both runs. Hence, the only difference between the two runs was in the hopper barge movements.

The simulation period for each run was 44,000 min, preceded by a 4,000-min warm-up period. Intermediate output was obtained every 4,000 min; hence, 11 observations of

Figure 1. Illinois-Mississippi 10-lock subsystem.

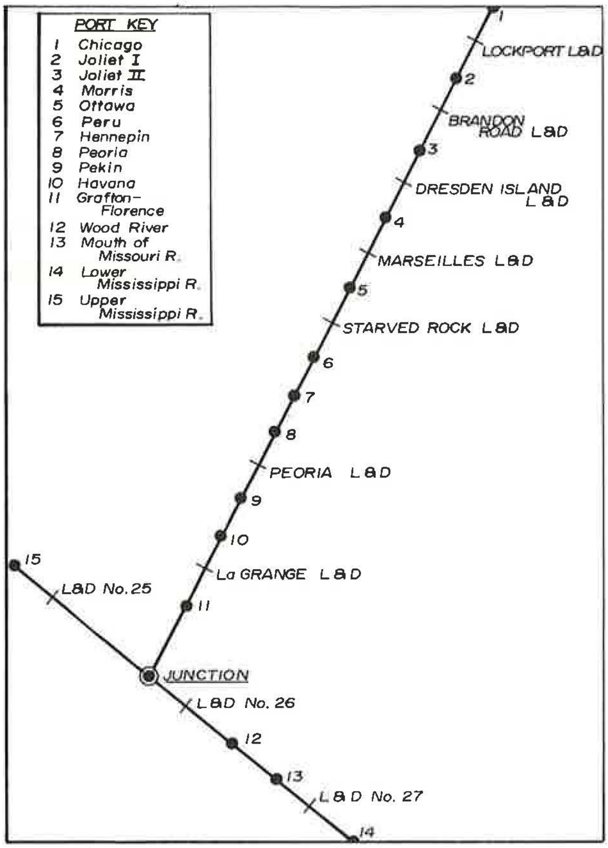

Table 1. Fleet characteristics for the Illinois-Mississippi system.

Barge Type	Commodities Carried	Average Tons per Barge[a]	Average Flotilla Size
Open hopper	Coal	1,300	
	Cement, stone, sand, and gravel		
	Iron and steel		
	Industrial chemicals (50 percent)		8
	Agricultural chemicals		
	Other		
	Miscellaneous		
Covered hopper	Grain	1,320	
Tank I	Petroleum	2,000	3
Tank II	Sulfur		
	Industrial chemicals (50 percent)	2,100	3.5

Note: 1 ton = 907 kg.

[a] 8.5-ft (2.6-m) average loaded draft.

Table 2. Hopper barge movements on the Illinois-Mississippi system.

Barge Type	Total Flow Initial	Total Flow Optimal	Barge Type	Total Flow Initial	Total Flow Optimal
Loaded			Empty		
Open hopper	1,719	961	Open hopper	1,175	520
Covered hopper	1,013	1,771	Covered hopper	976	471
Total	2,732	2,732	Total	2,151	998
			Total movements	4,883	3,730

Table 3. Selected simulation results for the Illinois-Mississippi system.

Location	Run 1: Initial Flows				Run 2: Optimal Flows			
	Total Barges				Total Barges			
	Loaded	Empty	Total Tows	ADPT (min)	Loaded	Empty	Total Tows	ADPT (min)
Lockport	995	675	393	58	980	608	382	88
Brandon Road	951	691	290	62	998	663	292	60
Dresden Island	1,024	754	310	24	1,025	700	308	25
Marseilles	964	698	294	34	908	511	276	23
Starved Rock	961	691	297	25	934	483	273	22
Peoria	1,189	999	363	29	1,120	419	296	21
LaGrange	1,107	933	364	23	1,081	506	317	20
L&D 25	742	722	241	11	886	89	156	7
L&D 26	2,018	1,715	609	91	1,988	515	461	48
L&D 27	2,107	1,722	603	2	2,087	516	460	1
Total	12,058	9,600	3,764	38	12,007	5,010	3,221	33

Table 4. ADPT observations and variables for selected locks.

Observation	Run 1: Initial Flows				Run 2: Optimal Flows			
	Lockport	Peoria	L&D 26	System	Lockport	Peoria	L&D 26	System
1	24.3	37.9	41.1	29.0	13.0	4.1	22.3	17.0
2	30.4	10.4	67.0	30.9	14.1	42.5	33.1	27.0
3	24.5	27.9	98.3	32.7	83.7	14.2	21.1	32.6
4	54.7	39.1	84.1	34.6	100.7	24.8	22.4	28.4
5	28.8	47.0	90.1	37.0	20.6	19.6	53.9	40.9
6	76.8	38.8	106.6	47.8	42.2	18.7	52.2	29.1
7	60.0	27.3	40.4	28.8	325.0	20.8	98.9	73.2
8	53.0	5.8	120.0	51.7	75.5	12.3	34.8	25.7
9	63.0	28.8	41.7	27.2	7.2	7.0	33.0	13.1
10	48.0	18.3	17.5	45.8	90.4	30.3	78.3	42.4
11	164.5	27.4	96.2	58.0	80.8	25.6	56.2	34.3
Σ	628.0	308.7	803.0	423.5	853.2	219.9	506.2	363.7
$\overline{X}$	57.1	28.1	73.0	38.5	77.6	20.0	46.0	33.1
S_x	39.7	12.6	33.3	10.6	89.2	10.9	25.0	16.0
$S_{\bar{x}}$	12.0	3.81	10.0	3.18	26.9	3.28	7.54	4.81

Table 5. Results of ADPT hypothesis tests.

Location	$\overline{X}_1 - \overline{X}_2$	T	Significance[a]
Lockport	-20.5	-0.697	0.50[b]
Peoria	8.1	1.63	0.062
L&D 26	27.0	2.16	0.023
System	5.4	0.935	0.192

[a] 20 degrees of freedom. [b] Two-tailed test.

system performance were available for each run.

Simulation Results

Selected traffic and delay statistics for each run after 44,000 simulated min of system operation are given in Table 3. There is very little difference between the two runs for the upper reaches of the Illinois River (except for an apparently anomalous delay situation at Lockport). From Marseilles lock, however, and through the rest of the system, fewer empty barges were procedded during the second run than during the first run, which gradually brought down the number of tows processed. The largest decreases occurred on the Mississippi River segment. At L&D 26, for example, in run 2 only one-third as many empty barges were processed and 140 fewer tows than in run 1.

Average delay values do not seem to respond so fast as the traffic data. The only large delay reduction is at L&D 26, where average delay for the second run is only about one-half of that for the first. Smaller reductions, of 11 and 9 min, were noted at Marseilles and Peoria. For an inexplicable reason, average delay at Lockport is 30 min higher for run 2, even though the traffic served there was very similar for both runs. For the system as a whole, average delay per lockage decreased by 4 min from run 1 to run 2.

Significance Tests

Because the results discussed above only apply to the operating history of the system at one point in time, nothing can be said as yet about whether the differences noted are significant. Mean tow delay and its associated variance cannot themselves be used for this purpose because the individual tow delay times are autocorrelated. Repeat observations on average delay per tow (ADPT), however, if taken at widely spaced intervals, can be treated as a random sample. Some results obtained by Rao (14), based on a technique developed by Fishman (15), indicate that the 4,000-min intervals used for these runs can be considered to be independent observations. Hence, ADPT values for selected locations for each interval were calculated (Table 4). Sample statistics are also given in the table.

Data for Peoria, L&D 26, and the system as a whole were included to determine the significance of the apparent delay reductions at those locations. Hence, an appropriate hypothesis test is

$$H_0\text{: } ADPT_1 = ADPT_2$$

against the one-sided alternative

$$H_1\text{: } ADPT_1 > ADPT_2$$

Lockport, on the other hand, was included to examine the anomalous higher delay observed there for run 2. Thus a two-tailed test is more appropriate (there being no a priori expectation concerning the directionality of the inequality condition).

T-statistics for testing the above hypotheses, calculated under the equal variance assumption, and their associated significance levels are given in Table 5. Only the large delay reduction at L&D 26 is highly significant. The 8.1-min savings at Peoria can be accepted as genuine if a 6.2 percent chance of making a type 1 error can be accepted. Systemwide delay reduction fares even worse, and the equality hypothesis cannot be rejected at normal significance levels. Fortunately, the seemingly strange result at Lockport turns out to be spurious, for the equality hypothesis cannot be rejected there, either.

These findings point out one of the difficulties involved in interpreting the results of simulation experiments. A highly insignificant increase in average delay occurred at Lockport because of the "luck of the draw" in the simulation model. This delay increase, however, was large enough to offset a highly significant delay reduction at L&D 26, so that the significance level of the systemwide delay reduction was raised to an unacceptable value. Given these somewhat conflicting results, it is the author's inclination to judge the improvement in system operations to be real, rather than the result of chance occurrences.

SUMMARY

The simulation results indicate that optimization of barge flows can have a substantial effect on system operating performance. For the particular system studied, elimination of a great number of empty barge movements allowed the same tonnage to be serviced with significantly lower delays at the key bottlenecks. Hence, transportation costs were reduced not only through greater equipment use but also through decreased system congestion at critical locations.

These results have several implications regarding effective use of the LP model. From the fleet scheduling viewpoint, it must be realized that optimization of vehicle flows will produce a change in transit times at any service facility that has flow-dependent delays. These changes may be significant enough to alter the unit transportation costs input to the model. Hence, it may be necessary to iterate through the scheduling process several times and to reestimate flow costs for each trial, before a satisfactory equilibrium is attained.

From the planning viewpoint, these results show that system performance indexes are a function of the degree of efficiency of equipment use that is assumed when traffic demand estimates are prepared. The LP model assumes that cooperation among shippers is close enough that optimization of total barge flows can be accomplished. If this degree of cooperation is lacking, flow predictions based on the LP model will underestimate actual demand.

CONCLUSIONS

This paper deals with the general problem of determining the origin-destination flows of cargo vehicles, both loaded and empty, that are required to serve a specified transportation demand matrix. The model derived in the paper applies directly to a particular class of such problems in which one set of commodities must be shipped in a special class of vehicles and the other cargo can be shipped in either the special vehicles or general-purpose vehicles.

The particular application used throughout the paper, that of predicting covered hopper and open hopper barge movements, is only one example of how the model might be used. The problem described by Gould (5) is another. Similar examples include refrigerated and nonrefrigerated trucks or railroad cars; container ships and break bulk ships (one could assume either that containers move only in container ships or that uncontainerized cargo moves only in break bulk ships); and even passenger aircraft and cargo aircraft.

It must be emphasized here that the model was devised for use in the context of transportation system planning. Hence, there is no provision in the model for considering vehicle availability. That is, it is assumed that enough vehicles will be provided so that the predicted number of vehicle trips can take place during the analysis period. For planning purposes, this is of little concern, since future commodity flows will normally not be known precisely enough to warrant a more detailed investigation of vehicle flows.

Inasmuch as the model is intended for use as a predictive tool, some objection might be raised to applying optimization techniques to obtain a solution. Indeed, in actual practice, vehicle flows are determined by transportation companies or private fleet operators so as to meet individual private objectives, rather than to minimize system-wide costs. If cost minimization can be accepted as the universal privately applied criterion, however, then the solution should not be far removed from what will actually occur.

This point can be argued as follows. Consider first the initial solution. This might correspond to the situation in which each shipper is using his own vehicles (either private or hired) to provide the necessary loaded movements. Now suppose shippers A and B are crosshauling loaded and empty vehicles between points i and j. It will be to their advantage to arrange to use the same vehicles and thus eliminate some of their empty vehicle trips.

What about shipper C, located at point k between i and j? He may be shipping from k to j and returning empties; shipper B is moving empty units from i to j. B and C could obviously reduce costs if B would carry C's loads from k to j. Other things being equal, this again is the sort of solution that tends to be provided by the model. The three movements involved will be replaced by an empty vehicle trip from i to k and a loaded trip from k to j.

The essential point to be made is that systemwide optimization is not necessarily opposed to minimization of individual costs. In fact, a system optimum will normally be composed of a great many solution elements that correspond to private optima as well. Of course, numerous hypothetical counter examples can be constructed, but real-world problems tend to be more like the waterways example presented. Some theoretical support for this line of reasoning is also available in some recent significant findings by Dafermos (16, 17).

As a final note of caution, it is recommended that for planning applications model predictions be compared with actual vehicle flows for the base year of the study. If substantial deviations are found, it will be necessary to use some other technique or to modify the data input to the model so that the ultimate vehicle flow matrix incorporates some of the inefficient vehicle utilization practices that sometimes occur in the real world.

The model can also be used as the first step of a fleet-scheduling model. The second step consists of specifying realizable vehicle itineraries that collectively provide for all of the movements indicated in the solution matrix. Normally more than one set of itineraries will be feasible, and the optimal set will have to be selected so as to satisfy the scheduling objective. If the number of feasible itinerary sets is not too large, a branch-and-bound method can probably be used to find the optimum.

As a second possible procedure, the LP solution matrix can be used as a set of flow constraints for a vehicle-scheduling mathematical program. Any minimum cost vehicle schedule must provide for the loaded and empty movements specified in the solution. The scheduling problem is to allocate specific vehicles to each movement requirement. Hence, given the LP solution, a relatively simple linear program for vehicle scheduling can be devised.

Regardless of whether the optimal vehicle flows specified by the model can be attained in actual practice, they can be used as a basis for measuring the overall efficiency with which a transportation system is being used. For this application, it is necessary to have available a model that analyzes or simulates the performance of the system in serving a particular matrix of vehicle flows. Inasmuch as the model can be used to generate a minimal demand matrix, it follows that system performance measures that are functions of traffic flow will also achieve their extreme values in serving this demand. Actual traffic flows and delay times observed in the field (or values of these quantities predicted by the system model) can then be compared with their optimal counterparts to assess the efficiency of system operations (or the potential effectiveness of plans for increasing utilization efficiency).

As a case in point, consider the Illinois-Mississippi waterway system studied above. For the 1968 commodity flow matrix, lockage delays and number of empty barges processed can be no lower than those observed in the second simulation run. Thus, for example, a tally of empty barges processed at each lock will indicate how effectively towing companies are using their equipment.

Another application of the model is in establishing the minimum capacity that a proposed facility must have if a specified future commodity demand matrix is to be served.

In summary, the model is applicable to many different types of problems, including prediction of cargo vehicle flows, vehicle scheduling, and establishment of minimum system vehicle processing requirements. With simple modifications, the model can incorporate such additional considerations as dedicated equipment, cargo-dependent transportation costs, unequal vehicle capacities, equipment availability, and multiple commodities. Perhaps the most attractive features of the model are its simplicity and its relatively small size. Hence, it could profitably be used to obtain suboptimal or approximate solutions for more complex problems that cannot be solved with complex models because of size limitations.

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PREDICTING TRANSPORTER'S CHOICE OF MODE

Brion R. Sasaki, U.S. Office of Management and Budget

Every investment decision for transportation projects requires an extensive examination of the amount of anticipated traffic. A statistical technique, discriminant analysis, was used to determine its feasibility and applicability in estimating future traffic. Discriminant analysis is a method to statistically weigh transportation characteristics. This paper discusses an application of discriminant analysis in which travel demand is divided between transportation modes on the Ohio River. This study uses time of transit, distance of transit, annual tonnage, average shipment size, transportation rate, and handling charges as mode characteristics. An increase in the transportation rate, the most significant characteristic influencing mode choice by the user, was simulated (everything else held constant) so that a demand curve for barge transportation could be constructed.

•FEDERAL investment to support the construction and maintenance of a transportation facility requires the development of projections to estimate the traffic that will use the facility. Based on these traffic projections, an analysis can be performed to determine the benefits of the proposed investment. Hence, estimating the amount of future traffic is a key portion of the investment decision. Numerous methods such as rate comparison, linear programs, and linear regressions have been developed and implemented on this subject. A most promising method that appears to be gaining recognition is discriminant analysis.

This paper describes the basic concept and usefulness of discriminant analysis as a tool for economic research and then presents an empirical example to demonstrate these capabilities.

In discriminant analysis, a linear function is established to separate a universe into predetermined populations or groups. Then a set of observations that possess the most similar a priori characteristics is assigned to a population. To simplify the analysis for this discussion, the paper only summarizes the mathematics of the two-population case.

TWO-POPULATION CASE

The two-population case is confined to the allocation of a random sample (of attributes of the universe) into one of two populations having known probabilities (10). Assume a single variate case x_1 that has two distributed populations with known means of u_1 and u_2 and a similar standard deviation for both populations, where u_1 represents the mean of variable x_1 for population 1 and u_2 represents the mean of x_1 for population 2 (Figure 1). To allocate attributes from the random sample to the proper population requires that the means not be equal. The boundary line between the populations is the arithmetic mean Z of the total sample.

For $u_1 < u_2$, the natural method of separating permits an observation to be placed into population 2 if the value of x_1 is greater than $\frac{1}{2}(u_1 + u_2)$ and into population 1 if x_1 is less than $\frac{1}{2}(u_1 + u_2)$. In other words, if $x_1 < Z$, the random observation will be placed in population 1; if $x_1 > Z$, it will be placed in population 2.

As can be seen in Figure 1, the two populations are obviously separated. However, two types of possible misclassification exist as indicated by the area of overlap. In this area, some population 1 observations are included in population 2 and vice versa.

The misclassification occurs because the tails of each distribution overlap, and misclassification will occur whenever

$$\frac{x - u_1}{\sigma} > \frac{\frac{u_1 + u_2}{2} - u_1}{\sigma} = \frac{u_2 - u_1}{2\sigma} = \frac{\gamma}{2\sigma}$$

where $\gamma = (u_2 - u_1)$ = the distance between the means.

Increasing the distance between the two means further separates the populations and reduces the overlap. This divergence minimizes the number of misclassifications. To widen the split requires more than one variable. Let us examine a multivariate case. Assume that there exist a number of variables normally distributed by x_{iw} for $i = 1, 2, \ldots, P$ and $w = 1, 2, \ldots, n$, which classifies the universe into two populations by separating the means of the two populations designated by

$$\delta_i = \bar{x}_i^1 - \bar{x}_i^2$$

To discriminate between the means, a linear function is developed that separates the two sets of variables (12).

$$Z = a_1 d_1 + a_2 d_2 + \ldots + a_p d_p$$

This function Z should be the maximum relative to its variance, and the variance must be proportional to

$$B = \sum_{i=1}^{P} \sum_{i=1}^{P} k_i k_m \sum_{w=1}^{M} x_{iw} x_{mw}$$

Keeping the variance constant and forming a Lagrange multiplier yield a maximum of

$$F = Z^2 - \lambda Q \sum_{i=1}^{P} \sum_{i=1}^{P} k_i d_i d_m - \lambda k_i k_m \sum_{w=1}^{n} x_{iw} x_{mw}$$

This function can be differentiated partially with respect to k_m $(m = 1, 2, \ldots, P)$. It can be simplified to obtain

$$d_m \sum_{i=1}^{P} k_i d_i = \lambda \sum_{i=1}^{P} k_i \, \Sigma x$$

Determining the k_i that are proportional to the estimates of the coefficient of the linear function allows the function to discriminate best between the two populations. This procedure divides the two populations by constructing an average Z-value that is equivalent in purpose to the previously discussed Z-values. This value can be obtained by adding all x_i variables for both groups and dividing by the number of cases to yield an overall general average for each x_i. Inserting these values into equations results in the general Z-values. If the observation has a Z-value less than the average Z-value, the sample is placed in population 1. If the observation is greater than the average Z, the sample is placed in population 2.

Given the discriminant function, a demand analysis for each population can be estimated by varying only one variable for the desired population and holding everything else constant (2). This process causes that population to shift toward the other, which increases the overlap and increases the probability of observations being misclassified. The economic interpretation is that, as a particular (price) variable increases in magnitude while other variables (quantities) are held constant, demand for that population decreases.

EMPIRICAL ANALYSIS

As a demonstration of this procedure, the model predicts the mode choice of a set of users and estimates the demand for barge transportation. Data for this analysis were collected during the summers of 1970 and 1971 and adjusted to reflect future modal characteristics (3, 4, 9). The data consisted of 92 actual coal movements within the Ohio River Basin by rail and barge. Each observation consists of six characteristics of rail and barge movements. These characteristics are annual tonnage per year x_1, distance of transit x_2, time of transit x_3, average shipment size x_4, transportation rate x_5, and handling charges x_6. A Univac 1108 executive computer and a 07M biomedical (BMD) computer program were used to perform the calculations (5). One of the main features of this program is that it enters the variables in a sequential order depending on their statistical significance. In this run, the actual transportation price proved to be the most important determinant in separating the populations. The pattern of entrance of the remaining variables is given in Table 1.

Table 1 also gives the mean values of each variable for the two modes. The dissimilarity of the mean values of the variables gives some indication of their use in classifying firms by mode. Discriminant analysis bases the separation of modes of transportation on the dissimilarity of the mean values of common variables and the order of importance. Thus the larger differences between earlier entering variables assist more significantly in classifying the user correctly. In this case, the cost of transporting coal enters the analysis first and displays a wide variation between the two modes. Railroad prices exceeded barge line prices for transporting coal on the average by more than four and a half times. Also, average transit time was approximately 50 percent longer by rail than by barge. These two dissimilarities and others indicate that the modes can be fairly well separated.

The second major output of the BMD program is the mode classification printout. This output tabulates the results of the analysis. The diagonal of the matrix indicates the modes of transportation correctly classified, and all modes off the diagonal are misclassified. The results of the aggregate analysis are as follows:

Mode	Observed	Estimated
Barge	53	53
Rail	39	34

Barge movements are perfectly classified, but the rail movements are not. Five rail movements are statistically categorized as barge movements. These errors occur because the observations exhibit characteristics more common to barge than rail. Closer examination of the data reveals that all misclassified movements are actually unit train movements. Values of the critical variables (annual shipment size, average shipment size, and time of transit) for train movements exceed one deviation from the rail aver-

Figure 1. Separation of populations.

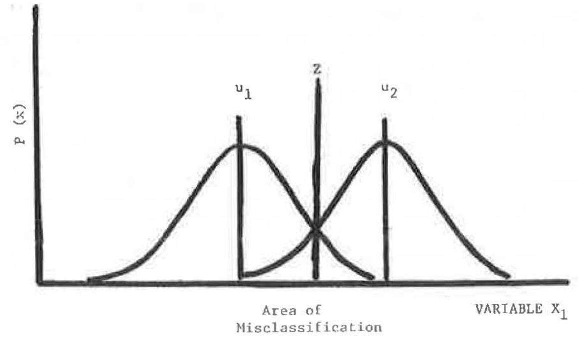


Table 1. Entrance order of variables and mean values.

Entrance Order of Variable	Description	Mean Value	
		Rail	Barge
x_5	Transportation rate, dollars	3.26	0.72
x_3	Time in transit, hours	92.08	62.2
x_2	Haul distance, miles	145.7	159.5
x_4	Average shipment size, tons	1,551	9,017
x_6	Handling charges	0.36	0.29
x_1	Annual tonnage/year	53,638	44,583

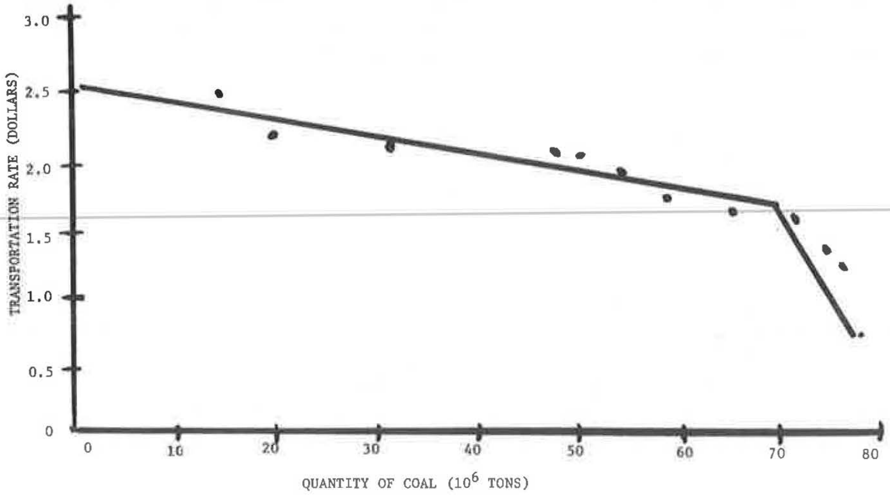
Note: 1 mile = 1.6 km; 1 ton = 907 kg.

Table 2. Demand schedule for barge transportation.

Price Increase	Classification of Firms		Barge Quantity (tons)	Price Increase	Classification of Firms		Barge Quantity (tons)
	Barge	Rail			Barge	Rail	
0.72	53	0	76,628,908	1.72	33	20	58,476,417
1.12	53	0	76,628,908	1.92	28	25	54,418,975
1.22	51	2	76,352,896	2.07	23	30	47,530,267
1.32	49	4	74,950,461	2.12	18	35	31,264,948
1.52	43	10	71,176,824	2.22	15	38	20,093,363
1.62	39	14	65,565,723	2.52	12	41	10,495,132

Note: 1 ton = 907 kg.

Figure 2. Demand curve for barge transportation.



age for those variables. In fact, the numerical values of these variables approach the barge mean values. Hence, the combination of these factors places these rail movements into the barge group. Because the model only misclassifies 5 percent of the sample and those movements can be explained, this method appears to be quite acceptable in predicting the mode of transportation a user will select.

DEMAND ANALYSIS

Manipulation of the data and the model enables a simulated demand curve for the barge transportation to be derived. This method uses a basic economic technique in which barge prices are altered while everything else is held constant. Implementation of this method indicates the responsiveness of barge demand to the alteration in prices. Plotting the demand for barge transportation at different prices produces a simulated demand for barge transportation (8).

Shifting the barge transportation price toward rail average transportation price reduces the difference between the two transportation rates, and each set of modal characteristics begins to more closely resemble the other. Consequently, the overlap of modal characteristics results in barge users being classified as rail demand. These misclassifications are economically interpreted as a decrease in demand for barge transportation because of the increased transportation price. Continuing to raise the price of barge transportation will eventually result in all anticipated barge users being allocated as rail demand.

DEMAND ANALYSIS FOR AGGREGATE DATA

Simulating the barge transportation price (positively) for the aggregate data results in a truncated demand curve. This curve consists of inelastic and elastic sections. The truncated point (kink) connects the two linear sections, which forms a simulated demand curve for barge transportation. The inelastic section stretches from the initial price of \$0.72 to a total price of \$1.67. The next point on the demand curve represents the unitary elasticity point. Points above the \$1.68 level display an elasticity coefficient greater than one. From Table 2, these points can be identified and plotted (Figure 2).

Within the inelastic section of the barge demand curve, the simulation technique estimates that 8.82 million tons (8.0 Mg) of coal will be moved by rail. However, the majority (72 percent) of users remain with the barge mode. This implies that the barge users find it economically more advantageous to absorb the additional barge costs than to switch modes. Continuing to increase barge prices eventually results in the unitary elasticity point. In the aggregate case, the kink lies between the \$0.90 and \$1.00 increase in the average barge rate. Estimation through graphic technique yields a value of \$0.95 (\$1.67 transportation rate) for the kink point. All positive values, increases above the kink point, for barge prices are considered part of the elastic portion of the demand curve, for the demand for barge transportation in this section displayed an elasticity coefficient greater than one. Increasing barge transportation price continues until the demand for the barge mode reaches zero. Thus, this procedure enables the derivation of the elastic section of the demand curve. Extrapolating the elastic section of the demand curve estimates the last point of the demand curve at \$2.65. Figure 2 shows that barge transportation price did not become equivalent to the average transportation price of rail before the barge elasticity coefficient exceeded unity. In fact, the barge simulated transportation price only attained 51 percent of the average transportation price of rail before the kink point occurred.

In conclusion, discriminant analysis has been demonstrated to be able to predict the observed behavior of users. This method also permits other monetary and nonmonetary variables to be included in the analysis to determine mode choice and provides a statistical technique for estimating the sensitivity of mode choice to each of the modal characteristics.

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THE TON-MILE: DOES IT PROPERLY MEASURE TRANSPORTATION OUTPUT?

Allan C. Flott, Lana R. Batts, and Ronald D. Roth,
Department of Research and Transport Economics,
American Trucking Associations, Inc.

The current unit of transportation, the ton-mile (megagram-kilometer), must be reevaluated. This paper traces the origins and uses of the ton-mile, exposes its shortcomings, and examines its current misuse as a measure not only of tons and miles (megagrams and kilometers) but also of efficiency, competition, and productivity. The use of the ton-mile as a measurement has been responsible for many problems in transportation policies and is probably the principle reason that so much confusion and controversy exist with respect to the national transportation system today. The paper recommends gross freight revenue (or the value of transportation) as a far better measurement because it more accurately reflects the relative worth of the various modes to the national effort of moving goods. It is suggested that the Transportation Research Board address the matter as a problem deserving its full and immediate attention.

•THE TON-MILE (megagram-kilometer), the movement of 1 ton (0.9 Mg) 1 mile (1.6 km), is the most widely accepted unit of transportation output in use today. Yet the ton-mile, along with its relative the passenger-mile, is unfit for many of the purposes for which is is used. Reliance on the ton-mile as a unit of transportation service has been responsible for much of the confusion and controversy that exist with respect to our national transportation system today.

Although the trucking industry has been the most persistent and vocal critic of the ton-mile as a general measure of transportation output in recent years, it was not the first nor the only industry to call attention to its lack of validity for many of the purposes for which it is used.

The origin of this hybrid unit of measurement is unknown. Perhaps (and this is pure speculation) it was used by the Phoenicians, the world's first great traders; or it may have evolved in the Middle Ages when tolls for the use of roads and waterways were common throughout Europe and the Middle East. Among the first recorded references to its use as a measurement of the cost of transportation was that by Stevens (1), who urged government ownership of railroads in 1824: "One ton might be transported 280 miles for 50 cents, which means 0.178 cents per ton-mile." A later reference can be found in Strickland's Report on Canals, Railroads, Roads, and Other Subjects, presented to the Pennsylvania Society for Promotion of Internal Improvements in 1826. The report (1) refers to traffic being conveyed for "less than half a farthing per ton per mile." Latrōbe, a civil engineer for the Baltimore and Ohio Railroad, however, is generally credited with originating the ton-mile as the railroad unit of work in 1847 (2).

Perhaps the principal impetus to using the ton-mile as a general measure of transportation came when it was used as a statistical unit by the Interstate Commerce Commission in its First Annual Report on the Statistics of the Railway in the United States for the year ending June 30, 1888. Individual ton-mile statistics were reported not only for each railroad but also for the railroads as a whole, in computations such as "revenue per ton of freight per mile" and "average cost of carrying one ton of freight one mile." The use of these statistics, however, carried the following admonition (3):

> There is, of course, some danger of misinterpreting or rather of misapplying such figures. . . .They are to be accepted as averages and not as an absolute standard. It lies in the theory of averages to eliminate everything that is peculiar; he, therefore, who makes use of an average for any particular problem must modify the standard to allow for what is peculiar in the conditions considered.

The warning was well made because, in the early days of the railroad industry, analysts were well aware of the limitations of the ton-mile as a measure of transportation output. Some authorities seriously questioned its usefulness for any purpose. For example, in 1904 Peabody (4) of the Atchison, Topeka, and Santa Fe Railway said:

> The origin of traffic is so widespread, the volume of traffic so large, and the conditions of traffic so diverse, as to make it manifestly impossible for any general statement to be made within comprehensible limits. . . .In the early days of railroading some man conceived the idea of working out the average earnings per ton-mile—a factor not only useless as conveying any information, but absolutely harmful because of the wrong impression thereby created.

English railroads were particularly apprehensive about the use of ton-mile statistics. In fact, of the 20,768 miles (33 415 km) of track in the United Kingdom, only one road, the North-Eastern with 1,656 miles (2665 km) of trackage, was using the ton-mile at the beginning of the twentieth century. Cecil (4), one of the directors of the London and South-Western Railroad, felt it would not have any "real, practical value on the small system of English railways."

Criticism of the use of ton-mile as a general measure of transportation output has persisted over the years. The use of a related unit, the passenger-mile, to measure the movement of people is as limited as ton-mile to measure output. Economist Barger raised this point in 1951 (5):

> It is argued here that the natural units for measuring transportation service are the passenger and freight ton-mile. . . .[But] an obvious extension of the notion that 16 passengers are not the economic equivalent of a ton of freight leads us to query the appropriateness of treating ton-miles and passenger-miles, respectively, as homogeneous. Certainly the services of transporting a ton of oil in bulk and a ton of package freight over the same distance sell for different prices; moreover, they may involve the use of different amounts of resources.

Another transportation authority, Troxel (6), in discussing transport cost in 1955, expressed similar doubts:

> Although ton-miles may be generally accepted, their conclusions still leave some questions about cost assignments, samplings and output units. . . .Indeed, the organization of transport operations is not much embraced in ton or ton-mile, passenger-mile, or even load units.

Milne (7) pinpointed a basic weakness of the use of ton-mile for general analytical purposes when he made the following observation:

> It is highly misleading to regard all transport facilities as parts of one industry, the transport industry, and as producing homogeneous passenger-miles in the case of passenger transport and homogeneous ton-miles in the case of goods transported.

Milne suggested use of "transport units" and "the train-journey, the bus-journey, the truck-journey, or the aircraft-journey as our unit of output." He also suggested that these various transport units be kept separate from "the pricing unit," which he called "individual passenger and the individual consignment."

Other economists, too, have had misgivings about the use of the ton-mile. For example, Wilson (8) aptly pointed out: "If one examines some of the principal textbooks in the field of transportation, he will note that the various diagrams that purport to show cost and demand relationships for transportation enterprises do not label the abscissa." Wilson gave as his examples the Economics of Transportation (9) and Increasing Returns in the Railway Industry (10). However, most textbooks seem to agree with Hurst's illogical conclusion (11) that, although the ton-mile "fails to capture some important qualities such as cost, speed, flexibility, and safety... no better measure appears to exist for use in comparing energy efficiencies of different transport modes." Such reasoning is reminiscent of the man who lost his collar button in the bedroom but looked for it in the bathroom because the light was better there. What good are data when they produce unreliable, spurious, and inconclusive results? Quast (12) certainly disagreed with Hurst's assumption that ton-mile is better than nothing, for he stated: "And as between accepting the ton-mile and rejecting economic analysis, acceptance would seem to be too high a price to pay."

Despite these legitimate criticisms, the use of ton-miles for inappropriate purposes persists. Perhaps the greatest shortcoming of the ton-mile for general analytical purposes is that it is not a homogeneous unit. It is merely a physical measurement with all the limitations of such measurements. Thus it is similar to pounds, gallons, and bushels used in other phases of the economy and must be used judiciously. No one would think of comparing goods without recognizing differences in their characteristics. Thus, no one would consider comparing milk with paint in terms of gallons, nor would gallons of paint be added to gallons of milk to measure total output. Imagine comparing the number of tons of steel, aluminum, and magnesium produced per gallon of fuel or per person-hour without taking into account the different characteristics of these metals or computing the output of metals by adding the number of tons of steel, aluminum, and magnesium produced together.

Indeed, supposedly meaningful analyses that are made by using the invalid ton-mile unit create serious problems. Among the more flagrant misuses of ton-miles for analytical purposes are measurements of relative productivity of labor over time and evaluations of the relative efficiency of different modes of transport. In the former case, the errors involve modal as well as intermodal comparisons.

Calculating trends in labor productivity over time by using only the ton-mile produces serious distortions, particularly with respect to railroads. A report of the Task Force on Railroad Productivity (13) devoted an entire chapter to this problem. A synopsis of the chapter follows:

> Conventional and widely used measures of railroad productivity, such as ton-miles per person-hour, indicate that rail productivity has grown at a rate of 5 to 6 percent a year during recent decades, considerably above the average growth of labor productivity in the private economy (3.0 percent) during these same decades. However, by using alternative assumptions and measures (e.g., allowing for changes in the composition of rail traffic), it can be argued that growth in rail labor productivity has been only about 3.7 percent. Capital inputs to the railroad industry have not declined nearly so rapidly as labor inputs, and the indicated growth of rail capital productivity is near zero. When labor, capital, and other inputs are weighed together, total rail productivity may have grown only 1 to 2 percent per year during recent decades. This low level of total productivity growth, considerably below the level of total productivity growth in the private economy (2.5 percent per year), is consistent with the railroads' losses of traffic to other modes and with the low rate of return on investment in railroad property.

However, the remainder of the report leans quite heavily on ton-mile analyses.

In addition, another widespread abuse of the ton-mile as a unit of transportation output is in intermodal comparisons. Currently this unit is being widely used to measure relative energy efficiency of the several modes of transport. To assume that the average number of ton-miles produced per gallon of diesel fuel or per Btu by the several modes of transport is a proper indication of their relative efficiency is absurd.

The number of ton-miles per gallon of fuel obtained by a given transport mode depends on so many variables that any generalization is bound to be misleading. This is true intramodally as well as intermodally. Some of the reasons that such comparisons are misleading follow.

1. Fuel use varies with the gross weight moved, not with the load carried. Relative fuel efficiency, however, is a factor of the cargo weight to the tare weight of the vehicle.
2. Fuel use varies with the actual distance freight is moved, not with the distance between the points served. This has significance in intramodal and intermodal comparisons.
3. Fuel use by mode varies with the volume of freight to be moved between the same points at a given time and over time.

The effect of carried load to tare weight on fuel consumption can be illustrated by an example using a passenger car: If an automobile that weighs 3,600 lb (1630 kg) empty carries a load of four persons weighing 100 lb (45 kg) each, the carried load is 400 lb (180 kg) and the gross weight is 4,000 lb (1810 kg). However, if the persons carried weighed 200 lb (90 kg) each, the load carried would be 800 lb (360 kg) and the gross weight would be 4,400 lb (1990 kg). The load carried would be twice as much with the heavier persons (800 lb versus 400 lb or 360 kg versus 180 kg), but the total gross weight would be only 10 percent higher (4,400 to 4,000 lb). If the car obtained 10 miles/gal (4.25 km/liter) with lighter persons and 9 miles/gal (3.8 km/liter) with the heavier, the fuel efficiency based on the carried load would be 2 ton-miles/gal (0.3 Mg·km/liter) for the 400 lb (180 kg) and 3.6 ton-miles (0.5 Mg·km/liter) for 800 lb (360 kg). There would be an actual increase in fuel consumption of 10 percent—if we assume that fuel consumption increases in direct proportion to the gross weight of the loaded vehicle—but an apparent increase in energy efficiency of 80 percent in ton-miles per gallon of fuel, based on the carried load.

Obviously, the importance of moving people cannot be determined on the basis of their weight; neither can efficiency. The same principle applies to the movement of freight. A flatbed truck combination carrying steel would have an empty weight of about 13.5 tons (12.2 Mg) and a load of about 23 tons (20.8 Mg), for a gross weight of 36.5 tons (33 Mg). A refrigerated combination carrying Boston lettuce would have an empty weight of about 15.5 tons (14 Mg) and a load of about 10.5 tons (9.5 Mg) for a total of 26.0 tons (23.5 Mg). The gross weight, the weight that influences fuel consumption (all other things being equal) of the combination loaded with steel would be only 40 percent greater than the one carrying lettuce, but its carried load would be 120 percent more.

Because fuel consumption would not increase in direct proportion to the increase in the carried load, the relative number of ton-miles that could be obtained between the same points per gallon of fuel when steel was hauled would greatly exceed those that would be obtained when lettuce was hauled. Nevertheless, steel is hardly a substitute for lettuce, and both must be hauled, regardless of the relative number of ton-miles per gallon.

In addition, the same shipment moving between the same points can produce different ton-mile aggregations, depending on several factors that must be considered when relative energy efficiency is compared. For example, railroad routes between the same points are rarely the same. If two railroads operate between identical points and railroad A operates over a route that is 20 percent longer than that of railroad B, the number of miles when multiplied by the weight of the shipment will result in 20 percent more ton-miles by railroad A in moving the same freight. Yet each railroad would be performing the same function, and, moreover, railroad B might be performing it better inasmuch as it probably would provide faster service at a lower total fuel consumption. The longer haul actually using more fuel would produce a greater rate of fuel efficiency when measured in ton-miles per gallon.

Moreover, circuity has a bearing on relative fuel efficiency in intermodal comparisons. Commenting on this point, Smith (14) wrote:

> The significant factor that has not been considered in any reports to date is that average Btu consumption per net ton-mile alone is not an accurate comparison between water and rail. Water interests have been silent about inland barge and coastwise vessel mileage circuity over rail mileage between common points.

When railway movements are compared to truck movements between the same points the effect of circuity is also significant. Railway routes between the same points are generally longer than highway routes. In some instances, the rail mileage is more than double the highway distance. Thus, on the same shipments between these points, rail ton-miles could be double truck ton-miles on this basis alone.

Generally speaking, railroads can move large quantities of goods between fixed points with a low expenditure of fuel per ton-mile. As the quantity to be moved at a given time declines, however, so does energy efficiency. On the other hand, trucks are relatively small transportation units, and their fuel consumption varies less with changes in volume. The differences in fuel consumption in relation to volume can be illustrated by an example involving passengers: If 1,000 persons wish to travel between two points and all can leave at the same time, a railroad could probably move them with a low consumption of fuel per passenger. However, if the number that could leave at one time dropped to 500, the energy efficiency of the railroad per unit would decline sharply. If only 50 could leave together, buses would undoubtedly be more efficient.

Finally, freight cannot move to and from rail terminals by itself, and cars must be assembled into trains. Both operations require fuel.

Admittedly, because tons, miles, and ton-miles are such misleading measurements of transportation output, an alternative method should and must be developed. The new measurement must be available from current data, reflect the relative importance of transportation to the total gross national product (GNP), and, yet, be adaptable to future changes in transportation technologies.

The broadest measurement of our economy is produced by aggregating the value of all goods and services including transportation. This method of measurement appears to be the best alternative. Indeed, value is the only means recognized as measuring productivity output in a service industry such as transportation. The U.S. Bureau of Labor Statistics (15) states:

> Output refers to the finished product or the amount of the product added in the various enterprises, industries, sectors, or the economy as a whole. Output is measured for industries producing not only goods, but also services that are difficult to quantify. . . . Further, when information on the amount of units produced is not available, as is often the case, output must be expressed in terms of the dollar value of production, adjusted for price changes.

As a result, the prices paid for transportation reflect the value of the service as perceived by the shipper. In other words, because transportation does not produce goods, modes cannot be compared by physical measurement. They can and should be compared by their dollar value of production, i.e., gross freight revenue or expenditure.

If this method is used, freight transportation analysis can focus on the value of service supplied and the value-determining physical attributes of that service. Consider Nelson's statement (16) in discussing trucking operations:

> The dollar value of service (freight revenue) provides a common measure of trucking output which may be used when comparing and analyzing the output of different carriers in any

Table 1. Ton-miles and value of transportation by mode of transport.

Mode	Ton-Miles (millions)	Percent	Value (millions of dollars)	Percent
Air	3,800	0.2	770	1.3
Pipeline	468,000	20.1	1,300	2.2
Rail	781,000	33.6	13,500	22.8
Truck	470,000	20.2	41,668	70.4
Water	603,000	25.9	1,982	3.3
Total	2,325,800	100.0	59,220	100.0

Note: 1 ton-mile = 0.56 Mg·km.

Table 2. Ton-miles, value of transportation, value of shipment, and value added by mode of transport.

Mode	Ton-Miles (millions)	Percent	Value of Transportation Expenditures (millions of dollars)	Percent	Value of Shipment (millions)	Percent	Value Added (dollars)	Percent
Rail	731,000	41.4	10,148	24.1	156,673	32.0	68,581	30.6
Truck	389,000	22.0	28,930	68.7	297,211	60.7	141,644	63.3
Other[a]	645,000	36.6	3,020	7.2	35,342	7.3[b]	13,602	6.1[b]
Total	1,765,000	100.0	42,098	100.0	489,226	100.0	223,827	100.0

Note: 1 ton-mile = 0.56 Mg·km.

[a] Oil pipelines (regulated and nonregulated), inland waterways (including the Great Lakes, but excluding international, coastal, and intercoastal), and airways.

[b] Excludes pipelines.

> single year. Adjusted for price level changes, revenues also provide the means for describing changes in the output of the same carrier or group of carriers from one year to the next.

Such analysis is readily adaptable in discussions of not only intramodal but also intermodal transportation. Table 1 gives the relationship of ton-miles (a physical measurement) to value (a monetary measurement). (The data in the table are from 1972.)

Although railroads carried 33.6 percent of the total ton-miles, the value of these ton-miles as reflected in the total amount of money spent for them was only 22.8 percent of the total spent for all freight transportation. Air carriers, on the other hand, handled only a small fraction (0.2 percent) of the ton-miles but spent 1.3 percent of the money. The value of truck service represented 70.4 percent of the total transportation dollar spent for all intercity transportation but accounted for only 20.2 percent of the ton-miles.

Another approach that might be taken is to consider the value of the goods moved as an indicator of the economic importance of transportation. This is given in Table 2. Note that, although trucks move fewer ton-miles, they carry items that are high in value. Shippers of these goods with higher values demand and can afford to pay more for the better service that trucks provide. Regrettably, the latest data for value of shipments are for 1967. However, when the 1972 data are made available, they will almost surely show that trucks moved even greater portions of high-value shipments.

Another measurement of transportation output that might be used is value added. As applied to manufacturing, value added is defined as follows (16):

> The difference between the value of goods and the cost of materials or supplies that are used in producing them. Value added is derived by subtracting the cost of raw materials, parts, supplies, fuel, goods purchased for resale, electric energy and contract work from the value of shipments. It is the best money gauge of the relative economic importance of a manufac-

turing industry because it measures that industry's contribution to the economy rather than its gross sales.

The value added for manufactured goods handled by each mode is also given in Table 2. This is computed by multiplying the percentage share of tons handled by each mode by the dollar value added by production, measured at the three-digit level of the standard industrial classification (SIC).

Unfortunately, value added can be measured currently only for manufactured goods. Services, including transportation, do not readily lend themselves to this type of analysis because they do not produce a physically measurable unit. Transportation's role merely reflects the percentage share of tons handled in relation to the value added produced by those tons. If data could be developed to determine specifically the value added by transportation, the measurement of transportation output would be greatly enhanced. Value added by Transportation could be applied intermodally as well as intramodally. Tying transportation to the national economy by using value added instead of measuring operating expenditures would be a refinement over other methods because the sum of all value added levels would equal, by definition, gross national product.

CONCLUSION

U.S. transportation policies have been hampered for too long by faulty analyses based on the inappropriate use of ton-miles (megagram-kilometers). The types of fallacious conclusions being drawn from such analyses must be exposed. More important, a realistic method or methods of measuring transportation that will permit meaningful comparisons of different kinds of transportation outputs must be developed. The need is urgent. We, therefore, urge that the Transportation Research Board address this problem on a priority basis and that it appoint a committee or subcommittee representative of government agencies, carrier representatives, and transportation engineers and economists to study this problem.

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DEVELOPMENT OF STATE RAILROAD PLANNING

John W. Fuller, Wisconsin Department of Transportation

As a result of new federal legislation, a number of states have begun to develop railroad plans. This paper reviews the history of government planning for railroads in the United States, examines the requirements of present laws, and outlines primarily through reference to activities under way in Wisconsin what a rail plan can contain and what rail planning might accomplish. Alternative futures for rail planning are then postulated. Included is a survey form pertaining to the major data-gathering effort in the Wisconsin plan—a detailed census of more than 11,000 business establishments in the state.

•AMONG the major transport modes, only railroads have been relatively neglected in recent years by government transportation planners in the United States. Tremendous post-World War II activity in planning, implementing, and financing highway and airport systems involved state, local, and national agencies playing reasonably coordinated roles. Inland waterway investment expanded, toll-free; ocean shipping was further subsidized at federal direction; ports obtained local and state support. Transit is increasingly viewed as a public responsibility at all government levels. And, in each of these transport fields, planning procedures and documentation evolved in concert to guide government strategy.

This has not been the case with U.S. railroads. During the last several decades, government action has been begrudging and almost solely of a negative type rather than promotional. Governments have stepped in to resolve conflicts at highway-rail grade crossings, service declines on branch lines or commuter rail routes, rate increases and competitive rate adjustments, freight-car shortages, and financial failures. The reasons for lack of government interest in support of the rails, compared with the situation in other countries, are undoubtedly numerous. Of course, for one thing no substantial portion of the population any longer travels by rail, and, in general, public attention is more keenly directed toward the passenger-carrying modes. Too, investment aid seems lavished primarily on new technologies, and the rail system ceased geographic expansion around the turn of the century. Government planners themselves seem interested in pressing beyond rail issues to the development of comprehensive programs for all transportation.

Yet the political, social, and economic climate is quickly changing. Added to steady environmental concern and the relative efficiency of the railroads for certain hauls are rapid inflation, energy and materials shortages, and the prospect of continued population growth and accelerated world pressure on sources of supply. Meanwhile, planners and social scientists have been slow to devise practical methodologies for accomplishing the modal trade-offs necessary to comprehensive planning, making the single-mode approach the most immediate means of producing investment programs. No new transportation or communications technologies seem close to meaningful implementation for the solution of transport ills. Relative neglect of the rail sector by government is ending. It still remains unclear whether rail transportation can contribute significantly to the solution of many national problems or whether the privately owned carriers should best be viewed henceforth primarily as instruments for the achievement of public policies in the United States (1, 2). Before the government is the prospect of focusing more attention on optimizing use of the rail system through mechanisms such as line rationalization, regulatory and pricing changes, constraint of other modes, and government subsidy or assistance in various forms. A new challenge, another field, and new responsibilities therefore face government transportation planners.

BACKGROUND OF RAILROAD PLANNING

Of course, the financial decline of rail transportation due to basic underlying forces has been recognized for decades (3). Despite technological improvements equal in some ways to those taking place in the other surface modes, the relative shares of intercity freight tonnage and revenue have been declining in the rail industry. But why should this decline not proceed, just as so many others have in a dynamic, progressive economy where firms and industries continually shift relative positions, go into decline, or emerge as suppliers of newly important goods or services? The necessity of forcing a change in public response toward the railroads has become apparent only with the realization that continued rail decline cannot be allowed to progress simply because there is no other mode capable of taking the place of railroads as a common carrier of freight. And with the effects of the Penn Central bankruptcy being felt, decline had gone sufficiently far by 1973 that major geographic areas were faced with either a complete loss of rail carriage or service so marred by safety hazards, lack of equipment, and uncertainty that it was nearly useless.

REGIONAL RAIL REORGANIZATION ACT

The threat of additional, far-reaching bankruptcy and service loss, specifically in the northeastern states, was a key influence in changing congressional attitudes about the government role in rail transport. After extensive investigation and a variety of proposed responses, the Regional Rail Reorganization Act of 1973 became law on January 2, 1974. Sponsored as a means of stopping the spread of chaos among shippers and receivers of freight, which appeared likely to result from closure of the bankrupt Penn Central, the RRR Act has numerous provisions and broad implications. It calls for a reorganization of all bankrupt roads in 17 northeastern and midwestern states plus portions of three contiguous states (as defined by the Interstate Commerce Commission) into an economically (and environmentally) viable system that is responsive to national and local demands for low-cost movement of goods and persons, energy conservation, and national defense. (The states involved are Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, West Virginia, Ohio, Indiana, Michigan, and Illinois plus the District of Columbia. The contiguous states, portions of which were involved, are Kentucky, Missouri, and Wisconsin.) Several new agencies were established: the U.S. Railway Association (USRA), to plan the system and distribute subsidies to states and localities for operations not made part of that system; the Consolidated Rail Corporation (ConRail), to operate the new railroad; and the Rail Services Planning Office (RSPO) of the Interstate Commerce Commission, which has responsibilities for promoting public participation in the entire effort, critically reviewing the planned system, and setting subsidy standards and other regulations.

After the USRA has developed a detailed step-by-step plan, the bankrupt railroads are to have their properties either (a) transferred to ConRail, (b) bought by a profitable railroad in the region, (c) purchased by or leased to Amtrak, (d) purchased or leased from ConRail by a state or local transportation authority for rail passenger service, or (e) used for other public purposes (4).

The rail system of the entire region will be shored up to retain a basic, minimum level of service. Initial financing to bring about the system involves $1.5 billion in federally guaranteed loans and $558.5 million in grants—including $180 million to subsidize or purchase lines that might otherwise be abandoned.

The RRR Act, then, produces a quasi-nationalized railroad supported by federal subsidies, and, through application of extensive planning processes, it allows additional government aid for other, non-ConRail operations. The act sets in motion the first substantial rail planning attempt by government since World War II.

EARLY RAILROAD PLANNING

There should be no misunderstanding, however, concerning past governmental traditions of rail planning. Despite the early promise of the Gallatin plan, assistance from every level of government to rail firms as they laid track during the midnineteenth century and later, and some uncertain degree of continuing governmental direction as a concomitant of economic regulation, the U.S. rail system was not rationally or carefully planned. The government could have taken a much different approach.

The Windom Committee report (which preceded federal control of monopoly practices under an 1887 act to regulate commerce) recommended national or state ownership of one or more railroads to secure competition and provide an example to the private sector (5). That model railroad, at least, would have been subject to planned development; however, the competitive emphasis of the Windom Committee report was shifted by the later Cullom Committee, whose concern was eliminating discriminatory practices. Thereafter, history records a 30-year hiatus for federal planning.

Previously, the most hopeful period for public rail planning began with the President's proclamation of December 26, 1917, placing the railroads and waterways of the country under federal operation for the war emergency. When the railroads were returned to private operation in 1920, the provisions of the radically different Transportation Act of 1920 required the Interstate Commerce Commission to adopt a voluntary plan for rail consolidation (6). After 2 decades of effort, including studies by the Office of the Federal Coordinator of Transportation under the Emergency Transportation Act of 1933 and the publication of several plans, no consolidations took place; the Transportation Act of 1940 removed the requirement (5, p. 251). The work of neither the Board of Investigation and Research, the National Resources Planning Board, nor any other World War II agency produced an acceptable plan for railroad operation (7). On the other hand, even as late as 1920 the free-entry policy and competitive service conditions in the U.S. rail industry, together with large capital requirements and the economies of scale and use available to the rail firm, had enabled the United States to put in place a reasonably efficient network without the necessity for comprehensive transport planning. The growth of new modes, plus revised government policies, has completely overturned that philosophy.

The RRR Act therefore stands out as the first modern attempt at large-scale rail planning by a nation with no history of success in the field. It is also the first attempt to switch from the past dismal results of centralized planning either solely within federal agencies or between federal government and the private sector to include state government in the process. The act is distinguished by the attention paid to state and regional government bodies and in that regard parallels other federalized transport activities in the United States. The new emphasis is appropriate because investment and promotional decisions that upset intermodal balances are often effected by the states.

STATE ROLE IN RAILROAD PLANNING

States and localities were very much involved with railroad operations before the existence of federal legislative direction (8, 9). But long-term planning of railroads by the states and even by the industry has been fragmented, uneven, and generally nonresponsive to public concerns.

Title IV of the Regional Rail Reorganization Act, entitled Local Rail Services, brings the states into the planning field by establishing subsidies for continued operation of rail lines that are not economically self-sustaining but that are important to local government for some other reason. Title IV sets the following conditions for subsidy eligibility (10):

1. The state must have established a plan for rail transportation and local rail services that is administered or coordinated by a designated state agency and that provides for equitable distribution of subsidies among state, local, and regional transportation authorities; and

2. The state agency must have authority and administrative jurisdiction to develop, promote, supervise, and support safe, adequate, and efficient rail services.

The process used is to be "comprehensive, coordinated and continuing" and designed to provide services that the state believes to be "essential to meet the economic, environmental, and energy needs of the citizens ... and to provide for the development of a coordinated and balanced transportation system." Further, the state must promote public participation and hearings and must provide various groups the opportunity for review and comment.

The plan itself, to be acceptable, should contain and be based on

1. What the state wishes to achieve through plan implementation and the state goals set for rail lines selected for subsidy;
2. A documented, acceptable process used in plan production;
3. Data on existing rail service and facilities, present and future rail service needs, modal substitution possibilities, economic, social, and environmental benefits and costs of alternatives, competitive effects, and means of achieving operation economies; and
4. A classification of the rail system by categories of lines (12).

These are concise and difficult requirements, inasmuch as no state or local planning base for rail planning existed. Moreover, they appear to exceed the planning required of federal agencies involved with rail reorganization. Evidently, states wishing to obtain federal funds have no choice but to mount thorough, intensive study efforts (the time-span allowed under the act is very short); the states under the jurisdiction of the act almost without exception began such efforts within a few months after the act went into effect in 1974.

Goals of the Rail Plan

The first step taken by most of the states in preparing rail plans was to postulate and adopt goals for the plan that set directions for rail transport in relation to the other transportation modes. After this initial action, the planning process should be tailored to achieve those goals as fully as possible, given the planning and implementation resources at hand (13).

Table 1 gives goal statements obtained from documents of two states, Wisconsin and Michigan, that are cooperating closely in their planning programs, particularly regarding joint ferry services on Lake Michigan. Both states have obtained research grants from the FRA, as well as from the Upper Great Lakes Regional Commission, to supplement their own resources (from $350,000 to $500,000 per state for a 12-month period), and input from their efforts will be part of a manual on rail planning now in preparation for wide distribution to interested states. Yet there are important differences between their goal statements. For Michigan, the statements are far-reaching and cover all conceivable desires of rail users. Conflicts among goals could easily arise for either state, but conflict possibilities stand out most strongly in the statements produced by Michigan. On the other hand, Wisconsin's goals lack specificity; What, indeed, can be done to measure net social benefits? Nevertheless, such lists should be an initial undertaking, and then, to the extent possible, the rail goals should be integrated with general state transportation policy statements.

The Rail Data Base

The information needed for state rail planning is perhaps less difficult to determine than are the goals of the plan. The data are, however, difficult to acquire. Moreover, the expense of collecting data rises proportionally with the thoroughness and detail of information desired. The cost of removing uncertainty, such as that needed to specify, say, 90 percent of the freight flow by commodity and tonnage, is great, except in the

Table 1. Goals of state rail plans.

State	Goals
Wisconsin	Provide an efficient rail transport system; make rail service decisions on the basis of total net social benefits; eliminate obstacles to intermodal transfers to promote modal integration; provide varied services to satisfy different social needs; promote a safe rail system; use the rail system to promote desirable development and to discourage overdevelopment or development in undesirable areas; create a balanced and coordinated transportation system that provides adequate, safe, and convenient transportation for all segments of society in an equitable manner and at a reasonable cost.
Michigan	Provide and maintain an adequate and efficient rail network; give consideration to the effects of changes in the rail system on the loss of jobs, decreases in tax revenues, and increases in welfare costs; promote financial viability within the system; maintain and improve the quality of rail services; promote stability in the rail services offered; provide rail services that meet public needs in terms of economic stability and development, social stability and development, and environmental protection; provide for and encourage economic and social growth and development; maintain rail services where economic and community growth show that such service is vital to continued prosperity of the region; provide rail services to the more remote parts of the state and avoid isolating any parts of the state from the rail network; avoid obstructing plans of private enterprise for increasing business and adding jobs; provide transport for commodities that are not amenable to shipment by alternative modes; maintain and improve essential services to agricultural communities; maintain and improve safe commuter rail service; explore the potential for implementing high-speed intercity rail service; ensure the safety of rail operations; maintain some excess capacity on the system; provide an adequate level of freight-car availability; maintain environmental quality, preserve natural areas, and improve energy efficiency of transportation; encourage cooperative service and the sharing of rail facilities; promote competition among transportation services and control the rates charged for noncompetitive services; enable local participation in subsidy funding to a degree consistent with the local importance of the service; minimize and compensate adverse effects on rail employees.

instance of specific key decision points, e.g., a particular branch line, a line segment where joint use of track is a possibility, or a junction point where competitive service is a special concern.

Compounding the difficulties of developing a rail data base is the fact that railroads infrequently fall within the boundaries of one state; data gathered by state or federal regulatory bodies must be prorated. Further, line-by-line data must be more specific than those that are typically available to outside parties so that individual line or line-segment viability can be determined. Also not likely to be collected is information on the social or environmental consequences of revising rail services. Although both the FRA and USRA hold significant data elements, only the railroads themselves and their customers can provide a major portion of the data.

To be gathered for a state plan are facts about traffic flow, composition, services, and rates; shipper attitudes toward and use of all modes; rail costs and costs of alternatives; and needs, desires, or plans of shippers and carriers. To indicate the types of data that are desired and to illustrate one instrument by which they may be obtained, a survey form was supplied to more than 11,000 firms in Wisconsin (including the entire manufacturing sector identified by five-digit SIC code).[1]

Although data collection of such magnitude and resultant data manipulation are extremely expensive—which should make planners wary of allocating most of their budgets to obtaining data and leaving too few resources for analysis—such an approach appears to the writer quite short-sighted. Rail planning is neither static nor a one-time affair. Time-series compilation should begin no later than at the inception of the planning process.

Demand Forecasts

Along with the current data base, forecasts must be made. The shipper survey cited can aid in providing projections and can be used in making short-run estimates to 1978 and 1980. Forecasts of future demand for the railroads and railroad supply conditions generally can be made either through scaling down national projections or by using specific survey and judgmental input.

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[1] The survey form, which was Appendix 1 in the original manuscript, is available in Xerox form at cost of reproduction and handling. When ordering, refer to XS-65, Transportation Research Record 577.

Wisconsin Example

Illustrative of the data collection, forecasting, and initial analysis phases of state rail planning are the tasks accomplished or to be undertaken for the Wisconsin rail plan.

1. The freight-operations phase involved detailed analysis of the data obtained in relation to factors such as present and potential economic activity, social and environmental impacts, and financial viability indicators. The steps include (a) defining freight subsystems, segments, and lines and preparing system segmentation maps; (b) collecting and assembling a total system freight flow data base; (c) developing a freight flow model; (d) preparing tabulations of Wisconsin freight flows; (e) developing freight projections; (f) conducting shippers' surveys; (g) analyzing the economic impact; (h) determining environmental and energy impacts; (i) analyzing the financial feasibility of rail operations; (j) developing rail operating and rehabilitation cost data; and (k) developing a transportation analysis package and running alternative simulations.
2. A particular subset of the freight operations phase was applied to Lake Michigan ferry operations and consisted of (a) inventories of physical plant (vessels, terminals), traffic (rail, automobile, truck, and passenger), user dependency (commodity and shipper surveys), ferry boat service and rates; (b) generation of alternative car ferry configurations, including route networks, service levels, and connections; (c) traffic forecasts by mode and route configuration; (d) impact assessment of alternatives for the planning period on costs (capital and operating), community service (employment and economic growth), environmental and energy considerations, rates, and routings; and (e) identification of institutional and funding arrangements and implementation possibilities.
3. The passenger service phase involves a comprehensive study of current Amtrak service and the potential for expanded passenger service in Wisconsin. This phase involves (a) determining passenger attitudes toward Amtrak and commuter train services through on-board surveys; (b) determining community attitudes on the desirability of expanded passenger service by using mail-out surveys to a sample of Wisconsin households; (c) collecting city-pair travel data for all transport modes so that the effect of improved rail passenger service on automobile, bus, and airline travel patterns can be evaluated; (d) forecasting ridership potential for both present and expanded rail service; (e) estimating the cost of expanding rail passenger service; (f) analyzing demographic and socioeconomic data to select new routes that have the best potential for expanded service; and (g) examining the social, environmental, and energy impacts of present and future rail passenger service to evaluate total social costs and benefits.

Elements of the Final Plan

The end result of successful data gathering, modeling, and simulation will be the generation of alternatives for the rail system, for shippers, and—to a limited extent—for competing modes. The state should be able to determine within some probability bounds what could happen were a merger to be effected, a branch line to be abandoned, operating costs to shift, or a new investment in plant or equipment to be effected. Priorities can then be set on line-segment reductions in order to allocate budgeted support funds. If goal priorities change, for example, to elevate unemployment concerns for a state or substate area, appropriate weights can be revised and new priorities can be obtained. How closely any state plan approaches this idealized description depends crucially on the data obtained and on the ability of the state to devise or adapt trade-off methodologies and analytical packages.

Clearly, the end result of rail planning relates more to yielding a process that will improve over time or an evolving tool that will answer the questions raised by decision makers than to providing a standardized document. With such a tool in hand states will be able to answer questions about whether railroad changes can help solve social problems. Of course, even the best rail planning process and single-mode analysis package cannot determine whether more effective means than manipulation of railroad or transportation instruments exist for the achievement of social goals.

ISSUES IN STATE RAIL PLANNING

The possibilities for meaningful state railroad planning and programming are vast, given the development of accurate planning processes, as described in this paper, and revised institutions. But major questions remain to be answered.

Are States the Proper Geographic Regions for Rail Planning?

The RRR Act identifies states as the primary focus for subnational actions involving railroads. Yet states differ tremendously in area, interests, and other attributes related to rail planning. Rail systems most frequently traverse state boundaries, thus making regional compacts necessary for such significant major actions as revising main-line configurations. Are not more intensive, nationwide federal rail planning and plan implementation superior to confederation? If not, what division of responsibility is best?

Does Rail Planning Conflict With General State Transportation Planning?

Today's methodologies are insufficient to permit comprehensive and coordinated planning of the total state transportation system, particularly when short-range priority setting or programming is necessary (11, 12). Is it possible to apply simulation techniques to the rail sector, and, if so, should suboptimization in rail transport occur? Long-term answers to these questions are perhaps impossible. The criticality of better management of rail resources in the United States and the immediacy of federal subsidy programs leave only one response. Rail plans must be developed. To the extent that rail systems, especially freight systems, are far simpler than total transport networks, the modeling effort is likely to prove successful in the larger sense.

How Might State Railroad Activities Be Financed?

Although rail planning is a new challenge for the states, it is relatively inexpensive. But plan implementation raises difficulties in providing matching shares for federal operating subsidies, assisting in rail line renovations, and helping relocate industry. Any form of user charge is likely to be instituted only with great difficulty. General state transportation funds are uncommon, and highway funds almost certainly will not be available for any major rail demands. If the rail sector requires extensive subsidy, the money can come only from federal or state general funds. The more pertinent question, though, is whether heavy or long-term subsidy is required. Most likely proper pricing of the several modes and removal of regulatory handicaps could prevent state budgetary drains. To this end, state support might well develop for substantial federal reform.

ALTERNATIVE FUTURES FOR RAIL PLANNING

At the minimum, the flurry of plan preparation and rail system investigation set in motion by the RRR Act is likely to greatly change state perceptions of the rail mode and to induce greater awareness of railroad concerns in state transportation decision making. Because rail planning is likely to expand with or even precede the probable increased coverage of the act and its successors, government promotion policies will be significantly revised in support of at least continuing at present levels the role of rail in the nation's freight transportation system. Private railroads, too, may become more open institutions, more aware of their comparative advantages, and more capable of cooperative activities with state transportation agencies. Railroads will be treated more closely on par with the other transport modes.

A hopeful outcome, unfolding during the decade of the seventies, will be the evolution of rail planning into general transportation planning wherein market forces and the direction of government resources from general-fund operating and capital budgets will be relied on as needed to remove bottlenecks and promote socially desirable services.

It is significant that the new beginnings of public planning activity for the U.S. railroad system can promise such far-reaching effects. If the initiation of railroad system planning can lead the states to effective multimodal planning, the northeast rail crisis will indeed have brought completely unforeseen benefits.

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LINEAR PROGRAMMING SIMULATION OF ROUTING EMPTY RAILROAD CARS

Edward Miller, U.S. Office of Management and Budget

This paper describes the application of a linear programming model to the routing of empty railroad cars to determine where excess capacity exists. One of the more important results is simply that the solution of a model of this size and complexity is feasible. The model showed that there were a number of railroad routes over which an appreciable flow of empty cars moved and that filling these cars could provide very low cost transportation. Finally, the solution of the linear programming problem provides a series of shadow prices for cars in different locations that can be used in setting rates, which is a new approach to incorporating directional factors into rate setting.

•THIS STUDY is one of several studies to improve railroad costing and transportation regulation (1, 2, 3). This research used several existing U.S. Department of Transportation data bases. As part of a national network model, the United States was divided into 529 zones. Each of the standard metropolitan statistical areas constituted a zone, and the rural counties were grouped into zones. Each zone was assigned a central point at which all traffic to and from the zone was considered to originate. These points were tied to a network model of the U.S. rail system, which included virtually all of the main lines (more than 200,000 miles or 320 000 km). Given a matrix of flows from each zone to each other zone, computer routines were available that routed traffic by the shortest route and then aggregated the flows over each link. This model was being used to determine the future flows of traffic over various links of the railroad network given the pattern of originations and destinations.

There was also available a special tabulation of the Interstate Commerce Commission 1965 1 percent waybill sample for railroad shipments between the different zones. At the time of the study this was the most recent data available although there were problems that prevented the classification of flows by car type. For zones that terminated more traffic than they originated, the number of tons (megagrams) of empty car capacity created each day was determined simply by subtracting the tons originated from the tons terminated. Likewise, for the originating zones, the car capacity required for loading was determined by subtracting the tons terminated from the tons originated. Then, the empty cars available in destination areas merely had to be matched with the cars required in originating areas.

There are of course a number of ways in which the empty cars could be assigned to the areas where cars were required for loading. In the real world, this would be determined by a host of institutional factors including the Association of American Railroads Car Service Rules. There was no way all of these complexities could be modeled in the initial effort. Thus, the decision was made to determine the assignment of empty capacity from termination zones to originating zones by a linear program instructed to minimize the total number of empty car miles incurred. The assignment was done by Control Data Corporation, which used the standard linear programming package, OPHELIE. The linear programming problem here is of the standard transportation type for which the solution procedures are well-known, and the only question was whether solving a problem of this size was practical. It was possible (at a computation cost somewhat in excess of $1,000).

After the empty capacity was assigned to traffic originating zones, the matrix of assignments was put into the network model and assigned to the shortest routes from the originating zones to the terminating zones. The flows over each link were then aggregated to give the total flow of empty capacity over that link. These parts of the computations were done by IBM and plotted by a CalComp plotter. The results showed routes over which there is a flow of empty cars that might be used to provide low-cost transportation.

THE MODEL

The study shows clearly that the dominant flow of empty cars is westbound, apparently reflecting the flow of raw materials into the industrial East. Superimposed on this is a flow toward the coalfields and away from the ports.

The Northwest

Perhaps the most important single result is the large capacity of empty cars flowing west from Chicago. The model assigns the largest single volume to the old Great Northern route from Chicago through Minneapolis to the state of Washington. Daily capacity is 23,000 tons (21 000 Mg) (1970 train average was 1,820 tons or 1650 Mg) leaving Chicago, 30,000 tons (27 000 Mg) out of Minneapolis, and 21,000 tons (19 000 Mg) across northern Montana. This represents the return of empty grain and lumber cars to the Great Plains and the Pacific Northwest.

Another flow of empty cars moves west from Chicago (38,000 tons or 34 000 Mg daily) and diminishes as it moves west, finally disappearing in Wyoming. A major branch (13,000 tons or 12 000 Mg) goes into Iowa. The flows on the other lines in the Great Plains are generally westward although in smaller volumes. There is a substantial amount of empty capacity on the Union Pacific (21,000 tons or 19 000 Mg) between Denver and Ogden. West of Ogden this capacity diminishes to 3,000 tons (2700 Mg) daily. West of Reno the flow of cars is eastbound (1,000 tons or 900 Mg daily), reflecting the return of cars used for exports out of San Francisco. On the Union Pacific from Ogden to Los Angeles, the flow becomes evenly balanced in southern Utah. In the Pacific Northwest the flow becomes eastbound near the ports of Portland and Seattle.

The policy implications of this generally westbound flow of empties are several. One is that there is a strong case for rates that are lower westbound than eastbound in this area. In particular, the cost of sending exports from the Midwest and Great Plains out through Seattle and Portland (and to a lesser degree San Francisco and Los Angeles) is much lower than the distances involved imply. Such exports can move most of the way in cars that would otherwise be returning empty. In contrast, exports through the nearer East Coast ports require not only using a car that would not otherwise be moving but also returning the empty car. On import traffic the opposite is true: The expense of importing to the West Coast is very high.

If directional rates are considered improper, the commodity rates should reflect whether the commodity can normally be handled as a backhaul or whether it is in the normal direction of commodity movement and as a result will require an equal empty car movement. For example, the movement of lumber out of the Pacific Northwest is in the direction of normal movement and as a result is relatively expensive. The rates should reflect this.

The West Coast

Along the West Coast the normal flow of empties is into the timber regions of Oregon from as far south as San Diego and as far north as Seattle.

The Southwest

In the Southwest the empty flow is westward from Houston to Los Angeles. However, the flows are relatively closely balanced, and the empty westbound capacity is small in comparison to the total flows involved. On the main track of the Santa Fe, the flow of empty capacity is only 1,769 tons (1604 Mg) daily west of Albuquerque and 0 leaving Arizona. On the Southern Pacific main line the flow drops to only 1,024 tons (928 Mg) daily in southern Arizona. The model shows no flow of empties for the Union Pacific into southern California. The flow of consumer goods into the population centers of California almost fills the empties left from the shipments or agricultural products out of California. It is likely that, with seasonal fluctuations, there is frequently no idle capacity on the southern transcontinental routes. This is a contrast with the situation for the northern routes where the large flows of eastbound lumber guarantee the possibility of using a backhaul westbound.

As a result, the marginal cost of hauling export traffic westbound is lower on the northern transcontinental routes than it is on the southern routes (where sometimes an empty backhaul cannot be found). This would make Seattle and Portland especially well suited for export traffic from the eastern United States and Los Angeles better suited for the import traffic.

The South

The flow of empties in the South is dominated by the return of empties to the coalfields and by the flow of empty cars from the ports toward the interior. Because the model does not distinguish between car types, it is difficult to separate out the two movements.

One stream of empties starts at Charleston and eventually grows to 77,000 tons (70 000 Mg) daily as it approaches the east Tennessee coalfields. Some of the empties from Savannah (4,000 tons or 3600 Mg daily) take this route. Part of this flow is clearly empty boxcars out of these ports. Virtually all southern ports show a flow inland from them, as shown below:

City	Empty Capacity (tons/day)	City	Empty Capacity (tons/day)
Wilmington	3,000	Pensacola	6,500
Charlestown	13,000	Mobile	6,000
Savannah	22,000	New Orleans	13,000
Jacksonville	17,000	Houston	34,000
Tampa	19,000		

In the case of Tampa, many of the empties are cars returning to the phosphate producing regions. In most cases, empties are moved only a relatively short distance before they are needed for loading somewhere in the interior South. One long-distance flow goes from New Orleans to Saint Louis, and another goes from New Orleans into southern Kansas although after it passes Texarkana empty capacity is less than 2,000 tons (1800 Mg) daily.

Contrary to expectations, this model shows no flow of empties from the North into the South (other than into the coalfields). The South (south of the Virginia-Kentucky line) meets its own needs for empties. Cars do, however, move from Texas and Louisiana to the Great Plains and the Pacific Northwest.

The one long-distance movement out of the South starts at Houston at 13,000 tons (12 000 Mg) daily and grows to 24,000 tons (22 000 Mg) daily northwest of Fort Worth. The movement lessens to 6,000 tons (3600 Mg) as it flows northwest through Colorado and eventually reaches the timber-producing regions of Oregon. In this case, optimal flow differs somewhat from what actually occurs inasmuch as the flow of loaded cars is not large along this route.

As shown above virtually all ports have a net flow of empties away from them. This is true of northern and Great Lakes ports also, although it is difficult to separate the flow of empty coal cars from that of box cars. As a result the cost of handling import traffic is substantially reduced because much of it can be handled as an empty backhaul. Likewise, export traffic will usually leave an empty car at a port that already has a surplus of empties. Thus, it will involve a return of the empties.

As a result export rates should generally be higher than domestic rates, and import rates should be lower. The actual pattern tends to be the reverse in which many export rates are below domestic rates and there are few special import rates. Part of the reason for this has been public pressure to improve the balance of payments by encouraging exports and discouraging imports. The reduced rates on exports are also due to the greater elasticity of demand for exports than for domestic sales. The American consumer frequently has little alternative to consuming American products, and sales will decline little if transportation costs are increased. However, foreign consumers have alternative sources of supply and, if the U.S. price is too high, will shift their purchases. Thus, American producers have frequently been able to convince the railroads that low rates are required if the traffic is to move. Although the same argument might seem to apply to import traffic, domestic producers have been able to argue that the railroads would receive less revenue from imports than they do from the domestic production that would be displaced. Thus special import rates have been relatively rare.

The Northeast

The optimal flow of empties in the East is heavily dominated by the return of empty coal cars to the coalfields. The largest single flow found on any link in the network was a capacity of almost 200,000 tons (180 000 Mg) going through western Virginia into the coalfields of West Virginia. This flow is fed from two sources. The return of empties from Hampton Roads accounts for 127,000 tons (114 000 Mg) per day. The remainder is a flow that starts at New York City and gradually grows as it moves South until it is 55,000 tons (50 000 Mg) per day passing out of Washington, D.C. This southbound flow probably includes a flow of nonhopper cars to the South, although the model sends all such cars to West Virginia. In actuality the coal trade is handled through inland lines and does not pass through Washington.

A second flow starts at Springfield and proceeds west to the Hudson and then south to Allentown where, at 15,000 tons (13 600 Mg) daily, it joins a much larger flow of 41,000 tons (37 000 Mg) daily out of New York. From there it proceeds southwest through Hagerstown into the coalfields of northern West Virginia; by then it has grown to 85,000 tons (77 000 Mg) per day.

Smaller flows go to Pennsylvania from Boston through Albany and Binghamton (peak of 34,000 tons or 31 000 Mg daily at Binghamton), from Rochester at 17,000 tons (15 000 Mg) daily, and from Buffalo at 11,000 tons (10 000 Mg) daily. Two major flows leave Toledo, Ohio. One starting at 40,000 tons (36 000 Mg) per day goes south toward Columbus, where it is joined by a flow out of Youngstown and Akron at 15,000 tons (13 600 Mg) daily and on into the coalfields of eastern Kentucky at which point it has grown to 86,000 tons (78 000 Mg) daily. The other flow out of Toledo at 40,000 tons (36 000 Mg) daily goes southwest into Indiana where at Muncie it is joined by a smaller flow from Detroit at 16,000 tons (14 500 Mg) daily. In southern Indiana the combined flow reaches 64,000 tons (58 000 Mg) daily before disappearing into western Kentucky.

There are a couple of smaller flows that do not appear to be due primarily to coal movements. There is a flow of empties of 17,000 tons (15 000 Mg) daily out of Chicago to the agricultural area south of it. Another flow of 11,000 tons (10 000 Mg) per day comes out of central Michigan and disappears into the agricultural areas of Indiana and Illinois. There are small flows of empties from Chicago, Detroit, Muskegon, Syracuse, and Albany back to the lumbering areas north of them.

Otherwise, the movement of nonhopper empties is completely concealed by the return of coal cars. Although there is certainly a movement of other cars from east to west, this is not shown by the map. Because all cars are considered identical, the model takes empty cars from cities such as New York, Boston, and Cleveland and uses them to meet the great demand for cars to carry coal from the coalfields. Any coal cars that arrive at Chicago are sent west to handle grain and lumber. It is suspected that some of the southwest flows of empties, notably those from Detroit, may not exist in practice and that the optimal pattern would be to send coal cars south to the coalfields and most other cars west.

POLICY IMPLICATIONS OF THE AVAILABILITY OF EMPTY HOPPERS

The actual amounts of available capacity in the direction of the coalfields are somewhat less than the model indicates because the flow of coal is out of the mountains toward cities at lower elevations. The empty cars usually must be hauled back against the grade. Thus, the amount they can carry without exceeding the hauling power of the locomotives is less than the amount of coal that was taken out of the coalfields. Fortunately, many of the coal-carrying lines appear to have sufficient backhaul capacity so that this constraint is not binding.

Because the flow of empties in the East is dominated by the return of coal cars, the largest economies of using backhauls will come from shipments of bulk commodities that can be moved in open hopper or gondola cars. These are principally raw ores, stone, gravels, and the like.

Perhaps the most important possibility is for movement of iron ore. Because coal and iron ore have nondirectional rates (and iron ore rates are higher than coal rates because of the threat of substituting other fuels for coal), the steel industry has tended to locate at points where iron ore could be unloaded from the boats—along the Great Lakes or the Atlantic Ocean. The desirability of a short haul for the iron ore led to much of the remaining capacity being near the Great Lakes (Pittsburgh and Youngstown). However, if iron ore is transported as a backhaul, the optimal location for much of the capacity is on or near the coalfields. The large volume of coal being shipped out for electric power generation guarantees the availability of backhauls for carrying the iron ore.

A steel firm located near Huntington, West Virginia, could use some of the large backhaul capacity from the Great Lakes ports, such as Toledo. The coal haul would be shortened by about 280 miles (450 km). The costs could be reduced further if a steel firm located in the West Virginia or Kentucky coalfields. However, to do this might lead to problems in finding a suitable plant site or a labor supply. Also the choice of coking coals might be somewhat limited. The Huntington area is where the C&O line from east Kentucky and Virginia, the C&O line from West Virginia, and the Norfolk and Western line from West Virginia converge. This gives an excellent selection of coals.

The transportation costs of steel would be reduced if a firm moved southward since the Great Lakes area has a surplus of iron and steel capacity. As a result much of the finished product must be exported from the area. Many of the markets now served by the Great Lakes industry could be served more cheaply from locations along the Ohio River. In some cases it would be practical to use the river as a shipment route.

Currently, the eastern steel mills that use foreign ore are located near Baltimore and Philadelphia where iron ore can be brought in by ship and coal by rail and where markets are nearby. A cost-minimizing location would probably be closer to the coalfields, perhaps near Roanoke, Virginia (from which products could be shipped northward along the N&W line to Hagerstown or southward to Winston-Salem and Durham and near which limestone is available). The large flow of empties out of Hampton Roads would be used to bring the iron ore inland 260 miles (420 km), which would shorten the coal haul by the same amount.

It must be realized that the cars used for hauling iron ore are not the same cars that are normally used for hauling coal. Iron ore is much denser than coal, and a coal car fully loaded with iron ore would exceed its weight limits. When iron ore is carried in coal cars, it is often loaded into two piles directly over the trucks. This calls for a more complex loading procedure and increases the risk of freezing. The other alternative is to use the short stubby iron ore cars for carrying coal. Regardless of which strategy is adopted, the advantage of using a backhaul is not eliminated because a less-than-optimal car must be used.

However, it would appear that there are significant public benefits to be gained from allowing very low rates for shipments that use what would otherwise be an empty car movement. In addition to iron ore, other commodities can probably use some of this empty capacity with suitable rates.

As can be seen, one of the major implications of allowing directional rates would be increased industrialization of Appalachia.

IMPLICATIONS FOR OTHER COMMODITIES

Unfortunately most commodities require cars different from those used for coal. Until the development of combination box and hopper cars, such as the ones Canada is experimenting with (such cars use a grating for the floor through which flowable materials can be emptied), the returning coal cars can be used only for certain commodities. However, the locomotive and crew capacity that was used to haul the load outbound is available for hauling a load inbound. For instance, if a shipment is made in a box car from Toledo to West Virginia, the loaded movement will be opposite in direction to the predominant flow of traffic. Going into Kentucky, the car and contents can be hauled in existing trains without additional train or crew miles. This makes the cost of the loaded line haul very low. However, when the empty boxcar is returned, it is moving in the same direction as the predominant flow of traffic. Thus the return of the car will require the running of additional trains and the hiring of additional crews. However, the weight hauled in the heavily loaded direction is only that of an empty car rather than that of a car plus load. Thus the costs for other commodities moving into the coalfields are reduced (and increased when it is outbound from the coalfields).

IMPLICATIONS FOR RATE MAKING

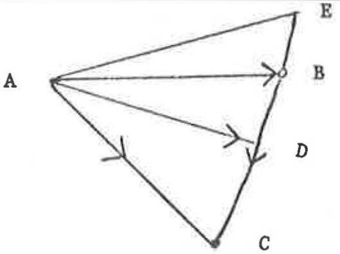
The discussion so far has dealt with the rather special case of shipments that parallel the predominant flow of empties. If the shipment being costed is in the direction of the flow of the empties, it is possible to use these empties for the movement. If the flow is in the opposite direction, the cost of returning the empty will be incurred. However, most real movements are not this simple. They may start out moving in the direction of an empty flow and then, after passing a point where a large number of empties are required, continue on against the empty flow.

Also shipments may move in a direction that is not the same as that of empty cars. Perhaps the simplest case is that shown in Figure 1. The normal movement of empties is from A and B to C. A and B are the same distance from C. If a carload is sent from A to B, the number of miles the empty car must travel to reach a point of loading is unchanged. The car will merely be sent to C from B instead of from A. This supposes that the car can be sent to C in accord with the car service rules. If the three links were owned by different railroads, it might be necessary to return the cars to A rather than C.

Assume that all three lines and the car are owned by the same railroad. Now suppose the shipment is to point D. After it is unloaded it is closer to C than it was before. In particular, the cost of moving the car the distance BD has been saved and can be used as an offset to the cost of the haul. Likewise on a shipment from A to E, the car is moved farther from where it will next be required. The added cost of hauling the car for the distance E to B represents a cost of the movement A to E.

Thus, it is possible to compute the cost of movements link by link if it is known whether they move cars

Figure 1. Possible movement of empties.



closer to or farther from areas of surplus.

USE OF SHADOW PRICES

However, there is a simpler approach. In the course of the original linear programming assignments of capacity to points of need, shadow prices were derived that represent the increase in the total empty ton miles produced by additional demand for cars in each zone. For instance, the New York metropolitan region has a value of 2,661 miles (4282 km). This indicates that a 1-ton (0.9-Mg) increase in unloadings at New York would increase the number of empty ton miles by 2,661. (The timber region of central Oregon is zero.) Likewise, Chicago has a value of 2,201 miles (3541 km). This means that 2,201 empty car miles would be added if the supply of empty cars was increased by one car at Chicago. The shadow price will be referred to as the car potential because it is analogous to the concept of potential in electrical engineering.

If a car is transported from New York to Chicago, the supply of cars in New York is decreased by one and that in Chicago increased by one. The car moved out of New York reduces the needed empty car miles by 2,661 and the added car at Chicago increases the empty car miles by 2,201. The net effect is a reduction of 460 miles (740 km) in hauls needed to return empties to where they are required. It should be noted that this is substantially less than the minimum railroad distance between the two points. Thus if a carload shipment between New York and Chicago would reduce the required empty car miles by 460, the cost of moving an empty car this distance is saved by having the loaded movement. To calculate the cost of the shipment from New York to Chicago requires that this saving in empty car miles be deducted.

Likewise, a shipment from Chicago to New York would increase the number of empty car miles required by the system by 460 miles (740 km). The cost of a carload from Chicago to New York should include the cost of these 460 added empty car miles. (In addition there will be the empty car miles needed to take the cars to and from central areas in each zone to the actual point of shipment.)

If in the optimal solution empty cars are actually sent from one area to another, the difference in shadow prices will be equal to the distance between the zones. If there are no flows between the zones, the difference in shadow prices may be less than the actual distance between the zones.

PATTERN OF SHADOW PRICES

The map of shadow prices falls into two zones. In the western United States shadow prices increase in all directions away from central Oregon. The rate of increase decreases, however, in the vicinity of the Mississippi River. In the East and South the variation of shadow prices is less, and between major metropolitan centers it is often small. This is especially obvious when the major ports are compared. For instance, some typical shadow prices are as follows:

Port	Shadow Price	Port	Shadow Price
New Orleans	2,504	Baltimore	2,465
Mobile	2,347	Philadelphia	2,571
Jacksonville	2,576	New York	2,661
Wilmington	2,596	Boston	2,926
Norfolk	2,503	Buffalo	2,518

Aside from Boston and Mobile, the differences between cities are small. Shipments from one of these cities to another have little effect on the total cost of getting cars where they are needed. Reasonably accurate cost computations can be made by assuming that car flows do not have pronounced directionality and that a movement from one city to another does not appreciably change empty car miles. Thus, an allowance for such miles is not needed in the costing (other than for local movements). In traditional costing terminology, the percentage empty is zero.

What is happening is that the car flows are to and from the interior (and notably to and from the coalfields) and the movements between the port cities are at right angles to these flows. Thus, as shown in Figure 1 the overall situation is little affected by shifting cars between these cities.

The loading and unloading of ships are probably the industry most sensitive to inland transportation costs. However, if the data given here are applicable for all types of cars, there is not much difference between the eastern ports in the number of empty car miles that result from using them. The situation is different on the West Coast, where there is a flow of empties parallel to the coast. For instance, the shadow price for cars at Portland is 233 miles (375 km), 940 miles (151 km) at Los Angeles, and 1,183.5 miles (1904.6 km) at San Diego. As a result east coast exports through Portland have the lowest cost, and routing imports through San Diego or Los Angeles has the lowest cost. The difference in costs between Portland and Los Angeles is equivalent to the cost of hauling an empty car 707 miles (1138 km).

There is an even larger difference between the two coasts in shadow prices. The minimum difference is between San Diego (1,048 miles or 1686 km) and Galveston (2,222.5 miles or 3576 km). This is still a difference of almost 1,200 miles (1900 km) of empty haul saved by exporting through San Diego and importing through Galveston. In most cases the saving in exporting through the West Coast and importing through the East Coast is even greater.

LOCOMOTIVE AND CREW USE

The work has been devoted to showing that it is possible to calculate shadow prices for cars, which can be used for costing purposes. To do this it was required that all types of cars be considered together. Thus it is possible that the shadow price pattern for the different types of cars would be substantially different from the composite pattern described here; therefore, the above conclusions should be checked by using separate models for different kinds of cars.

As discussed earlier, there is usually excess capacity in locomotive engines and crews in the direction of flow for empty cars. Even for goods carried in cars different from the empties being returned, there are economies in using the excess capacity in the engines or crews for hauling the cars. The results of this model should give reasonably good indications of where such economies are.

CONCLUSIONS

Several conclusions emerge from this work. One is that the use of linear programming for determining efficient routing of empty cars is computationally possible. It may have application for operational problems in which it is necessary to determine where cars should be sent after unloading. Such models might be especially useful if some type of national car pool is ever established.

Another conclusion is that, even with efficient car routing, there are substantial numbers of empty cars being moved over long distances in this country. It should be recalled that the model indicates minimum volumes of empty flows since the objective function used was to minimize the number of empty ton miles. In the real world, the disposition of empty cars is determined by a host of institutional factors. A railroad typically retains empty cars on its own lines, even though another railroad in the vicinity might need such cars for loading. When cars are off line, they are normally returned to the owning line by the most direct route. This need not be the most efficient procedure for the rail system as a whole. For instance, a railroad may have a steady flow of traffic from Seattle to Chicago and a steady flow of empties from Chicago to Seattle. Suppose this railroad loads one of its cars for shipment by a different railroad from Chicago to New Orleans. The empty car would normally be returned by that railroad to Chicago, from whence it would be sent to Seattle. The linear programming model would probably send the car by the direct route from New Orleans to Seattle, greatly reducing the total empty car miles. Finally, cars are of different types and are not completely interchangeable as is assumed in this model. For these reasons the actual capacity of empty car movements is greater than indicated by the model and perhaps in somewhat different locations.

Wherever there is an imbalanced movement of cars, there is an opportunity for carrying freight in the empty cars at a very low marginal cost. Conversely, when goods are carried in the predominant direction of movement, the marginal costs are high because every additional carload of freight implies the return of an additional empty car. Notice that this differs from standard ICC railroad costing, which uses a single empty return rate for each type of car regardless of the direction of the movement or the commodity carried. To induce shippers to use the excess capacity represented by empty cars probably requires that rates reflect the true marginal costs by being lower where empty backhauls can be used. Such directional rates have traditionally been opposed by the Interstate Commerce Commission as involving undue discrimination.

In most cases, giving low rates for backhauls merely permits the railroad system to capture some traffic from other modes or results in a small expansion in the capacity of shipments in certain directions. However, in certain cases more interesting effects on the location of industry may be anticipated. Unfortunately, only brief summaries of the results were presented because the full tabulation of flows is voluminous, and even when plotted the map is 5 by 7½ ft (1.5 by 12 m).

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