Use of Computer Graphics for the Display and Analysis of Railroad Traffic Flows

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This paper summarizes efforts to (a) obtain commodity-specific traffic volume data for all lines of the U.S. railroad system, (b) display those data on a national scale, and (c) analyze and better understand the absolute and relative distribution of the flow of these commodities. The procedure used to generate these data was a standard traffic assignment of historical traffic data contained in the Federal Railroad Administration (FRA) carload waybill statistics. For the purpose of this study, the 1976 waybill statistics report was expanded to match total annual terminating carloads by railroad and commodity as reported in the 1976 quarterly commodity statistics. Princeton University's Railroad Network Model, an enhanced version of the FRA network model, was used to assign these data to the (most likely) path actually traversed by each carload on the U.S. system. The traffic volume assigned to each link by direction of travel and commodity subgroup was accumulated over all carload records. Graphic displays of some of these accumulated volumes are presented.

The traffic-density chart has long been a useful management information tool. Operational and marketing personnel rely on the density chart to gauge past performance, to plan improvements, and to predict future traffic trends. With an increasing responsibility for financing and planning, the Federal Railroad Administration (FRA) also requires this same information, but on a national rather than a corporate level.

This paper summarizes efforts to (a) obtain commodity-specific traffic volume data for all lines of the U.S. railroad system, (b) display those data on a national scale, and (c) analyze and better understand the absolute and relative distribution of the flow of those commodities.

The 1976 FRA carload waybill statistics report was expanded to match the report of total annual terminating carloads by railroad and commodity in the 1976 quarterly commodity statistics. The data base provides a 1 percent sample of all loaded movement on the U.S. railroad system and furnishes the historical distribution patterns of origin to junction to destination that are characteristic of the U.S. railroad system. This data base was then used as an input for a standard historical traffic assignment by using the Princeton University Railroad Network Model, an enhanced version of the FRA network model.

The model assigns traffic volume to each link in the 17 000-link U.S. railroad system by direction of travel and commodity group. This information is then presented as the standard carload-density chart for the entire U.S. railroad system.

These density charts provide corporate, state, and federal rail planners with a valuable overview of rail movements previously not available.

DATA BASE

The 1976 carload waybill sample formed the base traffic data used to generate the commodity-specific link volumes. These data represent roughly 1 percent of the railroad traffic for the year 1976. They are collected by the Interstate Commerce Commission (ICC), and the sampled waybills are converted to machine-readable form by FRA and are enhanced by researchers at Princeton University. Additional documentation on the 1973-1977 carload waybill statistics is presented elsewhere (1-3).

The 1976 statistics were expanded to represent total annual traffic for that year. The sampling process used in accumulating the waybill statistics centers about a reporting requirement placed on the railroad that terminates the carload. Most of the bias in the sample is caused by uneven reporting by terminating railroads. To reduce the reporting bias, commodity- and railroad-specific expansion factors were developed (all commodity-specific expansion factors for 1976 are on tape IVOLID 3424, at Princeton). The factors expanded the waybill sample to equal total carloads terminated--by commodity [defined by standard transportation commodity code (STCC)] and by railroad--as reported in the quarterly commodity statistics (QCS) for 1976. The expansion factors ranged from 85 to 135; an example of the expanded statistics for railroad 190 of the Consolidated Rail Corporation (Conrail) is presented in Table 1.

Traffic assignments were produced for 19 unique commodity groupings plus a special grouping of all trailer-on-flatcar (TOFC) and container-on-flatcar (COFC) traffic and total traffic. Table 2 lists each of the commodity subgroups used in this study (based on the 1977 ICC STCC tariff 1-F).

PATH-FINDING AND TRAFFIC ASSIGNMENT ALGORITHMS

The algorithmic procedure used to transform the basic route data contained in each waybill record into carload volumes by direction on each link (segment) of the U.S. railroad system is encompassed within the Princeton Railroad Network Model. This model was developed by Princeton University through research contracts funded by both FRA and the ICC Rail Services Planning Office; it is kept on Princeton University's computer system. A more-complete description of the model is presented elsewhere (4).

The Princeton Railroad Network Model is, in fact, an enhanced version of the FRA network model. It consists of five basic elements: the link-node network, railroad traffic assignment model, computer-graphics module, cross-reference files, and submodels.

Link-Node Network

A machine-readable link-node description of the U.S. railroad system is the first basic element of the enhanced FRA network model. This link-node depiction of the railroad system has been enhanced to represent the actual U.S. railroad system more closely. Elements such as trackage rights are included, and all corporate railroad networks are connected. Also included are current versions of the networks for Conrail, Delaware and Hudson Railway Company, and National Railroad Passenger Corporation (Amtrak), as well as for all other class I railroads. The basic characteristics for the network links and nodes included in the network data base are presented below ("503 code" is the FRA Section 503 main-line--branch-line code, "SPLC list" is the standard-point-location-code list, and "FSAC list" is the freight-station-accounting-code list):

Link	Node
A-line node number	Number

Table 1. Example of commodity-specific expansion factor for 1976 terminated traffic.

Three-Digit STCC	1976 QCS Carloads	1976 Waybill Carloads	QCS/Waybill Ratio
11	63 981	705	90.753
12	13 375	164	81.55
13	20 987	252	83.282
14	994	12	82.833
19	607	7	86.714
84	144	11	131.273
86	64	0	0.0
91	135	2	67.5
101	188 931	1816	104.037

Table 2. Commodity subgroups.

Stratified Commodity Subgroup	STCC Number	Commodity
1	01	Farm products, field crops
2	10	Metallic ores
3	11	Coal
4	142, 144	Crushed stone, gravel and sand
5	09, 14 (except 142 and 144)	Fresh fish or other marine products, nonmetallic minerals NEC
6	204	Grain mill products
7	20 (except 204)	Food or kindred products NEC
8	08, 241	Forest products, primary forest products
9	24 (except 241)	Lumber or wood products NEC except furniture
10	26	Pulp, paper, and allied products
11	19, 28	Ordnance or accessories, chemicals or allied products
12	13, 29	Crude petroleum, natural gas, or gasoline; petroleum or coal products
13	32	Stone, clay, concrete, or glass products
14	33, 34	Primary metal products, fabricated metal products
15	37	Transportation equipment
16	40	Waste or scrap materials
17	41, 42, 44, 45, 46, 47	Miscellaneous freight shipments (41), containers, shipping, returned empty (42), freight forwarder traffic (44), shipper association or similar traffic (45), miscellaneous mixed shipments (46), small package freight shipments (47)
18	35, 36	Nonelectrical machinery, electrical machinery
19	NEC 21, 22, 23, 25, 27, 30, 31, 38, 39	Tobacco products (21), textile mill products (22), apparel products (23), furniture (25), printed matter (27), rubber or miscellaneous plastics products (30), leather products (31), instruments or photographic goods (38), miscellaneous manufactured products (39)

Note: NEC = not elsewhere classified.

Link	Node
B-line node number	Name, county, state
Distance	x-coordinate
Owner	y-coordinate
Track rights	Yard type
503 code	TOFC ramp (yes, no)
	SPLC list
	FSAC list

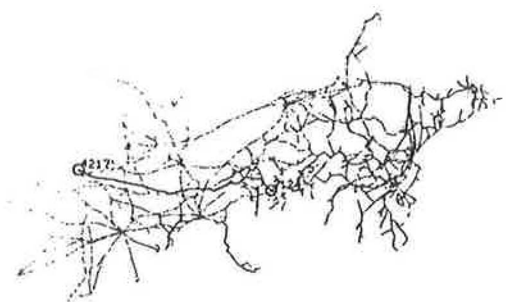
Railroad Traffic Assignment Model

This is the basic algorithm of the Princeton Railroad Network Model. It requires that the locations (network node numbers) at which traffic originated and left a particular railroad and a vector that contains the characteristics of the traffic that is traveling between any two nodes be input. The vector of characteristics can include a wide variety of items, such as total carloads, tonnage, revenue, TOFC cars, cars of flammable liquids (STCC 4910), covered hoppers, covered hoppers that carry grain, and covered hoppers owned by the Southern Railway Company that carry grain. For the purposes of this study, the vector of characteristics was total carloads of traffic in each of the four-digit STCC hazardous subclasses. The structure of the record input to the railroad traffic assignment model is presented in Table 3. The input data are normally obtained from waybill samples. The route contained in each waybill record is separated into segments unique to each railroad that participated in the carload movement. The origin, destination, and interline junction fields are used to define the on- and off-railroad nodes for each segment of the move. Other waybill data elements define the unique characteristic of the shipment and the quantity to be entered into the appropriate field of the input file. The file created from the waybill data (ABPAIR) is sorted by railroad number to segregate all movements handled by each railroad. This sorted file is termed ABSORT. The railroad traffic assignment model operates on all records for any one railroad at one time. For each record the algorithm finds the best (minimum-impedance) path on the railroad network in question. While any analytic impedance measure can be used, the model uses a simple measure,

Table 3. Structure of record input to railroad traffic assignment model termed ABSORT.

Field Number	Field Length	Description	Typical Value
1	3	Railroad	22 (Atchison, Topeka, and Santa Fe)
2	5	On-railroad node	4217 (Chicago)
3	5	Off-railroad node	1623 (Los Angeles)
4	5	Carloads farm products	3
5	5	Carloads metallic ores	12
6	5	Carloads coal	0
.	.	.	.
.	.	.	.
.	.	.	.
23	5	Carloads TOFC	1

Figure 1. Examples of computed best path between Pittsburgh and Chicago on Conrail.



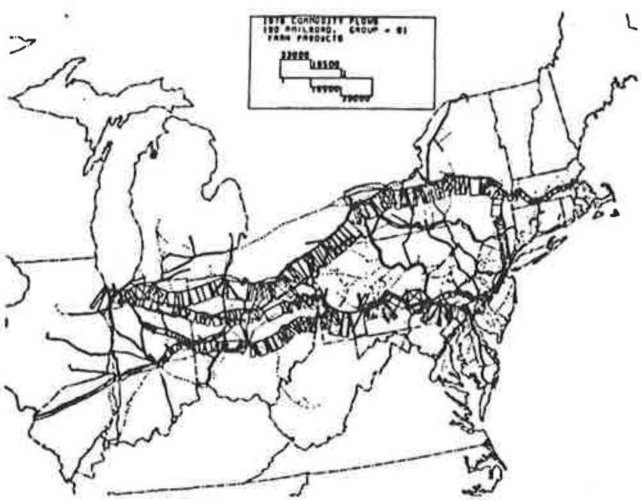
$$\sum_{k \in P} D_k MLC_k$$

where D_k = distance on link k, MLC_k is the FRA Section 503 main-line--branch-line code of link k (1 = A main line, 2 = B main line, 3 = A branch line, 4 = B branch line), and the sum is taken over the links that make up path P on the railroad in question. The best path P* is the path that minimizes the sum. An example of such a path computed on Conrail between Pittsburgh and Chicago is shown in Figure 1. Once the path P* has been

Table 4. Output file of railroad traffic assignment model specific to flow of 19 commodity subgroups.

Field Number	Field Length	Description	Typical Value
1	3	Railroad	22 (Atchison, Topeka, and Santa Fe)
2	5	Link number	11 632
3	5	A-line node	14 371
4	5	B-line node	14 370
5	5	Carload volume A-B farm products	82
6	5	Carload volume B-A farm products	47
.	.	.	.
.	.	.	.
.	.	.	.
43	5	Carload volume A-B TOFC	2
44	5	Carload volume B-A TOFC	4
45	7	Carload volume A-B total 1976	4632
46	7	Carload volume B-A total 1976	2573

Figure 2. Commodity flows: farm products (1976).



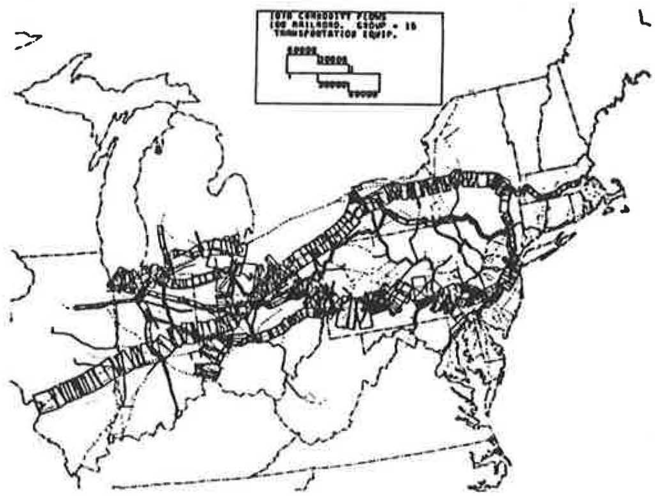
found, the algorithm increments direction-specific volume entries for each of the k links of path P*. The amount of the increment is the value of each flow characteristic.

The railroad traffic assignment model is extremely efficient in these computations. It takes advantage of an efficient algorithm that generates minimum spanning trees and a data-restructuring procedure that minimizes the number of times that the tree-generation routine is executed.

The output file of the railroad traffic assignment model contains total link and volume data for each railroad, as presented in Table 4. [The output files produced by this project were delivered to the Transportation Systems Center of the U.S. Department of Transportation in Cambridge, Massachusetts. The tape version is called 3424, the disk version of which is stored at Princeton University (MTH204, files 404, 405).]

Because a number of segments of the U.S. railroad system are used jointly by two or more railroads, the following process is used to obtain total link volumes. To calculate total characteristic volumes on a link, a separate buffer is created that contains two vectors 17 000 links long for each flow characteristic. By cycling through the volume data for each railroad and increasing the appropriate elements of the buffer, total volumes on each link are progressively accumulated. Thus, both railroad-specific and total link volumes, by direction, for each characteristic are computed for each link in the U.S. railroad system.

Figure 3. Commodity flows: transportation equipment (1976).



Computer-Graphics Module

The Princeton Railroad Network Model includes a battery of computer-graphic processors that provide rapid graphic displays of the input and output data. The graphic processor allows for the display of the railroad network in its entirety, by individual railroad, or by other specification. State and county boundaries, link volumes that use rectangles the depth of which is proportional to volume by direction (the rectangles are drawn on each side of the link to represent the flow in each direction), node volumes, and alphabetic characters are examples of other graphic displays. Copies of the graphics can be produced on cathode-ray-tube hard-copy units or by multicolor Calcomp plotters.

Two examples of railroad-specific traffic volumes are presented (Figures 2 and 3). They were computer drawn on a Tektronix 4015 terminal from which instant hard copies were made, which are shown here. Different types of lines were used for state boundaries, railroad links, and directional volumes. Figure 2 shows the flow of farm products on Conrail. Two principal routes are used, the so-called "water-level route" and the former Pennsylvania Railroad main line. The traffic volume on both is about equal. Note the almost total absence of traffic in the Northeast Corridor. In comparison, Figure 3 shows the flow of transportation equipment. The focus is Detroit, from which a large amount of southbound traffic goes to the Cincinnati gateway and westbound traffic to the St. Louis gateway. Good directional balance in flow exists on the water-level route west of Buffalo; however, east of Buffalo the flow is exclusively eastbound. The former Pennsylvania Railroad main line has a well-balanced flow, and the New Jersey portion of the Northeast Corridor has significant traffic volume.

Cross-Reference Files

The Princeton Railroad Network Model contains

Figure 4. Estimated carload volumes: farm products (1976).

Figure 5. Estimated carload volumes: metallic ores (1976).

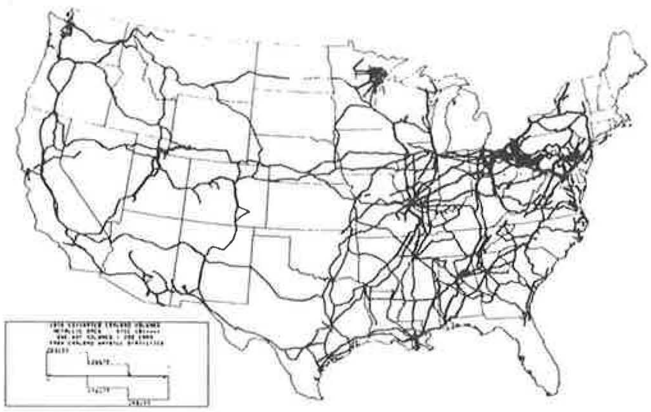


Figure 6. Estimated carload volumes: coal (1976).

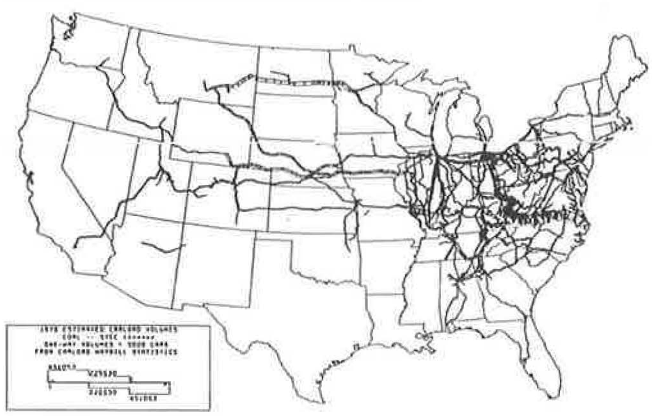


Figure 7. Estimated carload volumes: grain mill products (1976).

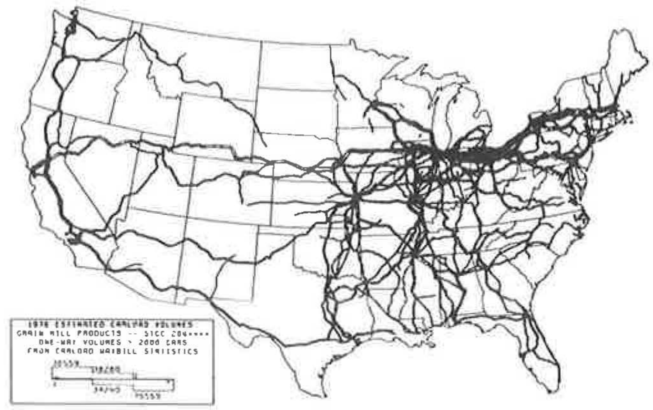


Figure 8. Estimated carload volumes: forest products (1976).

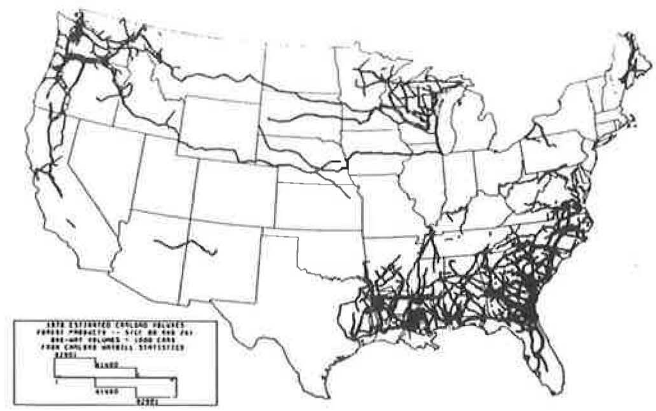
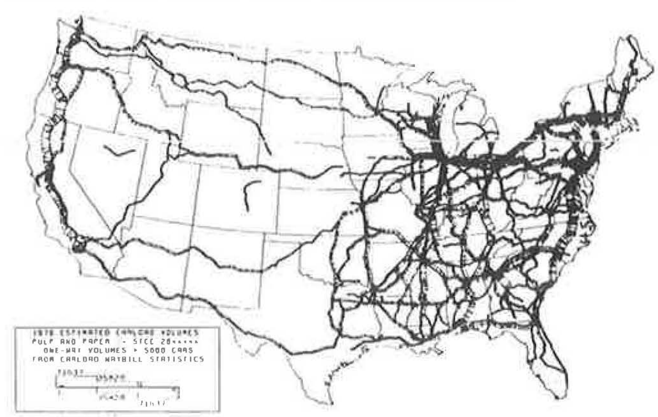


Figure 9. Estimated carload volumes: pulp and paper (1976).



cross-reference files that permit the translation of socioeconomic and railroad operations data so that they can be displayed graphically. Cross-reference files exist for correlation between network node numbers and the following data: the SPLCs, the Association of American Railroads mandatory rule 260 junctions (5), Amtrak station abbreviations, railroad accident record locations, and TOFC stations.

Submodels

Submodels included in the Princeton Railroad Network Model are an analytic division formula for allocating revenue to each carrier, an elementary cost model, and network and data editing modules that use computer graphics.

GRAPHIC DISPLAYS OF EXAMPLES OF CARLOAD VOLUMES

Figures 4 through 13 are examples of graphic displays of traffic volumes for some of the 19 all-inclusive commodity classes, for the TOFC volume, and for estimated total carload volume across the United States. Each map is drawn by using an autoscale function that selects the scale

Figure 10. Estimated carload volumes: ordnance and chemicals (1976).

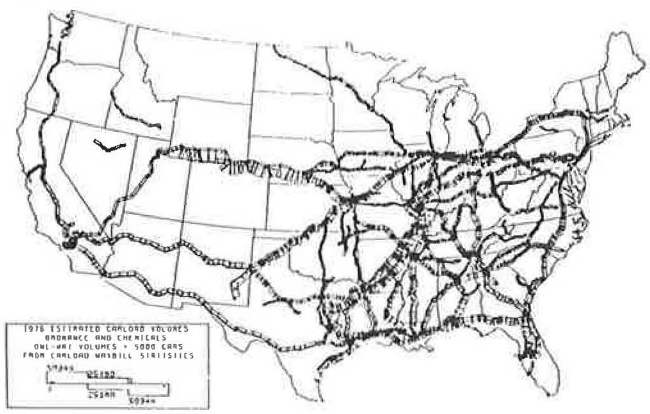


Figure 11. Estimated carload volumes: transportation equipment (1976).

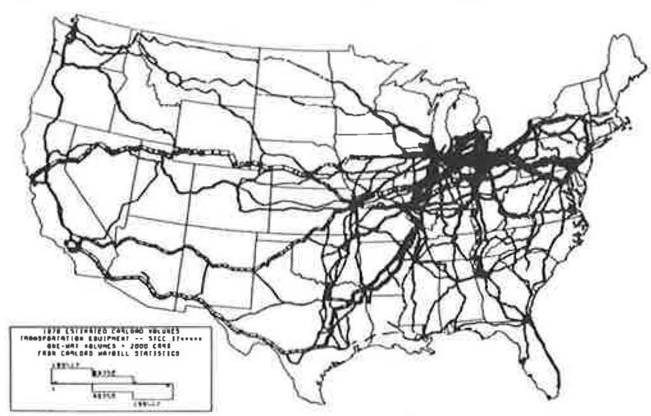


Figure 12. Estimated carload volumes: TOFC (1976).

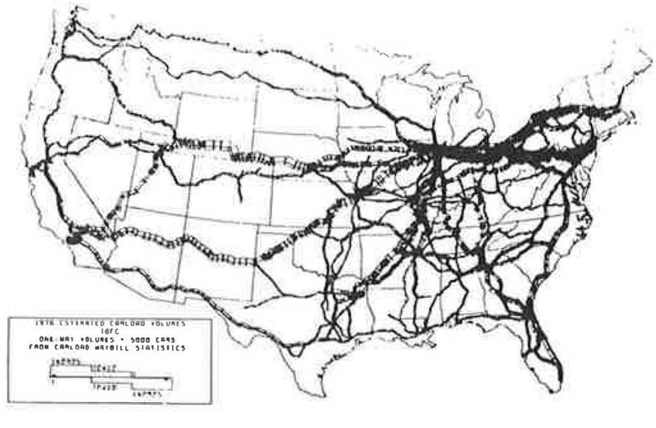
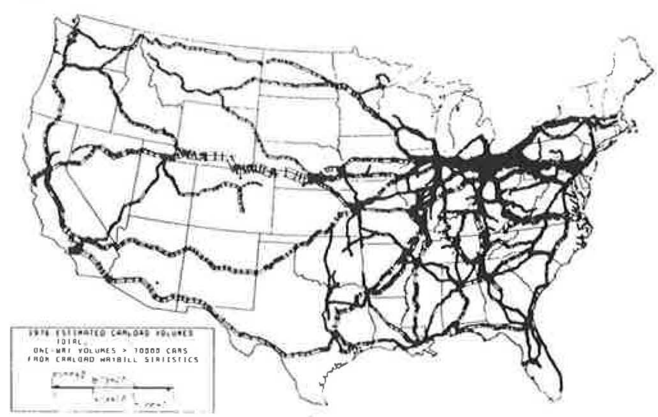


Figure 13. Estimated total carload volumes: (1976).



as a function of the traffic volume on the most heavily used link. Thus, one gets maximum resolution on each map; however, one cannot compare the volume on one map with that on another without careful consideration of the scale given in the legend of each map. Even with autoscaling it is impractical to display all 17 000 links of the network. Thus, only the most heavily used segments are displayed. Each legend describes the car volume threshold used to select those links that would be displayed. In general, each map displays approximately 5000 of the 17 000 links.

Each map relays a great deal of information about the flow of each commodity subgroup across the U.S. railroad system. Absolute as well as relative traffic densities are displayed. Direction of movement, directional balance and imbalance, and major production and consumption points are clearly identifiable. For example, farm products (Figure 4) are clearly westbound and southbound. The Union Pacific main line seems to be the most heavily used line for this commodity, whereas there are very large southbound flows to the ports of Houston and New Orleans, and the ports of Duluth-Superior and Norfolk also exhibit significant terminating volumes.

Metallic ores (Figure 5) exhibit totally different traffic patterns; there exist extremely large (and short-haul) traffic volumes around Duluth and the Louisiana panhandle and moderate flow in Pennsylvania and from Salt Lake City to Wyoming. The rest of the country has a relatively sparse volume of this kind of traffic.

TOFC traffic, on the other hand (Figure 12), is fairly well distributed and exhibits good directional balance. The former Pennsylvania Railroad main line, Conrail water-level routes, and the Union Pacific main line seem to be the most heavily used corridors for TOFC traffic. The Atchison, Topeka, and Santa Fe Railway and the Missouri Pacific Lines serve the southwest to Chicago, and the Seaboard Coast Line and the Louisville and Nashville Railroad Company (Family Lines) are the most heavily used in the corridor from the southeast to the northeast.

Total estimated carload volumes are displayed in Figure 13. The former Pennsylvania Railroad main line, the Conrail water-level route, the Union Pacific main line, and the Norfolk and Western line to Point Lambert, which carries coal downhill from Kentucky and West Virginia, are in the most heavily used corridors. Many other aspects and characteristics of the movement of railroad traffic are evident from the study of these computer-graphic maps.

ACKNOWLEDGMENT

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Analysis of Brokerage Feasibility for Unit-Coal-Train Shipments to the Midwest

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The purpose of this paper is to determine the feasibility of aggregating industrial and utility demands for coal and of serving the demands through a local brokerage operation to reduce transportation cost. This cost saving is associated with the economy of scale of unit-train shipments. The delivered price of western coal is calculated for local users in a given Midwest subregion based on current utility and industrial coal demands. The broker operation would consist of unit-train hauls from western mines, a receiving and storage terminal, local truck or rail transportation from the terminal to each user, and possible transshipment to distant waterfront users. The research focuses on the area of Green Bay-Kewaunee in Wisconsin. Applicability of this brokerage concept to other areas that receive western coal shipments is also discussed.

In order to decrease U.S. dependence on foreign energy products used by utilities and industries, the Carter Administration has mandated an increase in the share of coal-fired industrial and utility boilers. This will create the need for more coal that is capable of meeting clean-air standards. Western mines are the obvious source due to the plentiful amount of low-sulfur coals. These mines have entered into long-term contracts with many large utilities (1). These long-term commitments allow for reduced cost of delivery of the coal, largely due to the use of unit trains. Users of small amounts are unable to capture these reduced costs because of their low-volume shipments. As more utilities want to convert to western coal and as industrial coal-fired boilers become more prevalent, alternative distribution methods may be required to make coal a more cost-effective energy alternative for these users.

The objective of this paper is to present a concept called coal brokerage, by which the coal demand of an area is aggregated and served through a single facility in order to achieve the high volumes necessary to justify unit-train service. Once such a system is initiated, it is conjectured that those users whose orders are too small to receive unit trains individually can begin to capture the cost savings associated with unit-train service.

In order to analyze the coal-brokerage concept, the region of Green Bay-Kewaunee in Wisconsin was chosen as the site for analysis because (a) there had been speculation by lower-peninsula Michigan utilities about a Wisconsin transshipment site for western coal, (b) the area's paper industry uses a large amount of coal, (c) the Wisconsin Energy Office has researched coal consumption in depth and has an available data base for industrial boilers and their fuel type, (d) line-haul rail routes allow for adequate access from western mines to utility and industrial coal users, and (e) there is no single user or facility currently large enough to handle unit-train shipments.

In this paper, the existing geographical traits of the Green Bay-Kewaunee region, including the local transportation network, are detailed. Alternative brokerage setups and operational strategies are discussed. Total coal demand necessary to substantiate a brokerage and transshipment site is estimated. A detailed description of the current prices of line-haul rail, terminal and transshipment, and local distribution is given in order to calculate the total cost of coal to the subscribers of a brokerage operation, and these figures are compared with current local coal prices. Finally, the advantages and disadvantages of the brokerage concept are outlined, and their application to other sites and to bulk commodities is summarized.

SITE DESCRIPTION

The Green Bay-Kewaunee region is in northeastern Wisconsin and includes Outagamie, Brown, and Kewaunee counties. The area is delimited by Lake Michigan, Green Bay, and the Fox River, as shown in Figure 1. The Fox River is navigable only six miles upriver from the bay, where the port facilities and major industries are located. The industry in Green Bay primarily revolves around paper products. The paper and pulp mills are located along the riverfront due to their needs for coal shipments and for water. No significant industry is located in Kewaunee.

The industry of the area is relatively stable; no major growth trends are evident. No riverfront land is readily available for new industries, and the navigation aspects of the river channel restrict the use of larger vessels now under construction. However, a vacant industrial area along the bay not far from the river, called Bayport, is available for new industry and is the most likely location for a coal-brokerage terminal. The present industrial area has been declared an environmental nonattainment area, which means that air-pollution levels may force any new industries to locate farther away from the present industrial core.

Northeastern Wisconsin's transportation system consists of three railroad companies, adequate highways and streets, and port facilities for Great Lakes shipping. The Chicago and North Western