Elementary Theory of Traffic Diversions: A Tool for Analysis of Restructured Railroad Networks

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This paper outlines a computer-based methodology that may be used to estimate traffic diversions resulting from limited restructurings of the U.S. railroad system. A basis for the methodology is presented. Coefficients of diversion for various combinations of carriers and routings are suggested on the basis of experience and historical data. The availability of the 1 percent National Carload Waybill Sample data and of the Princeton version of the Federal Railroad Administration Network Model now makes it possible to carry out before-and-after diversion analyses rapidly by means of a computer algorithm. A preliminary application of these techniques to the restructuring proposal between the Illinois Central Gulf and the Southern Railway Company arising from recent legislation is described. The potential use of the results of the methodology as a basis for the planning of capital expenditures is discussed.

Throughout the long history of railroad activity in the United States, companies have continually rearranged the corporate structure of the railroad system—a process referred to as the geopolitics of railroad restructuring. Recently, interest in system restructuring has increased. The bankruptcy of the Penn Central system prompted legislation to simplify the regulatory procedure for the evaluation and approval of restructuring proposals. These laws, the Regional Rail Reorganization Act of 1973 and the Railroad Revitalization and Regulatory Reform Act of 1976, have led to numerous proposals for mergers, acquisitions, restructurings, and abandonments. Given the recent financial reports by Consolidated Rail Corporation (Conrail), terms such as rail use, mergers, acquisition, and perhaps even controlled transfer and controlled liquidation may be appropriate labels for railroad system restructuring exercises. Each of these approaches involves goals and objectives that encompass the many dimensions of structure and industry viability.

One major aspect of railroad restructuring is traffic diversion, that is, traffic gained or lost by the restructured system. Traffic diversion analyses have probably been a part of every merger proposal, but past analyses have been long and tedious manual exercises carried out by teams of traffic clerks. With the availability of comprehensive machine-readable traffic data bases, e.g., Carload Waybill Statistics, and a machine-readable network description of the U.S. railroad system as contained in the Princeton version of the Federal Railroad Administration (FRA) Network Model, background data are available that may allow the calculation of traffic diversions by computer. This paper takes the tried-and-true rules of thumb of the traffic clerk and converts them into a computer-based methodology capable of estimating traffic diversions resulting from limited restructuring of the U.S. railroad system.

Two theories of railroad traffic diversion may be postulated: an elementary theory—the subject of this paper—and an advanced theory. The elementary theory is based on historical traffic flows and market shares among existing routes and considers only incremental changes in those market shares resulting from mergers, acquisitions, or dismemberments. The advanced theory does not rely on historical routings. Instead, it calculates the best route for each competitor and assigns market shares on the basis of substitute measures of the level of service. The best route may be defined in terms of level-of-service measures such as distance, track conditions, and number of gateways encountered by each route. The advanced theory is required whenever there are significant changes in ownership patterns, e.g., many mergers, because shippers are more likely to completely reorient their logistic patterns rather than to make incremental adjustments. Because it is a behavioral model of shippers' route selection processes, the advanced theory defines the unrestrained potential of the restructured railroad system. On the other hand, the elementary theory is constrained to redistribute traffic over routes used prior to restructuring. The elementary theory is well suited to analyzing the impact of relatively small changes in network structure, such as the proposed Illinois Central Gulf (ICG)-Southern Railway (SOU) merger, the BN-Frisco merger, Family Lines-Chessie merger, or the acquisition of a portion of the Milwaukee by the Union Pacific.

DEFINITIONS

The following definitions are presented here as aids to understanding the discussion of railroad restructuring efforts:

1. Market refers to an origin-destination pair where the origin and destination each encompass a finite area in which shippers, receivers, or both are located. If an area is served by more than one railroad, then it is implicitly assumed that each railroad had access to each of the shippers and receivers in that area. Access can be either through direct siding, terminal railroad, or reciprocal switching agreement. This implicit assumption tends to limit the size of these areas so that artificial competition is not introduced. Analytically, such locations are designated by FRA Network node numbers of the Association of American Railroads' Standard Point Location Codes (SPLCs). The size of this area can be selected by the analyst but it should usually be smaller than the size of a county.
2. Route is a sequence of railroads and interline junctions that connect an origin and destination. Only those routes actually appearing in the historical waybill data are considered in the analysis, even though other routes may appear in published tariffs. (In special markets, it is possible to consider a small number of new routes by introducing dummy data into the waybill file. However, the amount of manual input required makes this impractical to be anywhere near exhaustive.)
3. Merger is the functional union of two or more railroad operating networks, irrespective of the financial or organizational arrangements under which they are brought together; thus, the term is used very loosely in this paper.
4. Best route, from the perspective of the shipper, is considered to be a function of level of service, defined quantitatively in terms of readily available route

and network characteristics. These include number of railroads required to construct the route, the route distance, the track quality (measured by its mainline-branchline designation), and the length of haul of the originating railroad. These characteristics can be compiled from the enhanced FRA Network Model and the Carload Waybill Statistics.

Other characteristics such as car availability (although this is considered implicitly in the allocation of traffic to the route that maximizes the length of haul by the originating railroad, subject to total route-distance circuity constraints), travel time (considered implicitly in the track-quality measure), and travel time reliability are not explicitly considered because of the lack of available quantitative data on them.

APPLYING ELEMENTARY THEORY

It is obvious that the elementary theory will be relevant and meaningful only in markets served before the system restructuring by one or more routes, at least one of which involves a carrier or carriers to be restructured. The elementary theory postulates that the restructuring will merely redistribute the existing traffic among the routes already observed; that is, the restructured railroad has no opportunity to enter new markets. This is one limitation of the elementary theory not applicable to the advanced theory. This limitation, however, also means that the number of markets and feasible routes to be analyzed is greatly reduced. Thus only readily available historical traffic data (such as the Carload Waybill Statistics) are needed to define the set of affected markets, and the differential (before and after) impact on carload routings of the restructuring may be readily computed.

PROCESS

The elementary theory of traffic diversion proceeds as follows:

1. Several years of waybill statistics are used to define the before market shares of all routes in each market, i.e., the percentage of the carload using each route between the same origin and destination.
2. The extent of probable traffic diversion in each market is estimated on the basis of the hierarchy of markets outlined in the next section of this paper.
3. After market shares are allocated to each modified route in each market. This traffic is assigned to the new railroad network configuration and yields traffic flow on each link of the railroad network as well as distances that allow for the computation of new divisions and costs.
4. Comparison of all before and after values of total, as well as link-by-link, transportation activity indicates the differential impact on each carrier involved, i.e., both the merged railroads and their neighboring unrestructured railroads.

HIERARCHY OF MARKETS

Each market is defined as an origin-destination pair, each of which is served by at least one independent railroad and for which railroad traffic has been observed. In general, there are an infinite number of ways to route traffic in each market, but, for example, routing traffic between Chicago and Detroit through Jacksonville, Florida, is illogical. A small number of these routes are feasible routes from a shipper's viewpoint because they are published in tariff books. Martland (1) has indicated that over 200 unique routes are published between Chicago and Boston. Unfortunately, these routes are not machine readable and are therefore unsuitable for use in computer analysis. In any event, only a few of these routes are actually used by shippers. A machine-readable history of a sample of the routes actually used by shippers is available in the form of the Carload Waybill Samples. These data are available for 1973 through 1977 and contain the railroad-junction sequences for each of the approximately 1 percent of the railroad carload traffic during each year. By reorganizing these data for one or several of these years, one gets a good picture of which routes are used and to what extent. Also, one obtains a quantitative picture of which railroads actually serve which geographical areas (origins and destinations). By first defining the size of the area encompassed by a general market endpoint, these data show the absolute and relative activity in carloads originated and/or terminated in each geographical area. (Various definitions can be used for the area. The most convenient are either various levels of specificity of the 6-digit SPLC or, what seems to be most appropriate, the FRA Net-3 nodes, which tend to encompass areas served in common by several railroads if competition exists in the area. Railroad freight station accounting codes are not appropriate because they are unique to each railroad.) For example, the following table lists the gross and share of the traffic originated or terminated in Toledo, Ohio, by competing railroads for 1974:

Railroad	Carloads Generated	Percentage of Carloads Generated
Ann Arbor	28	2
Chessie System	1503	51
Detroit and Toledo Shore Line	15	1
Detroit, Toledo and Ironton	84	5
Penn Central	811	28
Norfolk and Western	501	17

The Carload Waybill Sample data can define all of the railroads that actually generate (originate or terminate) traffic at either end of each market and can identify the number and relative strength of routes used in any market.

For a traffic diversion analysis these markets can be classified in such a way that all markets may be analyzed in an orderly sequential manner. These markets may be classified according to the following hierarchy:

1. No traffic diversion—markets that are unaffected by the network restructuring;
2. Single-carrier potential—markets that exhibit potential single-carrier service by restructured parts of the railroad network;
3. Long-haul potential—markets in which the restructured parts of the railroad network have the potential of increasing the length of their originating haul;
4. Retaliation—markets in which the restructured parts of the railroad network can be adversely affected by retaliation by the unrestructured railroads; and
5. Overhead—markets in which the restructured railroad participates only as an overhead carrier.

Each of the classes of markets, when considered as a hierarchy, covers all markets without double counting. Each market can be identified and analyzed in turn. The process is sequential and thus potentially efficient, certainly more efficient than an iterative process.

All markets can be considered; however, a large number of markets have very little traffic and thus few observations exist about the Carload Waybill Samples. At some point, because of the lack of observations, there is an insufficient basis for defining feasible routes. On the other hand, because of the small amount of traffic at stake in these markets, errors will have only minor impact. Thus, they simply can be dropped from the analysis. It is suggested that markets with fewer than five observed carloads of traffic be placed in the category of traffic in which there is no traffic diversion, i.e., category 1. Thus, they are contained in both the before and after summaries but are assumed to remain unchanged. Depending on the size of the carload data base, this may amount to as little as 10 percent or less of a railroad's traffic.

Each of the five classifications of markets has several level-of-service characteristics that would be affected by a restructuring of the U.S. railroad system. The level-of-service characteristics most affected include the following:

1. The number of railroads that cooperate to form a single route is important. A merger of two railroads will enable some markets to be served by a single railroad company. Other markets will have the number of railroads required to cooperate reduced by one. Historical traffic data indicate that shippers overwhelmingly route their carloads over routes requiring the fewest number of cooperating railroads. For 1974, 97 percent of the traffic in markets served by single-carrier service was captured by those single-carrier routes (2). Additional data can also be found in Strong (3).
2. Most traffic tends to travel over routes whose distance does not vary widely from the shortest of the observed route in each market. Rarely does any route that is more than 25 percent longer than the shortest observed route capture any of a market's traffic. This circuity constraint provides a convenient way to limit the search for alternate feasible junctions between railroads on routes that require cooperation among the restructured railroads and other independent railroads (4).
3. The track-quality measure of mainline-branchline provides a means by which the best route within any independent railroad network can be computed, using a minimum pathfinding algorithm. Used at Princeton is an impedance measure that simply multiplies link distance by FRA's "503" mainline-branchline code. A factor of one is applied to A mainlines, two to B mainlines, three to A branchlines, and four to B branchlines.

TRAFFIC DIVERSION IN EACH CLASS OF MARKETS

The following suggested diversion values can only be substantiated qualitatively, although Kornhauser (5) and Strong (3) do provide some quantitative support. Readers are encouraged to criticize the suggested values. (The analysis is structured so that the user can specify the amount of traffic to be diverted in any class of market. Thus, one can do systematic parametric analyses based on various assumed values of diversion.) All examples assume a merger between RR_1 and RR_2. Railroads $RR_3, \ldots, RR_n$ are other railroads whose network remains unchanged but compete in various markets with RR_1 and RR_2.

Unaffected Markets

These markets can be identified by the fact that neither RR_1 nor RR_2 appear in any observed route of these markets nor do either generate any traffic at the origin or destination of the market. These markets can be readily identified algorithmically. Markets that have very little traffic—for example, less than five observed carloads—may also be included and are also readily identified algorithmically. These markets are segregated and their after-merger routes and market shares are assumed identical to their before-merger values.

Potential Single-Carrier Service

A merger may result in new single-carrier service only if one of the merging railroads serves the originating station and the other serves the destination. The following subclasses cover all possibilities:

1. RR_1 and/or RR_2 only serve the route's origin and RR_2 and/or RR_1 serve the destination. No other competing routes are observed. Resolve: All traffic is diverted to the RR_1-RR_2 route having the minimum impedance as defined here.
2. This subclass is the same as the first, except other competing routes are observed that have RR_3 as the originating railroad:
   (a) The competing originator's route is a multiple-carrier route. Resolve: If the competing route involves two carriers, X (X may be 75 percent) of the competitor's traffic, is diverted to the new single-carrier route; if the competing route involves three or more carriers, Y (Y may be 100 percent) of the traffic, goes by the new single-carrier route.
   (b) One of the competing originator's routes is a single-carrier route. Resolve: In this case, it can be expected that the existing multiple-carrier routes retain their market shares; the existing single-carrier route and the newly established single-carrier route share equally in the remainder.

Potential Long-Haul Service

For shipments originating on RR_1 and destined beyond RR_2, the combined railroads have an opportunity to increase their length of haul and thus gain better revenue divisions. Resolve: All traffic originated on RR_1 is diverted to the most renumerative RR_1-RR_2-other railroad(s) route that appeared in the historical sample.

If the origin is competitive, the market shares of routes involving the same numbers of railroads can be expected to be equalized; if the new route has one less railroad than the best existing route, the new route can expect to capture about 85 percent of the market and, if it has two less railroads, it may capture 100 percent. If the new route involves more carriers than the best competitive route, its market share remains unchanged.

Retaliation: Merged Railroads Serve Only Destination

If the merged railroads serve only the destination in a given market, they are susceptible to retaliatory diversion by connecting railroads from which a significant amount of originated traffic has been diverted. Connecting carriers may be unfriendly (those who have been hurt by the merger) or friendly (those who have not been hurt).

1. The destination is captive to RR_1 and/or RR_2, and there is no change in the number of railroads in any route. Resolve: no change in market shares.
2. The destination is captive to RR_1 and/or RR_2, the merger has reduced the number of carriers in one or more routes, and the originating carrier is friendly. If the new route's number of railroads equals the best competitive route's railroad, each route with that number of railroads receives an equal share; if the new route has one less carrier, it may capture 85 percent of the

Figure 1. After-merger flows on the ICG-SOU.

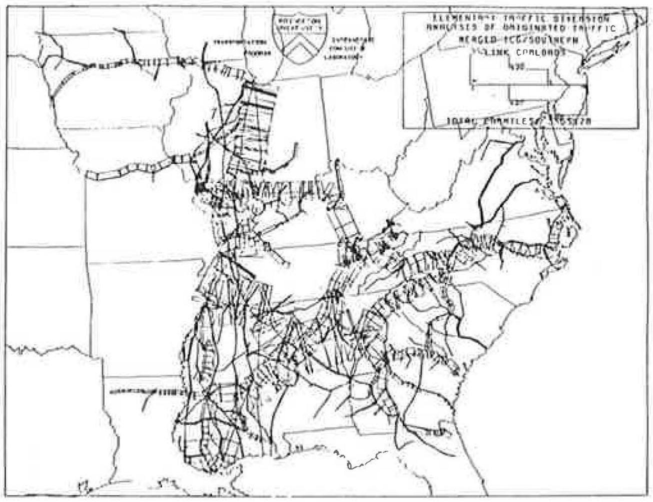


Figure 2. Traffic volume increases on the Memphis cutoff.

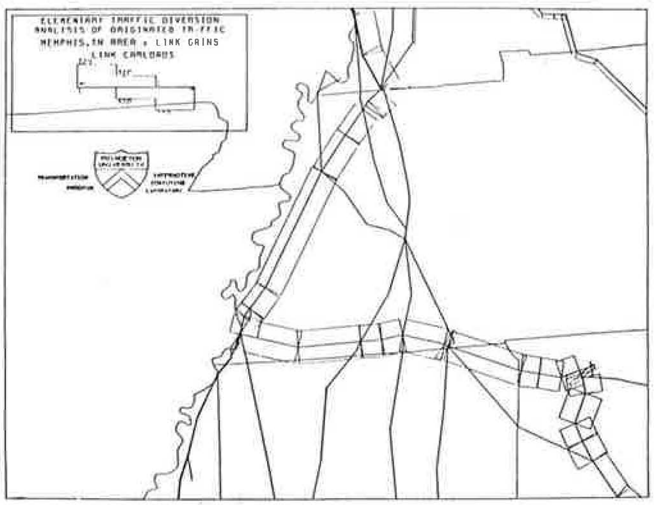
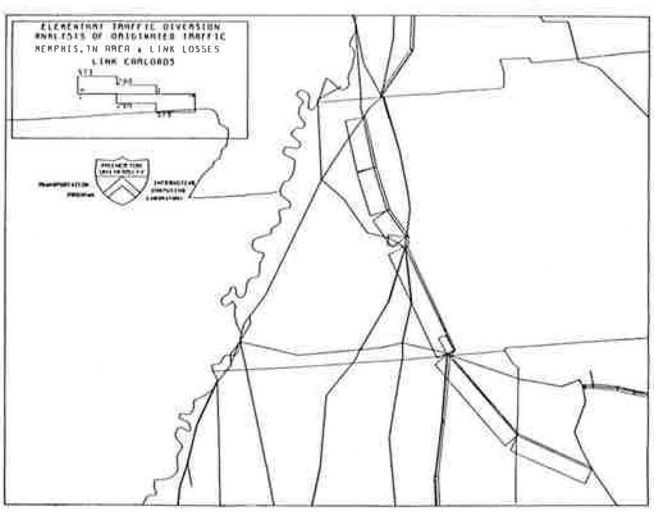


Figure 3. Traffic volume decreases on the Memphis cutoff.



traffic; and if it has two less carriers, it may capture 100 percent of the market.

3. The destination is competitive and the number of railroads in the past-merger route stays the same. If the originating railroad is friendly, there is no change in market shares; if it is unfriendly, the merged railroad terminates about 25 percent of its before traffic.

4. The destination is competitive, the number of railroads in the merged route is one less than before, and the connection is friendly. The new route receives 85 percent of the market if the number of carriers on the merged route is one less than on competing routes and 50 percent if the number of carriers is the same. If the new route still has more carriers than the competition, its market share remains unchanged. If the connection is unfriendly, the market share remains the same if the new route is one railroad shorter than the competition, retains 25 percent of its before traffic if the numbers of railroads are the same, and goes to zero if the number of railroads is one greater than on the competing route.

Overhead Traffic

If RR_1 and/or RR_2 serve a given market only as overhead carriers and the originating carrier is friendly, the market share can be expected to remain the same. If the originator is unfriendly and an alternate overhead route exists, the market share of the merged route probably goes to zero if the merged route involves more railroads than the competing route. If the number of railroads is the same, the merged route retains about 25 percent of its before traffic. If the number of railroads is one greater than the competing route, then the market share goes to zero.

RESULTS OF ANALYSES

The elementary theory of traffic diversions has been applied to one test case—the merger of the Illinois Central Gulf and the Southern Railway System. The test was carried out only through the potential single-carrier service step of the methodology. The data used in the example were the combined sample Carload Waybill Statistics for 1973, 1974, and 1975. Before traffic was assigned to the ICG, SOU, and neighboring railroads. Traffic volumes were accumulated by direction on each link of each railroad. Traffic that had historically originated on the SOU or ICG and that could be terminated by the ICG or SOU was diverted to a single-carrier SOU-ICG route. A new traffic assignment was made on the merged SOU-ICG system. This produced the after-link volumes displayed in Figure 1. By taking the difference between the before- and after-link volumes, one obtains the impact by direction on each link of the merged railroads.

Some interesting redistribution of traffic flows appeared on the merged system. Figure 2 shows traffic increases on a portion of the system in the neighborhood of Memphis, Tennessee. Figure 3 shows traffic decreases on other links of the merged system in the same neighborhood. The traffic decrease on the southbound leg of the cutoff is due to a reassignment of that traffic to a route combining the ICG mainline into Memphis and the SOU's mainline beyond. In the past, this southbound traffic had been longhauled by ICG. In the restructured system, the railroad might well take advantage of better track conditions on the ICG and SOU mainlines and opt for the more circuitous routing through Memphis. This one small result of the traffic diversion analysis has important implications for capital planning on the restructured system. Options that are suggested include (a) increasing the yard capacity at Memphis, Tennessee, and (b) improving the track on the Memphis cutoff to take advantage of the more direct route.

Other impacts of the merger on traffic volumes were made readily apparent by interactive graphic displays of the before and after traffic volumes. Such methods are extremely important in the ongoing strategic planning activities of railroads, particularly in contingency planning. Actual results for the ICG-SOU merger are not given here, principally because they are preliminary results intended only for planning and contingency analysis.

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Transportation Manpower Adjustments to Technological Change Through Collective Bargaining: The Crew-Size Dispute in the Railroad Industry

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Most industries adjust work-force size to technological and economic changes, but the number of brakemen on railroad crews is inflexibly fixed by labor agreements. This paper traces the controversial and still unresolved crew-size dispute from its origins in 1959 through 1978. The dispute was heated between 1959 and 1970 and was punctuated by strikes. The government intervened with a Presidential Railroad Commission, the National Mediation Board, Arbitration Board 282, and Emergency Boards 154 and 172. The federal courts were also involved. The brakemen succeeded in upholding their position and in securing a general rule of two brakemen per crew over management protests that technological changes had made one brakeman sufficient. The research involved in this study was divided into library research and field research. The former consisted of a comprehensive examination of the available literature. The latter consisted of (a) an examination of relevant documentation, including correspondence, and other primary sources of written information in the files of pertinent railroads and their General Committees of Adjustment and (b) interviews with railroad and union officials and with operating and nonoperating employees, as well as informed neutral parties (e.g., mediators and arbitrators). Policy recommendations for labor, management, and the government are also made.

The most protracted labor dispute in the railroad industry over the past 20 years concerns the size of road and yard crews. This still unresolved dispute stems from the 1959 demand by railroad management for the prerogative to specify the number of brakemen on train and yard crews, upsetting the position held by the railroad operating unions that crew size should be subject to the collective bargaining process. This issue highlights not only the labor relations problems endemic to the railroad industry, but also characterizes the larger quandary facing all the other transportation sectors (trucking, airlines, and longshoring)—the need for rationalization of employee job security with the exigencies of technological progress, which, in turn, is energized by competitive pressures.

The crew-size dispute was heated between 1959 and 1970 and was punctuated by strikes. The government intervened with a Presidential Railroad Commission, the National Mediation Board, Arbitration Board 282, and Emergency Boards 154 and 172. The federal courts were also involved. On June 13, 1977, the industry broke the uneasy truce that had been in effect since 1970 as a reaction to a union wage-increase demand by serving notice of its intention to gain the right to determine crew size. This analysis, therefore, seeks to contribute to an understanding of the critical issues that labor, management, and the government will have to consider in the near future.

Most existing crew sizes include a conductor (engine foreman on a yard crew) and two brakemen (called helpers on yard crews). Management has believed that the second brakeman or helper is unnecessary, whereas the United Transportation Union has asserted that at least two are needed. The dispute thus has a single clear-cut issue: Do some (management claims many) crews have an excessive number of brakemen? The ramifications of this basic issue are extremely complex.

It has been traditional for the number of brakemen