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# Rail Freight Transportation and Regional Economy: A Case Study of Northwest Indiana

**DOUGLAS A. LARK and KUMARES C. SINHA**

ABSTRACT

An understanding of the role of transportation improvements in economic revitalization of a region requires examination of the relationship between rail freight transportation and the local economy. A case study using northwest Indiana is being performed to determine the dependence of the region on rail. A brief summary of the rail network, railroad operations, and the commodity flow by rail in northwest Indiana is presented. The impact of rail on three potential long-range scenarios for economic development in northwest Indiana is also discussed along with the conclusions that can be reached on the basis of the present study.

A multimodal freight transportation study is being conducted at Purdue University to identify improvements in transportation and related strategies that can assist in the economic revitalization of a major industrial region. The northwestern Indiana region including Lake and Porter counties is the area studied in this project. It is situated at the south end of Lake Michigan and is physically and economically part of the greater Chicago metropolitan area.

An essential part of a regional freight transportation analysis is determining the role of railroads in providing transportation services to the local economy. To achieve this purpose in northwest Indiana, an inventory of the rail network, an analysis of railroad operations, and an assessment of commodity flows by rail was performed. A brief summary of this work is presented in this paper.

## RAIL SYSTEMS

Ten railroads and the National Railroad Passenger Corporation (Amtrak) operate in Lake and Porter counties. Railroad operations and the rail network in this region can be divided into two segments: mainline and terminal. Mainline operations involve through trains on the Class 1 railroads passing through northwest Indiana en route to and from Chicago. Terminal operations focus on the service provided to the local industry. Almost 100 percent of the terminal operations are performed by the Indiana Harbor Belt; Elgin, Joliet and Eastern; and the Baltimore and Ohio Chicago Terminal.

The major thrust of rail development in this region was to reach and serve Chicago; therefore, few terminal facilities developed in Lake and Porter counties in Indiana. Instead, the terminal and yard facilities developed closer to Chicago in Illinois. As a result rail freight tends to travel through northwest Indiana without stopping. Even freight destined for the region usually travels into Illinois to a major yard and is returned to Indiana on a local or transfer run.

## CHARACTERISTICS OF CORRIDOR SERVICE

An analysis of traffic capacity and existing traffic density indicates that the rail facilities in the region are not fully used at present and that many of the corridors have capacity far in excess of service volume. Furthermore, only about half of the corridors have a traffic density of 15 or more million gross tons per year (1). The capacity of some of the mainline segments, however, can be as high as 80 to 120 trains per day.

Few lines have traffic densities that approach half of the route capacity. This excess capacity makes it possible to consolidate lines and reroute traffic with little or no expansion of facilities. In addition, projections do not indicate that capacity will ever become a constraint. Despite the inevitable end to the current recession and associated reduction in traffic, the general economic decline of the northeastern part of the United States implies that most of the eastward rail lines will not experience traffic significantly above current levels.

Because of the current excess capacity and no expectation of major increases in traffic, several rail lines through the northwest Indiana region may be candidates for plant reduction. Most of the lines through the region are double track even though in many places traffic levels no longer justify a second main track. Double track lines, however, may be advisable in some urban areas so trains can pass and meet without stopping. This reduces the problem of blocking public road crossings and also reduces the opportunity of theft from trains.

## TERMINAL FACILITIES

The terminal infrastructure in northwest Indiana evolved at the turn of the century around the steel industry when rail was the dominant mode of transport. An intertwining maze of tracks was built throughout Gary, Hammond, East Chicago, and Whiting. Many of the larger companies are served by more than one railroad. Local industry is primarily served by the Indiana Harbor Belt; the Elgin, Joliet and Eastern; and the Baltimore and Ohio Chicago Terminal. Figure 1 shows a map of the terminal network in northwest Indiana, which is actually an extension of the Chicago terminal network. The yards and terminal facilities in the region are used primarily to service local industry. The classification of cars and most interchanges with other railroads occur in Chicago.

Although northwest Indiana was once considered a busy rail terminal, it is presently overbuilt and underutilized. Railroads are no longer the primary mover of goods, and improved technology and greater efficiency of the railroads have decreased the need for yards and associated facilities.

## RAIL OPERATIONS IN THE REGION

As part of the study, representatives from all three

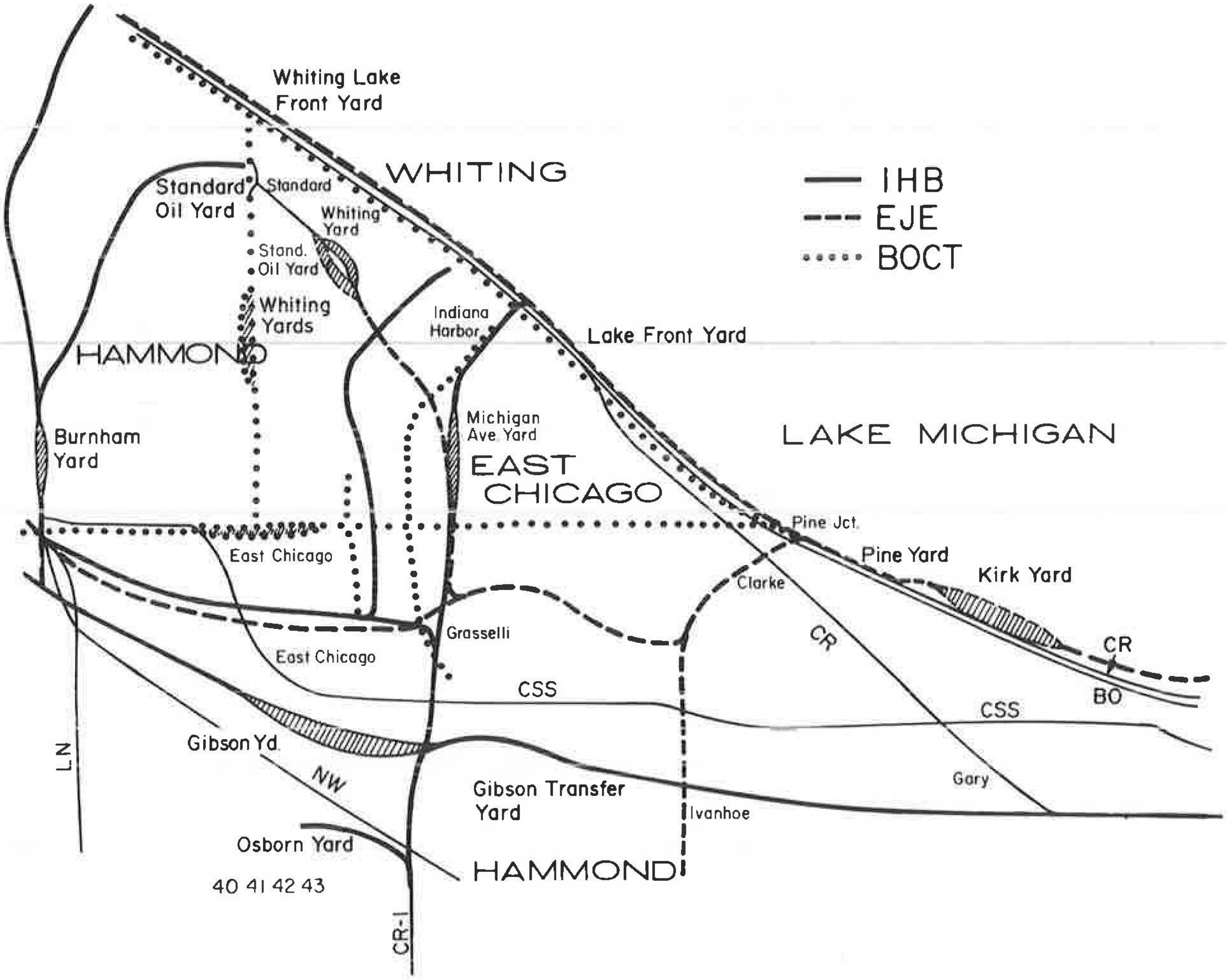


**FIGURE 1 Northwest Indiana terminal rail network.**

terminal railroads operating in the region were interviewed about their railroad's northwest Indiana operations. The following is a synopsis of the responses received.

The Indiana Harbor Belt (IHB) is a Class 1 terminal and switching railroad serving the Chicago and northwest Indiana region. The IHB is 51 percent owned by the Consolidated Rail Corporation (Conrail) and provides Chicago terminal operations for that railroad. The IHB also provides an interchange between all the railroads serving the Chicago area. The IHB operates more than 30 miles of running track and serves 25 industries in northwest Indiana.

Five yards are located in northwest Indiana on the IHB: Gibson, Burnham, Michigan Avenue, Whiting, and Lakefront. All industries in northwest Indiana are serviced out of one of these yards. Currently, engine crews only work out of the Burnham and Michigan Avenue yards. Each morning a train from the railroad's main yard in Chicago delivers cars to the Burnham and Michigan Avenue yards to be switched in the area. Local crews perform all industrial switching. In the evening a train departs from Burnham and Michigan Avenue to return to the main yard. Hence, nearly all cars originating or destined for northwest Indiana pass through Chicago. Conrail through freight trains on IHB tracks do not stop to perform switching.

Operations on the Baltimore and Ohio Chicago Terminal (BOCT) are similar to those on the IHB. All Chessie System trains enter Chicago from the East over the BOCT. However, these trains do not stop to pick up or drop off traffic.

The Elgin, Joliet and Eastern (EJE) is a Class 1 common carrier subsidiary of the United States Steel Corporation. The railroad provides in-plant switching at the various U.S. Steel plants in the Chicago area including the mill at Gary. The EJE also comprises an outer belt line around the Chicago suburban area beginning at Gary and running through Griffith to Joliet and then north and east to Waukegan. The railroad has several branch and industrial lines in northwest Indiana to serve local industry.

Approximately 65 to 70 percent of EJE traffic is steel related--either inbound raw materials or outbound steel products. Most of this traffic runs to and from the U.S. Steel mill at Gary and is interchanged to other railroads around the city. Because of its position as a belt railroad with a number of industries located on the route, almost all EJE traffic is interline movements.

Kirk yard in Gary is the EJE's main yard facility in northwest Indiana. The yard has a hump with 58 tracks in the bowl. The capacity of tracks in the bowl varies from 20 to 80 cars. There are seven inbound/outbound tracks on the north side of the yard and 14 on the south side. Each of these tracks is capable of holding 70 cars. Currently the tracks on the south side are being used for storage. When operating at capacity, between 40 and 50 cars an hour can be humped at Kirk yard.

A total of 105 firms were identified as having direct rail access in northwest Indiana. However, only 54 indicated they were active shippers by rail. Of these, 19 were served directly by more than one of the terminal railroads. These firms were also the larger shippers. Little interchange of traffic occurs among the terminal railroads in northwest Indiana. With the exception of unit coal trains, little traffic is interchanged by any of the railroads in northwest Indiana.

Consolidation of yards, tracks, and facilities of the terminal railroads could reduce excess capacity and duplication of operations without reducing service. The cost savings of a more efficient terminal operation could be passed on in rates charged to shippers. Such an effect would make rail a more attractive mode in northwest Indiana.

## COMMODITY FLOWS IN THE SEVEN-COUNTY REGION

Data were obtained from Reebie and Associates (2) on commodity flow by rail to and from the northwest Indiana region comprised of Lake, Porter, LaPorte, Starke, Pulaski, Jasper, and Newton counties. The data were based on 1980 movements and provide a broad overview of the importance of rail freight transportation in the region. The Reebie data also give origin and destination information by mode for 26 major business economic areas (BEAs). Lake and Porter counties have the most industry and the largest employment (almost 83 percent of the 1980 total) in the seven-county region.

Table 1 (2) gives the tons inbound and outbound for each commodity type by rail and the combined total tons inbound and outbound by commodity type. Because this paper focuses on the effect of railroads, tonnage for the other modes is excluded. Table 1 also gives the percentage that rail tons comprise of the total tons shipped inbound, outbound, and combined for each commodity.

Figure 2 shows the major corridors for goods shipped by rail to and from the seven-county region. The eastern and midwestern states are the primary trading partners with the seven-county region. The primary product moved on most of the major corridors is coal.

The Reebie data (2) indicate that for the seven-county region, 13 million tons were moved inbound by rail. This is 71 percent of the total inbound tons coming into the seven-county region. Rail also carried more than 8 million outbound tons, which is 27 percent of the total outbound tons. Hence, rail was responsible for the movement of more than 21 million tons or 43.6 percent of the total tons destined for or originated in the seven-county region.

The Reebie data showed that certain commodities were highly dependent on rail for their movement to and from northwest Indiana. Farm products, metallic ores, coal, nonmetallic minerals, waste or scrap materials, and containers were all identified as moving more than 90 percent of their tons by rail. The inbound movement of primary metal products and petroleum or coal products was 87 and 58 percent by rail, respectively. The outbound movement of chemicals or allied products and primary metal products was 56 and 32 percent by rail.

The high percentage of inbound tons by rail to the seven-county region is primarily a result of rail's superior ability to move low value, bulky materials (especially coal) efficiently and effectively. Coal comprises nearly 50 percent of all inbound tons and more than 62 percent of all inbound rail tons. More than 91 percent of the coal is moved by rail.

Because of the manufacturing nature of the region, a large percentage of outbound tons are finished products. Because finished products have a higher value and low-cost transport is not as essential, rail has a decreased importance in the movement of the goods. Primary metals account for the largest percentage of tons shipped outbound and are followed by farm products.

The corridors between northwest Indiana and Pittsburgh, Philadelphia, Baltimore, Johnson City, Charleston, Champaign, Duluth, and Cheyenne were all identified as shipping more than 80 percent of their tons by rail. It is not surprising that the Reebie data also identified four of these cities as being originators of coal to the region. Except for Duluth and Cheyenne, these cities are directly accessible by the railroads serving northwest Indiana. The corridors moving the highest percentage of rail tons to and from the region are Johnson City, Detroit,

**TABLE 1 Percentage of Rail Tons to Total Tons by STCC, 1980 Seven-County Region Data *(2)***

| STCC[a] | Tons Inbound ($10^5$) | Rail Tons Inbound ($10^5$) | Percentage of STCC | Tons Outbound ($10^5$) | Rail Tons Outbound ($10^5$) | Percentage of STCC | Total Tons ($10^5$) | Rail Total Tons ($10^5$) | Percentage of STCC |
|---|---|---|---|---|---|---|---|---|---|
| 01 | 0.0010 | - | 0.0 | 12.19 | 11.79 | 96.7 | 12.2 | 11.3 | 96.69 |
| 10 | 4.20 | 4.20 | 99.9 | 0.54 | 0.05 | 9.7 | 4.7 | 4.3 | 89.75 |
| 11 | 89.85 | 82.08 | 91.4 | - | - | - | 89.9 | 82.0 | 91.7 |
| 14 | 0.36 | 3.55 | 100.0 | 1.34 | 1.34 | 100.0 | 1.7 | 1.7 | 99.9 |
| 20 | 7.60 | 3.03 | 39.9 | 9.15 | 1.79 | 19.6 | 16.7 | 4.8 | 28.8 |
| 22 | 0.19 | - | - | 0.25 | 0.04 | 18.1 | 0.4 | 0.04 | 10.26 |
| 24 | 1.89 | 0.71 | 37.8 | 0.32 | - | - | 0.2 | 0.7 | 32.3 |
| 25 | 0.20 | 0.06 | 30.3 | 0.22 | 0.02 | 10.4 | 0.4 | 0.08 | 19.7 |
| 26 | 2.87 | 0.07 | 24.4 | 2.51 | 0.73 | 29.0 | 5.0 | 1.4 | 26.56 |
| 28 | 9.28 | 1.43 | 15.0 | 5.37 | 3.02 | 56.0 | 14.6 | 4.4 | 30.41 |
| 29 | 18.97 | 11.03 | 58.1 | 45.12 | 5.27 | 11.7 | 64.1 | 16.3 | 25.42 |
| 30 | 0.43 | 0.07 | 1.6 | 0.25 | 0.07 | 26.9 | 0.7 | 0.07 | 11.04 |
| 32 | 16.72 | 2.66 | 16.0 | 58.98 | 1.84 | 3.1 | 75.7 | 4.5 | 5.95 |
| 33 | 25.96 | 22.52 | 86.7 | 146.58 | 47.57 | 32.45 | 172.5 | 70.1 | 40.62 |
| 34 | 1.56 | 0.07 | 4.8 | 9.23 | 0.12 | 1.4 | 10.8 | 0.2 | 1.86 |
| 35 | 0.95 | - | - | 1.09 | 0.05 | 4.3 | 2.0 | 0.05 | 2.33 |
| 36 | 0.39 | 0.04 | 10.4 | 0.08 | - | - | 0.5 | 0.04 | 8.52 |
| 37 | 1.30 | 0.02 | 1.7 | 2.13 | 1.72 | 81.1 | 3.4 | 1.7 | 51.01 |
| 40 | 1.97 | 1.85 | 93.9 | 5.95 | 5.80 | 97.36 | 7.9 | 7.7 | 96.49 |
| 41 | 0.33 | - | - | 0.02 | 0.02 | 100.0 | 0.3 | 0.02 | 6.01 |
| 42 | - | - | - | 0.03 | 0.03 | 100.0 | 0.03 | 0.03 | 100.0 |
| 46 | 0.03 | - | - | 0.04 | 0.04 | 100.0 | 0.07 | 0.04 | 63.4 |
| Total | 185.01 | 130.77 | 71.0 | 301.47 | 81.33 | 27.0 | 486.4 | 212.10 | 43.6 |

[a]Standard transportation commodity code.

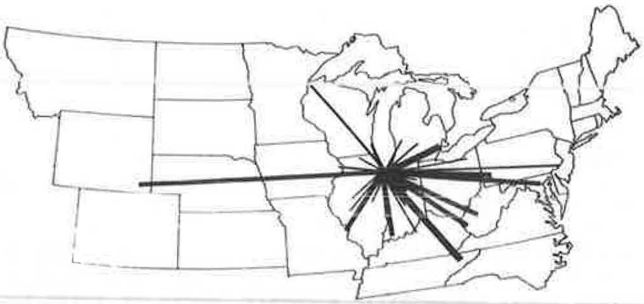

FIGURE 2 Commodity flows by rail.

St. Louis, Champaign, and Cheyenne. Coal or primary metal products comprise a large percentage of tons on these corridors.

The Reebie data (2) did not include most intermodal freight movements, nor does the shipment information include most agricultural products. Also, because the seven-county region is a part of the Chicago BEA, no interchange between the region and the Chicago area was included. It should also be noted that the freight carried by the steel companies by water was not included in the Reebie data. Consequently, the Reebie data would present much lower freight movement volumes than were actually carried.

## COMMODITY FLOWS IN LAKE AND PORTER COUNTIES

To get more direct information about the characteristics of freight transportation in the primary study area (Lake and Porter counties), the study team conducted a detailed survey of freight generators in the area in 1981-1982 (3). The 13 largest employers with 1,000 or more employees were contacted along with another 232 randomly selected generators of freight in the region. Completed questionnaires were received from the 10 largest employers and from 55 other employers. The respondents were requested to identify the commodity type, quantity, mode, value, and origin (for incoming flow) and destination (for outbound flow) for each shipment. Commodities were identified by the two-digit standard transportation commodity code (STCC).

The sample data were adjusted by appropriate factors based on the average productivity (tons of commodity per employee) for the sample by the number of employees in the population for a given commodity type (3). It was assumed that the average productivity of each employee from the usable responses in a commodity category is the same as that in the population. Carrying out these adjustments for a representative sample on a commodity-by-commodity basis minimizes the inaccuracies inherent in such a computation.

Table 2 (3) gives the tons shipped by commodity type and the rail tons shipped by commodity type for Lake and Porter counties. Data are given for both inbound and outbound movements along with the aggregated results. Rail accounted for 30 percent of the inbound tons, 15 percent of the outbound tons, and 25 percent of the total tons shipped to and from the two-county region. Unlike the Reebie data, the freight data in this survey included the movement of goods within the region. When the intraregional movement is considered, the percentage of rail tonnage is greatly reduced. Nevertheless, the relative significance of the inbound rail traffic over the outbound traffic is still reflected in the two-county survey data.

An analysis of the two-county survey data indicated that the inbound traffic was dominated by metallic ores, coal, and primary metal products. Together, these three commodities accounted for 75.5

**TABLE 2 Percentage of Rail Tons to Total Tons by STCC, 1981 Lake and Porter County Data *(3)***

| STCC[a] | Tons Inbound ($10^5$) | Rail Tons Inbound ($10^5$) | Percentage of STCC | Tons Outbound ($10^5$) | Rail Tons Outbound ($10^5$) | Percentage of STCC | Total Tons ($10^5$) | Rail Total Tons ($10^5$) | Percentage of STCC |
|---|---|---|---|---|---|---|---|---|---|
| 01 | 4.24 | 0.20 | 4.75 | - | - | - | 4.24 | 0.20 | 4.75 |
| 08 | 0.009 | - | - | 0.08 | - | - | 0.09 | - | - |
| 10 | 135.27 | 9.34 | 6.91 | - | - | - | 135.27 | 9.34 | 6.91 |
| 11 | 143.06 | 142.30 | 99.47 | - | - | - | 143.06 | 142.30 | 99.47 |
| 13 | 179.77 | - | 0.0 | - | - | - | 179.77 | - | - |
| 14 | 9.16 | 0.09 | 0.98 | 0.40 | - | - | 9.55 | 0.009 | 0.09 |
| 20 | 2.34 | 2.29 | 97.56 | 5.28 | 4.01 | 75.96 | 7.62 | 6.30 | 82.59 |
| 21 | 1.32 | - | 0.0 | - | - | - | 1.33 | - | - |
| 22 | 0.34 | - | 0.0 | - | - | - | 0.34 | - | - |
| 23 | - | - | 0.0 | 0.32 | - | - | 0.32 | - | - |
| 24 | 0.20 | 0.15 | 75.12 | 0.22 | - | - | 0.41 | 0.15 | 36.0 |
| 25 | 0.0 | - | 0.0 | - | - | - | 0.0 | - | - |
| 26 | 0.002 | - | - | 0.14 | 0.14 | 100.0 | 0.16 | 0.14 | 93.53 |
| 27 | 0.0 | - | - | - | - | - | 0.0 | - | - |
| 28 | 4.97 | 1.92 | 38.56 | 6.86 | 1.73 | 25.27 | 11.8 | 3.64 | 30.85 |
| 29 | 53.25 | 0.49 | 0.93 | 179.68 | 2.82 | 1.57 | 232.93 | 3.31 | 1.42 |
| 30 | 0.0 | - | - | 0.010 | - | - | 0.01 | - | - |
| 32 | 20.43 | 0.61 | 2.98 | 7.56 | 4.70 | 62.22 | 27.98 | 5.31 | 18.98 |
| 33 | 20.32 | 15.59 | 76.71 | 104.67 | 28.54 | 27.32 | 124.99 | 44.18 | 35.35 |
| 34 | 2.54 | - | - | 1.58 | 0.84 | 52.75 | 4.13 | 0.84 | 20.27 |
| 35 | 0.21 | - | - | 0.43 | - | - | 0.63 | - | - |
| 36 | 0.04 | - | - | 0.09 | - | - | 0.13 | - | - |
| 37 | 0.0 | - | - | 0.89 | 0.89 | 100.0 | 0.89 | 0.89 | 99.81 |
| 39 | 0.59 | 0.53 | 90.24 | 0.07 | - | - | 0.66 | 0.53 | 80.25 |
| 40 | 8.43 | 4.85 | 57.49 | 2.80 | 2.71 | 97.05 | 11.22 | 7.55 | 67.35 |
| 41 | 0.02 | - | - | 0.0 | 0.0 | 0.669 | 0.02 | 0.0 | 0.08 |
| 42 | 0.18 | 0.16 | 84.66 | 0.02 | 0.02 | 76.94 | 0.20 | 0.17 | 83.73 |
| 46 | 0.0 | - | - | 1.71 | 0.005 | 0.32 | 1.71 | 0.005 | 0.32 |
| 47 | 0.0 | - | - | 0.01 | - | - | 0.01 | - | - |
| 49 | 0.0 | - | - | 0.0 | - | - | 0.0 | - | - |
| Total | 586.68 | 178.42 | 30.46 | 312.83 | 46.48 | 14.86 | 899.51 | 224.89 | 25.0 |

[a]Standard transportation commodity code.

percent of all the incoming tons. However, coal was the major commodity shipped by rail and had an 80 percent share of all inbound rail tonnage.

Outbound traffic was dominated by primary metal products and petroleum products with 34 percent and 57 percent, respectively. Primary metal products accounted for 61 percent of the outbound rail traffic whereas petroleum products comprised only 6 percent. Clay, concrete, glass, and stone products was the second largest commodity type shipped by rail with 10.5 percent of the outbound traffic followed by food products at 9 percent and waste or scrap materials at 6 percent.

The combined inbound and outbound statistics indicated that at 26 percent, petroleum products represented the highest percentage of total tons shipped but comprised only 1.5 percent of the total rail tons. Crude petroleum was the second largest shipment at 20 percent followed by coal at 16 percent, metallic ores at 15 percent, and primary metal products at 14 percent. However, coal dominated the total rail tons with a 63 percent share. Primary metal products accounted for nearly 20 percent of all rail tons followed by fabricated metals and waste or scrap materials at 4 and 3 percent, respectively.

The two-county survey data indicated that the majority of the inbound freight shipments to Lake and Porter counties come from nine states: Colorado, Illinois, Kentucky, Michigan, Pennsylvania, Virginia, West Virginia, Wisconsin, and Wyoming. Most of these states are large coal producers, providing the resources required for the production of electricity and the manufacturing of steel.

Outbound shipments by rail traveled to nearly every state in the continental United States. However, Alabama, Illinois, Indiana, Michigan, Pennsylvania, Tennessee, and Wisconsin received a higher percentage of shipments than the other states. The data also showed that Chicago received 4.6 percent of all outbound shipments and that 10.8 percent remained within the two-county region.

When the inbound and outbound tons moving between the two-county region and the other states were combined, nine states were identified as being the most interactive with the region. These states and the percentage of total tons shipped by rail to and from them are Colorado (3.8), Illinois (13.9), Kentucky (3.95), Michigan (4.25), Pennsylvania (10.78), Virginia (5.2), West Virginia (3.68), Wisconsin (5.42), and Wyoming (18.2). Again the major coal producing states are represented highly in this group.

The use of the two-digit STCC does not permit specific identification of the product shipped. Some firms responded to the survey form simply by guess or estimation or using one commodity code to represent one or more STCC numbers for convenience. Because the analysis was sensitive to the weight of each commodity type recorded, a comparison using this value for each STCC may be biased. Also, data were not obtained from one of the major employers in the area.

## SURVEY OF RAIL-DEPENDENT ESTABLISHMENTS

To obtain a better understanding of rail terminal operations in northwest Indiana, a survey was conducted among those firms that had direct access to rail. The rail dependence survey was limited to Whiting, East Chicago, Hammond, Gary, Griffith, and Burns Harbor. The companies contacted were asked to provide information on the number of carloads shipped or received in the past year by commodity type, the railroad they were served by, and plant employment. The amount shipped was requested in carloads instead of tons because those figures are usually more easily available. An estimate of the number of tons shipped was made by using an average conversion factor given elsewhere (4). Using carloads as a measure can be beneficial because railroad operations are often measured in terms of cars handled and trains moved.

Although 105 firms were identified as having direct access to rail, a number of these firms indicated that they no longer use rail in their distribution systems. These firms along with those companies that reported five or less carloads shipped or received per year were removed from the data base. A total of 57 firms were used in the railroad analysis.

Table 3 (3) gives the results of the survey. Only 10 different commodity codes are identified because they comprised the majority of the reported carloads. The remaining commodities are recorded as "other." In all, 16 different commodity codes were reported. Table 3 also gives the ratio of each commodity code to the total amount shipped as well as information on the number of firms reporting under each STCC and their employment.

The results of the rail dependence survey are easily interpreted and fairly predictable. Coal dominates the rail carload traffic followed by primary metal products and then metallic ores. Petroleum products account for only a small percentage of the rail carload traffic.

Coal (STCC 11) is the predominant commodity shipped by rail to the region. The importance of coal to both the regional economy and the railroads cannot be underestimated. The inbound movement of coal represents nearly 80 percent of all inbound rail tons and 90 percent of all inbound rail ton miles in the

**TABLE 3 Rail Dependence Survey, 1982 Data *(3)***

| STCC[a] | Number of Firms | Employment | Total Carloads Received or Shipped | Percentage of Total Carloads | Estimated Tonnage | Tons per Carload |
|---|---|---|---|---|---|---|
| 10 | 4 | - | 13,979 | 3.4 | 1,118,320 | 80 |
| 11 | 4 | - | 182,000 | 44.3 | 18,200,000 | 100 |
| 24 | 3 | 115 | 228 | 0.06 | 12,312 | 54 |
| 28 | 6 | 700 | 2,683 | 0.65 | 179,761 | 67 |
| 29 | 2 | 2,250 | 7,890 | 1.9 | 444,840 | 56 |
| 32 | 4 | 475 | 12,512 | 3.0 | 750,720 | 60 |
| 33 | 17 | 63,275 | 152,254 | 37.1 | 9,744,256 | 64 |
| 34 | 5 | 565 | 4,772 | 1.16 | 305,408 | 34 |
| 37 | 4 | 1,840 | 7,269 | 1.77 | NA | NA |
| 40 | 3 | - | 11,380 | 2.8 | 508,380 | 51 |
| Other | 12 | 1,865 | 15,734 | 3.8 | 944,040 | 60 |

[a]Standard transportation commodity code.

two-county survey. Even though there are no outbound movements of coal from the region, coal still comprises 63 percent of all rail tons and 76 percent of all rail ton miles.

Because coal is a low-value, bulky commodity mined from inland sources, rail and water are the only practical modes currently available for its transport. Nearly 100 percent of the coal destined for northwest Indiana moves by rail.

The major coal users in northwest Indiana are the electric utilities and the steel producers. Both Commonwealth Edison and Northern Indiana Public Service Commission have large coal-fired generating plants. Bethlehem Steel, Inland Steel, Jones and Laughlin Steel, and U.S. Steel operate coke ovens; and Marblehead Lime Company uses coal in its production process.

Coal is delivered to northwest Indiana primarily by unit train. Three railroads, the IHB, the EJE, and the Chicago South Shore and South Bend deliver most of the coal to the industries in the region. However, all three of these railroads are essentially terminal railroads. Coal arriving in northwest Indiana must be transferred from a line-haul railroad to one of the previously mentioned railroads for delivery to the plant. This transaction is both time consuming and costly.

Most of the coal used in the production of steel comes from sources served by railroads operating in the region. The terminal cost of transferring railroads adds to the delivery cost of coal to the mills. It would, therefore, appear reasonable to assume that if the line-haul railroads could make direct delivery, the savings could be passed on to the steel companies.

Primary metal products (STCC 33) is clearly the second highest shipped commodity by rail. STCC 33 comprises 62 percent of all outbound rail tons and 20 percent of total tons. Almost 9 percent of all inbound rail tons is also classified as STCC 33. Maintaining an effective and reliable rail system to transport the region's primary manufactured product is important.

In northwest Indiana, 17 companies were identified that ship primary metal products by rail. The railroad survey found that in 1982 these 17 companies had a total employment of 65,631 and shipped a total of 108,697 cars in and out of the region. The steel manufacturers in northwest Indiana, however, dominate both the employment and the carloads of STCC 33. The seven steel companies in the region have a total employment of 63,200 and shipped or received about 106,500 carloads in 1981. The five largest manufacturers of steel are Inland Steel, Jones and Laughlin Steel, U.S. Steel, Bethlehem Steel, and Midwest Steel. Together, these five firms account for 62,000 employees and 105,973 carloads.

The total employment and the carloadings of the twelve other firms is inconsequential when compared with the five largest steel mills. The survey shows that of the firms using rail service in northwest Indiana, 89 percent of the employment is associated with primary metal products. Also, the railroad survey indicates that STCC 33 comprises 34 percent of all carloads shipped and received in the region. If shipments of coal, metallic ores, and waste or scrap materials are considered, the total carloads associated with the steel industry in northwest Indiana is 70 percent of all carloads.

The continued production of primary metal products and a viable rail network to handle the shipments are essential to the economy of northwest Indiana. The tons originated by rail in the region represent a high percentage of revenue to the railroads. The market for primary metal products produced in the region appears to be in the Midwest for those shipments moving by rail. The rail transit time and the level of service provided may be detrimental for markets northwest and west of Chicago where the railroads in northwest Indiana do not operate.

## REGIONAL ECONOMIC DEVELOPMENT SCENARIOS AND THE ROLE OF RAIL TRANSPORTATION

Three potential long-range scenarios for economic development in northwest Indiana have been developed by the study team (3). A brief synopsis of the scenarios and their impact on rail are presented in the paragraphs that follow.

Scenario one is steel and allied industry reindustrialization. This scenario emphasizes the reconstruction of existing old-line manufacturing industries. Because the rail network was originally developed to serve these industries, the railroads are well equipped to accommodate any new growth that might occur. The superintendent of one of the terminal railroads indicated to the study team that even if the steel manufacturers returned to peak production, his railroad would still have excess capacity and there would be little change in their operation.

The second scenario is steel reindustrialization and new enterprise vitalization. This scenario focuses on a decline in heavy industries and relies on the development of high technology and service industries. If this scenario were to occur, the need for direct rail service would be further diminished. This would result in more excess capacity in the region and possibly poorer service to the remaining companies. High switching rates can be anticipated as the railroads attempt to cover their costs from smaller traffic levels. However, use of trailers on flat car (TOFC) and containers on flat car (COFC) may increase. All the Class 1 railroads have extensive TOFC and COFC facilities within 20 or 30 miles of northwest Indiana in Chicago and are accessible by the freeways.

The third scenario is steel industry repositioning and regional economy diversification. This scenario assumes that the steel industry will redevelop as a smaller but more efficient and more competitive industry. Alongside steel industry repositioning would be the diversification of allied and high technology industries. The effect on railroads in this scenario would be similar to that of scenario two. Railroads would still deliver bulk commodities such as coal but would experience a decrease in other carload shipments. Because delivery by unit trains does not require extensive yard or terminal facilities, an overbuilt rail infrastructure would still exist and rates might increase to cover operating costs.

## CONCLUSIONS

The rail operation in northwest Indiana is a satellite system to Chicago. A number of conclusions can be reached about such a system on the basis of the present study.

Mainline consolidations are possible and would relieve safety and grade crossing problems in the local communities. Consolidation, however, is at the discretion of the operating railroads. Consolidation on a small scale has already occurred in northwest Indiana with the mergers in the last several years and Conrail's efforts to divest itself of excess trackage. The CSX corporation has also reported that it is studying the feasibility of consolidating more of its operations in the Chicago area.

Consolidation of the terminal yards, tracks, and facilities could reduce operating costs and release capital investments without a loss or decline of service to the local industries. An added benefit would be the availability of valuable real estate. Since the enactment of the Staggers Act, which permits greater freedom in rate making, the terminal railroads have increased their rates in an attempt to cover the operating costs. Consolidation could lower costs, which would make rail a more attractive shipping mode if the savings were passed on to the shipper. However, political incentive and local pressure would probably be needed to make such a consolidation feasible.

Transit time is increased for cars moving in and out of the region because northwest Indiana is a satellite operation to the Chicago terminal. Classification occurs at the main yard of the terminal railroads in Chicago. Transit time is also increased by the need to interchange between the terminal railroads and the Class 1 carriers. Transit time and possibly costs could be reduced for movements on eastbound railroads (Class 1) if direct deliveries or pickups were made in northwest Indiana. However, an incentive such as a significant traffic base at a centralized location would probably be needed to induce the railroads to make stops in the region. A consolidated or coordinated terminal system in the region might be the sufficient incentive required. On the other hand, operating agreements between the Class 1 and terminal railroads for unit coal trains should reduce both transit time and cost without consolidation.

A continued decline of heavy manufacturing industries in northwest Indiana will further erode the traffic base of the terminal railroads resulting in even greater excess capacity. The result could be an increase in rates and a decline in service. A domino effect could occur resulting in even fewer carloads shipped by rail.

Even with direct rail access, a number of companies do not use the service. The literature contains a variety of reasons for mode choice, but it is well known that rail is not the primary mover of goods that it once was. Rail shipments tend to be of low value or bulky.

Economic growth in northwest Indiana is dependent on fast, reliable, and cost-effective transportation. Recent mergers of railroads serving northwest Indiana have opened up new markets for goods produced in the region. The efficiency of the terminal operations could be the key to the ability of the region to capitalize on these new opportunities.

## ACKNOWLEDGMENT

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## REFERENCES

1. Indiana State Rail Plan: 1983 Update. Division of Railroads, Indiana Department of Transportation, Indianapolis, 1983.
2. Transearch. Rubic and Associates, Greenwich, Conn., 1982.
3. K.C. Sinha and D.A. Lark. Regional Multimodal Freight Transportation Analysis: A Case Study of Northwest Indiana. Interim Report. Automotive Transportation Center, Purdue University, West Lafayette, Ind., Jan. 15, 1983.
4. J.H. Armstrong. The Railroad--What It Is, What It Does. Simmons-Boardman Publishing Corp., New York, 1979.

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# The Cost of Empty Rail Car Supply: A Method of Allocating Empty Costs to Loaded Trips

**PATRICIA M. DAVIS**

ABSTRACT

More than one-third of a railroad's car miles are due to empty car movements. The cost of empty rail car movements is thus a significant portion of a railroad's variable cost. The cost of these empty movements must be allocated to movements of loaded cars to determine the full cost of each loaded move. This cost information is required by railroad management for internal decision making on pricing and for performance evaluation. The reason is demonstrated why previous methods of allocating empty car costs to loaded trips do not provide accurate costs for economic decisions and a new method is proposed for allocating empty trip costs to loaded trips using a network model. The proposed method assigns to loaded trips a cost equal to the opportunity cost of an empty car at the loaded origin node less the opportunity cost of an empty car at the loaded termination node. The dual values from the linear programming optimization of empty car distribution are used to obtain the opportunity costs.

A railroad car is empty for more than one-third of the miles it travels (1); therefore, the cost of empty rail car movements is a significant portion of the variable cost of a railroad. The cost of empty car movements must be allocated to loaded cars to determine the full cost of each loaded move. Railroad management needs this cost information to make decisions about pricing and to evaluate performance. Deregulation has increased the need for an accurate and systematic method of allocating these costs.

Revenue from a loaded trip should be greater than the sum of the cost of moving the loaded car and the cost of moving an empty car to support the loaded move. Although railroad pricing decisions should be based on competitive factors, it is important for a railroad to know the floor price for a trip (i.e., the minimum price that will cover the cost of providing the trip). Different methods of allocating the cost of empty movements to loaded trips can lead to large variations in a railroad's floor price for a particular segment of traffic.

A method for allocating the cost of empty car movements to loaded, revenue-producing trips is presented in this paper. It is the intention of the author to stimulate discussion of the theory behind the method and to elicit suggestions for improvements to the basic method presented.

Unfortunately the empty movement cost allocation schemes used by railroads for internal decision purposes are not publicly available. It is the understanding of the author, however, that these allocation schemes are all sophisticated variants of either the supply or return methods discussed in the second section.

There are two areas of published research relevant to this topic: (a) physical distribution of empty cars, and (b) cost structure of railroad operations. The car distribution literature uses network algorithms to develop optimal car distribution strategies. The literature on cost allocation separates the railroad's costs into components that can be attributed to car trips. This second body of literature has provided increasingly sophisticated methods for separating fixed and variable costs and for assigning these costs to trips, both loaded and empty, but has not provided an adequate method for allocating the cost of empty trips to loaded trips.

This paper draws on both the car distribution literature and the cost allocation literature to develop a method for allocating the costs of empty trips to loaded trips. Although this paper is not concerned with the optimal distribution of empty cars, it applies the dual values from the linear programming solution to that optimization problem. The dual values provide the opportunity costs of delivering additional empty cars to each location on the network. The method proposed here uses these opportunity costs (the shadow prices) to develop the appropriate empty trip cost to be assigned to each loaded trip.

The following topics are discussed in this paper:

1. A review of the two areas of published research mentioned previously.
2. The uses of empty car cost allocation and why previous approaches do not provide accurate costs.
3. A new approach to allocating empty car costs and its application to a hypothetical three-node network.
4. The results of applying the method to the movement of intermodal trailers on an actual railroad network.
5. Conclusions and suggestions for further research.

## LITERATURE REVIEW

The subject of the cost of empty car movements has primarily been addressed in the published research in terms of cost reduction rather than cost allocation. There is a substantial body of literature concerned with the actual movement of empty cars. This literature treats cost reduction as a primary goal for optimal distribution of cars.

The literature on car distribution has provided a series of increasingly sophisticated network models that can be used as tools in railroad operations (2-4). Instead of developing a complex network model for this analysis, a simple model is used in a new way. The contribution of this paper is to show how a network model can be used in cost allocation.

The idea of using a network model to determine the costs of moving empty rail cars was suggested by French (5). His work concerned the change in empty car cost that would occur with different foreign car reload strategies. He suggested using a network model to determine the effect of various policies on operations and thus costs. French was not concerned with allocation of empty car costs among loaded trips.

The work in the car distribution literature most closely related to this paper is the two-stage network model developed by Mendiratta (6). That application is similar because it specifically recognizes the usefulness of the dual solution to the linear programming minimization of car distribution costs. Mendiratta uses the dual values as opportunity costs that line managers must consider to ensure that the decentralized decision-making process of railroads is economically rational. Mendiratta, however, is clearly concerned with car distribution and cost reduction, not cost allocation.

On the other hand, the published research on railroad cost allocation has not fully addressed the costs incurred by empty car movements. The primary focus of the published literature on railroad cost allocation has been the distinction between accounting and economic costs and, concurrently, between fixed and variable costs (7,8). The allocation of the cost of empty car movements has not received debate in the literature. Allocation has been based on simple techniques, such as multiplying the loaded cost by the overall ratio of empty-to-loaded miles. Although these techniques serve to allocate empty cost among loaded trips, the allocations to specific loaded trips often do not reflect the costs incurred accurately. Railroad cost professionals, however, have debated the appropriate method for allocating empty movement costs for at least 20 years.

The Interstate Commerce Commission (ICC) policy has been to treat the empty car movement cost as a joint cost that cannot be differentiated by the direction of movement of the loaded trip (9,10). Recently the ICC has introduced a new costing system, Uniform Railroad Costing System (URCS), which provides regression equations to develop fixed and variable cost components. This system, however, continues to allocate empty car cost in a broad, imprecise fashion.

## Empty Car Cost Allocation

Empty car costs must be assigned to loaded trips so that management can compare the revenue generated from the trip with the variable cost incurred to make the trip. When total empty car movement costs are greater than a railroad's total contribution (revenue minus variable cost), the improper allocation of the railroad's empty car movement costs among the loaded trips may make unprofitable traffic segments look profitable and vice versa.

Deregulation has given railroad management tremendous flexibility in setting prices. Now accurate allocation of empty car movement costs are necessary for contract negotiations. A railroad's contract negotiators must have an accurate estimate of costs to avoid a contract that requires the railroad to move the traffic at a loss. Empty car cost must be accurately allocated and paired with the cost of loaded trips to develop a price floor below which the railroad cannot afford to accept the traffic.

An empty cost allocation method must address two issues: (a) supply versus return, and (b) backhaul. The first issue is essentially a chicken or egg question--whether a load should be assigned the cost of the previous empty (supply of an empty car to the loaded origin) or the subsequent empty (return of an empty car after a loaded trip delivery). Previous methods of allocating empty car movement costs to loaded trips have used either the supply or the return perspective. The second issue is whether some loaded moves actually reduce the necessity for empty movements and should therefore be allocated a credit rather than the cost of an empty trip.

## Supply Versus Return

The question of supply versus return is illustrated in Figure 1, which shows a simple railroad network with four nodes (A, B, C, and D) serving Grain Inc. and Lumber Company. Grain Inc. loads cars at B and ships them 500 miles for unloading at C. The cars are then moved empty for 200 miles from C to D. At D, Lumber Company loads the cars for a 500-mile trip from D to A. At A the cars are unloaded then moved empty for 400 miles to B. The cycle repeats starting with Grain Inc. at B.

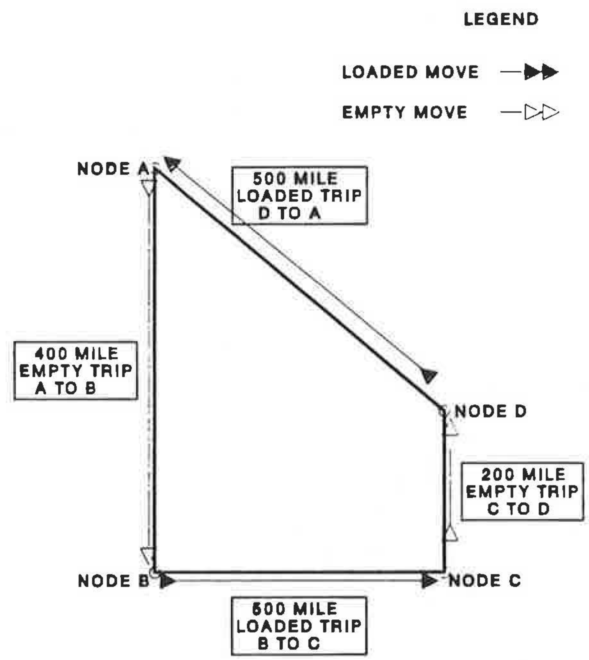


**FIGURE 1 Supply versus return.**

Fewer empty miles are incurred by moving the cars in a cycle instead of returning the empty car to its previous loading point. A total of 600 empty miles are incurred for the cycle. If the empties were reverse routed at their unloading point, 1,000 empty miles would be incurred. Given that the railroad moves cars in the more efficient traffic pattern, 600 empty miles must be allocated to the two shippers. If empty cars are viewed as goods supplied to a shipper, the loaded trip would be charged for the empty movement to the loading point. Thus Grain Inc. would be charged for the 400-mile empty movement from A to B and Lumber Company would be charged for the 200-mile empty movement from C to D.

An alternative view is that empty cars are the result of loaded moves, the unfortunate end result of a loaded termination. In this view loaded trips create empties that must be moved (returned) to the next loading point. From this perspective Grain Inc. should be charged for the 200-mile empty movement from C to D and Lumber Company should be charged for the 400-mile empty movement from A to B.

The merits of the supply viewpoint are illustrated in Figure 2. The railroad depicted here has a three-node network with all but one of its shippers moving loads between A and B. Lumber Company is located outside the bidirectional loaded flow; it loads cars at C that are destined for B. Clearly Lumber Company should bear the cost of moving the empties from B out to C. The return view is inappro-

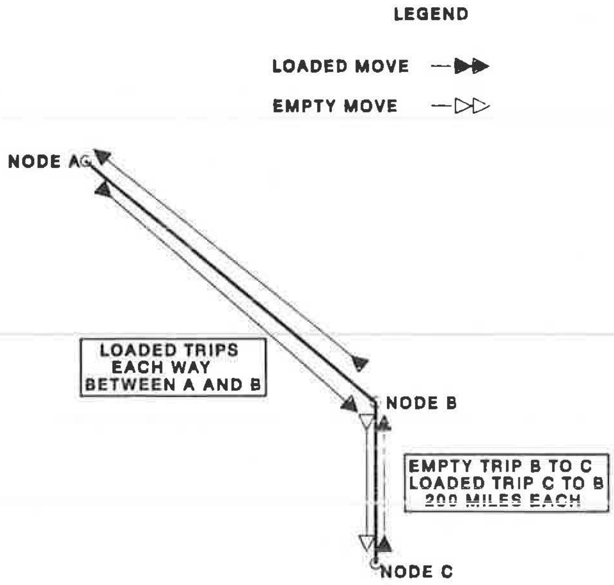


FIGURE 2 The supply view.

priate in this case because it would assign only some of the cost of moving empties from B to C to Lumber Company, leaving the other shippers to bear the remainder of the cost.

The merits of the return viewpoint are illustrated in Figure 3. As in Figure 2, the railroad has a three-node network with all but one of its shippers moving loads between A and B. Here the unusual movement pattern is caused by Grain Inc., which ships loaded cars out of B to C. In this case Grain Inc. should bear the cost of moving the empties from C back to B. The supply view is inappropriate because it would spread the burden of the C to B empty movements over all shippers when the cost is only incurred by Grain Inc.

Neither the supply view nor the return view is correct in all situations. However, each provides the correct solution in some situations. An allocation method based on either view would be in error because its perspective would be limited to the individual shipper's movements. An appropriate allocation method must reflect the implications for both supply and return of each shipper's movement. To do this the analysis must be expanded to recognize shippers' movements in a network context. The method must transcend the question of supply versus return to provide a way of analyzing network flows.

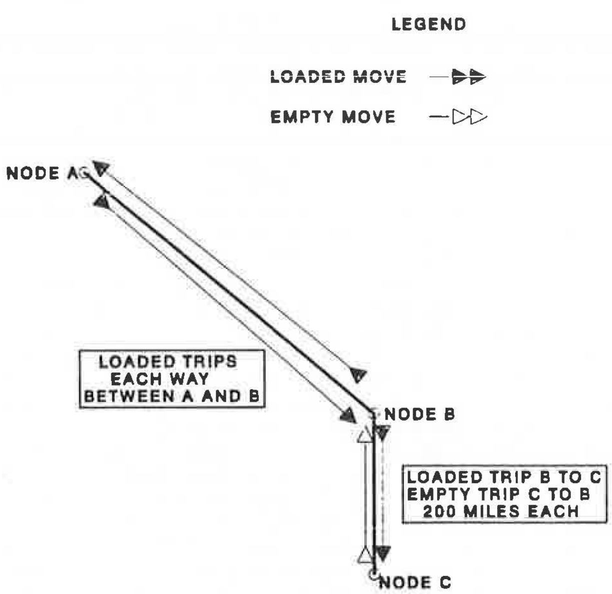


FIGURE 3 The return view.

## Backhaul Trips

The second issue an empty car cost allocation method must address is the treatment of backhaul trips, which are loaded movements in the direction empties are usually sent. Backhaul trips are desirable because they reduce the number of empties that must be moved. The backhaul load replaces one empty car movement.

Backhaul loads provide an economic benefit to the railroad. The cost of a loaded trip is incurred, but the cost of an empty car movement is avoided. The railroad's net cost for the backhaul movement is the loaded cost less the avoided empty car cost. For backhauls, instead of adding some empty movement cost to the loaded cost, the avoided empty movement cost should be subtracted from the loaded trip cost. Backhauls should get empty movement credits for the empty trips they replace.

An appropriate allocation method must assign empty car credits to backhaul loads while still allocating the full costs incurred in moving empty cars on the network. If the full empty cost incurred were assigned to loaded trips, then reduced by backhaul credits, the net result would be an allocation of empty costs that would sum to less than the total empty cost actually incurred. Backhaul credits cannot be included as an afterthought or the total cost will not be allocated. The allocation method must account for backhauls as an integral part of its allocation scheme.

The solution to the backhaul issue is basically the same as the solution to the supply versus return issue--treat each load as it relates to the system network. Both issues occur because trips are treated out of the network context, which gives rise to the necessity of empty movements. If empty car costs are allocated to loaded trips without considering the place of each loaded trip in the network, railroad management will not have the necessary economic information to make rational decisions.

# METHODOLOGY FOR A NEW APPROACH

It was asserted in the previous section that an appropriate allocation of empty car costs will occur only if the allocation method recognizes the place of each loaded trip in the network. In this section a method is developed that uses such a network perspective to allocate empty car costs to loaded trips.

Two concepts underlie the proposed method of allocating costs of empty car movements to loaded car trips:

- A loaded rail car trip not only transports goods from one location to another, but it also transports an empty rail car from one location to another.
- An empty rail car has a value to the railroad that is dependent on the rail car's location on the system.

Taken together, these concepts imply that a loaded car trip is taking, at the loaded trip's origin, an empty car worth one value and leaving, at the loaded termination, an empty car with a different value.

The loaded trip changes the value of the empty rail car by moving it from one location to another.

The proposed method is based on these two concepts.

- Determine the value of an empty at each node that reflects supply and demand for empties at that node; and
- Assign the empty car values to loaded trips (a) as a cost when the loaded move takes an empty from a node and (b) as a credit when the loaded move delivers an empty to a node.

The value at the node should be the opportunity cost to the railroad of providing an additional empty at that node. The empty car cost assigned to the loaded trip would then be the opportunity cost of having available the empty car used to supply the load, less the opportunity cost of the empty car the load leaves at the loaded trip termination.

Opportunity cost is an economic concept that means the value of the best available opportunity is foregone because of the action. A loaded trip is initiated by removing one empty car from the pool of available empty cars and targeting it for the loaded trip. The opportunity cost of the targeted empty is the amount of money that had to be spent to make the empty available at the location.

Information on the supply and demand for empties is necessary to determine the opportunity cost of empties at each node. At nodes with surplus empty cars, this value would be low because empties are readily available. At nodes with a deficit of empty cars (i.e., with more originations than terminations) the value would be higher because empties must be brought from distant points to meet the loading demand.

The following example demonstrates the concept of opportunity costs for the three-node railroad network shown in Figure 4. Table 1 gives the relevant loaded flow statistics. There are no interchanges in this example so all loaded and empty movements are between the three nodes: A, B, and C. Node A has more originations than terminations, so empty cars must be brought to A to meet loaded demand there. Conversely B and C have more terminations than originations, thus excess empties are available at these two nodes. Because there is no slack in the system, there is no question about car distribution. To meet the demand, all the excess empty cars at both B and C must be moved up to A.

This example is provided to show how the opportunity cost of an empty at each node is derived. Table 2 provides the relevant cost information. For simplicity it is assumed that the cost of moving between nodes does not vary with direction. Note that the total cost of moving the empty cars to loading points is $14,400 (i.e., 13 x $300 for moving empties from B to A plus 15 x $700 for moving empties from C to A). The value of having an additional empty car at A would be $700. A $700 cost could be avoided if one less empty car were moved from C to A.

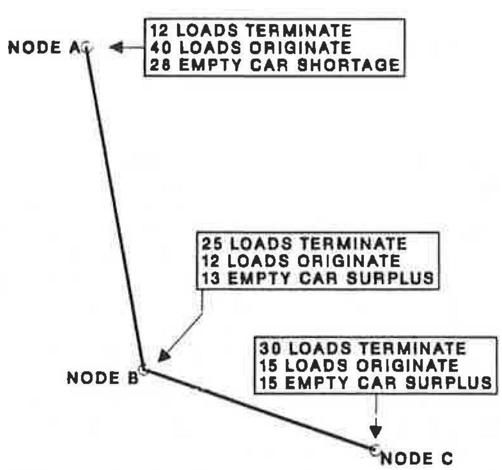


**FIGURE 4 An example for the proposed method.**

**TABLE 1 Loaded Car Movements**

| To | From A | From B | From C | Total Terminations |
|---|---|---|---|---|
| A | 0 | 2 | 10 | 12 |
| B | 20 | 0 | 5 | 25 |
| C | 20 | 10 | 0 | 30 |
| Total orginations | 40 | 12 | 15 | 67 |

**TABLE 2 Transportation Costs ($)**

| | Tare | Gross | Net |
|---|---|---|---|
| C to B | 400 | 550 | 150 |
| C to A | 700 | 1,050 | 350 |
| B to A | 300 | 500 | 200 |

If there were an additional empty car at B, the cost incurred by one empty car movement from C to A ($700) could be avoided. However, the cost of moving the additional car at B up to A ($300) would be incurred. The value of an additional empty car at B would be the $700 cost that would be saved less the $300 cost than would be incurred (i.e., $400). There would be no value to having an additional empty at C. C is the highest cost supplier of empties to A. Thus the values assigned to the nodes would be

| Node | Value ($) |
|---|---|
| A | 700 |
| B | 400 |
| C | 0 |

Loaded car trips would be assigned empty car costs as shown in Table 3. This method assigns backhaul credits for loaded trips moving from B to A and from C to A. This is appropriate because backhaul moves save the railroad money.

The total amount of empty car costs that would be assigned in this example is shown in Table 4. This sum is the same as the amount of empty car cost incurred. The proposed method for allocating empty car costs to loaded car trips will always result in al-

**TABLE 3 Costs Assigned per Loaded Car ($)**

| From | To | Loaded Cost | Origin | Termination | Net | Total Cost Assigned |
|---|---|---|---|---|---|---|
| C | B | 500 | 700 | 400 | 300 | 800 |
| B | A | 500 | 400 | 700 | -300 | 200 |
| A | C | 1,050 | 700 | 0 | 700 | 1,750 |
| C | A | 1,050 | 0 | 700 | -700 | 350 |
| B | C | 550 | 400 | 0 | 400 | 950 |
| C | A | 550 | 0 | 400 | -400 | 150 |

**TABLE 4 Total Empty Costs Assigned**

| From | To | No. of Trips | Empty Costs ($) | Total ($) |
|---|---|---|---|---|
| A | B | 20 | 300 | 6,000 |
| B | A | 2 | -300 | 600 |
| A | C | 20 | 700 | 14,000 |
| C | A | 10 | -700 | -7,000 |
| B | C | 10 | 400 | 4,000 |
| C | B | 5 | -400 | -2,000 |
| Net cost assigned | | | | 14,400 |

located empty car costs that exactly equal actual empty car costs incurred if three conditions are met:

- Actual car distribution is optimal;
- Loaded moves occur in a repeating pattern; and
- There is no slack (i.e., there are only just enough empty cars to satisfy demand).

The first condition would have been violated in the example if an empty car had been moved from B to C and then to A. This would appear foolish in the example; but on more complex networks, when loaded demand cannot be perfectly predicted in advance, such suboptimal moves do occur. These moves are the result of imperfect knowledge and do not necessarily reflect badly on the skill of car distributors.

The second condition, assumed to occur in the example, also will not exactly occur in the real world. Although railroads do experience consistent loaded movement patterns, an exact car-for-car repeat is not likely to occur. Exclusion of slack, the third condition, requires the same number of loads in each period. This is also unlikely.

To summarize, the method proposed in this section meets the two criteria established previously. The proposed method provides the appropriate network view, which reflects the implications of both the empty supply and return of the loaded move. This formulation of a network model is achieved by assigning opportunity costs as empty car values at each node. The method also provides the appropriate backhaul credits because the cost assigned, the difference between nodes, will be negative when a load moves from a low-value node to a high-value node. However, the proposed method has two potential problems:

- The development of opportunity costs requires a thought process that may be difficult to apply to large networks, and
- The allocated empty car costs will not exactly equal the empty car cost actually incurred, except under ideal circumstances.

The following section addresses these potential problems. It shows how opportunity costs can be easily derived and it provides an estimate of the error introduced by not exactly satisfying the conditions for assuring that allocated costs exactly equal actual costs.

## APPLICATION TO MOVEMENT OF INTERMODAL TRAILERS

The opportunity costs for the three-node network were readily derived without the use of a computer. Most railroads, however, have more complex networks and could not easily derive the necessary opportunity costs. It is therefore proposed that the dual values from the linear programming optimization of car distribution be used to provide estimates of the railroads' actual opportunity costs. This section explains how the dual values can be obtained and reports the results of an application of the proposed empty car cost allocation method to a railroad's intermodal dry trailers.

Linear programming will generate the appropriate empty car values to assign to each node. The dual solution to a linear programming formulation of an empty car distribution problem also provides the opportunity costs for the nodes (shadow prices). The dual values represent the benefit of having additional empty cars at the nodes. Thus, the dual values are the opportunity costs required for the proposed empty car costing method. The only necessary assumption for these values to be accurate is that the railroad's actual car distribution closely approximates the ideal (optimal) distribution.

To formulate the linear program that would be used for the example discussed above, the node relationships must be redefined in terms of matrix variables as follows:

| | To | | |
|---|---|---|---|
| From | A | B | C |
| A | X(1,1) | X(1,2) | X(1,3) |
| B | X(2,1) | X(2,2) | X(2,3) |
| C | X(3,1) | X(3,2) | X(3,3) |

The linear programming formula is

$$\begin{aligned}\text{Minimize } Z = {} & 0\ X(1,1) + 300\ X(1,2) + 700\ X(1,3)\\ & + 300\ X(2,1) + 0\ X(2,2) + 400\ X(2,3)\\ & + 700\ X(3,1) + 400\ X(3,2) + 0\ X(3,3)\end{aligned}$$

subject to:

Supply

$$X(1,1) + X(1,2) + X(1,3) \leq = 12$$
$$X(2,1) + X(2,2) + X(2,3) \leq = 25$$
$$X(3,1) + X(3,2) + X(3,3) \leq = 30$$

Demand

$$X(1,1) + X(2,1) + X(3,1) \geq = 40$$
$$X(1,2) + X(2,2) + X(3,2) \geq = 12$$
$$X(1,3) + X(2,3) + X(3,3) \geq = 15$$

The resulting dual values are

Supply Equations

A 700
B 400
C 0

Demand Equations

A -700
B -400
C 0

The dual values for the supply equations can be interpreted to represent the cost reduction that could be obtained if additional cars were available at the nodes. These values are the same as the opportunity costs in the previous section. As expected, linear programming produces the same values as the opportunity costs developed previously. The dual values for the demand equations are equal in magnitude but opposite in sign to the dual values for the supply equations. This is because the demand equation dual values represent the increase in cost that would occur if more empties were needed at the nodes.

The proposed method was applied to a railroad's intermodal dry trailers. The three-node linear programming formulation was expanded to 14 nodes to represent the railroad's 14 major intermodal ramping areas. The supply and demand constraints were developed from actual April 1983 loaded trailer moves. Loaded trailers originating in an area were counted as demand for trailers and loaded trailer terminations were counted as supply. Loaded trailers received from other railroads at interchanges were excluded from the demand count and interchange-forwarded loads were excluded from the supply count. Empties received at interchanges and empties forwarded at interchanges were added to the supply and demand counts, respectively.

The costs for the objective function were developed from 6 months of historical data; and when available, the average cost of empty movement for the node pair was used. The costs were direction specific. When no observations existed for a node pair, costs from other corridors were extrapolated.

After the dual values were obtained from the solution of the linear programming model they were applied back to the loaded trips as costs at origins that were reduced by the value of empty cars at terminations. Interchange traffic received a 0 value at the interchange point. Thus, the empty cost allocated to a load that was received at an interchange was zero minus the value of an empty at the terminating location.

This method was able to allocate 79 percent of the empty trailer cost that had actually been incurred in April. The 21 percent of empty cost that was not captured by this method was attributed to three factors: the time frame used in the study, uncertainty of supply and demand, and operating decisions unrelated to cost.

The time frame is a problem of static analysis. By aggregating 30 days of demands and supplies into 1 month of data, the linear programming model did not have to face momentary supply imbalances that actually occurred. Examination of the actual flows of empties over the month showed empties being sent from A to B as well as from B to A, which appeared at first glance to be inefficient and nonsensical. However, these movements were not due to faulty empty car distribution decisions but rather to a surplus at A at the start of the month and a deficit at A later in the month.

The second factor, uncertainty of supply and demand, is discussed by Jordan (11). Decisions regarding the distribution of empties must be made before complete information is available regarding the availability of empties and the need for empties. A model using historical information can always efficiently distribute empties.

The third factor, operating decisions not rigorously based on cost criteria, mostly relates to car distribution decisions based on customer relations rather than cost efficiency. When an important customer is ready to load, distribution may be based on satisfying that customer first and not striving for optimal car movement on the network. Although a slight delay may result in additional loaded terminations providing empties in close proximity to the customer, customer satisfaction takes priority over waiting for these potential economies to develop.

To complete the test application, the 21 percent of actual empty trailer cost not allocated by the method was applied as a flat charge to each trailer. Statistics on profitability by corridor were then calculated using this new allocation of empty trailer costs and compared with the results of more traditional methods.

This new proposed allocation appeared to provide the best ordinal ranking of corridor profitability. However, costs for individual loaded moves ranged from the cost of the tare weight of the loaded move to many times that amount. Although it was agreed that these costs accurately represented the economics of the moves, the large swings in cost for similar distance moves was startling. (Specific cost information is proprietary and cannot be presented here.)

## CONCLUSIONS

This paper presented a new use for the linear programming formulation of empty car distribution. Although previous research efforts using linear programming have focused on car distribution itself, this paper assumes that car distribution is adequate and attempts to allocate the associated costs to loaded trips. Current cost allocation schemes do not reflect empty cost incurrence adequately. The proposed method appears to reflect cost incurrence correctly in ideal circumstances and was shown to approximate closely actual cost incurrence of a railroad's intermodal trailers.

Empty car costs are a significant portion of a trip's variable cost and can have a dramatic effect on profitability studies and pricing decisions. As railroads have more flexibility in pricing because of deregulation, they need more precise cost analysis of traffic segments. The proposed method of allocating the cost of empty cars has theoretical appeal. It resolves the conflict between empty supply and empty return and it provides backhaul credits. As was shown, the method can be computerized using linear programming.

Although this paper reported the application of the proposed method to intermodal dry trailers, the method can also be used for any car type. However, each car type should be modeled separately. Because distribution patterns vary considerably by car type, an aggregation of all car types would provide meaningless results.

This method allocates the line-haul portion of empty car costs. The cost of local train gathering and distribution of empty cars should be costed separately. It is suggested that through train crew change points serve as nodes. This results in more accurate modeling of actual car distribution decisions and also reduces the size of the linear programming formulation. Thus, although a railroad may have many thousands of stations, only approximately 50 nodes are used to apply this technique to car types. For intermodal trailers, as previously discussed, only 14 nodes were required.

Any railroad could use this method by adding a linear programming capability to their computer system. The railroad would only need to know the origination points and termination points of its loaded moves and the nodes and volume of interchange traffic. If route-specific costs were not available, a railroad could use for the objective function a system average-per-mile line-haul cost multiplied by mileage; however, some concerns remain regarding this method:

1. Use of this method provides startling results compared with average cost data. However, if the ordinal ranking of costs is accepted, this ranking could be preserved while modifying the values.
2. Calculation of shadow prices is based on a 1-month snapshop of supply and demand when actual car distribution is limited to a much smaller time frame.
3. Calculation of shadow prices is based on discrete time periods for supply and demand when a moving window in time would more accurately reflect railroad operations.
4. Backhaul credits are applied to all loaded trips into empty car deficit nodes. This definition of backhaul may be too broad.

Despite these drawbacks, it is believed that it resolves important theoretical issues. It is hoped that this paper will stimulate additional research in empty movement cost allocation.

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REFERENCES

1. P. French. Managing Freight Cars in a Period of Surplus: Does Utilization Matter? Railway Age, Feb. 1981.
2. S.C. Misra. Linear Programming of Empty Wagon Disposition. Rail International, Vol. 3, March 1972, pp. 151-158.
3. B.P. Markowicz and A.L. Kornhauser. Car Management Opportunities: Actual Return Mileage vs. Optimal Return Mileage. Princeton University, Princeton, N.J., 1983.
4. W.C. Jordon and M.A. Turnquist. A Stochastic, Dynamic Network Model for Railroad Car Distribution. Transportation Science, Vol. 17, No. 2, May 1983.
5. P.W. French. Car Surplus Decision Making: System Car/Foreign Car Trade-Offs. Proc., Freight Car Management Seminar, Memphis, Tenn., Jan. 1982.
6. V.B. Mediratta. A Dynamic Optimization Model of the Empty Car Distribution Process. Ph.D. dissertation. Northwestern University, Evanston, Ill., June 1981.
7. H. McFarland. Major Studies of Railroad Costs: A Review. Working Paper. Transportation Center, Northwestern University, Evanston, Ill., 1976.
8. M.E. McBride. An Evaluation of Various Methods of Estimating Railway Costs. The Logistics and Transportation Review, Vol. 19, No. 1, 1983.
9. Explanation of Rail Cost Finding Procedures and Principles Relating to the Use of Costs. Statement 7-63. Bureau of Accounts, Interstate Commerce Commission, Washington, D.C., 1963.
10. Rail Carload Cost Scales: 1977. Statement 1C1-77. Bureau of Accounts, Interstate Commerce Commission, Washington, D.C., 1977.
11. W.C. Jordon. The Impact of Uncertain Demand and Supply on Empty Railroad Car Distribution. Ph.D. dissertation. Cornell University, Ithaca, N.Y., 1982.

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# General Model of Multirailroad Freight Car Management

**RICHARD V. MUEHLKE**

ABSTRACT

The freight railroad system of North America is comprised of many independent railroads. Most freight cars are loaded on one railroad and unloaded on another. The question of how to use the originating railroad's car once it has become empty has a long and complex history involving the railroads, shippers, and government regulatory bodies. This issue is so complex that traditional solutions to it have used one variable only--the amount of money received from other railroads for the time one's own cars are in use by those railroads. This has been supported frequently by a marketing strategy that stresses the value of placing for loading only those cars with the originating carrier's marks. The result of this and similar strategies has been a gross underutilization of and excessive investment in freight cars. The model described is a close approximation of present-day freight car management. It shows clearly the costs associated with lack of cooperation among railroads. It also can be used to try out solutions to those problems. Better use of existing freight cars will reduce future ownership and present operating costs of all railroads.

The model described in this paper focuses on a few of the variables of a complex system--multirailroad freight car management. By taking a simplified view of what is a complex subject, the model can show the underlying reasons for certain inefficiencies in traditional practices by individual railroads. It shows that cooperative efforts among railroads are necessary if an individual railroad is to improve the level of service to shippers and reduce costs.

The model uses only two railroads: A and B. Each railroad has 1,000 miles of line. Activities related to railroad A are shown on the left half of each diagram, and activities related to railroad B are shown on the right half of each diagram. There is

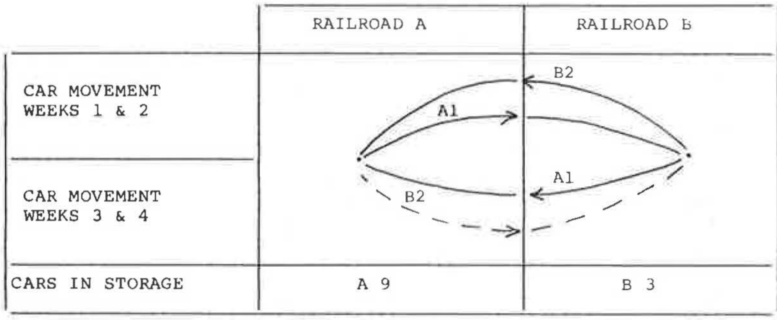


**FIGURE 1 Sample car movement diagram.**

only one loading and unloading point on each railroad. Railroad A owns 10 cars and railroad B owns 5 cars. There is only one car type. Loadings from A to B are always higher than loadings from B to A. It takes a car 7 days from origin to interchange, and 7 more days from interchange to destination. Loading and unloading are instantaneous. Empty travel from origin to destination takes the same length of time as loaded travel (14 days). The model in this paper is limited to a 4-week period for each situation. Thus, each car is always back at its starting point at the end of the time covered by the model. Car movements in weeks 1 and 2 are shown on the top half of each diagram, and car movements in weeks 3 and 4 are shown on the bottom half of each diagram.

The diagram accompanying each situation, or case, uses curved lines with arrows to show car movement over the single route between A and B. Car ownership and the number of cars involved are shown on top of each line. Loaded movements are shown as solid lines, and empty movements are shown as dotted lines. In the interest of brevity a diagram is not shown for each situation. A sample diagram is shown in Figure 1.

Costs are set as follows:

1. Ten dollars per day or $70 per week are owed by railroads to financial institutions for the long-term lease of one car.
2. The same rate ($10 per day or $70 per week) is owed by the railroads to each other for each day a car from another line (foreign car) is used (loaded or empty).
3. Ten cents per mile for each loaded mile is for transportation (e.g., fuel, labor, clerical).
4. Five cents per mile for each empty mile is for transportation (e.g., fuel, labor, clerical).

No cost is allocated for placing or keeping a car in storage. The model does not recognize the difference in maintenance cost between empty cars in motion and empty cars in storage. There are no mileage payments by one railroad to the other--only time payments. All these costs could, however, be added in a more elaborate version of the model.

Table 1 gives the situation sample that is used to tabulate all independent and dependent variables and gives the operating and financial impacts of various strategies used by the railroads in dealing with shipper demand and car management. In every situation described in this paper, the number of cars owned (column 1) by A is 10 and by B is 5. This is represented as 40 car weeks or 280 car days for A, and 20 car weeks or 140 car days for B. At $10 per car day or $70 per car week, ownership cost, therefore, is always $2,800 for A and $1,400 for B.

The per diem paid (column 2) is always $70 per car week or $10 per car day for every day a foreign car is on line. This can be adjusted by per-diem-free agreements or cash payments between the railroads. Per diem received (column 3) by one railroad must always equal per diem paid by the other. It is calculated on the same basis as column 2. Net per diem paid (column 4) is the algebraic sum of column

**TABLE 1 Situation Sample**

| | (1) Car Ownshp. Cost | | (2) Per Diem Paid | | (3) Per Diem Rec'd | | (4) Net Per Diem Pd | | (5) Net Car Time Cost | | (6) Loaded Mile Cost | | (7) Empty Mile Cost | | (8) Revenue | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| UNITS | 40 CW[a] | 20 CW | | | | | | | | | | | | | | |
| RATE | $70/CW | | $70/CW | | $70/CW | | $70/CW | | $70/CW | | 10¢/mi | | 5¢/mi | | $1.00/mi | |
| DOLLARS (000) | 2.8 | 1.4 | | | | | | | | | | | | | | |
| | | | | | | | (2)+(3) | | (1)+(4) | | | | | | | |

| | (9) Cars Stored | (10) Shipper Demand | (11) Loads Originated | (12) Loads Hauled | (13) Total Cost ($000) | (14) Contribution ($000) | (15) L/E[b] Miles | (16) E Miles Per Load | (17) E Car Days OnLine | (18) E Car Days/ Load |
|---|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | | |
| B | | | | | | | | | | |
| TOTAL | | | | | | | | | | |
| | | | | | (5)+(6) +(7) | (8)-(11) | (6)÷(7) | (7)÷(12) | | (17)÷(12) |

[a] Car week.
[b] Loaded/empty ratio.

2 and column 3. It can be negative if a railroad receives more than it pays. Net car time cost (column 5) is the algebraic sum of car ownership cost (column 1) and net per diem paid (column 4).

Loaded mile cost (column 6) is calculated at 10 cents per mile and is absorbed completely by the railroad handling the car. There is no mileage payment to the car owner, although this could be included in a more sophisticated version of the model. Empty mile cost (column 7) is figured at 5 cents per mile in the same way. Revenue (column 8) is determined by multiplying the number of loaded car miles (column 6) by $1 per car mile.

Cars stored (column 9) counts the number of its cars each railroad does not use for transportation, either involuntarily (no demand) or voluntarily (as part of a strategy to reload foreign cars).

Shipper demand (column 10) is the number of cars needed by each shipper (one on A and one on B) during the 4-week period depicted. As long as the car is supplied within the first 2 weeks and gets to its destination by the end of the 4-week period, this demand is considered satisfied. This is reflected in loads originated (column 11). Loads hauled (column 12) is simply the total loads a railroad handles, both outbound and inbound. Total cost (column 13) is the sum of net car time cost (column 5), loaded mile cost (column 6), and empty mile cost (column 7). Contribution (column 14) is the difference between revenue (column 8) and total cost (column 13).

Four measures of a car fleet's efficiency that are frequently used in the railroad industry are also calculated for each situation. Loaded/empty miles (column 15) is loaded miles (column 6) divided by empty miles (column 7). Empty miles per load (column 16) is empty miles (column 7) divided by loads hauled (column 12). Empty car days on line (column 17) is taken from the movement/storage diagram (Figure 1). It includes all empty cars, whether stored or moving, system or foreign. Empty car days per load (column 18) is derived by dividing empty car days on line (column 17) by loads hauled (column 12). As for all other variables, these measures are calculated for each railroad.

The situations are shown in Table 2 where each is identified by a Roman numeral and a letter. The Roman numeral indicates the shipper demand for cars. The letter C or R after the Roman numeral indicates a current or recommended car management strategy in response to the shipper demand. In some situations there is more than one recommended practice. These are indicated by Arabic numbers after R. The remainder of this paper illustrates the application of the model to the situations and strategies shown in Table 2.

## SITUATION I-C: HEAVY DEMAND, 20 PERCENT RELOAD

There is a heavy demand for cars (20 on A and 10 on B). Each railroad, therefore, allows only 20 percent of its cars to be reloaded by the other. This situation is illustrated in Figure 2.

A loads all 10 of its cars to B, and B loads all 5 of its cars to A. B reloads 2 A cars and sends 8 A cars back empty. A reloads one B car and sends 4 back empty.

The results of the current practices are given in Table 3. Out of a total of 30 possible loads, only 18 were realized. Because each railroad wanted to get its own cars back, 12,000 empty miles and 84 empty car days were generated on each railroad. This yields a load/empty ratio of only 1.5, and empty-car-day-per-load ratio of 4.7.

## SITUATION I-R: HEAVY DEMAND, 100 PERCENT RELOAD

The same demand exists (20 cars on A and 10 on B) as for situation I-C. In this case, however, neither railroad puts restrictions on the loading of its cars by the other. Situation I-R is illustrated in Figure 3.

A loads all of its 10 cars to B, and B loads all

**TABLE 2 Situation and Strategies**

| SITUATION | CAR MANAGEMENT STRATEGY |
|---|---|
| I. Heavy Demand | C - Traditional 20% Reload<br>R - 100% Reload |
| II. Mild Recession | C - Car Warfare - No Storage<br>R1 - Unilateral Storage by B<br>R2 - Unilateral Storage by A<br>R3 - Shared Storage<br>R4 - Per Diem Relief |
| III. Severe Recession | C - Car Warfare No Planned Storage<br>R1 - Maximum Storage by B<br>R2 - Maximum Storage by A<br>R3 - Shared Storage Plus Per Diem Relief |
| IV. Severe Recession | C - Car Warfare No Planned Storage<br>R1 - Maximum Storage Shared by A & B Only<br>R2 - Maximum Storage by A<br>R3 - Shared Storage Shared by All Three Railroads |

5 of its cars to A, as in situation I-C. In weeks 3 and 4, however, A reloads all 5 B cars on line. B loads 5 A cars, thus filling all demand and returns the 5 surplus A cars empty.

The recommended practice results in several improvements, which are given in Table 4. A originates 4 more loads and B originates 3 more loads, resulting in each railroad handling 25 loads, or 7 more than before. Moreover, although the total miles remain the same for each railroad, loaded miles go up and empty miles go down by 7,000 on each railroad. Total cost increases by $350, but revenue goes up by $7,000 on each railroad, causing contributions to rise by the same amount. Improvements in loaded/empty mile ratio, empty miles per load hauled, and empty car days per load are also achieved (Cols. 13-16).

Situation I-R is a simplified version of what happens on railroads that participate in the freight car clearinghouse. When the supply of cars is small, each railroad uses more foreign cars for outbound loads and empty handling is reduced.

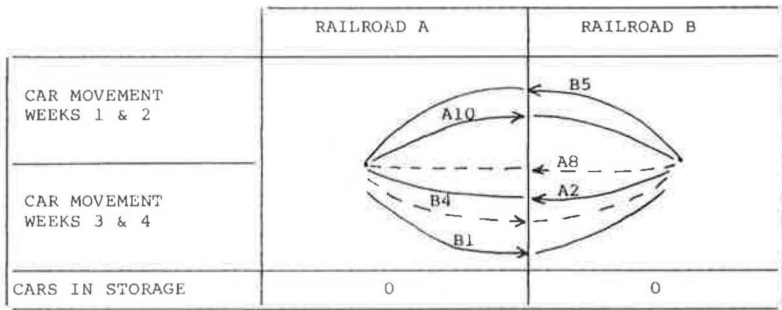


**FIGURE 2 Situation I-C: Heavy demand, 20 percent reload.**

**TABLE 3 Situation I-C: Heavy Demand, 20 Percent Reload**

| | (1) Car Ownshp. Cost | | (2) Per Diem Paid | | (3) Per Diem Rec'd | | (4) Net Per Diem Pd | | (5) Net Car Time Cost | | (6) Loaded Mile Cost | | (7) Empty Mile Cost | | (8) Revenue | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| UNITS | 40 CW[a] | 20 CW | 10 CW | 20 CW | 20 CW | 10 CW | -10 CW | 10 CW | 30 CW | 30 CW | 18K mi | 18K mi | 12K mi | 12K mi | 18K mi | 18K mi |
| RATE | $70/CW | | $70/CW | | $70/CW | | $70/CW | | $70/CW | | 10¢/mi | | 5¢/mi | | $1.00/mi | |
| DOLLARS (000) | 2.8 | 1.4 | .7 | 1.4 | 1.4 | .7 | -.7 | .7 | 2.1 | 2.1 | 1.8 | 1.8 | .6 | .6 | 18 | 18 |

| | (9) Cars Stored | (10) Shipper Demand | (11) Loads Origi- nated | (12) Loads Hauled | (13) Total Cost ($000) | (14) Contri- bution ($000) | (15) L/E[b] Miles | (16) E Miles Per Load | (17) E Car Days OnLine | (18) E Car Days/ Load |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 20 | 11 | 18 | 4.5 | 13.5 | 1.5 | 667 | 84 | 4.7 |
| B | 0 | 10 | 7 | 18 | 4.5 | 13.5 | 1.5 | 667 | 84 | 4.7 |
| TOTAL | 0 | 30 | 18 | 18 | 9.0 | 27.0 | 1.5 | 1334 | 168 | 9.4 |

[a] Car week.

[b] Loaded/empty ratio.

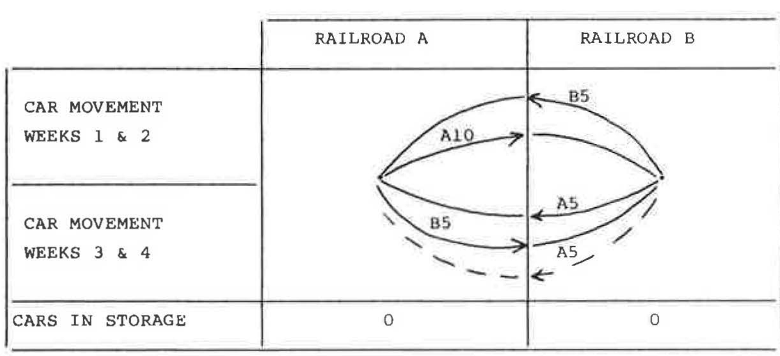


**FIGURE 3 Situation I-R: Heavy demand, 100 percent reload.**

**TABLE 4 Situation I-R: Heavy Demand, 100 Percent Reload**

| | (1) Car Ownshp. Cost | | (2) Per Diem Paid | | (3) Per Diem Rec'd | | (4) Net Per Diem Pd | | (5) Net Car Time Cost | | (6) Loaded Mile Cost | | (7) Empty Mile Cost | | (8) Revenue | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| UNITS | 40 CW[a] | 20 CW | 10 CW | 20 CW | 20 CW | 10 CW | -10 CW | 10 CW | 30 CW | 30 CW | 25K mi | 25K mi | 5K mi | 5K mi | 25K mi | 25K mi |
| RATE | $70/CW | | $70/CW | | $70/CW | | $70/CW | | $70/CW | | 10¢/mi | | 5¢/mi | | $1.00/mi | |
| DOLLARS (000) | 2.8 | 1.4 | .7 | 1.4 | 1.4 | .7 | -.7 | .7 | 2.1 | 2.1 | 2.5 | 2.5 | .25 | .25 | 25 | 25 |

| | (9) Cars Stored | (10) Shipper Demand | (11) Loads Originated | (12) Loads Hauled | (13) Total Cost ($000) | (14) Contribution ($000) | (15) L/E[b] Miles | (16) E Miles Per Load | (17) E Car Days OnLine | (18) E Car Days/ Load |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 20 | 15 | 25 | 4.25 | 20.15 | 5.0 | 200 | 35 | 1.4 |
| B | 0 | 10 | 10 | 25 | 4.85 | 20.15 | 5.0 | 200 | 35 | 1.4 |
| TOTAL | 0 | 30 | 25 | 25 | 9.7 | 40.3 | 5.0 | 400 | 70 | 2.8 |

[a] Car week.

[b] Loaded/empty ratio.

SITUATION II-C: MILD RECESSION, CAR WARFARE

In this situation there is a mild recession. Demand on A is for 10 cars and on B is for 5 cars. Each railroad allows reloading of all its cars by the other.

A loads all of its 10 cars to B, and B loads all 5 of its cars to A. To keep its own cars off line earning per diem, each railroad has allowed the other to reload any of its cars. For the same reason, however, each railroad sends the other's cars home empty. This mutual returning of foreign empties and favoring of system cars for loads could be called car warfare. Results of the model are shown in the summary table (Table 8) under situation II-C.

Each railroad has met 100 percent of its shippers' demand by using only its own fleet. By using only its own cars for outbound loads, each railroad has prevented a deterioration in its net per diem compared with situation I (heavy demand).

The corollary of this policy, however, is that empty miles increase at the same time as loaded miles and therefore revenue is dropping. This is precisely what happened in 1980 compared with 1979, as shown by the figures given in Table 5. The first half of 1979 was a period of heavy car demand. The first half of 1980 was a period of mild recession. The first five railroads are clearinghouse railroads, and the last three railroads are not. The car types included are the seven included in the clearinghouse (e.g., general-purpose boxcars, gondolas, and flats).

Another way of illustrating excessive car movement and lack of storage is to count the number of general-purpose cars delivered and received at an interchange in a loaded or empty condition. Five railroads were studied, and the results are given in Table 6. The car types are general-purpose, 50-ft box and general-purpose gondolas; and all ownerships are included (system plus foreign). The five railroads shown are not the same as those used in Table 5.

The figures in Table 6 show that although handling of loads dropped by 129,100, handling of empty cars increased by 74,300. This is shown also by the drop in the loaded/empty ratio from a healthy 1.61 to a very inefficient 1.09. It is the thesis of this paper that the railroad industry cannot afford the

**TABLE 5 Situation II-C: Effects of Car Warfare on Utilization of Foreign General-Purpose Cars**

| | LOADED MILES (MILLIONS) | | | | EMPTY MILES (MILLIONS) | | | | L/E RATIO | |
|---|---|---|---|---|---|---|---|---|---|---|
| RR | First Half 1979 | First Half 1980 | CHANGE | CHANGE% | First Half 1979 | First Half 1980 | CHANGE | CHANGE% | First Half 1979 | First Half 1980 |
| A | 161. | 116. | -45.7 | -28 | 87.1 | 84.0 | - 3.0 | - 4 | 1.86 | 1.38 |
| B | 38.8 | 33.6 | - 5.2 | -13 | 17.7 | 32.2 | +14.5 | +82 | 2.19 | 1.04 |
| C | 73.2 | 63.7 | - 9.5 | -13 | 39.2 | 52.4 | +13.2 | +34 | 1.87 | 1.22 |
| D | 75.1 | 64.3 | -10.8 | -14 | 35.5 | 50.0 | +14.5 | +41 | 2.11 | 1.29 |
| E | 39.8 | 32.1 | - 7.7 | -19 | 18.4 | 20.7 | + 2.3 | +13 | 2.16 | 1.55 |
| F | 12.9 | 12.6 | - .3 | - 3 | 4.7 | 7.5 | + 2.8 | +59 | 2.73 | 1.67 |
| G | 275. | 242. | -32.6 | -12 | 170. | 213. | +43.5 | +26 | 1.62 | 1.14 |
| H | 28.9 | 24.3 | - 4.6 | -16 | 14.9 | 18.2 | + 3.4 | +23 | 1.94 | 1.33 |
| TOTAL | 705 | 589 | -116.6 | -17 | 387 | 478 | +91.1 | +24 | 1.82 | 1.23 |

**TABLE 6 Cars Handled in Interchange: General-Purpose, 50-Foot Box and General-Purpose Gondola—All Ownerships (second quarter 1979 versus second quarter 1980)**

| | Railroad A | | Railroad B | | Railroad C | | Railroad D | | Railroad E | | SUBTOTAL | | GRAND TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DEL[a] | REC[b] | DEL | REC | DEL | REC | DEL | REC | DEL | REC | DEL | REC | DEL + REC |
| Loaded Cars 1979[c] | 29.1 | 43.7 | 62.2 | 45.5 | 110.4 | 141.6 | 68.5 | 52.1 | 43.0 | 44.7 | 313.4 | 327.6 | 641.0 |
| 1980[c] | 26.7 | 41.9 | 55.4 | 38.7 | 76.9 | 107.6 | 50.1 | 39.5 | 36.8 | 38.3 | 245.9 | 266.0 | 511.9 |
| Change | -2.4 | -1.8 | -6.9 | -6.8 | 33.5 | -40.0 | -18.4 | -12.6 | -6.2 | -6.5 | -67.5 | -61.6 | -129.1 |
| Change (%) | -8.3 | -4.1 | -11.1 | -14.9 | -30.4 | -23.9 | -26.8 | -24.2 | -14.4 | -14.5 | -21.5 | -18.8 | -20.1 |
| Empty Cars 1979[c] | 30.2 | 15.2 | 27.7 | 46.1 | 90.9 | 55.2 | 27.9 | 44.8 | 30.1 | 29.2 | 206.8 | 190.5 | 397.3 |
| 1980[c] | 38.9 | 22.1 | 33.3 | 49.8 | 93.0 | 68.1 | 41.0 | 52.9 | 36.5 | 35.0 | 243.6 | 228.0 | 471.6 |
| Change | 8.7 | 6.9 | 5.6 | 3.7 | 2.1 | 12.9 | 14.0 | 8.1 | 6.3 | 5.9 | 36.8 | 35.5 | +74.3 |
| Change (%) | 28.8 | 45.6 | 20.2 | 8.0 | 2.4 | 23.4 | 50.3 | 18.1 | 21.1 | 20.2 | 17.8 | 19.7 | +18.7 |
| Loaded/Empty Ratio 1979 | 0.96 | 2.88 | 2.25 | 0.99 | 1.21 | 2.57 | 2.46 | 1.16 | 1.43 | 1.53 | 1.52 | 1.72 | 1.61 |
| 1980 | 0.69 | 1.90 | 1.66 | 0.78 | 0.83 | 1.58 | 1.20 | 0.75 | 1.01 | 1.09 | 1.01 | 1.17 | 1.09 |

[a] Delivered

[b] Received

[c] In thousands

kind of inefficient practices represented by these numbers.

Particular attention is directed to the "delivery empty" numbers. These are foreign cars being sent home. A good portion of these probably could have been used for outbound loads if system cars had been stored. Comparing empty deliveries to empty receipts, one can see that for a given railroad the numbers do not balance. For the system as a whole, of course, they must balance. This is shown in the subtotal column--36,800 deliveries is approximately equal to 35,500 receipts. There is a difference of 1,300 because these five railroads do not represent all the railroads in the country.

In Table 6 the increase in empty cars delivered for railroads A, B, D, and E is greater than the increase in empty cars received. That these railroads are pushing more empties than they are being pushed by empties obscures the fact that empty deliveries and receipts should be declining for all railroads because of the recession. The numbers show clearly that for every railroad, handling of both delivered and received empty cars increased even though the number of loaded cars delivered and received (revenue business) had declined. The average increase in handling of empties was 18.7 percent, and the average decrease in handling of loads was 20.1 percent. This inefficiency is reflected in the model when II-C (recession) is compared with I-C or I-R (strong demand).

## SITUATION II-R-1: MILD RECESSION, UNILATERAL STORAGE BY A

A loads all of its cars to B. On the assumption that it will be better off by reducing empty car miles to a minimum, B stores all 5 of its cars. B then uses 5 of the A cars to fill all of its demand, and returns 5 A cars empty. Results of the model are shown in the summary table (Table 8) under situation II-R-1.

Storage of the maximum number of its cars by B has caused several important changes. First, net car time cost for A has dropped by 10 car weeks because it is not paying B anything for foreign cars on line. Net car line cost for B has risen by the same amount. Second, empty miles have indeed been reduced--by 10,000 on each railroad. The contribution for A has risen by $1,200. Because of the high value of car time and the relatively low value of car miles, however, the impact on the bottom line for B is less contribution than under situation II-C. B therefore rationally returns to car warfare as its best option.

## SITUATION II-R-2: MILD RECESSION, UNILATERAL STORAGE BY A

Given the same shipper demand, what would happen if railroad A stored 5 cars? Results are shown under situation II-R-2 in the summary table (Table 8).

As can be seen from the previous discussion, A finds itself in the same quandary as B if it absorbs the total responsibility for storage of cars. This solution produces the highest contribution yet attained for B ($11,850), but the worst bottom line for A. During car warfare (situation II-C) A produced a contribution of $10,650; now it has only $10,450.

In each of the solutions attempted, the best situation for one railroad is the worst for the other. The total contribution is higher than car warfare in either case by $1,000, but the relatively greater importance of car time compared with car miles prevents either railroad from taking a unilateral action to solve the problem so that both railroads would be better off than in the car warfare situation.

## SITUATION II-R-3: MILD RECESSION, SHARED STORAGE

What if A and B share the storage responsibilities? Because it has already been established that 5 cars must be stored to eliminate all excess empty miles, one solution might be for A to store 2 cars and B to store 3 cars.

A loads 8 of its cars to B, and B loads 2 of its cars to A. A reloads the 2 B cars, thus meeting all demand. B reloads 3 of the A cars and sends the remaining 5 home empty. The results are shown under situation II-R-3 in Table 8.

By sharing the storage of surplus cars the railroads have eliminated all unnecessary empty car movements, and each has achieved a higher contribution than under current practices. These contribution figures are not as high as when the other railroad absorbed all storage costs, but they are a large improvement over car warfare ($640 for A and $360 for B). The important conclusion is that if car time cost is high enough and car mileage costs are low enough, the cost of per diem revenue foregone must be shared.

Another solution to this problem would be for one railroad to pay the other railroad to store the necessary number of cars. This payment would equal the difference between the amount received by that railroad under an optimal solution (e.g., the one above), and the amount received under unilateral storage (situation II-R-1). In this case A would pay B $560 if B would store 5 cars rather than 3.

A comparison of situations I and II reveals a major weakness of the present clearinghouse arrangement. The clearinghouse improves utilization of cars when demand increases, but it neither encourages nor requires mutual storing of cars when demand drops.

## SITUATION II-R-4: MILD RECESSION, PER DIEM RELIEF

Another variant on the sharing of cost for storage has been used, or at least proposed, in the past. It provides, for example, that if railroad A loads a railroad B car rather than sending it home empty, B will forgive A all the per diem on that car while it is held by A. Although the arrangement focuses on whether or not to load a foreign car, it is really a way to encourage and pay for the storage of a system car (in this case an A car). This is similar to the proposal the Consolidated Rail Corporation (Conrail) made to the other railroads in September 1980. Situation II-R-4 in Table 8 gives the result.

The model shows that this strategy results in the perfect division of cost for storage of cars. A pays no per diem but receives per diem as usual. B receives no per diem for its cars off line, but it pays per diem as in the past. By using all of B's cars possible (in this case 5), A ends up storing half of its own fleet; and all excess empty miles have been eliminated. Contribution is exactly equal for both railroads, and contribution is better than situation II-C (car warfare) by $500 on each railroad.

The advantage of this solution is that it does not set up a new method of payments between the railroads. A knows exactly what to pay or not to pay B based strictly on activity and decisions on its own lines.

## SITUATION III-C: SEVERE RECESSION, CAR WARFARE

Shipper demand for transportation has dropped off sharply. Railroad A has orders for only 6 cars, and shippers on B want only 3 cars. The current industry practice would be a continuation of car warfare. A fills all its demand with its own cars, as does B. Each returns the foreign cars empty. Four A cars and 2 B cars are stored unintentionally. They are surplus in spite of the generally inefficient use of rolling stock. Situation III-C in Table 8 shows the condensed effect.

The results are similar to, but more extreme than, traditional practices in a mild recession (situation II-C). Compared with situation I-R each railroad hauls 25 loads with only 5,000 empty miles, the railroads now haul 9 loads with 9,000 empty miles each.

## SITUATION III-R-1: SEVERE RECESSION, MAXIMUM STORAGE BY B

The recommended practice during a severe recession is maximum storage of cars. One way to achieve this would be for B to store all 5 of its cars and A to store the remaining excess--5 cars.

**TABLE 7 Situation IV-C: Severe Recession, Car Warfare—Three Railroads**

| | (1) Car Ownshp. Cost | | | (2) Per Diem Paid | | | (3) Per Diem Rec'd | | | (4) Net Per Diem Pd | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C |
| UNITS | 280 CD[a] | 140 CD | 0 CD | 36 CD | 72 CD | 36 CD | 96 CD | 48 CD | 0 CD | -60 CD | 24 CD | 36 CD |
| RATE | $10/CD | | | $10/CD | | | $10/CD | | | $10/CD | | |
| DOLLARS (000) | 2.8 | 1.4 | 0 | .36 | .72 | .36 | .96 | .48 | 0 | -.6 | .24 | .36 |

| | (5) Net Car Time Cost | | | (6) Loaded Mile Cost | | | (7) Empty Mile Cost | | | (8) Revenue | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | A | B | C | A | B | C | A | B | C |
| UNITS | 220 CD | 164 CD | 36 CD | 7200 mi | 7200 mi | 3600 mi | 7200 mi | 7200 mi | 3600 mi | 7200 mi | 7200 mi | 3600 mi |
| RATE | $10/CD | | | 10¢/mi | | | 5¢/mi | | | $1.00/mi | | |
| DOLLARS (000) | 2.2 | 1.64 | .36 | .72 | .72 | .36 | .36 | .36 | .18 | 7.2 | 7.2 | 3.6 |

| | (9) Cars Stored | (10) Shipper Demand | (11) Loads Originated | (12) Loads Hauled | (13) Total Cost ($000) | (14) Contribution ($000) | (15) L/E[b] Miles | (16) E Miles Per Load | (17) E Car Days OnLine | (18) E Car Days/Load |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 4 | 6 | 6 | 9 | 3.28 | 3.92 | 1.0 | 800 | 166 | 18.4 |
| B | 2 | 3 | 3 | 9 | 2.72 | 4.48 | 1.0 | 800 | 110 | 12.2 |
| C | N/A | 0 | 0 | 9 | .90 | 2.70 | 1.0 | 400 | 18 | 2.0 |
| TOTAL | 6 | 9 | 9 | 9 | 6.90 | 11.10 | 1.0 | 2000 | 294 | 32.7 |

[a] Car days.
[b] Loaded/empty ratio.

**TABLE 8 Summary of Situations**

| SITUATION | CAR MANAGEMENT STRATEGY | CARS STORED A | CARS STORED B | CARS STORED TOTAL | EMPTY MILES (000) A | EMPTY MILES (000) B | EMPTY MILES (000) C | EMPTY MILES (000) TOTAL | CONTRIBUTION ($000) A | CONTRIBUTION ($000) B | CONTRIBUTION ($000) C | CONTRIBUTION ($000) TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I. Heavy Demand | C -Traditional 20% Reload | 0 | 0 | 0 | 12 | 12 | | 24 | 13.5 | 13.5 | | 27.0 |
| | R -100% Reload | 0 | 0 | 0 | 5 | 5 | | 10 | 20.15 | 20.15 | | 40.3 |
| II. Mild Recession | C -Car Warfare No Storage | 0 | 0 | 0 | 15 | 15 | | 30 | 10.65 | 10.65 | | 21.3 |
| | R1-Unilateral Storage by B | 0 | 5 | 5 | 5 | 5 | | 10 | 11.85 | 10.45 | | 22.3 |
| | R2-Unilateral Storage by A | 5 | 0 | 5 | 5 | 5 | | 10 | 10.45 | 11.85 | | 22.3 |
| | R3-Shared Storage | 2 | 3 | 5 | 5 | 5 | | 10 | 11.29 | 11.01 | | 22.3 |
| | R4-Per Diem Relief | 5 | 0 | 5 | 5 | 5 | | 10 | 11.15 | 11.15 | | 22.3 |
| III. Severe Recession | C- Car Warfare No Planned Storage | 4 | 2 | 6 | 9 | 9 | | 18 | 4.82 | 5.38 | | 10.2 |
| | R1-Maximum Storage by B | 4 | 5 | 9 | 3 | 3 | | 6 | 5.99 | 5.71 | | 11.7 |
| | R2-Maximum Storage by A | 7 | 2 | 9 | 3 | 3 | | 6 | 5.15 | 6.55 | | 11.7 |
| | R3-Shared Storage + Per Diem Relief | 5 | 4 | 9 | 3 | 3 | | 6 | 5.57 | 6.13 | | 11.7 |
| IV. Severe Recession Three RR's | C -Car Warfare No Planned Storage | 4 | 2 | 6 | 7.2 | 7.2 | 3.6 | 18.0 | 3.92 | 4.48 | 2.70 | 11.1 |
| | R1-Maximum Storage Shared by A & B | 5 | 4 | 9 | 2.4 | 2.4 | 1.2 | 6.0 | 4.2 | 4.56 | 2.94 | 11.7 |
| | R2-Maximum Storage Shared by All 3 RR's | 5 | 4 | 9 | 2.4 | 2.4 | 1.2 | 6.0 | 4.16 | 4.72 | 2.82 | 11.7 |

A uses 6 of its cars to move its 6 loads to B. B uses 3 of the A cars to move its entire demand to A and returns 3 A cars empty. The car utilization and financial impacts are shown in Table 8.

As in situation II-R, maximum storing of cars by the railroads involved in the loaded movements results in a better solution for both railroads than car warfare (situation III-C). Although B receives no per diem, it saves 6,000 empty car miles. A receives a higher net per diem and also saves 6,000 empty car miles. Contribution increases by $1,170 for A and $180 for B.

As in situation II-R-1, the savings from reduced empty car miles are unbalanced in favor of the railroad with the highest number of cars in service. The decision as to which railroad's cars should be used and which stored can be worked out in any of the numerous ways illustrated in situation II-R. The essential change is that between them the railroads must store the 9 excess cars so the full 12,000 empty car miles are eliminated.

SITUATION III-R-2: SEVERE RECESSION, MAXIMUM STORAGE BY A

If railroad A were to store the maximum number of cars instead of railroad B, the situation would be as shown under situation III-R-2 in Table 8.

Railroad A is worse off under situation III-R-2 than III-R-1 because it loses 12 car weeks of per diem receivable. This causes its contribution to drop to $5,150; however, it is still better than during car warfare (situation III-C) where it was making only $4,820. The lesson is the same for a severe recession as for a mild one--all surplus cars must be stored.

SITUATION III-R-3: SEVERE RECESSION, SHARED STORAGE, AND PER DIEM RELIEF

To match the benefits exactly between the two railroads the difference in benefits must be determined

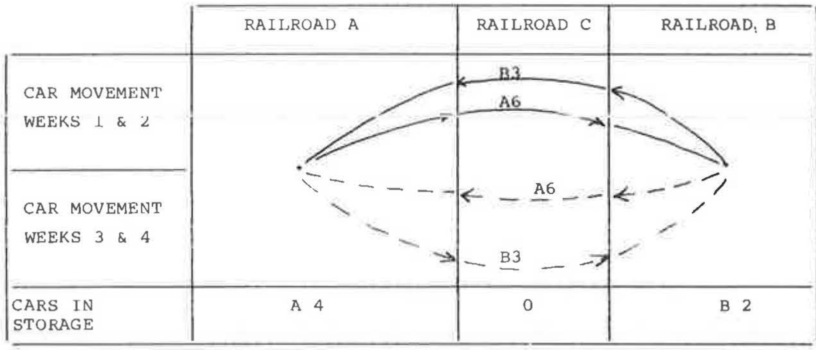


**FIGURE 4 Situation IV-C: Severe recession, car warfare—three railroads.**

between storing 9 cars instead of only 6 under car warfare. Under car warfare the total contribution is $10,200. Under maximum storage the total contribution is $11,700. The increased contribution of $1,500 should be split evenly, so each railroad would receive an increase of $750. This would leave A with $5,570 and B with $6,130. To do this would require that A store 5 cars and B store 4 cars and that A give B per diem relief for the use of one of its cars.

Why would A agree to do this? Because B is capable unilaterally of pushing A back into car warfare (situation III-C), causing A to end up with the least contribution of the four alternatives. "Half a loaf is better than none" could be said to be the moral of the story. That is, sharing the cost of storing surplus cars is preferable to the certainty that all cars will come home empty and all inbound loads will be in foreign cars.

## SITUATION IV-C: SEVERE RECESSION, CAR WARFARE--THREE RAILROADS

The model can be adapted to accommodate more than two railroads. This is an example of the same system except that it now has a third (bridge) railroad (C) that neither originates nor terminates cars. It also owns no cars. The model shows that such a railroad might benefit more than originating or terminating railroads by maximum storage of excess cars in a recession and also how this problem could be ameliorated (see Tables 7 and 8).

In this situation the length of haul for A and B is 800 miles each, and for C it is 400 miles. The total length of haul is thus kept at 2,000 miles. For simplicity, it is assumed that both A and B take 6 days to move a car over their lines, and C takes 2 days to move a car over its line. Thus, the origin-destination time of 14 days is kept constant. For clarity of display, all car time rates have been changed from $70 per car week to $10 per car day. Traditional railroad practice would be as shown in Figure 4.

The model shows overall utilization totals equal to the two railroad situation. By not owning any cars, railroad C pulls a high portion of its total revenue to the contribution category, in spite of hauling one empty car mile for every loaded (revenue) car mile.

## SITUATION IV-R-1: SEVERE RECESSION, SHARED STORAGE BY A AND B--THREE RAILROADS

One recommended practice, as in situation III-R-3, is to have A store 5 cars, B store 4 cars, and have A give B one of its cars per diem free (see situation VI-R-1 in Table 8).

This solution makes all three railroads better off than they were during car warfare (situation IV-C). The contribution for A is up by $280, for B up by $180, and for C up by $240. From the viewpoint of equity, however, A and B might object to this. Without any help from C, A and B have lowered costs for all three railroads. If A or B wanted to, it could force C back to a contribution of only $2,799, and C could do nothing to prevent it. One might say that C should benefit to the extent of having few empty car miles, but C should assist A and B on the time cost of cars that are stored. This solution can be worked out with the help of the model.

## SITUATION IV-R-2: SEVERE RECESSION, STORAGE SHARED BY ALL THREE RAILROADS

What if railroad C received only the mileage savings resulting from maximum storage of cars and the remaining savings were divided between A and B? The car movement and storage diagram would be the same as situation IV-R-1, but the financial result would be as follows.

C would save 2,400 empty car miles, at 5 cents per mile (or $120), compared with situation IV-C. The contribution for C would thus go from $2,700 to $2,820. Therefore $480 of the total increase in contribution of $600 ($11,700 minus $11,100) would be left to railroads A and B. If $240 were added to A's original contribution of $3,920, A would get $4,160. If $240 were added to B's original contribution of $4,480, B would get $4,720.

The model shows that by having C pay B $120 and A pay B $40, all the savings can be apportioned in a fair manner. Why will A and C agree to do this? They will agree because they know that if they do not, B's car ownership and outbound loads can force both of them back to situation IV-C and its lower contribution amounts.

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# Characteristics of Double-Trailer Trucks in New York State

**DAVID T. HARTGEN**

ABSTRACT

The characteristics of double-trailer truck operations are described for a selected location on the New York State Thruway in upstate New York. Vehicles were observed during a typical weekday for an 8-hour period and their characteristics were recorded. Of 13,999 vehicles passing the observation point, 1,322 (9.4 percent) were semitrailers and 90 (0.65 percent) were double trailers. Even though the New York State Thruway permits flexible operation of such vehicles, they were found to be quite uniform in overall characteristics. In 90 percent of the observed vehicles, one of two axle configurations were observed: eight or nine axles. For 51 percent of the observed vehicles, an out-of-state registered trailer was pulled by a New york State registered tractor; and 30 percent of the vehicles had New York registrations on both tractor and second trailer. Almost 90 percent of the vehicles observed were hauling two long trailers; that is, trailers 40 feet or more in length (double-bottoms). No combinations were observed in which the first trailer was shorter than the second trailer. Of all vehicles, 90 percent were owned by commercial transportation companies, but these represented only a handful of large transportation companies. United Parcel Service, Consolidated Freight, and Oneida Express accounted for 44 percent of the observed vehicles. Only nine vehicles were privately owned. The paper concludes that despite the flexibility permitted in operations, the double-trailer market operating on the New York State Thruway is represented by a narrow spectrum of vehicle types and companies.

For some time, the operation of longer combination trucks (often referred to as tandems, double-bottoms, doubles, and tripples) has been sanctioned in a number of western states and on selected toll facilities in eastern states. However, the Surface Transportation Assistance Act of 1982 substantially relaxed the regulatory environment within which such trucks will be permitted to operate.

New York State Department of Transportation (DOT) uses the term double-bottoms to refer to long (40 or more feet) double-trailer trucks operating only on the New York State (NYS) Thruway, and the term tandems to refer to 28.5-ft double-trailer vehicles. Only the latter would be permitted to operate on the national network. In this paper, the term double-trailer is used to refer to all truck vehicles hauling two trailers, regardless of length; thus it includes both doubles and tandems.

The Act specifies that larger vehicles be permitted to operate on a national network of routes designated by the Secretary of Transportation. On this system, federal law allows trucks with total weights up to 80,000 lb, per-axle weights up to 20,000 lb, and tandem-axle weights up to 34,000 lb. Further, trucks may carry tandem trailers up to 28.5 ft long, semitrailers may be up to 48 ft long, and trucks can be up to 102 in. wide. The Act requires that the states permit reasonable access to the national network to and from terminals and facilities, for fuel, food, rest, and repairs.

The Act specifically prohibits the states from imposing or enforcing more stringent-than-federal size and weight restrictions on the national network system. In addition, the Act directs the Secretary of Transportation to report to Congress concerning the potential benefits and costs, if any, associated with the development of a controlled access network for use by longer combination commercial motor vehicles. The Act also substantially increases heavy vehicle use and fuel taxes and mandates that states require proof of payment of such taxes before issuing licenses. On balance it indicates an intent by the federal government to ease interstate commerce regulations for the operation of large trucks.

These legislative actions have highlighted the clash of issues about whether the potential benefits (if any) of such vehicles are achievable and to whom they accrue (e.g., truckers, unions, or consumers) versus whether safety, operational characteristics in handling, vehicle congestion, and pavement damage are likely to be significantly impaired and by how much. Full analysis of these issues requires a complete and thorough assessment of present and anticipated double-trailer operations in the United States. Such a review would require the collection of additional data describing operations; a thorough documentation of current operations; the development of reasonable alternatives to the current operating environment; the evaluation of alternative operational plans on productivity, safety, and pavement damage; and implementation of recommendations. However, the baseline data necessary for comparison are rapidly disappearing, because the operating environment is changing rapidly. If background information on the present operation of doubles is not immediately collected and summarized, it will be difficult if not impossible to show how the expanded operating situation is different (better or worse) than the situation it replaced. This paper is a first step in that process, because it obtains an initial baseline reading on the characteristics of the only present (August 1983) operating environment for double-trailer vehicles in New York State. Although the data base for this assessment is narrow, and as will be seen, the time frame is limited, this information is better than none at all and can be expanded if necessary in the future.

The published literature on the operational characteristics of double-trailers and triples focuses largely on safety, rather than economic or other impacts. In 1973 the California Highway Patrol undertook an assessment of accidents with double-trailer trucks (1) and concluded that the accident rate of such vehicles, based on a review of 32,000 accidents, was favorable when compared with other classes of vehicles. The study also reviewed handling characteristics and found them to be adequate: a 65-ft (total length) tandem was found to have a smaller required track width in a 60-ft radius turn than a 60-ft tractor semitrailer. Passing maneuvers around the tandem were found to be no more hazardous than passing any large truck or bus. The study concluded that tandems were at least as safe as tractor-semitrailer combinations and were more maneuverable.

Operational problems associated with the hitches of double trailers (e.g., dynamics of turns, braking, and fishtailing) were examined in a Canadian study (2) and found to be minimal. However, a report by White (3) showed that in 1972 accidents in Ontario involving double-articulated vehicles were more severe than those of single-articulated vehicles. Revised California assessments (4) based on 1974 data were inconclusive; they showed that doubles had a greater rate of accidents per million vehicle miles but that single vehicles had higher accident rates on the basis of cargo ton miles. A recent review of this literature by FHWA (5) showed that apparently conflicting results actually involve different populations of trucks and that the quality of data and analysis in several of the studies was questionable. Clearly, therefore, the issue of the safety of such vehicles remains unsolved.

Some theoretical models of vehicle dynamics have also been applied to double-articulated vehicles (6). These include theoretical studies of lane changing behavior and weight characteristics (7). A recent simulation model, the Truck and Tractor-Trailer Dynamic Response Simulation, developed by the Highway Safety Research Institute, has been used to investigate the effects of increased truck size and weight on vehicle handling (8).

Operational experience with triples has been reported from the early 1970s. Studies in Canada (9) concluded that triples did not create any special hazards to traffic safety and that pavement deflection was less than the stress created by five-axle semitrailer trucks. An 8-day road test in Sacramento in October 1971 (10) evaluated braking, acceleration, exterior noise, backing and off-tracking, and operation in traffic. No specific conclusions were drawn by the testing agency, but findings were generally favorable after reviewing approximately 1,800 miles of operation on various types of roads (11). Despite an apparent fuel savings of as much as 21 percent (12) and favorable operating experience in reducing operating costs and conserving fuel in Utah (13), triples have apparently not substantially increased their share of the market beyond that developed in the early 1970s.

## NEW YORK SITUATION AND TEST SITE

New York State law permits the operation of semitrailer trucks up to 60 ft in overall length on any public highway in New York. Under state law tandem-trailer trucks of up to 65 ft in overall length have been allowed since 1981 to use 777 miles of New York's Interstates, and 503 miles of non-Interstates that have at least four lanes. The routes are all upstate (north of New York City). In addition, the NYS Thruway, a toll road stretching from New York City to the Pennsylvania line, has for many years permitted special tandems (double-bottoms) of up to 114 ft in overall length. These larger vehicles are also permitted on the Massachusetts Turnpike and its connection to the NYS Thruway, thus permitting operation in the Boston-Albany-Buffalo corridor.

Pursuant to the Surface Transportation Assistance Act of 1982, the Secretary of Transportation has designated (Federal Register, September 14, 1983) a system of other primary routes, in addition to the Interstate system, on which tandem trailers would be permitted to operate. This system includes New York's 503-mile system noted earlier, SR-219, and US-4 and SR-254, which connect the Northway to the Vermont state line. New York has passed enabling legislation and rules designating the upstate portion of this system; the downstate portion, including the Interstate routes, is still under discussion. Figure 1 shows the federal network as

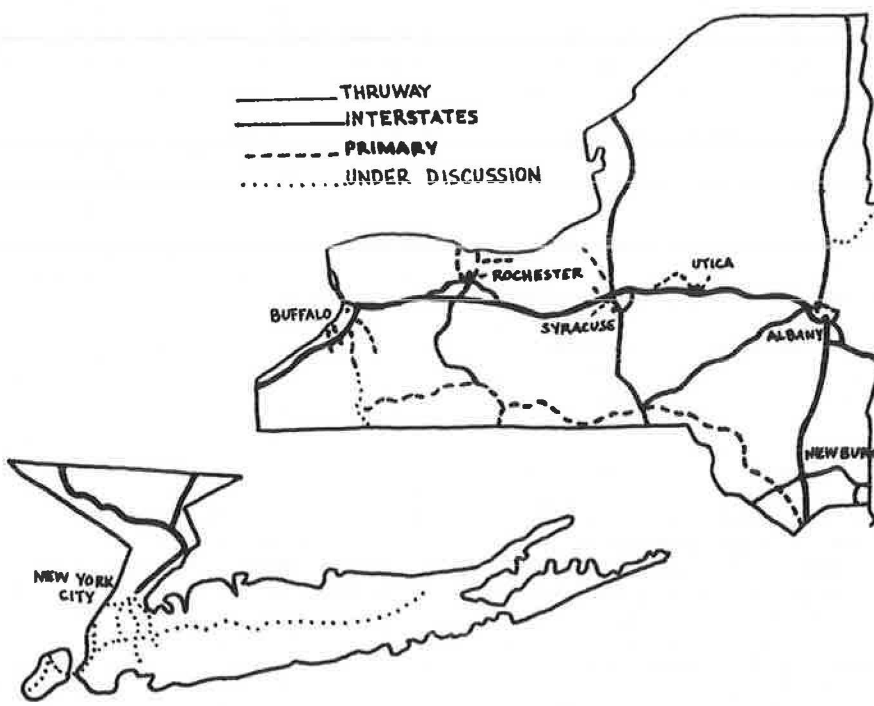


**FIGURE 1 National network, New York portion.**

designated in the Federal Register, September 14, 1983.

The site chosen for the classification study was just outside of Albany, New York, between Albany and Schenectady. Figure 2 shows the site, which is located on a bridge over the NYS Thruway. Traffic on the Thruway observable from this bridge would include traffic moving from Buffalo to Albany, and traffic moving from Albany (and New York City) west to Buffalo; New York City-Albany traffic would not be observable from this site. This particular section of the Thruway is heavily traveled (the annual average daily traffic from January 1983 through July 1983 was 30,100) and contains a high proportion of commuting vehicles. It is six lanes wide (three per direction) and generally straight and flat. Since the enactment of the 1978 Surface Transportation Act, vehicles originating from I-88 that are destined to I-87N do not pay a toll; otherwise, the traffic is subject to toll.

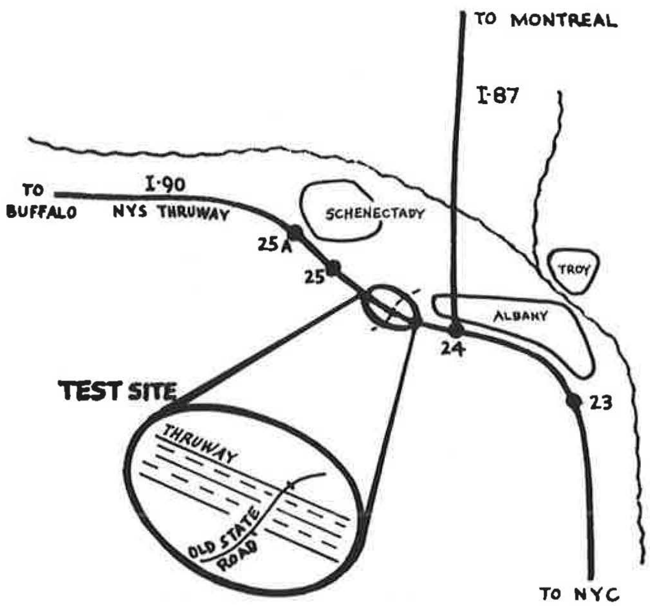


FIGURE 2 Observation site.

The ticket structure of the NYS Thruway does not permit the identification of double-trailers. The vehicle classification was undertaken to determine the exact size and other characteristics of such vehicles. No vehicle weighing was done nor were the commodities being transported determined. The study took place on Wednesday, July 27, 1983. Classification was for 8 hours from 8:00 a.m. to 4:00 p.m. Because no nighttime classification information was obtained, it is not possible to determine whether the proportion of such vehicles operating at night is greater than observed here or whether their characteristics are different.

RESULTS

Overall Percent Distribution

Of 13,999 vehicles observed during the 8-hour period, 90 (0.65 percent) were double-trailers and 1,322 (9.4 percent) were semis. Figure 3 shows that doubles constituted less than 1 percent of all vehicles observed and less than 7 percent of heavy trucks.

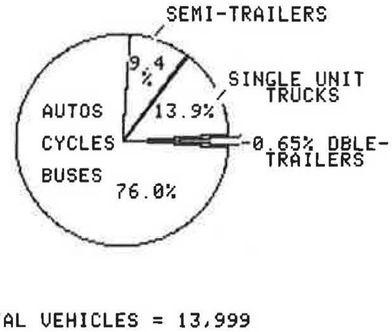


FIGURE 3 Vehicles by classification.

The distribution of vehicles by hour (Figure 4) shows fairly constant traffic at this location. The distribution of double-trailers by hour is too fine to distinguish; however, the distribution of heavy trucks by hour shows a pattern similar to that of total vehicles.

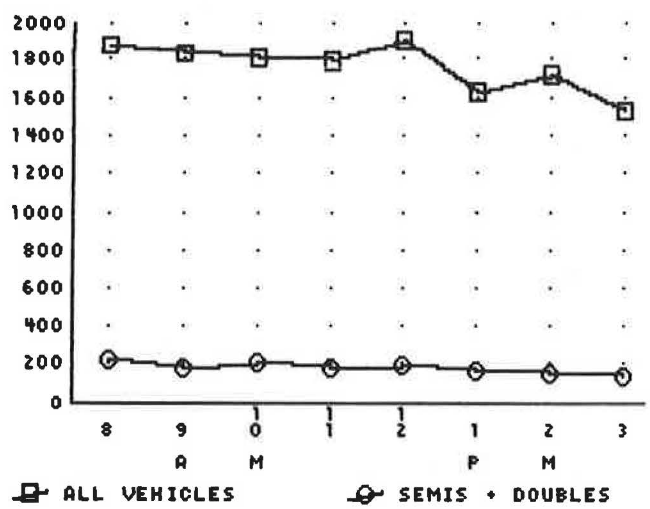


FIGURE 4 Vehicles by hour.

Axle Configuration

Most of the vehicles in the double-trailer group were operating with eight or nine axles. Configurations were largely 3S2-3 and 3S2-4 (Figure 5).

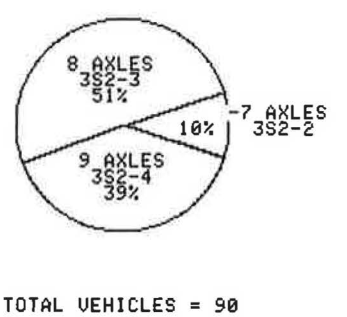


FIGURE 5 Double-trailer axle configurations.

Length and Site

Lengths were estimated as long (40 ft or more), medium (20 to 40 ft), and short (less than 20 ft). Because vehicles were not stopped and measured, it was not possible to determine these lengths exactly. However, the New York State DOT has considerable confidence in its ability to distinguish groups of trailers by length.

The particularly permissive operating environment on the Thruway apparently has led to the predominance of longer trailers. As Table 1 shows, the predominance of vehicles were long (40 ft or more) trailers (double-bottoms) in both the first and the second trailer position. Of the combinations observed, the combination long-long was the most common, followed by the combination short-short, and the combination medium-medium. No vehicles were observed operating with the first trailer shorter than the second trailer.

**TABLE 1 Trailer Lengths**

| First Trailer \ Second Trailer | L | M | S | TOTAL |
|---|---|---|---|---|
| L | 80 Double Bottoms | 1 | 1 | 82 |
| M | — | 3 Tandems | — | 3 |
| S | — | — | 5 Tandems | 5 |
| TOTAL | 80 | 4 | 6 | 90 |

L = Long 40 ft or more
M = Medium 20 to 40 ft
S = Short 20 ft or less
(Estimated)

Vehicle Registration

Vehicle license plates were recorded for the tractor and for the last trailer. As Figure 6 shows, 83 percent of the vehicles observed were being pulled by a New York registered tractor; however, 59 percent of the vehicles were trailering out-of-state trailers, indicating that the operations being observed were not all within New York State, even though these vehicles are not operating extensively on other roads.

Body Type

Of the 90 vehicles observed 87 were box-type combinations, 2 were tank combinations, and 1 was a flatbed combination. No vehicle with mixed body type was observed.

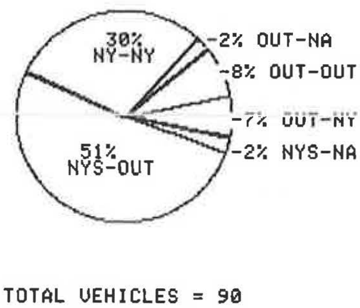


**FIGURE 6 New York State and out of state tractor and trailer registrations.**

Major Operating Companies

The classification team recorded names on tractors and trailers, where possible. The results were classified according to whether one, two, or all three names were legible and identical. A surprisingly high proportion of vehicles were owned by a few common freight carriers. United Parcel Service (20 trucks), Consolidated Freight (13 trucks), and Oneida Freight (7 trucks) accounted for 40 vehicles, or 44 percent of the total. St. Johnsbury, Red Star, KJ Transportation, and Freihofer's (a local baking company) accounted for 12 more vehicles. An additional 14 trucks were observed operating with the same names on all sections; of these, 5 were private companies and 9 were commercial transportation companies. For trucks on which one or more names were not legible or blank, the vehicles were dominated by commercial transportation companies.

Based on this survey, double-trailer traffic on the NYS Thruway is dominated by a small number of major freight haulers. Private (nontransportation) companies appear to have made limited use of their own double trailers: of the 90 vehicles observed, only 7 were identified on the tractor as belonging to nontransportation corporations. However, a number of mixed-operating situations were observed, in which commercial haulers were pulling trailers identified as belonging to private nontransportation corporations (5 cases). One operator, Consolidated Freight, accounted for 4 of the 5 observed small trailer combinations.

DISCUSSION OF RESULTS

Only one site was observed, and truck operating characteristics for the Thruway are undoubtedly not applicable to other locations. Nevertheless, the observations made from the data are instructive in understanding the present nature of double-trailer use.

In spite of the considerable flexibility permitted in operation, most vehicles conformed to one of two axle configurations (3S2-3 and 3S2-4). The majority of trailers observed were long, that is, up to the limit allowed by the NYS Thruway. Few mixed-length combinations were observed, probably because companies tend to buy vehicles of similar dimensions for purposes of providing freight services. Few private nontransportation companies appear to have taken advantage of double-trailer services by operating their own vehicles. Major haulers were represented by a few large transportation companies; it appears that few private companies have enough concentrated freight markets to move their products with their own double-trailer vehicles.

Although state-to-state restrictions on vehicle operation may hinder some commerce, in this survey a considerable portion of vehicles observed were registered out of New York State. Therefore the operating restrictions may not be as severe as they appear to be. Connections west to (but not through) Pennsylvania and east to Boston were possible on Interstate routes; the eastern connection already permits long doubles. These policies have been in place for a number of years, and therefore it may be concluded that the traffic structure has stabilized.

It is surprising perhaps that more double-trailer vehicles were not observed in the traffic stream: in spite of flexibility in operations, double-trailers account for less than 1 percent of observed traffic and less than 7 percent of heavy truck traffic. Market restrictions, of course, offer one explanation, but a more likely explanation is that east-west movement of this type is not a substantial portion of total movement, because many truck movements are not that long. Given the additional staging and terminal requirements necessary to connect and disconnect them, double-trailer vehicle operation would appear to be more feasible for that portion of the traffic which is particularly long haul. To the extent that such traffic constitutes a major share of the given market, therefore, these vehicles would account for a disproportionately greater share. In this case study, however, numerous cities between New York and Buffalo, and Buffalo and Boston, intervene to trim off their own share of the through traffic.

## POLICY IMPLICATIONS

How does this study assist in the clarification of the issues identified earlier? Because the sample size is small and the data are highly constrained to a controlled operating environment, only preliminary assessments can be made. However, the data suggest the following policy implications:

### Productivity

Considering the time double-bottom operations have been permitted on the Thruway (since the late 1960s), the present small market share of double-bottoms suggests that overall productivity for trucking has not substantially increased. If the observed double-bottom trailers were hauled separately, a net increase of only 6.4 percent of truck traffic (and 0.65 percent of all traffic) would have been observed at this location.

The increased flexibility of operation permitted by a designated doubles network, however, would probably have the effect of increasing the range of opportunities for which such vehicles are economically feasible. The number of firms capable of benefiting from the use of such vehicles is therefore likely to be greater. Most trucking movements would not be diverted to a doubles operation for the reasons described previously, but the proportion is likely to be greater than the 6.4 percent observed here.

Overall double-trucking traffic might increase by as much as 10 percent nationwide but for large trucks only. The operations of delivery vans and smaller vehicles are not likely to be affected substantially. Operations of middle-sized trucks may be affected outside of urban areas where such movement is not delivery oriented; this is a fairly small portion of all truck traffic.

### Efficiency of Operation

A small number of carriers, relative to the many thousands in operation, have found it worthwhile to expand into large doubles operation. These particular carriers, both private and public, presumably have undertaken the expansion because the savings in labor associated with double-trailers more than outweigh the additional cost of breakdown at each end of the Thruway portion of the trip. Clearly, such movements improve efficiency most when terminal costs are low relative to overall savings.

An example will serve to describe the situation. If a 1-hour trip (on the Thruway) is contemplated, the savings by operating a double rather than two semis would be a driver for 1 hour. Assuming a doubles-related terminal/staging time of an hour (which is likely even for terminals that are close to Thruway exits), then no overall savings would be achieved because labor costs would merely be shifted to terminal operations rather than over-the-road operations. Assuming equal pay scales, therefore, the cutoff point for efficient double operation would appear to be at least 1.5 hours. There are many pairs of cities on the Thruway that are closer than this distance and, therefore, not likely to be significantly affected by doubles operations. (The average truck trip length on the Thruway is 71 miles.) The time saving factor would not be the same for operations where direct access to terminals is permitted; however, this example illustrates the point that opportunities for doubles are not as extensive as one might think.

### Fuel Savings

No data were available on the relative fuel savings of doubles operations versus operations of semitractors. One study mentioned in the review of literature suggested that fuel use would be greater than for semis on a per vehicle mile basis (obviously) but lower on a ton mile basis. Because fuel is a relatively small portion of total transportation costs, and transportation costs themselves are a small portion of the delivered prices of commodities, it appears unlikely that fuel savings would be the driving force behind the decisions to operate doubles. Given that other positive forces are present, however, it is likely that fuel savings would count favorably toward doubles operation.

### Impact on Consumers

On the positive side, there should be a small (perhaps not measurable) decrease in the price of delivered goods as a result of doubles operation. Because only a small portion of the cost of delivered goods is in transportation, and an even smaller portion of that could be diverted to doubles, it is unlikely that the cost of commodities could, on balance, be decreased by more than 0.5 percent as a result of doubles operation. Numbers in this range are extremely difficult to detect because they tend to be overshadowed by the general economy and supply and demand of particular goods.

### Operation

The section of the Thruway studied in this test was wide, straight, and contained multiple lanes. There was no evidence during the classification studies that doubles pose a traffic hazard or operational difficulties for other vehicles in the traffic stream. Many doubles were observed operating in the center lane of three lanes, and cars were observed both passing and being passed by doubles, on both the left and right. The operation of such vehicles on city streets, however, is another matter entirely.

Over the years a number of questions have been raised concerning the ability of motorists to pass doubles, particularly in slippery or icy road conditions. Wind drafts around these trucks are more complex than around semitrailers, and small, light cars are particularly affected if passing is attempted at high speeds under conditions of blowing snow, and so forth. So far as can be determined, no studies have been undertaken on these on the Thruway, but the matter warrants investigation.

### Geometry

Certain geometric features of highway sections (particularly number of lanes, lane width, curve, grade, and sight distance) may substantially affect the operation of doubles and may impinge substantially on safety. Table 2 provides data on certain features of the New York State designated network. Although the proportion of miles with two lanes or substandard lane width is not large, marginally substandard lane width (9 to 11 ft) predominates on the primary portion of this network. Further, a substantial portion of the mileage is in poor condition, consists of old rigid or overlay pavement, and has a variety of special problems, particularly faulting.

The cost of bringing this mileage up to standard and correcting pavement deficiencies would be substantial, and Congress has provided no special funds for this work. New York particularly has numerous Interstate systems sections where lanes are inadequate; some of these miles are at toll plazas or large interchanges, but many are in New York City where some older roads were incorporated into the Interstate system. For these roads, narrow lanes and shoulders pose special problems for 102-in.-wide trucks, as well as doubles.

**TABLE 2 Selected Geometric Features, New York State Designated Network, 1983 Data**

| | Centerline Miles | | | |
|---|---|---|---|---|
| | NYS Thruway | Other Interstates | Other Primary | Total |
| No. of lanes | | | | |
| 2 | 0 | 7.73 | 72.87 | 80.60 |
| 4 or more | 556.49 | 944.43 | 475.62 | 1,976.54 |
| Total | 556.49 | 952.16 | 548.49 | 2,057.14 |
| Lane width (ft) | | | | |
| 8 or less | 0 | 8.02 | 0.51 | 8.53 |
| 9 to 11 | 0 | 14.01 | 26.64 | 40.65 |
| 12 or more | 556.49 | 930.13 | 521.34 | 2,007.96 |
| Total | 556.49 | 952.16 | 548.49 | 2,057.14 |
| Pavement type | | | | |
| Rigid | 216.32 | 628.00 | 316.97 | 1,161.29 |
| Flexible | 0 | 202.06 | 63.97 | 266.03 |
| Overlay | 340.17 | 122.10 | 167.55 | 629.82 |
| Total | 556.49 | 952.16 | 548.49 | 2,057.14 |
| Pavement problems | | | | |
| O.K. | NA | 671.09 | 354.42 | 1,025.51 |
| Faulting >¼ in. | NA | 121.70 | 39.21 | 160.91 |
| Faulting <¼ in. | NA | 108.16 | 129.11 | 237.27 |
| Shoulder washout | - | 0 | 5.56 | 5.56 |
| Distortion | NA | 0 | 0.58 | 0.58 |
| Local distress | - | 45.10 | 16.03 | 61.13 |
| Other | NA | 6.11 | 3.58 | 9.69 |
| Total | 556.49 | 952.16 | 548.49 | 1,500.65 |
| Surface condition (lane miles) | | | | |
| Poor (1-5) | 79.91 | 478.47 | 147.78 | 706.16 |
| Good (6-8) | 987.95 | 3,253.99 | 1,604.11 | 5,846.05 |
| Excellent (9-10) | 133.09 | 800.78 | 355.76 | 1,289.63 |
| Total | 1,200.95 | 4,533.24 | 2,107.65 | 7,841.84 |

### Pavement Damage

Pavement damage is known to be largely a function of equivalent axle loads, rather than the number of passes of individual vehicles. Pavement damage increases exponentially with axle load. Operation of doubles might have the effect of decreasing overall damage if the loads carried in such vehicles tend to be fairly light (and are spread over a larger number of axles). Many of the operations on the Thruway were package-oriented vehicle movements, moving fairly light vehicles containing prewrapped packages for numerous destinations (e.g., United Parcel). A preliminary calculation shows that, if the doubles traffic observed on the Thruway were carried by semitrailers, only a 0.65 percent increase in the number of trucks would be necessary, but the increase in equivalent axle loads would be as great as 10 percent. Because these additional axle loads may occur late in the life of a pavement, additional damage could be as much as 20 percent. These questions remain open to speculation.

## CONCLUSIONS

What situation might be expected to evolve as the provisions of the Surface Transportation Assistance Act of 1982 take effect? Although it is tempting to say that a large increase in the number of tandems is likely, that is not believed to be the case. The greater density of destinations in the eastern United States, coupled with continuing restrictions on tandem access to primary as well as to Interstate highways, means that the market is not as large as might be expected. The recently initiated double-trailer monitoring study by the Transportation Research Board should shed considerable light on this question. It is anticipated that double-trailer traffic, as an important element of the trucking system, will increase, building on the flexibility provided by the provisions of the act; however, a large increase is not anticipated.

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## REFERENCES

1. R. Zeiszler. Accident Experience of Double Bottom Trucks in California. Operational Analysis Section, California Highway Patrol, Sacramento, April 1973.
2. E.C. Mikulcik. Hitch and Stability Problems in Vehicle Trains. Calgary University, Canadian Ministry of Transport, Ottawa, Ontario, Nov. 1973.
3. J.G. White. Articulated Vehicle Accidents in Ontario in 1972--An Analysis of Police Accident Data. Road and Motor Vehicle Traffic Safety Office, Canadian Ministry of Transport, Ottawa, Ontario, Dec. 1974.

4. C.S. Yoo, M.L. Reiss, and H.W. McGee. Comparison of California Accident Rates for Single and Double Tractor-Trailer Combination Trucks. Bio-Technology, Inc., Falls Church, Va., FHWA, U.S. Department of Transportation, March 1978.
5. M. Freitas. A Review of Accident Research Involving Truck Size and Weight. Public Roads, Sept. 1982.
6. R.L. Eshleman, S.D. Desai, and A.F. D'Souza. Stability and Handling Criteria of Articulated Vehicles. IIT Research Institute; National Highway Traffic Safety Administration, Washington, D.C., Aug. 1973.
7. O. Nordstrom and L. Strandberg. The Dynamic Stability of Heavy Vehicle Combinations. Report 67A. National Swedish Road and Traffic Research Institute, Linkoeping, Sweden, 1975.
8. T. Gillespie, C.C. MacAdam, G.T. Hu, J. Bernard, and C. Winkler. Truck and Tractor-Trailer Dynamic Response Simulation, Vol. 2. Report FHWA-RD-79-124. Highway Safety Research Institute, Ann Arbor, Mich.; FHWA, U.S. Department of Transportation, Dec. 1980.
9. Report on the Testing of Triple-Trailer Combinations in Alberta. Alberta Department of Highways and Transportation, Canada, April 1970.
10. M.C. Kaye. Sacramento Triples Test. Freightliner Corporation, Portland, Oreg., Nov. 1971.
11. Triple Trailer Study in California. California Business and Transportation Agency, March 1972.
12. T.D. Hutton. Freightliner Corporation, Why Not Triples? Society of Automotive Engineers, New York, N.Y., Aug. 1974.
13. D.E. Peterson and R. Gull. Triple Trailer Evaluation in Utah. Research and Development Unit, Utah Department of Transportation, Salt Lake City (undated).

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# Characteristics of Double and Triple Trailer Truck Combinations Operating in the United States

CHIEN-PEI YU and C. MICHAEL WALTON

ABSTRACT

The enactment of the Surface Transportation Assistance Act of 1982 may have signaled the beginning of more widespread use of double and triple trailer truck combinations in the United States. This enactment has provided a new incentive to the ongoing study of doubles and triples; past works focused on the economics, operations, use, and safety aspects. This work concentrates on the characteristics of doubles and triples found in the Truck Inventory and Use Survey (TIUS) and the Truck Weight Study (TWS). TIUS and TWS are the two major data bases of the nation's truck resources. The TIUS has a well-designed sampling strategy but has a rather small sample of doubles and triples. The TWS has a large sample size, but when compared with TIUS it does not have a well-designed sampling strategy. To assist further in the monitoring of the development of the nation's truck resources on highways, some modifications may need to be made in both data bases, particularly for the doubles and triples. Data obtained from TIUS and TWS on some aspects of the doubles and triples are analyzed and the results are presented.

The enactment of the Surface Transportation Assistance Act of 1982, and the various provisions relating to double and triple trailer truck combinations, will have a significant effect on the transportation sector in general and the motor carrier industry in particular. It may be the beginning of a new era of more widespread use of multitrailer truck combinations. One provision outlines a study to be performed of the feasibility of a designated Intercity Truck Route Network that will allow the operation of multiple trailer units up to 110 ft in overall length. This increased emphasis on the longer truck combinations has provided a new incentive to explore various characteristics and important features of these trucks.

The data on doubles and triples from the Truck Inventory and Use Survey (TIUS) (1) and the Truck Weight Study (TWS) (2) conducted by FHWA in cooperation with various state highway departments were used as the basis for the analysis presented in this paper. The analysis is not a comprehensive treatment of the subject; much more work could be done to characterize the double and triple trailer combinations from these two files.

## TIUS DATA BASE: USE AND LIMITATIONS

The TIUS is performed by the U.S. Bureau of the Census. Its primary purpose is to "collect and publish data on the physical and operational characteristics of the nation's truck resources." Passage of the Surface Transportation Assistance Act of 1982 has made the understanding of the operational characteristics of doubles and triples more urgent because there is a stated requirement for a study to monitor the establishment of a Designated Interstate Truck Route Network. The TIUS is one of the most comprehensive data sources on truck inventory and use. Twenty-nine items of information are required from the truck owner for each truck. Information is required on the engine type, products carried, mileage traveled, range of gross vehicle weight, type of maintenance performed, area of operation, base of operation, and so forth; this information is valuable from the viewpoint of administration, funding, and planning. However, TIUS is only conducted every 5 years, and the information it contains projects an overall picture of inventory and use instead of dealing with a specific topic.

For this reason, out of the 96,494 records in the 1977 TIUS, only 286 records were for doubles or triples; of these, 212 records were western doubles with a two-axle tractor (2-S1-2 in AASHTO code) and 70 were triples with a tandem axle tractor (3-S1-2 in AASHTO code). Only four records of turnpike doubles were found in the entire sample. Such a small collection of doubles and triples (0.2 percent of the entire sample) is due to the indiscriminate sample gathering policy of TIUS. Hence, the predominant truck type represented in the file is the small truck. The reliability of the sample would be much enhanced if the sample were larger; nevertheless, because this is the only TIUS sample available, the sample is used in the study of doubles and triples.

TIUS does not identify an entire truck combination in one single information item; instead each truck is identified separately by its tractor or trailer. A two-stage process must be used to capture a double or triple from the file. The researcher must check the tractor and then the trailer type of each record and match that against standard configurations to determine if the record is a double or a triple.

In presenting many of the characteristics of doubles and triples in this paper, the expansion factor used by Sydec is also used to extrapolate the characteristics of the samples so that it is representative of the entire population.

## TWS: USE AND LIMITATIONS

Since 1966 the TWS has been reported annually or biennially by FHWA, which obtains data on truck weights and commodity movements in each state. The data, gathered either manually or through automated weigh-in-motion systems in the field, are coded on cards or stored on magnetic tapes and sent directly to FHWA. The data sampling scheme is determined by each state highway department. FHWA, while encouraging accuracy and reliability in the data obtained, only provides a guideline for each state; therefore, the accuracy and reliability of the data varies widely.

This is one of the drawbacks of TWS. Although a large amount of data is available, the sampling technique in each state as well as the reliability of the sample is not known. A large number of specimens are available, yet it is difficult to calculate the reliability or probability of the samples. The TIUS is almost at the opposite end of the spectrum. TIUS has a structured sampling program, yet it does not have many samples. It is interesting to look at the characteristics of doubles and triples from both ends of the spectrum, judge the results, and determine what should be done in the future to improve the data base, as well as to enhance the sampling technique.

## SOME CHARACTERISTICS OF DOUBLES AND TRIPLES AS OBSERVED FROM TIUS

The previous section stated that there were 286 records of doubles and triples captured from the 1977 TIUS. The TIUS provides a large amount of data for each truck, and in this analysis these data were arranged in a variety of ways to provide insight to the characteristics of the larger truck units.

The following are examples of analyses performed on the TIUS data:

1. Gross vehicle weight distribution,
2. Annual mileage distribution,
3. Weight-to-horsepower ratio,
4. Primary products carried, and
5. Operator class.

Figures 1 (1) and 2 (1) show graphical illustrations only for the findings of the western doubles with a two-axle tractor (2-S1-2), although findings concerning other types of doubles and triples are mentioned. All sample sizes shown on the vertical axis reflect the actual size in the TIUS files multiplied by the expansion factor.

### Gross Vehicle Weight Distribution

Gross vehicle weight (GVW) distribution is an important operating characteristic of the vehicle. Figure 1 illustrates that the majority of the two-axle tractor, western doubles have a GVW ranging between 60,000 and 80,000 lb based on TIUS data; 77.6 percent of the GVWs for the western doubles fall within this range.

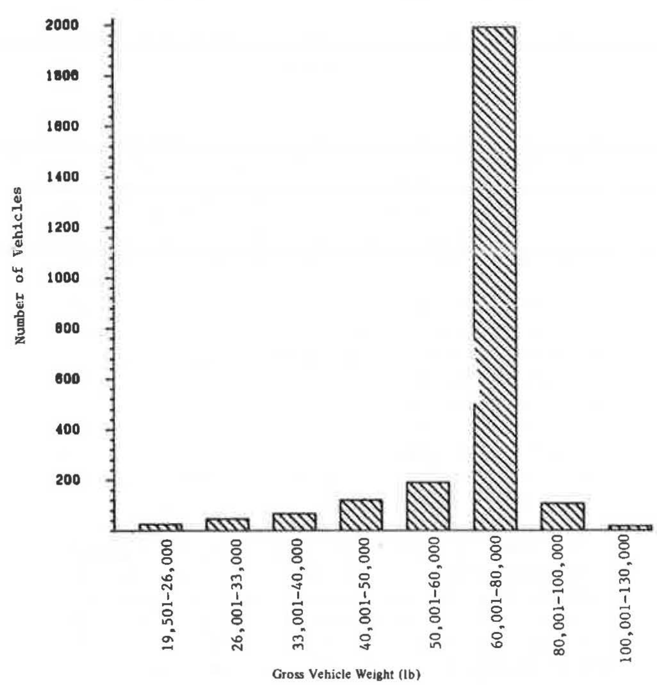


**FIGURE 1 Gross vehicle weight distribution for western doubles with two-axle tractor (*1*).**

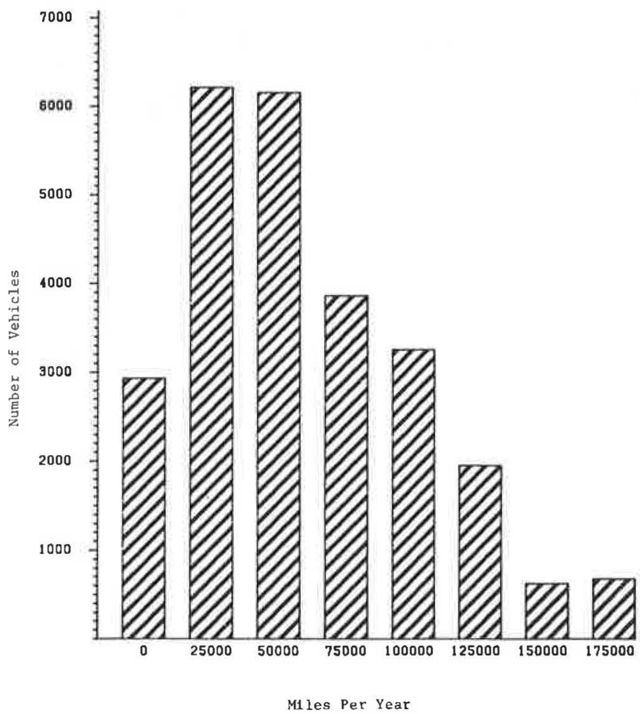


**FIGURE 2 Annual mileage distribution for western doubles with two-axle tractor** *(1)*.

### Annual Mileage

Figure 2 shows that most western doubles have annual mileage between 25,000 and 100,000 miles. A statistical analysis indicated that for each of the vehicle types the mean and the standard deviation of the annual mileage were as follows:

| Vehicle Type | Average Annual Mileage | Standard Deviation |
|---|---|---|
| Western double (two-axle tractor) | 59,286 | ±41,686 |
| Western double (three-axle tractor) | 68,037 | ±50,855 |
| Triple | 47,952 | ±17,855 |

### Weight-to-Horsepower Ratio

Weight-to-horsepower ratio is important in determining a truck's ability to negotiate a grade. The distribution for the TIUS samples is summarized in Table 1 (1). This should be compared with weight-to-horsepower data assumed in AASHTO design policies for climbing lane design; for example, previous performance data assumed a 400:1 ratio for large trucks. This suggests a higher performing capability for the doubles and triples or, to state it differently, these truck units should be able to travel most grades without difficulty. This assumes that the highway segment was designed to AASHTO standards.

### Primary Products Carried

Table 2 (1) gives the primary products carried for doubles and triples as recorded in the TIUS files. It can be seen that 2-S1-2s were used mainly for carrying farm products, processed foods, building materials, and mixed cargoes; 3-S1-2s were used for products similar to those carried by 2-S1-2s, although less for farm products than for petroleum or petroleum products.

**TABLE 2 Primary Products Carried by Doubles and Triples** *(1)*

| Primary Products Carried | 2-S1-2[a] (%) | 3-S1-2[b] (%) | 3-S1-2-2[c] (%) |
|---|---|---|---|
| Farm products (crops, fruit) | 30.5 | 8.6 | 87.5 |
| Live animals | 1.7 | - | - |
| Mining products | 0.7 | 2.0 | 6.3 |
| Logs and other forest products | 0.7 | 2.0 | - |
| Processed foods | 8.0 | 6.8 | - |
| Textile mill products | 0.3 | - | - |
| Building materials | 20.6 | 19.6 | 6.3 |
| Household goods (moving) | - | 3.1 | - |
| Furniture or hardware | 0.2 | - | - |
| Paper products | 1.4 | - | - |
| Chemicals or related products | 2.7 | 0.6 | - |
| Petroleum or petroleum products | 1.0 | 14.6 | - |
| Primary metal products | - | 1.3 | - |
| Fabricated metal products | 1.4 | 3.1 | - |
| Machinery (except electrical) | 0.3 | 1.9 | - |
| Transportation equipment | 0.8 | - | - |
| Scrap, refuse, garbage | 0.7 | 5.8 | - |
| Mixed cargoes | 28.4 | 31.0 | - |
| Other | 0.9 | - | - |

[a] Western double with two-axle tractor.
[b] Western double with three-axle tractor.
[c] Triple with three-axle tractor.

### Operator Class

Table 3 (1) shows the operator class distribution for each of the three vehicle types; 2-S1-2 and 3-S1-2 were mostly operated by private operators, Interstate Commerce Commission (ICC) common carriers, and intrastate carriers. The sample for triples is too small for statistical analysis.

## CHARACTERISTICS OF DOUBLES AND TRIPLES FROM TWS

### Types of Doubles and Triples Represented

Altogether 58,279 records of trucks were classified

**TABLE 1 Weight-to-Horsepower Ratio for Doubles and Triples** *(1)*

| Weight-to-Horsepower Ratio | Western Double, Two-Axle Tractor (%) | Western Double, Three-Axle Tractor (%) | Triple, Three-Axle Tractor (%) |
|---|---|---|---|
| 0:50 | 70.9 | 36.6 | 32.3 |
| 51:100 | 16.0 | 26.3 | 67.7 |
| 101:150 | 0.8 | 4.2 | |
| 151:200 | 0.7 | 4.2 | |
| 201:250 | 3.4 | 14.3 | |
| 251:300 | 6.4 | 6.4 | |
| 301:350 | 1.3 | 6.5 | |

**TABLE 3 Area of Operation for Doubles and Triples** *(1)*

| Area of Operation | Western Double, Two-Axle Tractor (%) | Western Double, Three-Axle Tractor (%) | Triple, Three-Axle Tractor (%) |
|---|---|---|---|
| Local | 35.6 | 29.1 | 12.5 |
| Over the road (one way less than 200 miles) | 38.2 | 38.3 | 87.5 |
| Over the road (one way 200 miles or more) | 25.6 | 32.6 | |
| Off the road | 0.7 | | |

as doubles and triples in FHWA TWS files from 1966 through 1980. Of these records, 99.3 percent were doubles, and the remainder were triples. There were 67 types of doubles in the file and 12 types of triples. Figures 3 and 4 show the major types of doubles and triples found in the TWS from 1966 to 1980. The average GVW, average wheelbase, and the sample size for each major type are also given.

The figures illustrate that the doubles with the more widespread use are the 2-S1-2 (83.2 percent) and 3-S1-2 (8.6 percent), which corresponds with the observation from the TIUS. The turnpike double (3-S2-4), which has received much attention, was represented by only 164 records, or 0.3 percent of the total records of doubles and triples. This suggests that although this vehicle type has strong economic potential, it is not widely used. Among the various triple trailer combinations, the most widely reported was the 2-S1-2-2, which had 260 records out of the total 391 records of triples (66.5 percent); the three-axle tractor triple (3-S1-2-2) ranks second with 83 records or 21.2 percent of all triples records. No records of the two-axle tractor triple were found in TWS. Perhaps this is due to the small sample size of triples provided by the TWS.

## Weight of Doubles and Triples

Figure 5 shows the number of doubles weighed in each of the 48 contiguous states that conducted surveys in 1980 and their mean, minimum, and maximum weight.

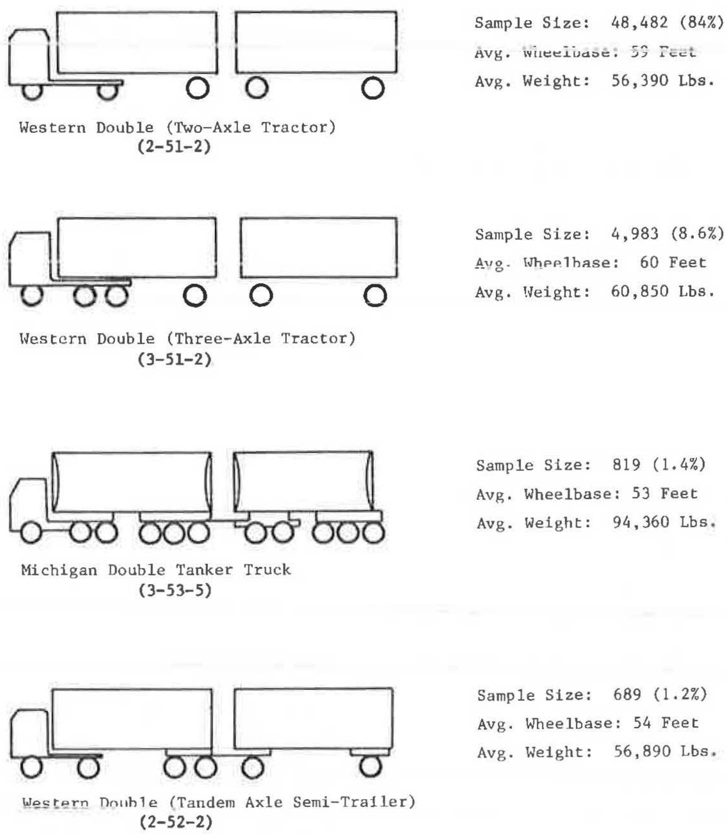


**FIGURE 3 Major types of doubles in the TWS file: 1966 to 1980.**

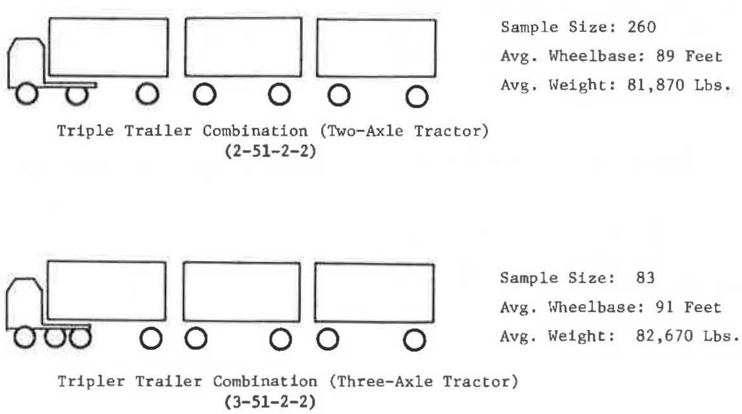


**FIGURE 4 Major types of triples in the TWS file: 1966 to 1980.**

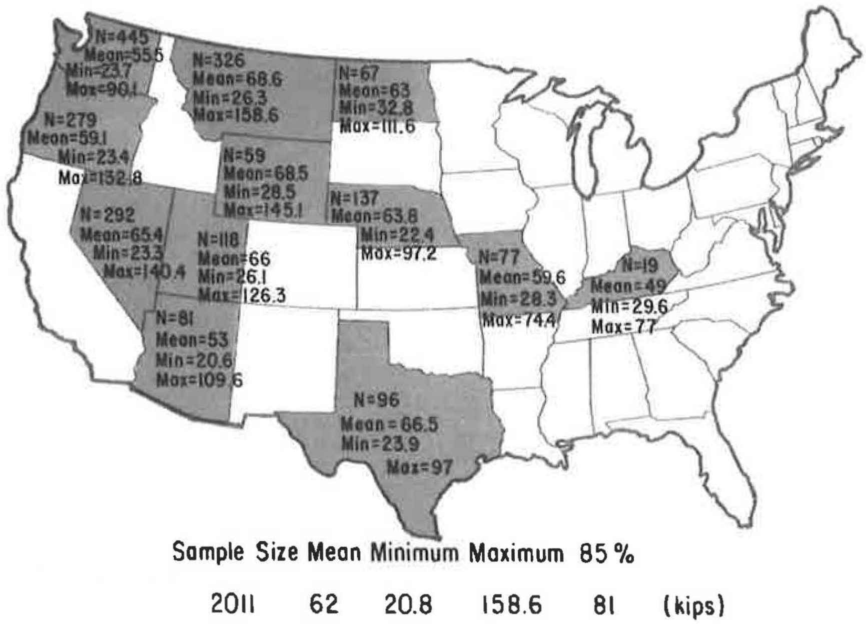


**FIGURE 5** Sample size and weight range of doubles weighed in the 48 contiguous states in 1980.

Also the 1980 national summary is provided, including the 85th percentile of the weight of doubles. Figures 6 and 7 show the sample size and the weight ranges of turnpike doubles and triples weighed in 1980, respectively. A similar set of figures was prepared for doubles and triples for each year from 1966 to 1980. A review of the data suggests that the western doubles show more widespread use where they are permitted by law. The use of turnpike doubles is restricted to the western states, the state of Michigan, and designated turnpikes in the eastern states. The use of triples was almost entirely restricted to a few western states, except in 1974, where two triple combinations were also weighed in Michigan.

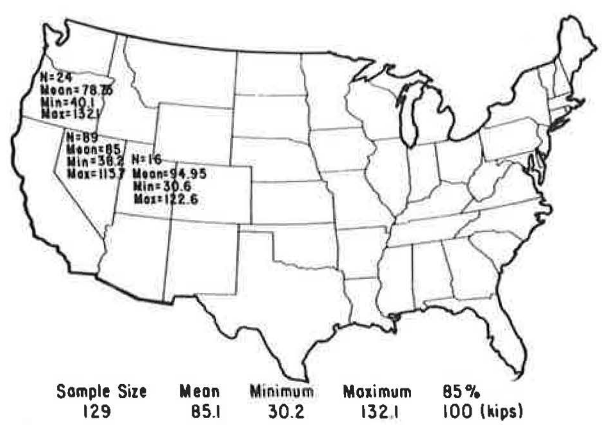


**FIGURE 7** Sample size and weight range of triples weighed in the 48 contiguous states in 1980.

## Share of Doubles and Triples in Traffic

Figure 8 shows the mean percentages of truck combi-

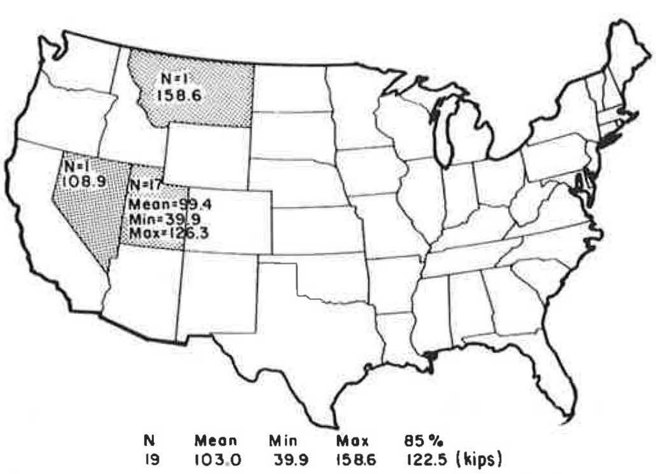


**FIGURE 6** Sample size and weight range of turnpike doubles weighed in the 48 contiguous states in 1980.

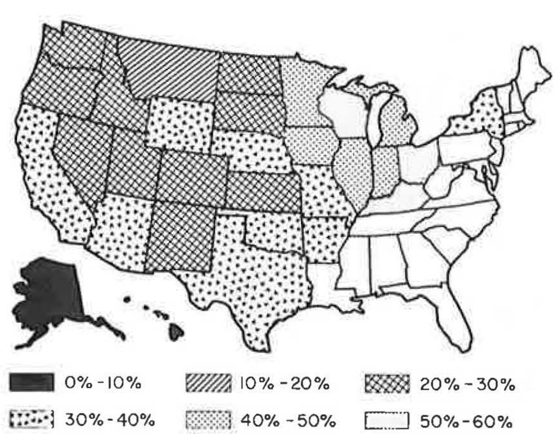


**FIGURE 8** Mean percentage of combinations in truck traffic in the United States, 1966 to 1980.

nations in the truck traffic from 1966 to 1980. The illustration is based on the classification survey data reported by the states to FHWA. States that are blank are those that do not allow doubles or triples, that did not report any observations, or those with insignificant data. It is interesting to note that combinations make up a large percentage of the truck traffic in many states around or close to the Great Lakes, such as Ohio, Wisconsin, Kentucky, Michigan, Indiana, Illinois, Iowa, and Minnesota. Figure 9 shows from a slightly different perspective the average percentage of trucks in total traffic from 1966 to 1980. Results show that 13 states (i.e., Kentucky, Indiana, Wisconsin, North Dakota, Montana, Wyoming, Colorado, Texas, Oklahoma, Arkansas, Arizona, Oregon, and Alaska) have, on the average from 1966 to 1980, between 30 and 36 percent of trucks in total traffic. Figure 10 summarizes the data in Figures 8 and 9, showing the spread of combinations in relation to traffic in the United States from 1966 to 1980.

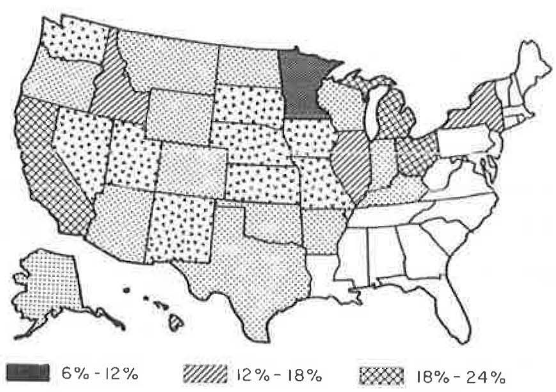


FIGURE 9 Mean percentage of trucks in total traffic in the United States, 1966 to 1980.

## Steering Axle Weight

In size and weight studies, the interesting point is the steering axle weight of the truck. This parameter is significant from a number of perspectives. One, it is useful in establishing the practical maximum gross vehicle weight (PMGVW) a vehicle can carry, which is an important parameter in shifting procedure. Steering axle weight is also important from a safety and highway loading viewpoint. For convenience, the 67 types of doubles in the truck weight survey from 1966 through 1980 were grouped into three categories according to the lengths of their wheelbases. Those with a wheelbase of 65 ft or less are referred to as small doubles, those with a wheelbase between 65 and 85 ft as medium doubles, and those with a wheelbase greater than 85 ft as large doubles. The data show that the average steering axle weight for small and medium doubles from 1970 through 1980 is about 9,000 lb and that large doubles fall somewhere between 9,000 and 10,000 lb. The average steering axle weight for triples has been about 9,500 lb. The distribution of average steering axle weight for small doubles is shown in Figure 11.

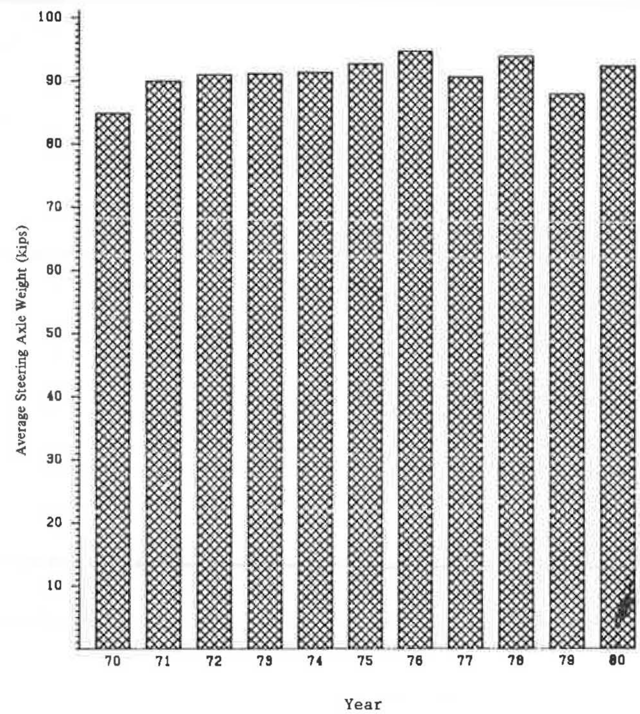


FIGURE 11 Mean steering axle weight for small doubles, 1970 to 1980.

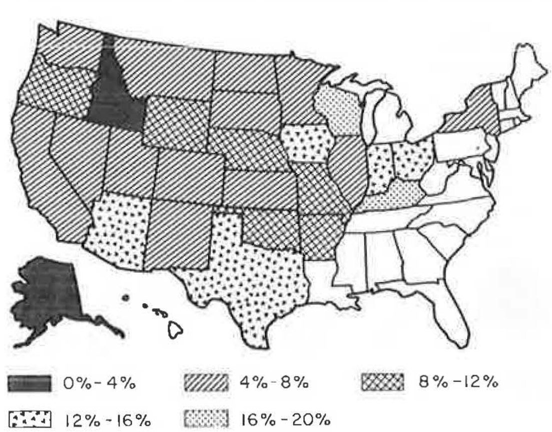


FIGURE 10 Mean percentage of combinations in total traffic, 1966 to 1980.

## Gross Vehicle Weight

GVW distribution is important mainly from the points of view of highway loading, vehicle payload, and vehicle weight violation. Figures 12 and 13 show the GVW data for two-axle tractor, western doubles for the years 1967 and 1980, respectively. In Figure 12, the two peaks indicate that the empty weight is close to 30,000 lb, and the loaded weight is approximately 75,000 lb. Comparing Figure 12 with Figure 13, a rightward shift is noted in the national weight distribution; the left peak shifted to 35,000 lb while the right peak remains at 75,000 lb. A slightly greater percentage of overweight vehicles is also observed.

Figure 14 shows the GVW distribution of triples in 1980. A total number of 129 samples were collected in that year, indicating a significant increase in the reported use (or observations) of triples since 1970. The figure shows that many of

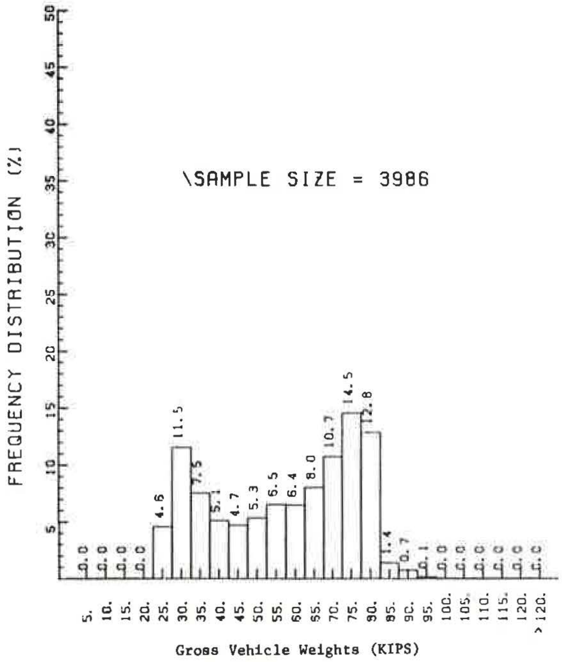


FIGURE 12 National gross vehicle weight distribution of western doubles in 1967.

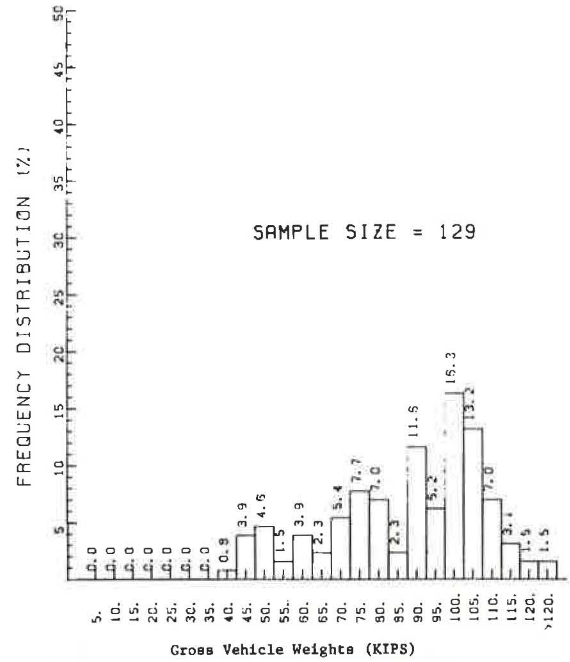


FIGURE 14 National gross vehicle weight distribution of triple trailer combinations in 1980.

the triple combinations are operating at weights greater than 80,000 lb; the largest group observed weighed more than 100,000 lb.

## Weight Violations

Examples of violations by doubles and triples in Texas are used in this discussion. Figure 15 shows violations of single-axle weight limits from 1970 through 1980 for the two-axle western double. The figure provides a comparison of the number of western doubles weighed in Texas that were not in violation of the single-axle weight with those over the legal limit. The results suggest an increase in recorded small doubles operating in excess of the legal limit.

## Empty Vehicle Trips

Another important fact obtainable from the files of doubles is how often a particular vehicle type runs empty on the highway. Figure 16 shows that the aver-

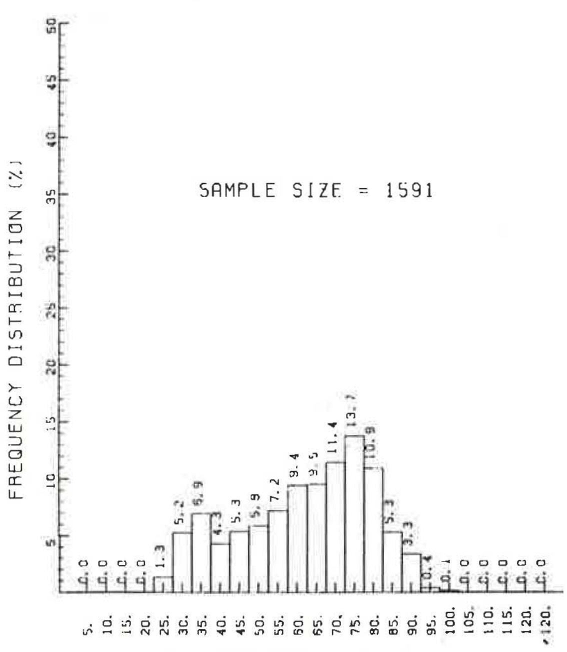


FIGURE 13 National gross vehicle weight distribution of western doubles in 1980.

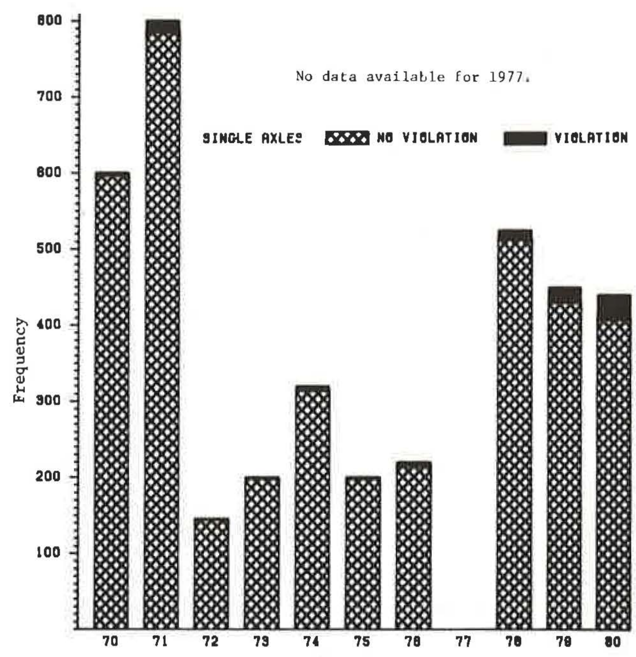


FIGURE 15 Frequency of single-axle weight violations for western doubles in Texas, 1970 to 1980.

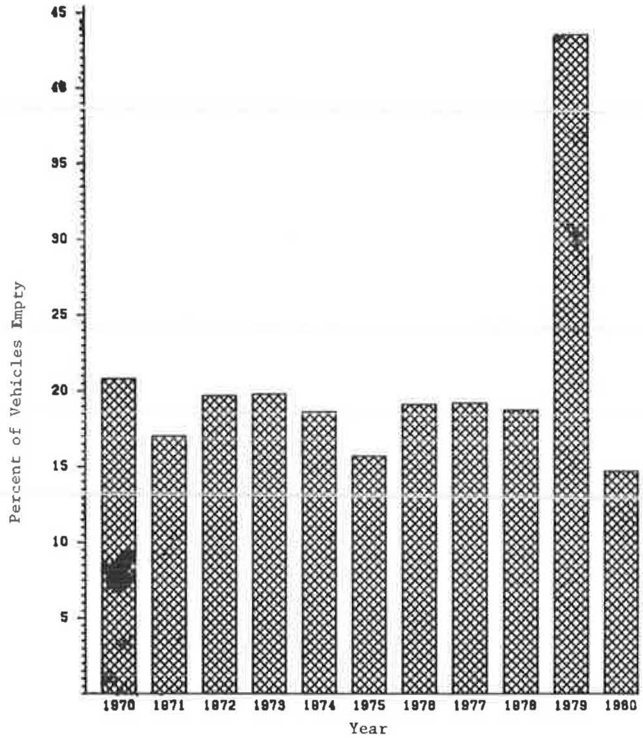


**FIGURE 16 Percentage of vehicles empty, doubles, and triples in the United States, 1970 to 1980.**

age percentage of doubles and triples from 1970 through 1980 that were recorded as operating empty ranges from 17 to 20 percent. The data for 1979 are anomalous, although the cause has not yet been found.

## Commodities Carried

The question of what types of commodities are carried by these trucks is also an important one. It must be noted, however, that because dynamic weighing methods are used, much commodity-related information is no longer available from TWS and commodity information from TWS must be used judiciously. Therefore, only data from states where manual weighing and driver interviews are still conducted may be relied on. For the sample as a whole, the TIUS commodity information is more accurate than TWS, because TIUS has a more uniform sampling procedure. This does not nullify the usefulness of TWIS in providing commodity-related information; however, the data must be qualified, and the validity of the data should be accepted only from states where driver interviews are still included in the study.

## SUMMARY AND CONCLUSIONS

Figures 1-16 have shown some of the important or interesting aspects of the operation of doubles and triples in the United States from 1966 to 1980 based on the two most available data sources on trucks: TWS and TIUS represent two ends of a sampling spectrum. The TIUS is conducted by the Bureau of the Census, has a well-planned sample design, and is aimed at getting a broad picture of the entire range of the nation's truck resources.

The TWS represents the other end of the spectrum. It has a very large sample, is conducted either annually or biennially, is conducted by each state highway department in cooperation with FHWA, and lacks a cohesive, well-planned sampling strategy. The sampling plans are often varied according to the budget of the state highway department.

The TIUS is answered by truck owners on their company premises, whereas TWS is conducted on the road. Although TWS is also aimed at obtaining a knowledge of the nation's trucks, it is obtained from a different perspective and places more emphasis on the dimension and loading aspects of the vehicle. For data on vehicle loading and axle spacing, TWS is definitely a much better resource than TIUS. However, for other aspects of the truck resources, such as the commodity carried, operator classification, engine makeup of the vehicle, TIUS is the preferred source.

At present, researchers or students of the field can only take these facts into consideration and make the best use of these two data sources when studying doubles or triples. Although the statutory environment for doubles and triples may be quite different after the passage of the Surface Transportation Assistance Act of 1982, the data collected in the past can still be useful both in ascertaining the trend of development of doubles and triples in the past and in serving as a guide to the future. The shortcomings of the past data sets, discovered in the course of this study, will surely help to determine future data requirements.

Although the TWS and TIUS data may have met current needs, both data sets are inadequate in some aspects to understand the operations and performance of doubles and triples in the future. As noted previously, TIUS has been structured to examine the truck resources in the United States across the whole spectrum. It does not target any specific needs of doubles and triples, or other vehicle types. In the future it may be necessary to include a special section of the survey to deal with specific questions. If doubles and triples have sufficient economic potential to have widespread use in the future, and if the need to understand such vehicle types also increases, a special section in the survey to deal with specific issues is warranted.

As for TWS, if a better sampling structure can be incorporated into the program, the reliability and usefulness of the data will definitely be much enhanced. At present the nonuniform techniques used from state to state make it difficult to characterize trucks on a nationwide basis. However, if the sampling plan is better defined and implemented on a national basis, statistical techniques could be used to process data and to assist federal, state, and local governments in their policy decisions.

## REFERENCES

1. U.S. Census of Transportation, 1977: Truck Inventory and Use Survey. Technical Document. U.S. Bureau of the Census, Washington, D.C., 1979.
2. Guide for Truck Weight Study Manual. FHWA, U.S. Department of Transportation, April 1981.

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# Department of Transportation Planning for Bureau of the Census Transportation Surveys

GEORGE F. WIGGERS

ABSTRACT

An overview and options are presented for a U.S. Department of Transportation (DOT) strategy for sponsorship of and participation in transportation surveys conducted by the U.S. Bureau of the Census. The purpose is to provide a focus for discussion and debate on DOT's need for census data, on the current and future programs supporting these data-collecting activities, and on how DOT should best coordinate its efforts to meet its needs for census transportation data. Each of the surveys used within DOT is also described.

The U.S. Department of Transportation (DOT) spends millions of dollars annually on data required to develop policy, manage programs, evaluate the impact of DOT policies and programs, and respond to national emergencies within its area of responsibility. Much of this information is provided by the U.S. Bureau of the Census as part of its program to gather general demographic and economic data or by special surveys the Bureau conducts under sponsorship of DOT and other federal agencies. The Bureau occupies a unique place within the federal establishment because it is authorized by law, Title 13, United States Code, to require responses to many of its surveys. It has an unquestioned reputation for maintaining confidentiality, and it enjoys credibility for its published statistics. These attributes are often essential for the credibility of the policies and programs of the DOT.

Most of DOT's needs for census data may be categorized into person and commodity movements. The person movement data are obtained from household surveys in which residents are asked to report on trips by all modes of transportation, to provide supplemental information on the socioeconomic characteristics of the household (including household-owned vehicles), and to report other information, such as use of seat belts. This information is used for a wide variety of purposes within DOT including

- Forecasting future passenger and vehicle travel, which is used in estimating public investment needs for the various passenger modes;
- Analyzing the demographic and socioeconomic characteristics of travelers as a means of assessing equity and income transfer characteristics of federal transportation programs;
- Effectively managing DOT highway and public transportation grant programs by advising grantees on the effective use of grant funds; and
- Estimating exposure rates for classes of automobile passengers and vehicle types; this information is used in formulating highway safety regulations.

Commodity movement information is collected in several forms by the Bureau of the Census for many uses within the DOT including

1. Preparing research reports to support DOT initiatives, such as economic justification of waterway user charges, equitable allocation of highway user charges, deregulation of highway and rail industries, and federal investment in highways and waterways;
2. Responding to national emergencies (such as a nationwide strike against the railroads that cuts off the movement of goods required for the health and safety of the country, an embargo on the importation of petroleum, port congestion delaying exports of coal and grain, or a major earthquake) and support of defense mobilization planning;
3. Making determinations of maritime subsidies based on reports of cargo carried by U.S. and foreign vessels in the various foreign trade services; and
4. Responding to congressional requests for major studies on issues such as truck size and weight, highway cost allocation, and the movement of energy materials.

The uses of census data cited in this paper are only a small sample of those within DOT. Many of the uses are ad hoc, although information on the nature or extent of a problem often has a profound influence on decisions made by the public and private sectors.

## PAST AND CURRENT CENSUS SURVEYS

Ten census surveys are of major interest to DOT. The first three are sponsored every 5 years by the Census Bureau as part of the Census of Transportation.

1. The National Travel Survey (NTS) collects information on intercity passenger travel by all modes of transportation. The 1982 NTS was cancelled because of budget cutbacks.
2. The Commodity Transportation Survey (CTS) provides data on manufacturers' shipments by all modes of transportation. Technical and budget difficulties resulted in postponement of the 1982 CTS.
3. The Truck Inventory and Use Survey (TIUS) collects information on the characteristics and use of registered trucks. The 1982 TIUS is now in progress.
4. The Nationwide Personal Transportation Survey (NPTS) has been sponsored by several agencies within DOT. It collects information on all personal travel by all modes of transportation. The 1983 NPTS is now in progress.
5. The Annual Housing Survey (AHS) is sponsored by the U.S. Department of Housing and Urban Development (HUD). A DOT-sponsored supplement to this survey provided journey-to-work data for national, state, and local transportation analysis. The AHS had been conducted annually until about 1980, but budget limitations have curtailed the frequency of this survey.

6. The Decennial Census (DC) is conducted every 10 years, and every U.S. resident is required to respond. The information used by DOT is reported on 5, 15, and 20 percent samples of the population from the DC.

7. The Commodity Transportation Survey Expansion (CTSE) would expand the CTS to cover nonmanufacturing industries. The next CTS is expected to include the mineral and grain wholesale industries, with possible expansion to other wholesale groups in 1987.

8. The proposed Truck Activity and Commodity Flow (TACF) survey would obtain origin, destination, highway use, and other information on trucks and their loads for a sample of truck trips over a year. It would be based on the results of the TIUS survey described above.

9. The survey Inland Movement of U.S. Foreign Trade (IMFT) has been sponsored at various intervals by DOT and other federal agencies and was last conducted in 1976. It obtains information on the inland origins or destinations of exports and imports and the mode of domestic transportation for these goods.

10. Foreign Trade Data are collected by the U.S. Customs Service and the U.S. Department of Commerce but compiled and processed by the Census Bureau. This data set contains information about each import and export shipment into and out of the United States by all modes. The information is used by the U.S. Maritime Administration in designating essential trade routes, finding the extent of foreign competition on such routes, and determining subsidies for American flag vessels.

## SURVEY ISSUES AND OPTIONS

A number of issues and options are addressed that are related to each of the major census surveys of interest to DOT. These issues are framed in the context of three overall budgeting considerations:

1. For surveys sponsored by the Census Bureau, funding is usually planned and committed about 6 years in advance. Although this approach generally ensures stability in the census program, it reduces program flexibility.

2. DOT's shorter budgeting cycle generates different problems. Because many of these surveys are conducted at 5-year intervals, the uneven level of expenditures strains the modest research budgets that fund the surveys.

3. A single agency in the DOT can rarely justify the cost of a census survey based on its needs alone; therefore, the surveys are usually sponsored by several agencies that pool their funds. Pooling increases survey efficiency and helps reduce the burden on respondents, but it requires substantial coordination.

The years 1985 and 1986 are critical to several of the surveys covered in this paper. Planning for the 1987 Census of Transportation surveys must begin early next year. Major issues for each survey are

1. Supplementing NTS home interviews with telephone interviews should be considered for 1987 so that the sample size can be increased while holding down survey costs.

2. Coordination of the NPTS with the NTS will be needed in 1987 to ensure maximum utility of person movement data. Substantial coordination will be required to ensure that user agencies obtain needed data at a reasonable cost. The methodology should be improved to increase the utility of the survey for analysis of public transportation and safety issues.

3. Negotiations for the content of the AHS are now ongoing between the Census Bureau and HUD. DOT should become involved quickly to ensure collection of mid-decade journey-to-work data.

4. Planning for the DC should be completed in the next year or two because of the long lead time necessary to put together this large survey. This is important because of major changes in the design and conduct of the DC that are now being debated.

5. The methodology planned for the 1984 CTS needs to be evaluated for 1987. It should be expanded to include grain and other wholesale shippers. A substantial increase in funding is needed for this survey or a line item should be added to DOT's budget to cover the increased cost.

6. Consideration should be given to incorporating the TACF survey as an element of the 1987 TIUS. The TACF survey promises a major advancement in DOT's ability to monitor the movement of goods on the nation's highway system.

7. A fiscal year 1984 study effort should consider the need for repeating the IMFT survey, including coordinating it with the Economic Censuses and including export movement data in the CTS.

8. Efforts should be continued to determine the feasibility of including inland origin and destination data in the regular reporting of the Foreign Trade Data.

## PROGRAM ISSUES AND OPTIONS

Three major program issues related to census surveys are addressed in this section. Although specific recommendations for resolving these issues are not provided, several management options and their pros and cons are identified. The issues are as follows.

1. Assuming that DOT will continue to make substantial investments in census transportation surveys, how should DOT fund and budget for these amounts?

Although some of the census surveys may not continue to meet the needs of DOT agencies in the future, DOT will continue to be dependent on many of the surveys. Consequently, it makes sense to address the broader issue of planning and budgeting for these surveys as a whole, without passing on the merits of individual surveys.

One option is to establish one or more line items in the DOT budget to fund census projects. The primary advantage of this approach is that it would avoid draining research budgets in those years when large amounts are needed to finance census surveys and avoid arbitrary cutbacks in census projects when research budgets are cut. The primary disadvantage is that a line item may make the program more vulnerable to a congressionally mandated cancellation or cutback.

2. Should DOT and other user agencies provide an increased level of funding for census transportation surveys, or should the Census Bureau be responsible for the basic costs of these surveys, with user funding covering only one-time specialized needs?

Unless DOT obtains a budget line item to fund census projects, as discussed, the only practical way for DOT to provide the basic funding required for these surveys would be to continue to pool the funds for the various user agencies. Coordinating pooled funding for a census program is an expensive undertaking in itself (i.e., in the time and effort it takes to obtain commitments from potential cosponsors). It also may increase the risk of the project being cancelled if one sponsor develops budget problems. For example, the 1982 NTS was cancelled when the Research and Special Programs Administration was unable to honor its commitment to support that survey.

On the other hand, financial sponsorship by the user of a survey provides substantial leverage to ensure that the survey is responsive to the needs of the sponsor. The Census Bureau is continually under pressure from many federal agencies, Congress, state and local governments, and the private sector to accommodate many different and sometimes conflicting data requirements. Consequently, the greater control a user has over the funding for a survey, the more leverage the user has in determining the scope and content of that survey.

3. How should DOT coordinate and negotiate its requirements with the Bureau of the Census and other user agencies regarding transportation surveys?

Historically, DOT has always had an identifiable organizational unit with specific responsibilities for articulating the information needs of DOT and for coordinating interagency projects required to satisfy these needs. The resources currently assigned to this function have been cut back to the point that coordination, if done at all, is often accomplished by individuals in the various DOT agencies without reference to an organizational focal point within DOT. Consequently, opportunities for developing more efficient survey projects, articulating DOT data needs in interagency forums, and reducing the burden on respondents, have been diminished. Three options for improving the DOT's statistical coordination function are suggested: (a) creating a larger staff, (b) centralizing data responsibilities for census projects, and (c) making the program more visible to higher management.

Publication of this paper sponsored by Committee on Freight Transportation Planning and Marketing.

# Methodology for Assessing and Predicting Pavement Performance in Oil Field Areas

JOHN M. MASON, JR., BRYAN E. STAMPLEY, and THOMAS SCULLION

ABSTRACT

A basic methodology for estimating the amount and type of oil field traffic on a selected roadway is outlined. The Texas Pavement Distress Equations were used to predict reductions in pavement service life caused by oil field truck traffic. The procedure used a case study example to identify and delineate major oil field activity centers. Several density maps were developed to depict the extent of drilling and production activity in the study area. Truck traffic generated in these centers was converted to 18-kip equivalent single axle load repetitions; these were analyzed for their effect on 6- and 10-in. surface-treated pavements. Resulting pavement service lives were compared for various measures of pavement distress (pavement serviceability index, rutting, alligatoring, flushing, and raveling). This technique can be used to anticipate resurfacing intervals and rehabilitation requirements.

The Arab Oil Embargo of 1973 spurred an increase in oil field development throughout the nation. In the oil-rich regions of Texas, this increased activity had an adverse effect on many light-duty rural highways. These highways were intended to service low volumes of passenger cars and light trucks and were not built to withstand the impact of the load-intensive, special-use oil field traffic.

The Texas State Department of Highways and Public Transportation (TSDHPT) found it necessary to determine the effects of oil field development on rural highways. Phase I of the research identified traffic and vehicle characteristics associated with oil field development and estimated a reduction in pavement service life due to this specialized user (1).

Phase II of the research involved developing and applying a method of assessing the current effects, and predicting the future effects, of oil field development on any particular rural highway. The method is in the form of a computer program, Oil Field Damage Program, fully described in Research Report 299-2 (2). Although it was developed as a means of predicting the present and future effects of oil field development, the same basic principles can be used to develop programs for examining the effects of other types of load-intensive, special-use traffic.

STUDY PROCEDURE

An overall picture of oil field development was necessary to estimate and describe oil field traffic on a specific roadway. Once an impacted region was identified, individual roads were delineated within the major producing areas. The affected roadways serve both intended-use traffic and the special-use oil field traffic. Because an existing roadway must therefore accommodate an increased demand, the anticipated design life is shortened considerably. A methodology for assessing and predicting the effects of oil field development was prepared so that the resulting change in pavement performance could be defined.

The study procedure shown in Figure 1 illustrates the need to identify specific activity centers, describe the associated traffic characteristics, and estimate the effect of changes in traffic demand on a roadway pavement.

Oil field activity in a region is assessed by the following steps:

1. Develop a base map of the study area.
2. Identify (plot) related oil field activity centers.
3. Prepare a composite of the impacted area and surrounding areas of influence.

## Base Map

The base map used for this study (Figure 2) is of Brazos County and was supplied by TSDHPT. The county boundaries and pertinent roadways were traced on a 24 x 36-in. sheet of Mylar paper at a scale of 1 in. equals 2 miles. This map size was satisfactory for showing minor roads and streets, creeks, rivers, ponds, and lakes, as well as lines of latitude and longitude. The lines of latitude and longitude orient the base map and serve as an initial map grid system.

State regulations governing oil well density were taken into consideration when the size of the map grid system was developed. In Texas oil field activity is regulated by the Texas Railroad Commission, which typically allows a maximum density of one well to each 40 acres (3). At the selected map scale each sector represents 284 acres and could contain a maximum of seven oil wells.

## Oil Field Activity Centers

The map grid system divides the county into sectors. The number of activity centers for any given oil field related activity was determined for each sector. Then each activity was plotted on a separate density map. The resulting density maps show the extent of a particular activity. Oil field activity was segregated into three general types: service companies, wells drilled, and producing wells.

Service companies in each sector were located by using telephone books and city maps. A system was established to classify and tabulate the number of service companies in each sector, as shown in Figure 3.

The status and location of existing oil and gas wells throughout the state were available from large-scale maps prepared by private agencies. Depending on the density of activity, a county may need to purchase maps of several sections to obtain full coverage. Pertinent map information includes property ownership, lease information, and geographical data, such as roads, rivers, and lines of longitude and latitude. The number and status of oil wells were determined for each map sector and tabulated. Then the sum of oil wells drilled in each sector was calculated and used to develop the drilling location density map shown in Figure 4.

The number of producing wells in each sector was also available from the completed activity identification sheets. These sums were used to develop the map showing the density of producing oil wells shown in Figure 5.

The density maps convey information on the relative levels of activity in the area and the amount of growth in oil field activity. When the density maps for service companies, wells drilled, and producing wells were overlaid one on the other (Figure 6), oil field activity centers became apparent. Because these maps were developed for April 1981, and updated as of July 1, 1982, the movement and development of new oil wells could be readily identified. Documenting oil production on a regular basis helps monitor oil field traffic activity in an area. Iden-

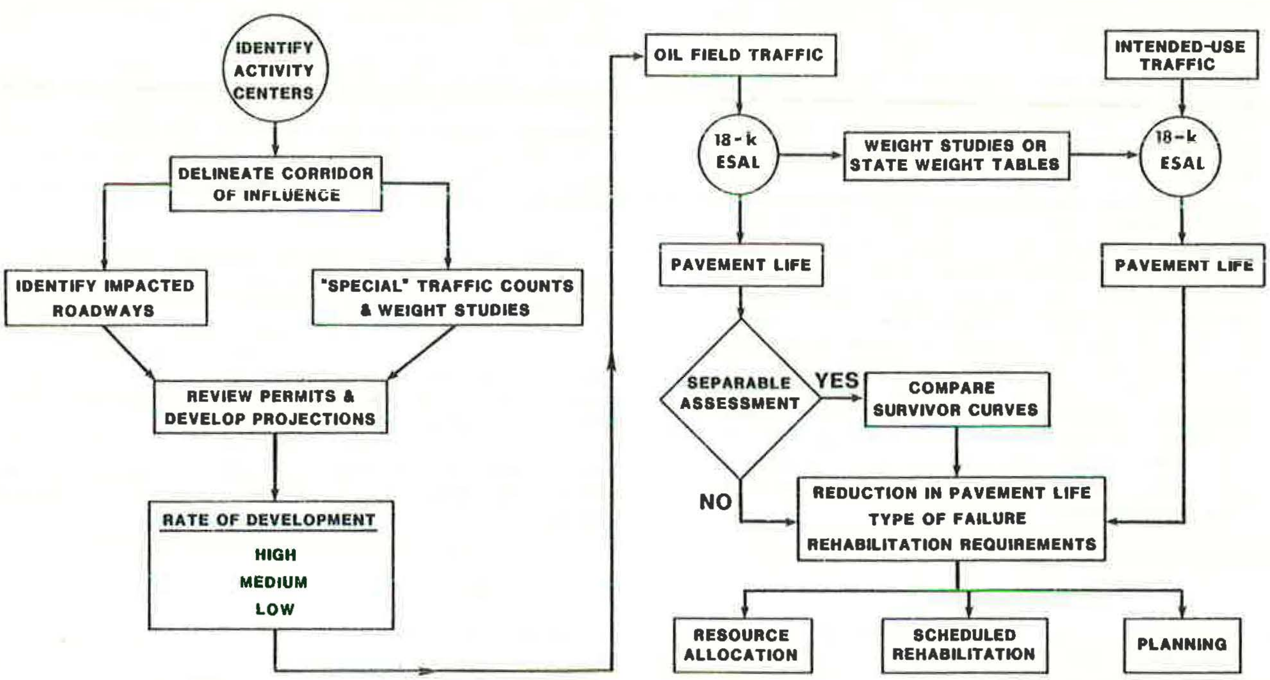


FIGURE 1 Phase II research procedure.

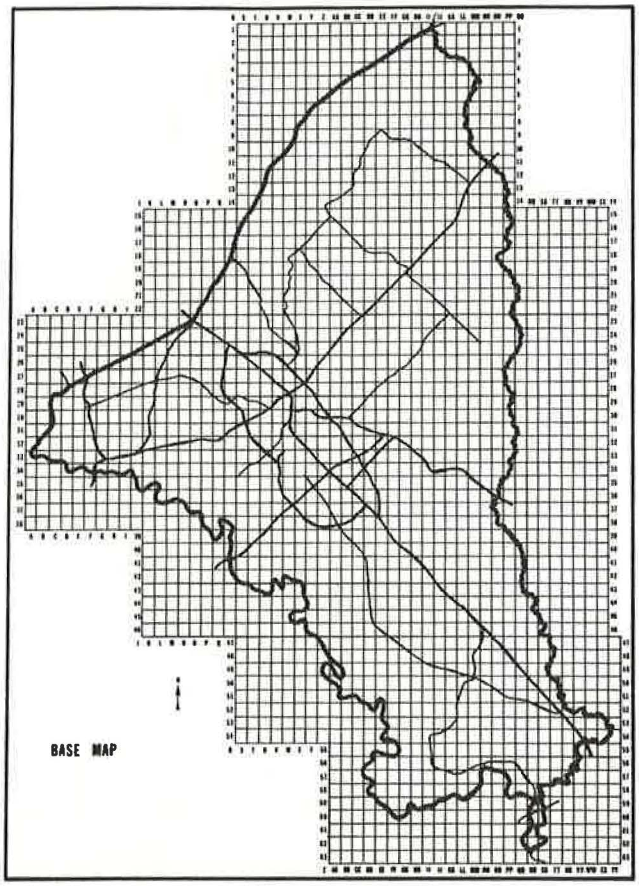


FIGURE 2 Base map (Brazos County).

| Sector | | Number of Service Companies |
|---|---|---|
| F | 36 | 18 |
| | 37 | 18 |
| K | 32 | 1 |
| L | 32 | 2 |
| | 33 | 2 |
| P | 42 | 8 |
| R | 25 | 2 |
| | 28 | 1 |
| | 29 | 1 |
| | 31 | 1 |
| S | 29 | 1 |
| | 30 | 6 |
| | 31 | 11 |
| | 32 | 3 |
| U | 27 | 2 |
| | 31 | 1 |
| | 38 | 1 |
| V | 24 | 1 |
| | 27 | 3 |
| | 32 | 2 |
| | 33 | 3 |
| | 34 | 1 |
| | 35 | 1 |
| W | 26 | 3 |
| | 27 | 3 |
| | 29 | 4 |
| | 30 | 6 |
| | 31 | 1 |
| X | 24 | 1 |
| | 25 | 1 |
| | 27 | 19 |
| | 28 | 1 |
| | 30 | 3 |
| | 32 | 3 |
| | 33 | 2 |
| | 34 | 1 |
| Y | 25 | 1 |
| | 27 | 19 |

| Sector | | Number of Service Companies |
|---|---|---|
| | 28 | 1 |
| | 32 | 2 |
| Z | 24 | 1 |
| | 32 | 3 |
| | 33 | 2 |
| AA | 25 | 3 |
| | 31 | 3 |
| | 32 | 3 |
| | 33 | 1 |
| | 35 | 3 |
| BB | 30 | 1 |
| | 32 | 3 |
| | 35 | 2 |
| | 36 | 2 |
| | 37 | 2 |
| CC | 22 | 2 |
| | 23 | 1 |
| | 34 | 3 |
| | 36 | 4 |
| DD | 22 | 6 |
| | 34 | 1 |
| | 38 | 5 |
| EE | 33 | 1 |
| | 38 | 2 |
| FF | 38 | 1 |
| GG | 19 | 9 |
| | 20 | 3 |
| KK | 23 | 1 |
| PP | 10 | 5 |
| QQ | 37 | 1 |
| WW | 56 | 5 |

FIGURE 3 Summary sheet for locations of service companies.

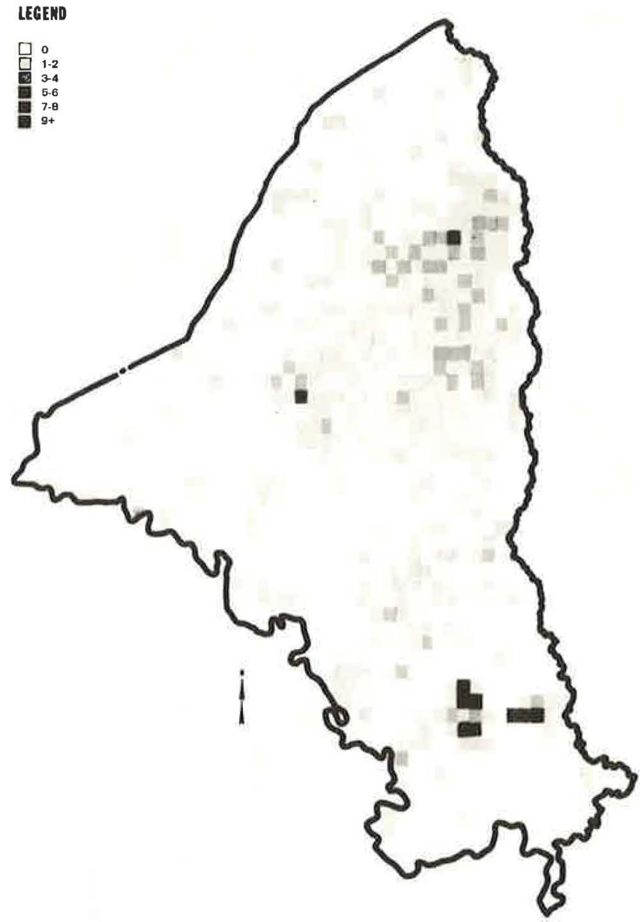


FIGURE 4 Drilling location density map.

tifying this additional traffic demand is essential in assessing current pavement conditions and in planning maintenance and rehabilitation strategies.

## Case Study Example

Three major centers of oil field activity are shown in Figure 6, and because the Kurten area was the largest, it was selected for closer study. This region contains several low volume roads. When the activity centers map was overlaid on a TSDHPT county map, a light-duty, surface-treated road [farm-to-market (FM) road 2038] was found to be the primary roadway serving the Kurten oil field area.

To estimate the amount of oil field traffic using FM-2038, an area of influence for the road was established, as shown in Figure 7. Basically all traffic within this area of influence uses FM-2038 when entering and exiting the area. It is helpful to think of the area of influence as being analogous to a tributary watershed. Traffic was visualized as flowing from the far reaches of the influence area down small tributary roads and emptying into the main stream, FM-2038, before leaving the area. Vehicles were assumed to travel on the most direct and best roads available, avoiding major natural obstructions.

## TEXAS PAVEMENT DISTRESS EQUATIONS

The AASHO Road Test conducted in Ottawa, Illinois, in 1960 has been a major source of pavement perfor-

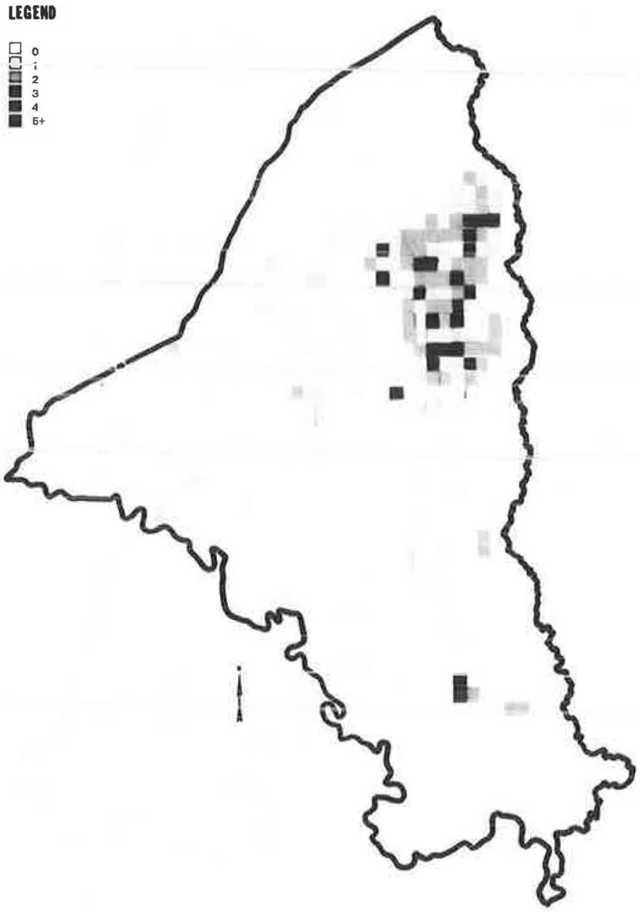


FIGURE 5 Producing oil well density map.

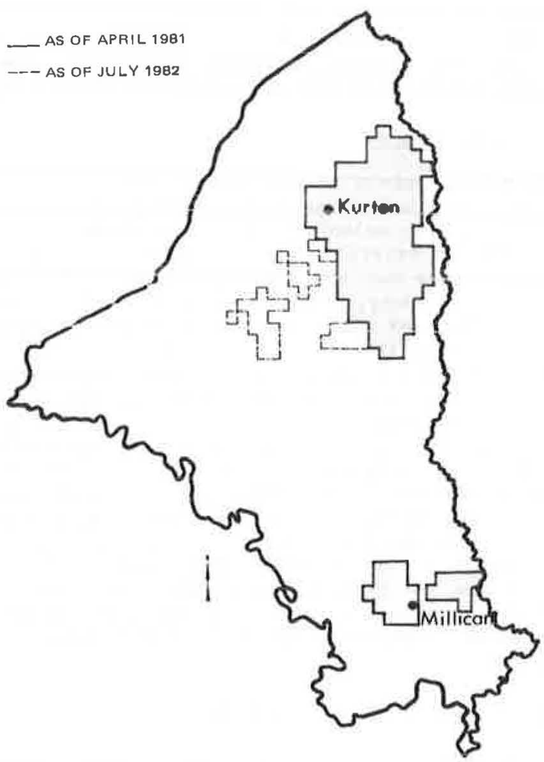


FIGURE 6 Location of activity centers.

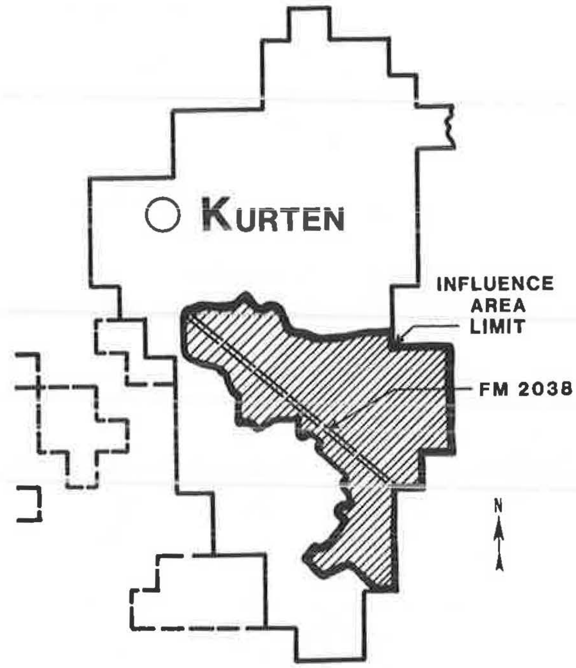


FIGURE 7 Limit of FM-2038 influence study area.

mance data. Because the AASHO Road Test equation was developed from data collected on flexible pavements with a minimum 2-in. asphalt surface course, it did not yield reasonable predictions of pavement life for the surface-treated pavements considered in this study.

Texas began maintaining a flexible pavement data base in 1972, with the ultimate goal of developing a series of equations. These equations would provide performance models for various types of flexible pavements in Texas. Pavement distress equations were developed for the following pavement distress types: alligator cracking, transverse cracking, longitudinal cracking, rutting, raveling, flushing (or bleeding), and patching. Equations were also developed for ride quality [present serviceability index (PSI)] and pavement score (PS). Pavement score is a composite index that describes overall pavement condition as a function of pavement distress and loss of ride quality.

Correlation coefficients ($R^2$) for the Texas Pavement Distress Equations generally range from 0.30 to 0.60. The overall reliability is expected to improve as pavement condition monitoring continues and pavement utility techniques and familiarity improve. The current versions of the equations, nonetheless, do more closely replicate the actual performance of Texas surface-treated pavements (4).

## ASSESSMENT CASE

One objective of this project was to use the Texas Pavement Distress Equations through a program entitled, Oil Field Damage Program, to assess the condition of a roadway pavement under oil field traffic. This objective was satisfied by using the prepared density maps to estimate the traffic demand placed on the roadway in a major oil field area. The assessment period for FM-2038 was from July 1978 to July 1982. Initially FM-2038 was a 6-in. surface-treated pavement. In July 1978 it was reconstructed using a cement-stabilized subgrade with a 10-in. surface-treated pavement section.

Oil well ownership maps as of July 1982 showed a total of 285 producing wells in Brazos County. Drilling permit records for the county from the Texas Railroad Commission showed that 154 oil wells had been drilled between July 1978 and July 1982. Therefore, 131 wells were producing oil before the July 1978 reconstruction of FM-2038.

To estimate the number of oil wells developed within the FM-2038 influence area during the 4-year study period, it was assumed that oil drilling activity was uniformly distributed throughout the three major activity centers and that the probability of a well being drilled within any influence area was equal to the ratio of the influence area to the total area of the major activity centers.

Approximately 22 percent of the wells drilled in Brazos County during the 4-year study period occurred within the FM-2038 influence area. The percentage is the ratio of the influence area (35 sectors) to the total area of the major activity centers (160 sectors). Therefore, during the 4-year study period, 34 oil wells were assumed to be drilled in the area that affects FM-2038.

However, not all wells drilled in the county produced crude oil. The drilling density map (Figure 4) indicated that a total of 55 oil wells had been drilled within the FM-2038 influence area as of July 1982. Information from the production density map (Figure 5) showed that 46 of those wells (83.6 percent) were actually producing. Using this 83.6 percent success rate, 28 oil wells were assumed to be actually producing within the FM-2038 influence area during the 4-year period.

## ASSESSMENT OF OIL FIELD DEVELOPMENT

To illustrate the use of the Texas Pavement Distress Equations as an assessment tool, two computer runs were made for FM-2038. The first run assessed the present condition of the 10-in. pavement after 4 years of oil field activity. The second assessed the condition of a theoretical 6-in. pavement subjected to 4 years of oil field activity. The simulation assumed that the 1978 reconstruction had only restored the pavement to a 6-in. thickness. The effect of a 1978 cement stabilization of the subgrade was included by changing the subgrade plasticity index from 23 percent to 12 percent.

### Evaluation

Results obtained from the two computer runs were used to answer the following questions:

1. What is the current condition of FM-2038, a 10-in. surface-treated pavement serving 28 wells?
2. How much additional damage would have been inflicted on FM-2038 if the pavement had been only rehabilitated as a new 6-in. surface-treated pavement?
3. What pavement distresses are expected under intended-use traffic?
4. What pavement distresses are particularly sensitive to oil field truck traffic?

The various distress measures that were calculated using the Texas Pavement Distress Equations are summarized in Table 1. Limiting distress values are tabulated for each distress type. A comparison of the intended-use and oil field-use distress values demonstrates markedly that oil field truck traffic reduces pavement service life.

Figures 8-13 show the performance of a 6- and 10-in. pavement under intended-use and oil field traffic. Each figure represents estimated changes in pavement distress levels over time. The initial distress measure assumes a newly reconstructed pavement section. Pertinent limiting values are also shown for each type of distress.

Pavement performance is rated as either a measure of severity or area of distress. Both ratings should be examined to obtain a true description of pavement condition. In certain circumstances, small areas of localized intense distress, such as those caused by poor construction techniques, may inaccurately reflect overall pavement condition. Such areas, however, should be identified and remedied because they are aggravated by load-intensive, oil field truck traffic.

Because the intent of this study was to demonstrate the utility of the analysis methodology, selection of the critical rating for the different distress types was based on which rating (area or

**TABLE 1 Estimated Distress Values for FM-2038 (July 1982)**

| Distress Type | Distress Measure[a] | Limiting Distress Value | Intended Use | Oil Field Use |
|---|---|---|---|---|
| Ride quality | P.S.I. | 1.5 | 4.15 | 3.56 |
| Pavement score | P.S. | 35.0 | 90.5 | 29.0 |
| Rutting | Area | 50.0 | 8.0 | 61.2 |
| | Severity | 30.0 | 3.5 | 51.0 |
| Alligator cracking | Area | 50.0 | 0.0 | 23.8 |
| | Severity | 50.0 | 0.0 | 47.0 |
| Raveling | Area | 80.0 | 1.7 | 41.6 |
| | Severity | 30.0 | 3.8 | 59.2 |
| Flushing | Area | 80.0 | 4.5 | 61.3 |
| | Severity | 30.0 | 5.2 | 66.1 |

[a]Pavement performance is rated as either a measure of severity or an area of distress.

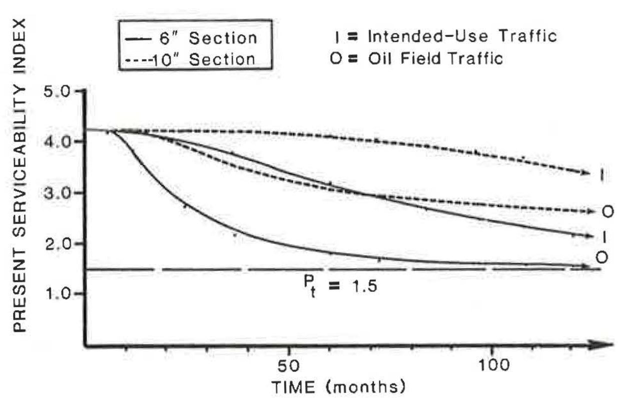


**FIGURE 8 Present serviceability index versus time.**

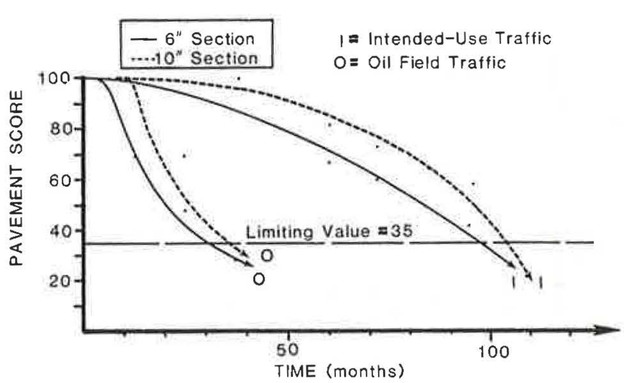


**FIGURE 9 Pavement score versus time.**

severity) reached its limiting value first (Table 1). Only in the case of rutting did the actual area of pavement distress approach its critical limit before the severity rating (depth of rutting) exceeded its limit. For all other distress types, the severity rating value reached its critical limit before the area rating value was exceeded.

## Results

1. Current condition of 10-in. pavement. Figure 9 demonstrates the reduced service life due to increased traffic demand. The limiting pavement score of 35 was projected to occur after approximately 102 months (8.5 years); instead it was reached after only 41 months (3.4 years), which represents a 60 percent reduction in its normal life. Severe rutting and alligator cracking had been predicted, as well as excessive flushing and raveling.

A visual site inspection made in October 1982 generally confirmed the severe flushing and raveling predictions. Localized rutting was observed along the roadway length; however, alligator cracking was minimal. The cement-stabilized subgrade may be responsible for the indications of favorable strength. The visual inspections were based on standardized identifications of distress types described in the Highway Pavement Distress Identification Manual (5).

2. Expected damage to 6-in. pavement. The results indicate, as would be expected, that the thinner pavement reaches its limiting value in less time. However, one pertinent observation from each diagram (Figures 8-13) is that percent reduction in service life appears constant for each distress type for both the 6- and 10-in. pavements. Table 2 summarizes the loss of service time and categorically demonstrates the similarities in actual overall percent reduction.

3. Expected intended-use pavement distress. The pavement distress program can be used to predict service life under normal traffic conditions and to assist in selecting a desired pavement thickness. The distress limits for rutting area and flushing and raveling severity are reached in a 7- to 8-year time period. The 6-in. pavement appears susceptible to severe rutting, reaching its critical limit in 32 months.

4. Pavement distresses sensitive to oil field truck traffic. Oil field truck traffic induces rapid development of pavement distress. The reductions in pavement service life are shown in Figures 8-13 and summarized in Table 2. Traffic associated failures such as flushing and raveling are non-load-associated failures, whereas rutting and alligatoring on the thin 6-in. pavement shows sensitivity to repeated increases of equivalent axle loads.

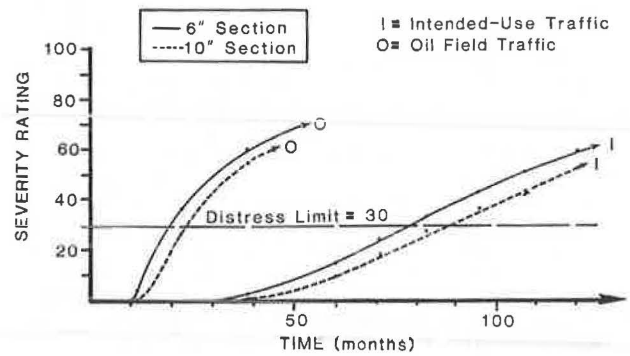

FIGURE 13 Flushing severity versus time.

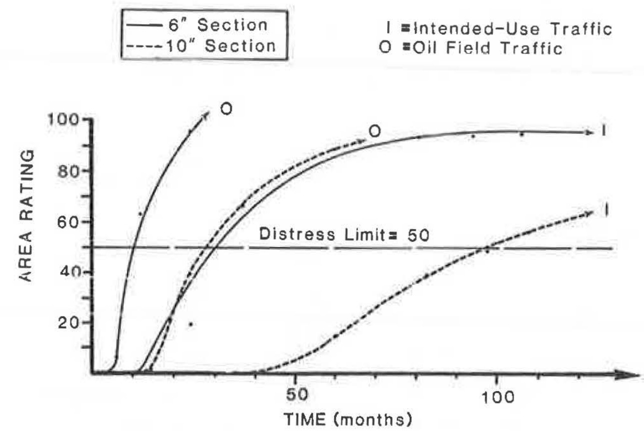

FIGURE 10 Rutting area versus time.

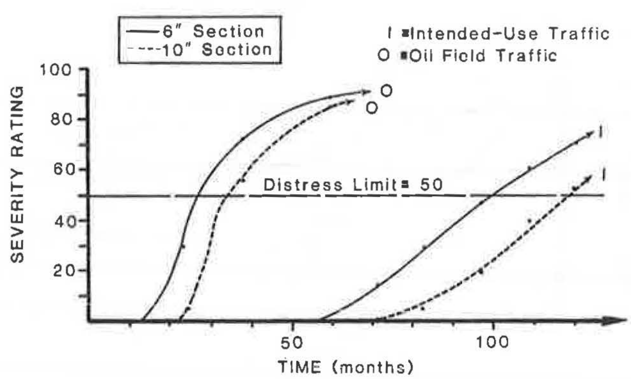

FIGURE 11 Alligatoring severity versus time.

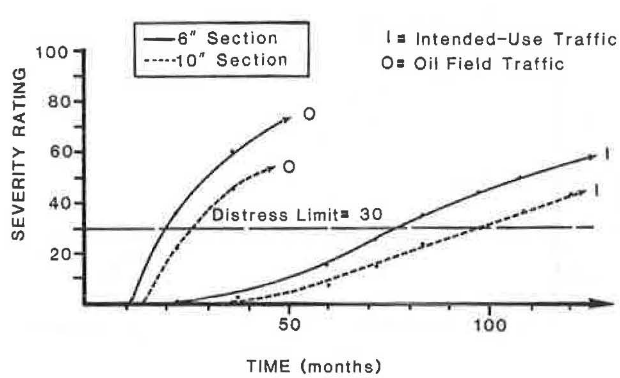

FIGURE 12 Raveling severity versus time.

TABLE 2 Comparison of Reduction in Pavement Service Life

| | 10-In. Pavement | | 6-In. Pavement | |
|---|---|---|---|---|
| Distress Type | Loss of Time[a] (months) | Reduction (%) | Loss of Time[a] (months) | Reduction (%) |
| Pavement score | 104 - 41 = 63 | 61 | 97 - 31 = 66 | 68 |
| Rutting | 88 - 35 = 53 | 60 | 32 - 14 = 18 | 56 |
| Alligatoring | 116 - 50 = 66 | 57 | 99 - 35 = 64 | 65 |
| Raveling | 96 - 23 = 73 | 76 | 80 - 21 = 59 | 74 |
| Flushing | 88 - 22 = 66 | 75 | 80 - 20 = 60 | 75 |

[a]Time to failure under intended-use traffic minus time to failure under intended use plus oil field traffic equals loss of pavement service time.

## PLANNING SCENARIO

Another objective of the project was to demonstrate the use of the Texas Pavement Distress Equations to predict the condition of a pavement under future levels of oil field development. Projections of future pavement condition are imperative in anticipating needed financial resources and in distributing allocated funds. This study's estimates of pavement service life provide a basis to predict the impact of future oil field activity on roadways.

Future oil field development along FM-2038 was selected as the case study example for the planning scenarios. A 5-year planning horizon was used to demonstrate the use of the pavement distress program. The study period begins at the conclusion of the previous assessment case study problem, July 1982, and will continue until July 1987.

### Rate of Oil Field Development

Because the rate of oil field development fluctuates in an area, three general activity rates were defined: low, medium, and high. The actual number of wells drilled as well as the rate of drilling varies. However, both the magnitude and the rate can be estimated based on records maintained by the Railroad Commission (RRC) of Texas.

Records of drilling activity in Brazos County from July 1977 to July 1982 served as the basis for the general activity rates. The 15th, 50th, and 85th percentile conveniently segregated the drilling rates into high (six wells per month), medium (three and one-half wells per month), and low (one well per month) activity. Table 3 summarizes these three levels of drilling activity.

**TABLE 3 Summary of Drilling Rates and Traffic Conditions for FM-2038 Influence Area**

| | Low | Medium | High |
|---|---|---|---|
| Drilling Rates for Brazos County | | | |
| Wells per year | 12 | 42 | 72 |
| Wells per month | 1 | 3.5 | 6 |
| Drilling Rates for FM-2038 Influence Area | | | |
| Wells per year | 2 | 6 | 12 |
| Months per well | 6 | 2 | 1 |
| Traffic Conditions (18-kip ESAL Repetitions) | | | |
| Intended use | 25,600 | 25,600 | 25,600 |
| Oil field | 15,683 | 49,166 | 99,383 |
| Intended use plus oil field | 41,283 | 74,766 | 124,988 |

The three levels of development translate into drilling rates of 12, 42, and 72 wells per year. Applying the influence area ratio of 22 percent and a success rate of production of 83.6 percent, two, six, and twelve wells per year were calculated as the rate of development in the influence area. Table 3 also summarizes the rate of oil well activity and presents the resulting 18-kip equivalent single axle load (ESAL) repetitions for the 5-year analysis period. The analysis includes the projected total annual wells drilled and the actual production expected for each rate of development. The calculation of the resulting 18-kip ESAL repetitions has been reported completely elsewhere (1,2).

### Prediction of Effects of Development

To illustrate the prediction capabilities of the Texas Pavement Distress Equations, several computer runs were made on a reconstructed, 10-in. surface-treated pavement section. The program was run for an intended-use traffic condition and at low, medium, and high traffic-use rates for the future development cases.

### Evaluations

The results demonstrate the capability of anticipating pavement performance under varying rates of oil field development. Figures 14-19 show the performance of a 10-in. pavement under the three rates of development. The expected intended-use condition is

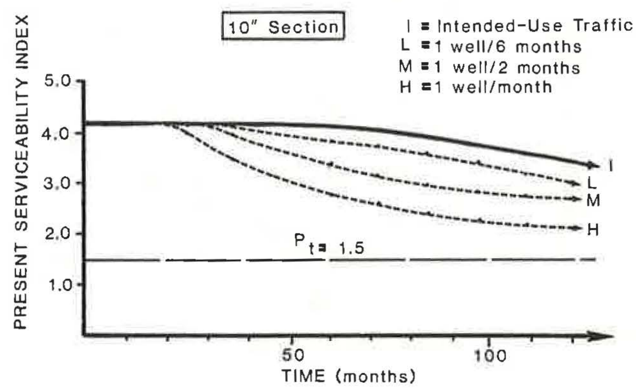


FIGURE 14 Present serviceability index versus time.

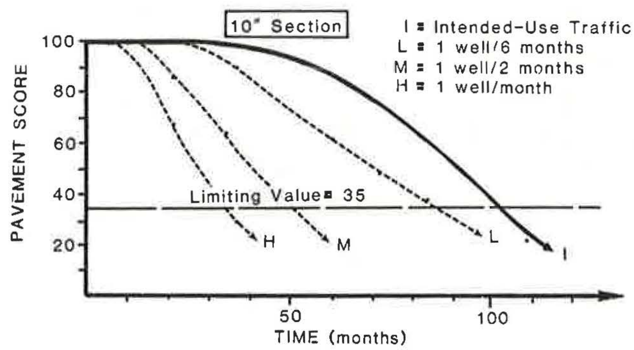


FIGURE 15 Pavement score versus time.

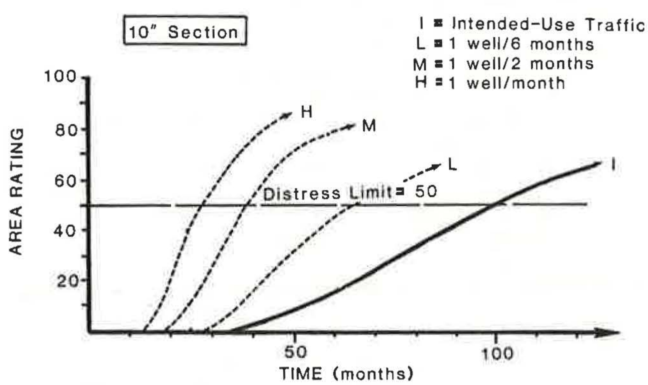


FIGURE 16 Rutting area versus time.

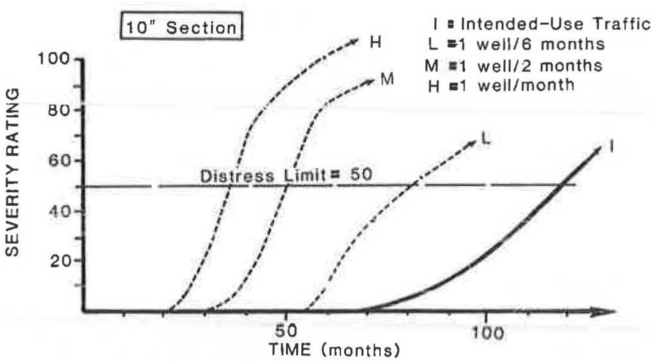


FIGURE 17 Alligatoring severity versus time.

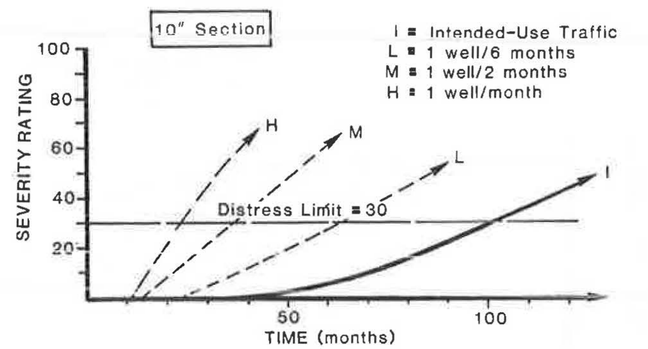


FIGURE 18 Raveling severity versus time.

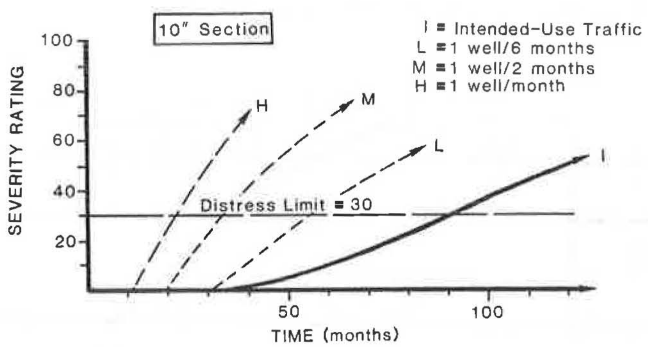


FIGURE 19 Flushing severity versus time.

also shown. Because the results of the previous assessment case indicated that FM-2038 would require reconstruction, the planning example assumed a rehabilitated pavement section. The pertinent limiting values for each type of distress are shown for the critical measures of performance rating.

The primary purpose of including these results in this project was to demonstrate the potential of using the overall methodology as a planning tool. Although the rate of oil field development varies among regions and fluctuates over time, general trends can be documented in site-specific areas.

The results of the planning scenarios indicate that even under low rates of development (two wells drilled per year in a known area of crude deposits), the service life of a 10-in. pavement section can be reduced. A review of the pavement score diagram (Figure 15) shows an overall potential loss of 16 months under a low oil field development rate. Although this loss of service life is not as dramatic as for higher activity rates or as detrimental as it might be for thinner pavements, Figures 16-19 demonstrate the specific distress problems that need to be anticipated.

Load-associated distresses, such as rutting and alligatoring, could result in reducing the expected service life by at least 3 years. Traffic-related measures of performance, such as raveling and flushing, also indicate a reduction in roadway utility of about 3 years. Again, these reductions are based on the conservative low rates of oil field development.

Predicting future conditions assists with planning appropriate maintenance as well as selecting adequate and economic pavement thicknesses. A reduction in pavement life is inevitable on any roadway; however, the effects of increased site-specific axle load repetitions cannot be ignored. Identifying and quantifying future levels of expected reduced service life can also be used in justifying requests for additional maintenance and rehabilitation funds.

## CONCLUSIONS AND RECOMMENDATIONS

The presence of oil field traffic on a roadway causes a substantial reduction in expected pavement life. A 60 to 75 percent loss of predicted service life is possible on thin surface-treated pavements. The actual amount of increased pavement distress is a function of pavement thickness, average daily traffic, percentage of trucks, several environmental factors, and subgrade characteristics. To evaluate the effects of oil field traffic under various conditions, a methodology has been developed for assessing and predicting site-specific and regional impacts.

The Texas Pavement Distress Equations (Oil Field Damage Program) can be used to evaluate the current condition of an existing roadway or to predict its distress levels under future traffic conditions. Several rehabilitation strategies can then be examined. In the future, alternative pavement thicknesses can be analyzed to determine their long-range maintenance and reconstruction needs.

It is recommended that the primary use of this research be at the local state highway district level. The site-specific activity is first observed at the local level. If the district maintains density maps that reflect current activity, the engineer can readily identify the impacted roadways. The influence area could be delineated and monitored to anticipate future serious pavement failures.

At present, the development of the density maps requires manual manipulation and drafting of oil field related plans. However, to improve the comprehensiveness of the overall methodology for statewide use, current research is being conducted to create computer plotted density maps directly from computerized permit and drilling records.

On the state level this technique can be used to help the department allocate funds by locating roads that are in need or soon will be in need of maintenance or reconstruction monies. The versatility of the program not only allows the highway agency to predict where work will be needed but also to indicate the type of work required and when it will be required.

In future research, other special-use activities that impact the Texas highway system beyond its original intended use will be identified. The traffic characteristics and axle loads of trucks used by the timber, grain, and gravel industries are also atypical. Their isolated demands differ from those of vehicles associated with normal operation situations. To make the most effective use of planning strategies for pavement rehabilitation, site-specific data also need to be collected and analyzed for these unique truck demands.

ACKNOWLEDGMENT

This paper has been developed as part of an ongoing research project entitled, Effects of Oil Field Development on Rural Highways, sponsored by TSDHPT. The findings are the result of the Phase II efforts to develop a methodology for estimating reduced pavement service life on low volume farm-to-market roadways. A technical advisory committee acted as an integral part of this study; their continuous guidance and support are greatly appreciated.

REFERENCES

1. J.M. Mason, M.J. Metyko, and N.J. Rowan. The Effects of Oil Field Development on Rural Highways, Phase I: Identification of Traffic Characteristics, Pavement Serviceability and Annual Cost Comparison. Research Report 299-1. Texas Transportation Institute, Texas A&M University, College Station, Feb. 1982.
2. J.M. Mason, T. Scullion, and B. Stampley. Estimating Service Life of Surface-Treated Pavements in Oil Field Areas. Research Report 299-2. Texas Transportation Institute, Texas A&M University, College Station, March 1983.
3. Rules and Regulations of the Texas Railroad Commission. Vol. I. R.W. Byran and Co., Austin, Texas, April 1976.
4. J.M. Mason and T. Scullion. Investigation of Effects of Oil Field Traffic on Low-Volume Roads. In Transportation Research Record 898, TRB, National Research Council, Washington, D.C., 1983, pp. 72-79.
5. R.E. Smith, S.M. Herrin, and M.I. Darter. Highway Pavement Distress Identification Manual. Interim Report, 1977-1979. FHWA, U.S. Department of Transportation, 1979.

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