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Theory for Estimating Traffic Diversions on a Restructured U.S. Railroad System

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Each proposal to restructure the U.S. railroad system involves an analysis of the extent to which traffic will shift from existing routes to new routes offered by the restructured network. Classically, this exercise was conducted manually by traffic clerks and marketing personnel; however, the recent availability of machine-readable nationwide railroad traffic data enables these analyses to be done efficiently by a computer. An elementary model of traffic diversions suitable for estimating traffic diversions that result from a limited restructuring of the U.S. railroad system (i.e., individual mergers such as the Burlington Northern and the St. Louis-San Francisco Railway Company) is based on the redistribution of traffic among existing routes and new routes on the merged railroads. However, if all or most of the railroads are merging or changing configuration, all or most of the existing routes will be modified and therefore all new routes must be generated; this is termed the advanced model. This paper develops in detail the underlying theory for estimating traffic diversions on a vastly restructured railroad system. Historical shipper behavior data are presented to justify route selection and traffic assignment procedures. A stepwise application of the method is described and results are presented.

At present, the railroad industry is besieged with proposals that call for the restructuring of the operating jurisdictions of its various constituent companies. Proposals to merge, acquire, abandon, provide direct service, or otherwise consolidate are being forwarded by the railroad industry as well as by government agencies such as the Interstate Commerce Commission (ICC), the Federal Railroad Administration (FRA), the United States Railway Association, and the New England Regional Commission of the U.S. Department of Commerce. This jostling for position is not new. The railroad industry has undergone a continual restructuring of its geographical operating territory during its 150-year life. The current trend was, in a sense, spurred by the bankruptcy of the Penn Central Transportation Company and the enactment of the 1976 Railroad Reorganization and Regulatory Reform (4R) Act, but it is also simply the newest cycle of railroad geopolitics. A previous cycle founded the Penn Central, the Burlington Northern, the Seaboard Coast Line and the Louisville and Nashville Railroad Company (Family Lines), and the Chesapeake and Ohio, Baltimore and Ohio, and Western Maryland Railway Companies (the Chessie System). The present cycle may lead to mergers of the Burlington Northern and St. Louis-San Francisco Railway Company; the Chessie System and Family Lines (CSX); Missouri Pacific and Union Pacific; the Boston and Maine Corporation, Maine Central Railroad Company, and the Bangor and Aroostook Railroad Company (New England Rail Company); Core-Consolidated Rail Corporation (Core-Conrail); Core-Chicago, Milwaukee, St. Paul and Pacific Railroad Company (Core-Milwaukee); controlled liquidation of the Chicago, Rock Island, and Pacific Railroad Company; and a host of abandoned lines. Each proposal has either been formally presented to the ICC or is under active study by government agencies. Other restructuring of conventional and bureaucratic interests go as far as to include consolidations that would lead to a U.S. railroad system composed of only several east-west and north-south railroads.

A major impact of these consolidations is that the shippers who patronize the railroad industry will be faced with a significantly different logistic environment and with different intramodal as well as intermodal competition. This will cause the shippers to rethink their logistic patterns and thus there will be a significant effect on the distribution of traffic, which will affect the fundamental operation and validity of economics of each member carrier of the restructured railroad system.

The purpose of this paper is to describe a computer-based analytical method for estimating the shipper's logistic response to a vastly restructured system of railroad networks and thus its impact on traffic distribution, revenue potential, and costs of each railroad. In a recent publication, Kornhauser (1) described a method for estimating the effect on traffic flow of a limited restructuring of the U.S. railroad system, i.e., the evaluation of the traffic impact of a single merger or a single abandonment. This elementary theory of traffic diversions is based on the premise that a shipper will need to make only incremental changes in logistics patterns as the result of a single merger. Thus, routing decisions are heavily biased toward historical routing patterns. This premise allows for the reliance on historical traffic data and the creation of new routes only in those markets in which new single-carrier service is created by the merger. Otherwise, traffic is assumed to be shifted among existing routes.

Faced with a vastly restructured railroad system,

shippers will generally not have old routes to choose from and will be faced with a completely new set of logistic choices. Accurate assessments of the impact of each consolidation must include accurate forecasts of the shipper's response to these choices. Although it is appropriate to assume that shippers will select routes that are consistent with their historical choice patterns, the historical routes may, in general, no longer be the preferred routes. New routes must therefore be generated that are consistent with the behavior of shippers in selecting routes.

Traffic diversion analyses have been part of all merger applications and serious consolidation proposals for at least the last 60 years. However, these analyses have always been done manually by using teams of traffic clerks and marketing personnel. The procedure generally consists of the evaluation of each market through the use of expert judgment. This method leads to the inclusion of all kinds of qualitative factors in the traffic diversion process, which can lend greater accuracy to the forecasts than is possible in a rigid analytical framework. However, this process is extremely costly in terms of time and personnel, cannot be audited, is in general not consistent or repeatable, and provides no sensitivity information. The computer-based method described here tends to overcome these drawbacks.

The purpose of this paper is to describe a method for forecasting the distribution of traffic over a vastly restructured U.S. railroad system. The method itself has been termed the advanced theory of traffic diversions. This theory uses a three-dimensional visualization of the U.S. railroad network, the Quanta-Net Intercarrier Route-Choice Model, which attempts to replicate shipper behavior. The model's data requirements and applications are described.

ELEMENTS OF THE ADVANCED MODEL OF TRAFFIC DIVERSIONS

As described above, the advanced theory of traffic diversions assumes that only the origin, destination, and tariff of railroad traffic of various commodities are known. It is the objective of the method to identify the route or routes over which that traffic will flow. Once all traffic is routed, the traffic captured by each railroad, its distribution over various segments, commodity breakdown, gross revenues, and even costs may be computed.

The method depends on (a) two primary models, a route-choice model (the Quanta-Net Intercarrier Route-Choice Model, an extension of the Intracarrier Route-Generation Model) and a market-share model; (b) traffic demand data, which are assumed to provide the origin, destination, and tariff of all railroad traffic in the forecast time frame; and (c) network data, which are link-node characteristic data of each railroad configuration in the forecast time frame.

Network Data

The railroad network data required for the model must give information on (a) the nodes, which are the locations at which traffic can be originated, terminated, and interchanged between railroads, and (b) the links, which are the connecting segments. These data are now available in the Princeton Railroad Network Model, which contains all fundamental node and link characteristics of the U.S. railroad network. The basic network consists of some 16 373 Net-3 nodes and 17 874 links that connect these nodes. Characteristics for each node include (a) x,y-coordinates that permit geographic display of the network and correlation with any geographic data such as political boundaries and socioeconomic statistics (e.g., population) and (b) translation tables between Net-3 node numbers and station name, the standard point location code (SPLC), freight station acounting code (FSAC) (2), Association of American Railroads (AAR) Rule-260 interline junction code (3), FRA 1975-1978 accident statistics (4), trailer-on-flatcar (TOFC) ramp file (5), the FRA yard file, and National Railroad Passenger Corporation (Amtrak) stations. The FSAC, SPLC, and junction translation tables allow for the conversion of all pertinent traffic-generation and route data contained in the carload waybill statistics so that they can be correlated with the network data. The most important of these correlations enables the traffic data to be assigned to the network in a classical traffic assignment process and displayed geographically.

The link data consist of characteristics that identify the ownership, trackage rights (if any), distance, and FRA Section 503 code for the main line and branch line of each link. The link data base also includes speed, grade, curvature, signal system, and number of tracks of many (but not all) links.

Information that is not contained in the data base includes the location of specific shippers, travel time, and travel-time reliability. It would be beneficial to have the travel-time data; however, it is believed that distance and route impedance measures based on the Section 503 codes for the main lines and branch lines serve as adequate surrogates.

Traffic Data: Carload Waybill Statistics

Under the terms of ICC Order 49 (Code of Federal Regulations, Section 1244), line-haul railroads that have operating revenues of more than $3 million are required to submit a sample of audited waybills to FRA. The waybills submitted are to be those that terminate on the submitting railroad and end in the numbers 01. FRA converts these waybills to machine-readable form. Each year's sample represents slightly less than a 1 percent sample of the year's carload movements (between 175 000 and 200 000 carloads/year for 1973-1978). Each waybill contains fundamental data that identify the shipment (e.g., number of cars, net tons, commodity, car type, car owner and number, and total revenue) and fundamental route data (origin, origin railroad, destination, destination railroad, and, since 1973, each overhead railroad and interline junction). The fundamental route data base has been enhanced by researchers at Princeton University (6, Chapter 7) to (a) reconstruct many of the defaulted junction codes; (b) include Net-3 numbers, which facilitate the use of the data in conjunction with the network data base; (c) estimate mileage for each railroad segment of the route; and (d) calculate the impedance of each route segment, which is equal to the sum of the impedances of all links that make up the route (the impedance of a link is equal to its distance times its Section 503 code for main line and branch line. The impedance, distance, and number of interline junctions provide surrogate measures for the quality of the waybill's route.

Although the carload waybill statistics are an imperfect sample (7-9), some of the imperfections have been corrected, and they are (in our opinion) the best data available for any mode of freight transportation. The data are certainly adequate for purposes of strategic planning and policy and market analysis.

Intracarrier Route-Generation Model

The waybill data described above provide a basis for observing shipper route choice and thus for constructing a behavioral route-choice model. It is the shipper's (consigner's) responsibility to specify the railroad-interline junction sequence for each carload, although this is often done in conjunction with or by sales representatives of the originating railroad. It is the responsibility of the operating department of each railroad to route the shipment from the point at which it receives or originates the shipment to its forwarding or terminating location. Railroad operations are based on yard-to-yard blocking patterns and train schedules. At present no algorithm exists that can efficiently reconstruct such patterns; however, one consequence of such patterns is that major yards are located along or at intersections of main lines, and traffic tends to flow along main lines and avoid branch lines. Thus the traffic-flow impacts of railroad operations can be embodied in an algorithm that tends to route traffic along the shortest main lines and uses branch lines only for continuity or to avoid very circuitous alternate routes. These observations suggest that a simple minimum-impedance route-finding algorithm whose impedance measure is distance weighted by main-line--branch-line classification may lead to an adequate method for reconstructing intracarrier routes. The particular impedance measure used in the Princeton Intracarrier Route-Generation Model is simply the sum of the impedance on each link (I_j) of route k:

$$I^k = \sum_{j \in k} I_j \qquad (1)$$

The impedance of link j is

$$I_j = D_j MLC_j \qquad (2)$$

where D_j = the distance on link j and MLC_j = the Section 503 main-line--branch-line code for link j. MLC_j = 1, 2, 3, or 4 depending on whether link j is an A main line, B main line, A branch line, or B branch line, respectively. This impedance measure has the effect of greatly discouraging routes that use branch lines and of forcing the traffic (if reasonable) to flow on main lines, as is observed in practice.

No rigorous analytical calibration of the impedance formula has been performed; however, an extensive qualitative validation has been undertaken (10). Many minimum-impedance routes have been analyzed graphically by operations personnel of many major railroads. In all but a few instances, the routes generated correspond to actual routings used. The traffic does flow through major yards and on main lines, and the algorithm does reconstruct aggregate operational practices.

Elements of Shipper Route-Choice Behavior

The Intracarrier Route-Generation Model is an integral part of the Quanta-Net Intercarrier Route-Choice Model discussed in the following section. It is also an essential element for studying the elements of shipper route-choice behavior. When applied to historical data, it provides additional performance measures about shippers' observed routing patterns. Studies of these patterns of route choice (11,12) indicate that

1. Single-carrier service is preferred overwhelmingly over multiple-carrier service, except in markets more than 1000 miles distant where only run-through routes obtain sizeable (but rarely dominant) market shares;
2. Routes that have fewer carriers are generally preferred;
3. Relative impedance is a better measure than distance for identifying dominant market-share routes when each route uses an equal number of railroads; and
4. If given a choice of interline junctions, the originating carrier tends to get the long haul.

These historical route-choice patterns define shipper behavior and also suggest an analytical framework for forecasting routes over a restructured railroad system. By including an impedance for each interline transfer, a minimum-impedance route-choice model would tend to find routes that minimize the number of interline transfers. By using a constant unilateral discount for the impedance on all links of the originating railroad, minimum-impedance routes would tend to use the originating railroad as far as possible; thus the long-haul principle would be simulated. Finding the discount for the originating carrier's link impedance is straightforward. Consideration of junction impedance requires the reformulation of the network node-link data by using the three-dimensional quantum-network concept, the Quanta-Net Intercarrier Route-Choice Model.

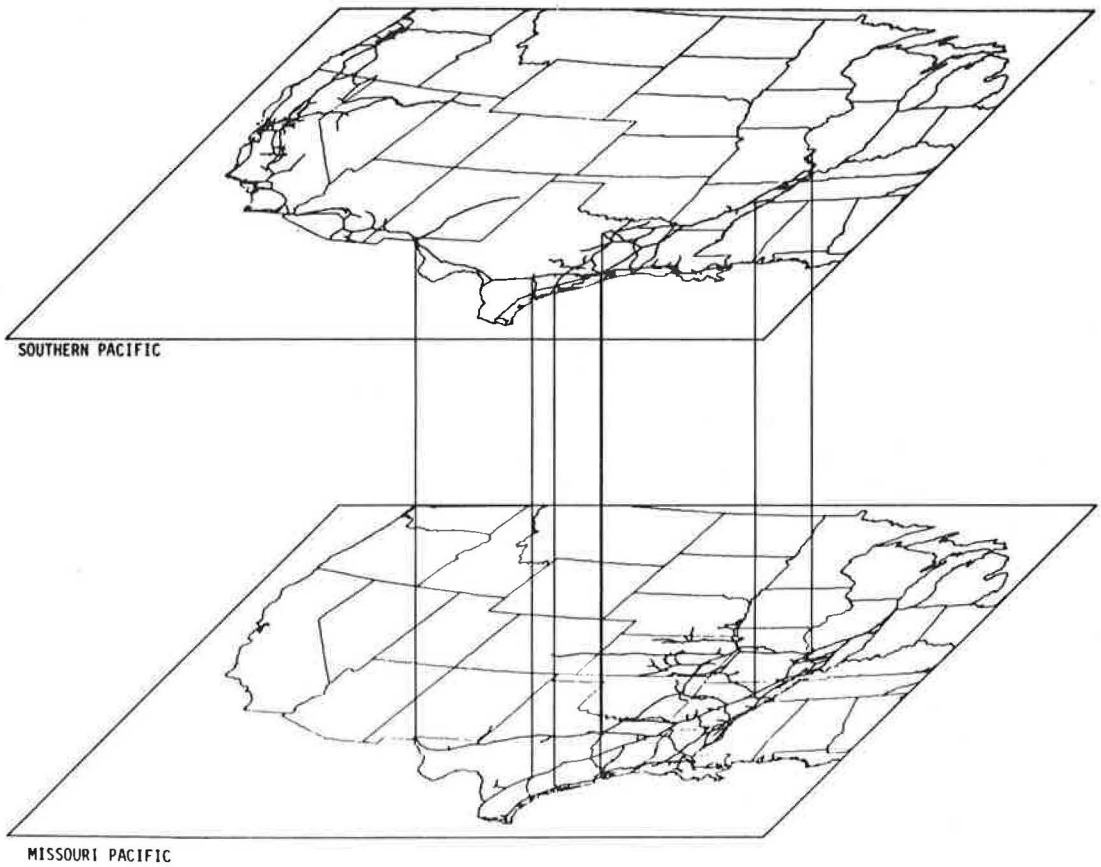
Quanta-Net Intercarrier Route-Choice Model

Concept of the Model

One method of generating multicarrier routes in a way commensurate with shipper behavior is to conceive of each carrier's network as a distinct entity connected to other carriers at certain points by junction links (instead of nodes), where each junction link has an appropriate impedance (13). The realization of this concept requires a redefinition of the network data so that each node (as well as each link) of the quantum network is unique to a (single) carrier and so that additional links are added to the network data to serve as jumps between unique carriers. Thus each carrier can be considered to operate on a unique plane, or quantum level. Jumps to another quantum level (carrier) can only occur by junction links in which an impedance penalty is incurred during the transfer from one energy level to another. This concept can be visualized in Figure 1, which shows the Missouri Pacific on one plane and the Southern Pacific on another. Junction links are shown at the major junctions between these railroads. Special interline operational efficiencies such as run-through operations may be simulated by reducing the impedance at those junctions, while junctions that have poor facilities or unmatched schedules can be replicated by increasing the junction impedance. If the distance between the quantum levels is to be proportional to the nearby junction impedance, Figure 1 would need to be modified so that each railroad occupied a surface warped by the relative value of the junction impedance.

The quantum-network configuration can be constructed through a sequential enumeration and translation of the nodes and links of each carrier and the manual definition of the Net-3 location of each junction and its interchange carrier. Hornung (14), in one definition of a quantum network, identified the 408 most-active junctions in the United States (those junctions that have an average of at least 10 carloads/day of interchange traffic). This configuration of the 41 largest railroad companies is made up of a network of 17 172 unique nodes,

Figure 1. Quanta-Net structure between Southern Pacific and Missouri Pacific railroads.



18 175 carrier links, and 408 junction links.

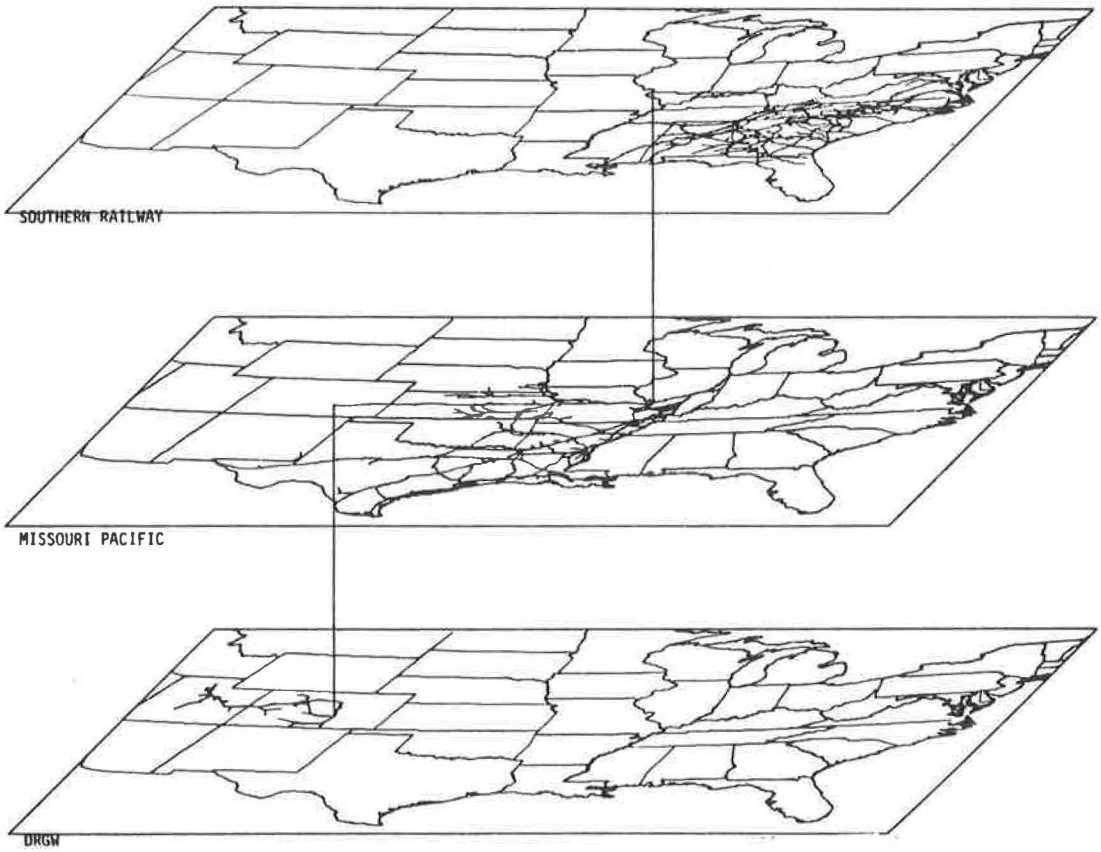
When applied to the restructured quantum network, the Intracarrier Route-Generation Model described earlier yields the route from any quantum-network origin (a unique origin location and originating railroad) to all quantum-network destinations (unique destination location and destination railroad). Since the originating railroad is specified by the quantum-network origin node (each quantum-network node is unique to one carrier), it is trivial algorithmically to consider discounts for the links of the originating railroad; thus, long-haul shipper behavior is simulated. Appropriate differential values of junction impedance will simulate biases between junctions. An example of a minimum-impedance three-carrier route between a Southern Railway Company origin in Atlanta and a Denver and Rio Grande Western Railroad Company (DRGW) termination in Denver is shown in Figure 2. The route forecast involves an interchange at St. Louis with the Missouri Pacific, which interchanges in Pueblo with the DRGW. This route conforms with historical routings.

Calibration of the Long-Haul Discount Factor

Through the application of the Quanta-Net Intercarrier Route-Choice Model to a historical (say, 1977) railroad network configuration in which shipper choices are known through the carload waybill statistics, one can calibrate the values of both the long-haul discount factor and the junction impedance so that the model best replicates observed shipper behavior. Such a calibration can provide insight into fundamental shipper behavior and can also reflect the effectiveness of railroad sales and marketing departments and interline operation. Preliminary investigations of the long-haul discount factor focused on its sensitivity, variability between railroads, and varibility between origins on the same railroad. An experiment was designed to provide a first insight into these characteristics, in which routings generated by the quantum model were compared with historical routings. The experiment consisted of two parts. In the first, routings from origins on several different railroads were investigated to determine the sensitivity of the discount factor and its variability between railroads. For simplicity (and to isolate this experiment as much as possible from the effects of various values of junction impedance), only two-carrier waybill movements were investigated. The junction impedance was set at the arbitrarily large value of 1000 miles of A main line. The two-carrier portion of the 1977 carload waybill sample was extracted as a historical reference, and the origin on each railroad in the sample that had the largest number of destinations was found. This provided a group of source nodes with a relatively high number of historical records for the largest sample size for each quantum-network minimum-impedance tree generated.

Five railroad origin locations were chosen for investigation from the above group. Three were on carriers thought to have strong marketing departments and long first hauls: Atlanta, Georgia, on Southern Railway Company (which serves 86 destinations); Houston, Texas, on Southern Pacific (131 destinations); and Golden, Colorado, on Burlington Northern (53 destinations). The others were on carriers thought to be less successful at achieving a long first haul: Bayonne, New Jersey,

Figure 2. Minimum-impedance Quanta-Net route between Denver on Denver and Rio Grande Western and Atlanta on Southern Railway.



on Conrail (86 destinations) and Birmingham, Alabama, on Family Lines (84 destinations). The initial discount factors chosen to be investigated were 0.6, 0.8, 1.0, and 1.2; several others were added for the Atlanta origin on Southern Railway in order to obtain a more-detailed profile of a single origin. Comparisons were to be made both with all historical records and with only those records that had junctions in the set of 408 coded on the network. The following measures of the merit of the various discount factors were to be taken:

1. Number of movement-group (unique origin-destination groups) records reproduced exactly,
2. Number of carloads routed exactly (on the theory that those markets that have low volume would be more likely to have unusual routings not predictable by the model),
3. Average difference in the length of the first haul between the generated and historical waybills, and
4. Standard deviation of the difference in distance (as a measure of variability).

An example of the results is shown in Table 1 for the Atlanta-Southern route. Figure 3 shows a plot of long-haul discount factors versus mean mileage differences (generated minus historical). The following general observations can be made:

1. The best estimate of long-haul discount (in which the mean mileage difference is zero) varies widely among the railroads tested, from 0.58 for Southern Railway from Atlanta to about 1.38 for Family Lines from Birmingham. The values do seem to correspond to the generally accepted impressions of the different railroads' ability to capture the long haul.
2. The percentage of carloads routed correctly for records with coded junctions varies for the best long-haul discount from 67 percent for Family Lines to 81 percent for Southern Railway. In general, one can expect to replicate the route of 75 percent of the carloads exactly.
3. The standard deviation of mileage differences is quite high in most cases, usually more than 100 miles. It does seem to be reduced in the vicinity of the best long-haul discount, however.
4. The accuracy of routings is fairly insensitive to the value of long-haul discount in the range studied here. This implies that, for many movement groups, there exists one best choice of junction and all other junctions are seen to be vastly inferior.

The second part of the long-haul calibration experiment examined two additional origins, one on Family Lines and one on Southern, to determine the intrarailroad variation. Origin locations were exchanged (Birmingham on Southern Railway and Atlanta on Seaboard Coast Line) so that geographical differences would not enter into the results. In general, the results indicate that the long-haul discount factor is fairly constant within a railroad; however, more experiments are needed to reach a definite conclusion.

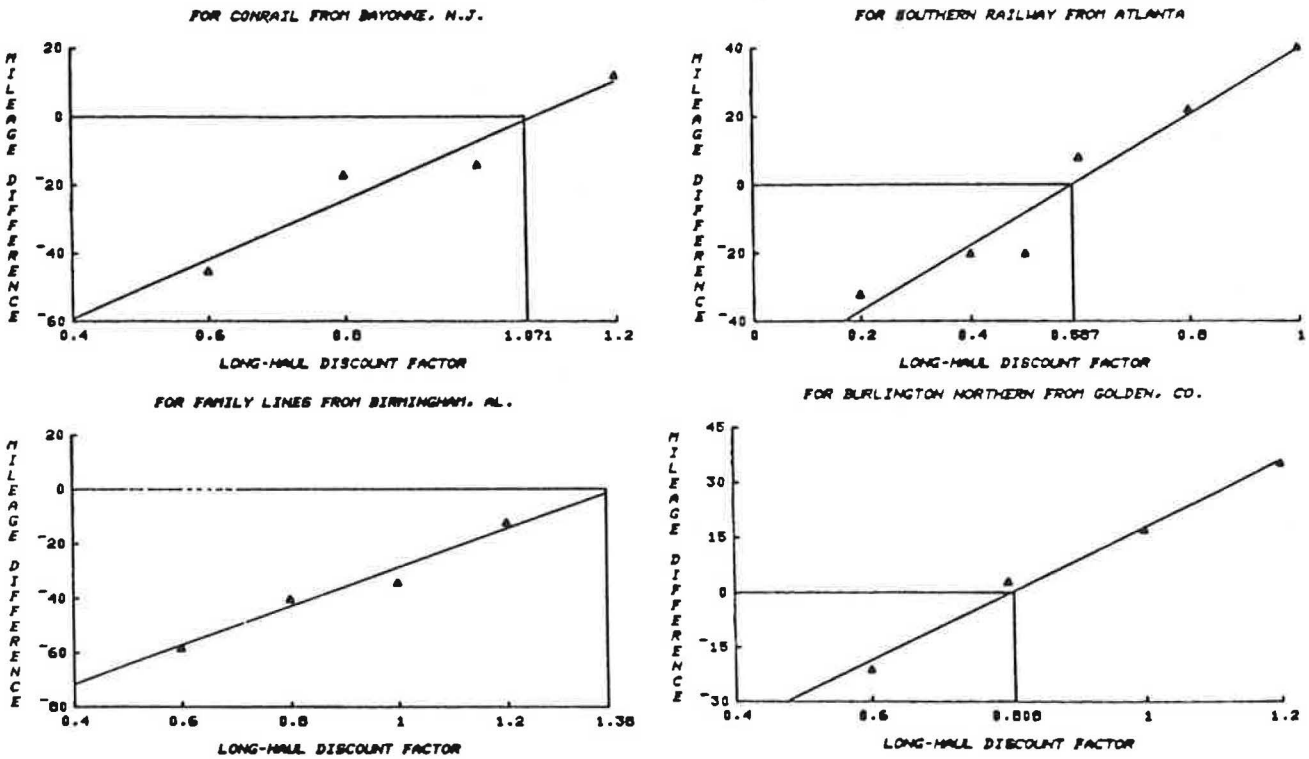
A thorough calibration of appropriate values of junction impedances is still under study; however, very high values are indicated. This solidifies the observation that shippers are more inclined to choose routes that require the minimum number of intercarrier transfers.

Table 1. Results of experiment 1: Southern Railway originating in Atlanta.

Long-Haul Discount	Junctions Found Exactly	N (%)	P (%)	Carloads Routed Exactly	NC (%)	PC (%)	For All Records: Mean Mileage Difference	For All Records: SD	For Records with Coded Junctions: Mean Mileage Difference	For Records with Coded Junctions: SD
0.2	59	69	73	197	77	80	-32	119	-32	120
0.4	62	72	77	200	78	81	-20	109	-20	109
0.5	62	72	77	200	78	81	-19	111	-20	109
0.6	57	66	70	180	70	73	8	137	8	137
0.8	56	65	69	179	70	72	21	135	22	135
1.0	55	64	68	172	67	70	45	131	40	132

Note: N = number of movement groups (86); P = number of movement groups with coded junctions (81); NC = number of cars (256); PC = corresponding number of cars (247).

Figure 3. Calibration of long-haul discount factors.



Market-Share Model

The market-share model is a user-specific model based on relative distance, impedance, and intercarrier transfers on competing routes in the same market (origin-destination pairs). Competing routes exist for all markets served either by competitive originating railroads or by competitive terminating railroads. The Quanta-Net Intercarrier Route-Choice Model will forecast a single route for each unique combination of origin railroad and destination railroad; the model cannot provide for competitive overhead carrier routes. All other routes are assumed to serve none of the market's traffic. However, traffic must be distributed over the competitive routes generated. Some of those routes should be assigned zero market share because the originating or terminating carrier provides only a zero-length haul. These routes are generated as a requirement of completeness among the unique origin-destination railroad combinations. For example, for the market on the East Coast to Memphis, the quantum-network model would specify routes where the Chicago, Rock Island, and Pacific Railroad Company terminates the traffic. In each of these routes another railroad brings the shipment to Memphis and switches to the Rock Island, which terminates the movement. The assumption is that all railroads that serve Memphis have access to all shippers; thus there is no need for a switching movement and in fact shippers would not select such routes. Shares among the market's other routes could be assigned by using the judgment of expert witnesses or possibly by a calibrated multidimensional logit model that is a function of the relative impedance (combination of line and junction) and relative distance between the various best routes such as that shown below (research at Princeton is continuing in an attempt to calibrate such a model):

$$MS_k = \exp(I_k)/\sum_j \exp(I_j) \quad (3)$$

where MS_k = market share of route k and I_k = impedance of route k.

STRUCTURE FOR APPLYING THE ADVANCED MODEL OF TRAFFIC DIVERSIONS

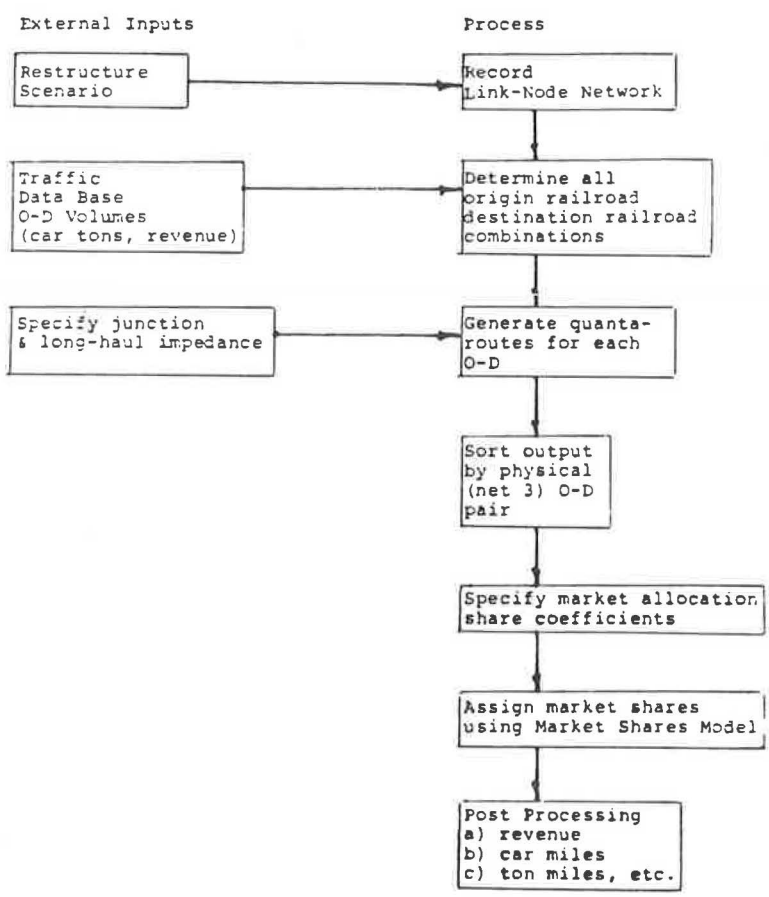
After having described each of the elements that make up the advanced model of traffic diversions, we now show how the elements may be sequenced for a particular application. The discussion uses the following example: Suppose that the Rock Island discontinued all service and that the ICC issued directed service orders to various railroads that required them to provide service over specified portions of the Rock Island. [Johnson (15) describes a method that indicates which railroad is most suitable to operate and acquire which portion.] Given that these railroads eventually acquire these portions, the model is to assess the long-term impact of these acquisitions on the distribution of traffic in that area.

Computational Procedure

In the short term the status quo would continue; however, in the long term new competitive patterns would emerge, and some traffic would travel over new routes. The forecasting of these traffic shifts could proceed as follows (see Figure 4):

1. Record link-node network: The various portions would be merged into their appropriate acquirers by using interactive computer-graphic techniques.
2. Select traffic data base: This may be one or several years of carload waybill statistics or forecast-year FSAC-to-FSAC demand data.
3. Determine all combinations: For each market contained in step 2, the combinations of origin railroad and destination railroad should be determined. Each railroad that serves each node of the restructured network can be determined from the node data in step 1.
4. Generate quantum routes: For each origin and destination, a unique record of origin-origin railroad (unique quantum-network node) to destination-destination railroad would be created. This record would be a unique quantum-network node pair. Appended to each record should be the first origin-destination Net-3 number.
5. Choose values of junction impedance and long-haul discount factors: These values could be historical values or values modified by anticipated interline junction agreements and shifts in marketing and sales efforts.
6. Generate minimum-impedance quantum-network routes: For each record produced in step 4, the railroad-junction-railroad sequence of each route would be appended, as well as the mileage of each railroad segment, the total mileage, and the total impedance.
7. Sort output by actual (Net-3) origin-destination pairs: For the file created in step 6, this will coalesce all quantum-network routes for each actual market. Each route will have distance and impedance values.
8. Identify market-share coefficients: These should be specified for the market-share model.
9. Assign market shares: These are determined for each quantum-network route in each market by using the market-share model.
10. Perform postprocessing steps: These steps

Figure 4. Computation of procedure for advanced diversion model.



are to determine (a) revenue--use formula for prorating mileage to compute revenue for each carrier and accumulate data for each railroad; (b) car miles--multiply carrier mileage by cars on each record and accumulate data for each railroad; (c) ton miles--use same process as that for car miles; (d) traffic distribution--use intracarrier route-choice model to accumulate car and ton assignments on each link and plot car and ton density charts for each railroad; (e) cost--use car-mile and ton-mile statistics to obtain rough value of costs by using unit-cost method; and (f) sensitivity analysis--compare values from (a) to (e) with historical value or values by using different network configurations, traffic data bases, or impedance values.

Reflections on the Method

Each element of the method described in the previous section has been carried out for several independent studies; however, the entire method has not been executed in a unified application. Some of the elements are rather simple and straightforward. Some are complicated and consume time and personnel and computer resources. The development of a restructured scenario can become a very involved process by itself. Johnson (15) has provided some analytical suggestions. The recording of links and nodes is made very efficient by using interactive computer-graphic techniques. A scenario such as the one discussed above can be coded in less than three person days. Step 2, selection of the traffic data bases, is simple if one chooses to use the carload waybill statistics but can become most expensive if one attempts to put together total traffic data from individual railroads. Commodity statistics from the Bureau of Economic Affairs tend to be too aggregated geographically to be used by themselves. They can be used to factor waybill statistics to a forecast year. In any application, not all traffic would be analyzed; possibly only the markets that represent, say, 85 percent of the affected traffic would be surveyed. Such an assumption reduces the number of movement groups by about 40 percent. Steps 3 and 4, finding all combinations of origin-destination railroads, is a straightforward operation by using the network node data. These steps form an intermediate output provided during the formation of the quantum network. Step 5, specification of impedance values, requires a great deal of subjective judgment, but the analysis is not overly sensitive to the choice of these values. Step 6, generation of quantum routes, is a straightforward but a very computer-time-consuming process. The computation time to generate all routes from a single (Net-3) origin (one tree) is about 2.5 s of central processing unit (CPU) time on an IBM 3033, by using a machine-language algorithm. Although this is quite fast, when one considers that several thousand trees will be generated for a single analysis, the cost is considerable. A mechanism to generate routes on intermediate tree branches does allow a saving of one-half to two-thirds. Work is continuing to try to further reduce the computer time. Step 7, sorting of the output, is trivial, but the specification of market shares in step 8 is probably the most sensitive and subjective element of the analysis. Step 9, the assignment of market shares, simply uses the intracarrier traffic-assignment model, with which there has been a great deal of experience. For all railroads, this step should consume less than 20 min of CPU time on an IBM 3033. Step 10 is simply a post-data-processing step that is tailor-made for each application. The only difficult element is the estimation of costs. There are serious questions as to the accuracy of any existing macroscale cost models.

In summary, the model does have a strong theoretical base; it needs a more computationally efficient quantum route-generation algorithm; it is not overly sensitive to assumptions except in the specification of route-share coefficients; and it does provide the traffic impacts on all carriers.

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