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Container Competitive Strategies of Two Atlantic Ports

CHARLES E. SHAW, CHARLES H. BANKS, WILLIAM W. DELANEY, and

DAVID J. SHUMAN

ABSTRACT

With large new-generation container ships "load centering" at fewer ports, competition between ports for container traffic is expected to reach fever pitch. The level of business required to justify massive investments in modern port facilities will be attained only if efficient port and inland transport services at competitive rates are aggressively produced and marketed. The contrasting strategies of the ports of Halifax and New York and New Jersey (NY-NJ) for attracting containerized cargo are reviewed in light of their respective markets, transport characteristics, regulatory constraints, and competitive postures. Although both ports are investing heavily in new facilities and pressing for modified labor rules, NY-NJ has pursued and reached agreement with railroads on double-stack container services. Halifax, on the other hand, is giving priority to establishing alternative rail services on the Montreal route to create effective competition with Canadian National Railways (CN Rail). Although CN Rail has experimented with double-stack container cars, no innovative inland transportation arrangements have been consummated. Without greater efficiency in overland movements to and from Halifax, Montreal will probably continue to significantly constrain Halifax's competitive position until large container ships that cannot reach Montreal begin to dominate the trade, which will further stiffen competition from NY-NJ.

Mass containerization of ocean freight was successfully inaugurated in 1956 when a ship owned by Pan Atlantic Steamship Corporation departed from Port Newark, New Jersey, destined to Houston, Texas, with 58 freight containers. From this modest beginning, containerized freight handled by ocean carriers has grown dramatically. More than 300 ports around the world now have container-handling facilities and some 70 percent of U.S. ocean liner trade is containerized.

In recent years fierce competition among steamship lines and between railroads and truck lines has fueled a search for greater efficiency in ocean as well as inland transportation of containers. Container ships with capacity of approximately 4,400 20-ft equivalent units (TEUs) are being placed in service and 10,000-TEU ships are envisioned, which will result in a reduction in the number of ports of call to maximize productivity, a trend popularly known as load centering. Although trucking continues to dominate the movement of containers to and from shipside at U.S. ports and modest feeder services are provided by coastal vessels, there has recently been a sharp increase in railroad movement of containers between ports and inland points using a new generation of two-tier (double-stacked) intermodal rail cars.

These developments, accelerated by the loosening of regulatory reins on land transportation through the Staggers Rail Act of 1980 and the Motor Carrier Act of 1980 and on ocean shipping through the Shipping Act of 1984, have greatly intensified competition between ports. As individual ports strive to become regional load centers, expenditures on specialized general cargo facilities (primarily container facilities) are expected to increase dramatically. During the 1983-1989 period, such expenditures should reach approximately 55.5 percent of total U.S. port investment compared with 38.2 percent during the 1973-1982 period (1).

In this paper are profiled the markets, transportation infrastructures, regulatory issues, competitive postures, and evolving competitive strategies of two North American ports, Halifax and New York-New Jersey (NY-NJ), as each works to improve its position in the rapidly changing world trade scene. Particular stress is given to the manner in which the two ports have sought maximum advantage from utilization of innovative railroad service in conjunction with the new generation of container ships. Although Halifax is not expected to divert significant traffic from NY-NJ, the two ports will be competing for much traffic currently moving directly between Europe and Montreal, while Halifax will be fighting a defensive battle to preserve its present inland markets.

MARKETS

Located on the eastern shore of Nova Scotia, Halifax is on the Great Circle Route between North America and Europe. As the most easterly mainland port, as indicated by the map in Figure 1, Halifax is the closest North American port to Europe. With costs of owning and operating new mega-container ships ranging upwards of $50,000 per day (2), the shorter voyages between Europe and Halifax are attractive to ship operators offering transatlantic or round-the-world services. Mileage between selected European ports and NY-NJ and Halifax is given in the following table.

European Port	NY-NJ	Halifax
Amsterdam	3,411	2,792
Cherbourg	3,127	2,690
Copenhagen	3,934	3,322
Hamburg	3,634	3,001
Southampton	3,156	2,562

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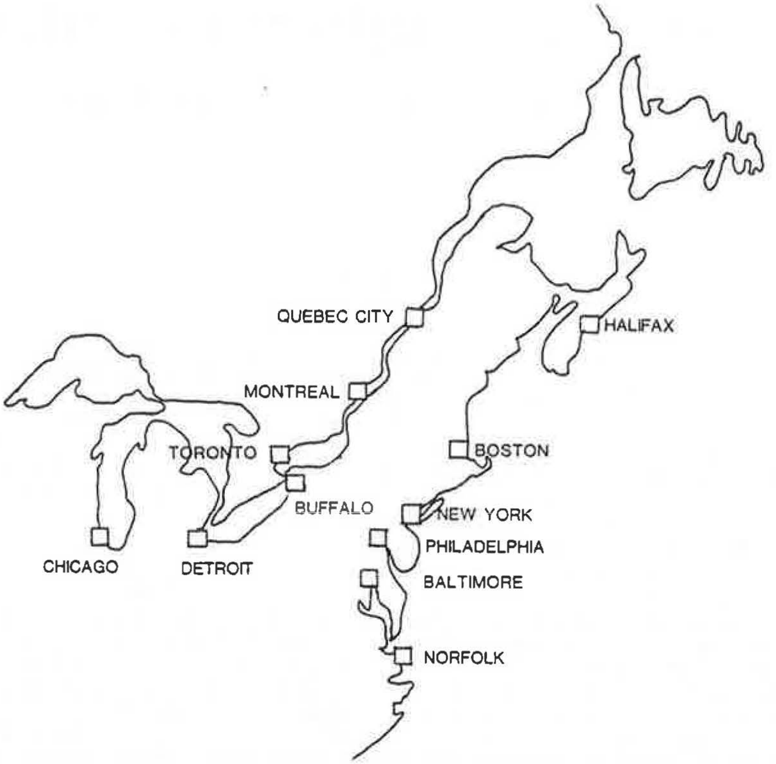

FIGURE 1 North Atlantic and Seaway ports.

During the first 6 months of 1984, cargo moved through Halifax at an annual rate of approximately 16.1 million tons, of which 2.2 million tons were containerized. The percentage of tonnage represented by each major commodity handled at the Port of Halifax in 1982 is given in Table 1.

TABLE 1 Tonnage Percentages of Major Commodities Handled at Port of Halifax, 1982[a]

Cargo	Percentage	Cargo	Percentage
Bulk Cargo		General Cargo	
Crude oil	30.6	Container	12.6
Refined oil	27.0	Break-bulk	3.0
Gypsum	18.0	Ro-ro[b]	1.4
Grain	5.1	Total general	17.0
Other bulk	2.3		
Total bulk	83.0		

[a] Information is from Halifax-Dartmouth Port Commission as of January 1983 and is partly estimated.
[b] Vehicles and motorized equipment rolled on and off ship on their own wheels.

With Canadian population and commercial activities concentrated in southern Quebec and southeastern Ontario, the future prospects of the Port of Halifax depend on its inland links with these two areas as well as with the densely populated areas of the midwestern United States, such as Chicago and Detroit. In 1983 approximately 80.5 percent of overseas container traffic moving through Halifax originated or terminated in Quebec and Ontario, predominantly Montreal (768 mi from Halifax) and Toronto (1,107 mi inland), and an additional 8.2 percent originated or terminated in the U.S. Midwest, primarily Chicago (1,619 mi from Halifax). Origins and terminations of the remaining 11.3 percent of Halifax container traffic were divided between the Atlantic provinces of Canada (3.9 percent) and the New England states (7.4 percent) (telephone conversation with Halifax-Dartmouth Port Commission).

As might be expected with such a high percentage of Halifax container traffic moving long distances inland, about 88.8 percent moved via rail; the remaining 11.2 percent included highway and coastal vessel feeder traffic to and from other Canadian and New England ports.

In sharp contrast with Halifax, NY-NJ is located closer to major freight consuming and generating areas. The 1980 population of New York, New Jersey, and Pennsylvania alone, for instance, totaled 36.8 million people, some 2.4 times the combined population of Ontario and Quebec, the primary economic hinterland of the Port of Halifax. In addition, as the data in the following table indicate, NY-NJ is some 400 to 600 mi closer to major North American markets outside the New York-New Jersey-Pennsylvania area.

	From	
Distance to	NY-NJ	Halifax
Montreal	383	768
Toronto	509	1,107
Detroit	763	1,335
Chicago	988	1,619

In 1984, 60.3 million tons of cargo in foreign trade moved through NY-NJ, including 14.7 million tons of general cargo of which approximately 11.5 million tons (78.2 percent) was containerized. Approximately 84 percent of the general cargo moving through NY-NJ originates or terminates domestically within a radius of 300 mi, and almost all of it is carried inland by truck. Truck movements of general cargo to and from inland points accounted for some 95 to 97 percent of the total market, with the remainder moving via rail and water feeder service (telephone conversation with Port of New York and

TABLE 2 Tonnage Percentages of Leading Commodities Moved Through NY-NJ, 1984[a]

Commodity	Percentage	Commodity	Percentage
Import		Export	
Alcoholic beverages	8.4	Waste paper	20.7
Bananas	6.7	Plastic materials	5.0
Hydrocarbons	5.3	Textile waste	3.4
Road motor vehicles	5.0	Machinery (general)	3.0
Coffee	2.7	Organic products	2.3
Vegetables and vegetable preparations	2.5	Road motor vehicles	2.1
Plastic and rubber materials	2.2	Paper and paperboard	2.0
Lumber	2.1	Hydrocarbons	1.8
Alcohols	2.1	Steel plates and sheet	1.7
Fixed vegetable oils	2.0	Photo supplies	1.7
Other commodities	61.0	Other commodities	56.3
Total import	100.0	Total export	100.0

[a] Information is from Port Authority of New York and New Jersey and is partly estimated.

New Jersey). The following table gives a summary of the proximity of NY-NJ and Halifax to respective markets and modes of inland transportation.

	NY-NJ (%)	Halifax (%)
Markets		
Within 300 mi	84	
Beyond 700 mi		88
Inland transportation		
Truck	96	
Rail		89
Other	4	11

Given in Table 2 are the 10 leading import and export oceanborne general cargo commodities, in terms of tonnage percentage, which moved through NY-NJ in 1984.

In both ports, and indeed in all ports, containerized traffic has an importance that far transcends its relative tonnage. Because it has now largely superseded break-bulk handling, it constitutes the standard by which competitive port posture is measured in the movement of high-value manufactured products. In contrast with bulk commodities such as petroleum and coal, which are far more rigid in their movement patterns, containerizable commodities are highly sensitive to rate and service fluctuations and thus more susceptible to interport rivalries.

TRANSPORTATION INFRASTRUCTURE

With a depth of nearly 70 ft at low tide, Halifax is one of the world's deepest ports. Two container terminals are located in the port: Halifax International Container Terminal, which is accessible directly from the ocean, and Fairview Cove Container Terminal, located at the inland mouth of the Narrows in Bedford Basin. Both terminals are served by Canadian National Railways (CN Rail) and Canadian Pacific Limited (CP Rail), through its subsidiary Dominion Atlantic Railway, as well as several trucking firms.

The Port of New York and New Jersey has five separate container facilities:

- Port Newark-Elizabethport Marine Terminal, the world's first and largest container terminal;
- Northeast Marine Terminal, located on the Brooklyn shoreline just north of the Narrows in Upper New York Bay;
- Global Marine Terminal, located on the west shore of Upper New York Bay;
- Howland Hook Terminal on the west side of Staten Island; and
- Red Hook Container Terminal, located in the Atlantic Basin area of the Brooklyn Port Authority Marine Terminal.

All five have both highway and rail access.

REGULATORY ISSUES

U.S. ports have recently gained significant advantages over their competitors to the north as a result of deregulatory legislation that has affected both marine traffic and inland connections. These laws and concomitant regulations have fostered increased competition between ports and carriers and created an environment much more conducive to innovation than that which it superseded. In time, however, and probably sooner rather than later, these advantages will be countered by Canadian responses.

The Staggers Rail Act of 1980 opened the floodgates to contract rate making and new, market-responsive, innovative, and cost-saving inland transportation alternatives. Although the Interstate Commerce Commission had permitted the negotiation of contracts between railroads and individual shippers since 1978, the 1980 legislation initiated widespread promotion of the concept. Dedicated trains using advanced technologies may now be used to exploit cost and service advantages heretofore unavailable because of rate-making rigidities.

Motor carrier deregulation, which was enacted almost simultaneously with that affecting railroads, has led to a rapid increase in the number of trucking companies providing container services and, some would claim, destructive competition as rates have plummetted in key markets.

Liberalization of regulation on the inland portion of international freight movements also has heightened competition among ports within the United States. The leverage that large ports can now exert over railroads, and the railroads' desire to retain traffic flows, has intensified pressures on inland carriers to reduce rates wherever volume or potential volume is heaviest. For example, Consolidated Rail Corporation (Conrail) has largely equalized container rates from Chicago to New York, Philadelphia, and Baltimore, whereas in 1977, due to its greater proximity to midwestern cities, Baltimore held a 12 percent rate advantage over New York and a 3 percent advantage over Philadelphia. Although this rate equalization suggests divergence from seemingly efficient cost-based pricing and return to former port equalization policies, the example is a manifestation of market power influence on rate setting. The new level of competition between ports (aggravated by the apprehension that a port will wither away if it cannot achieve load center status) has strengthened the competitive threat of U.S. Atlantic ports vis-à-vis their Canadian counterparts, primarily Halifax and Montreal.

The Shipping Act of 1984 has brought some of the advantages of inland transportation deregulation to the marine mode. The act encouraged contract rate flexibility and, by not substantively changing tariff filing requirements for noncontract movements, produced even greater incentives to contract. This, combined with restructuring of the transatlantic conferences, has created a no-holds-barred environment in the United States. Because of a lack of corresponding legislation, however, the Canadians compete at substantial disadvantage.

Compensating freedoms, spurred by the loss of transborder traffic caused by the current imbalance in Canadian and U.S. regulatory regimes, inevitably will be instituted in Canada. At present, Canadian railways are in the uncomfortable posture of being both confined by archaic Canadian regulations and subject to U.S. antitrust laws; this situation is unpalatable not only to the railways but to ports, such as Halifax, that depend on Canadian rail service for transborder as well as domestic market position. New transportation legislation, soon to be introduced in Canada, will undoubtedly redress the imbalance.

The Canadian Ministry of Transport, in July 1985, issued a white paper entitled Freedom to Move: A Framework for Transportation Reform, which summarizes several proposals, some of which would directly meet the competitive thrust of the United States. The report is intended, after a review and comment period, to inform new legislation. In the report, greater flexibility in transportation arrangements and promotion of intermodalism are advocated, confidential contracts would be permitted for railways and marine carriers, and multimodal rates could be quoted by shipping conferences. Despite the continued role of conferences, steps would be taken against collusion and independent action would be encouraged.

COMPETITIVE POSTURE

Halifax Versus Montreal

The prime competition to the Port of Halifax for container traffic has historically come from the Port of Montreal. During the 5-year period between 1979 and 1983, container tonnage moving through Montreal exceeded Halifax tonnage by approximately 85 percent. Steamship lines serving Montreal, unlike those stopping at Halifax, operate exclusively between Montreal and Europe. The relative volume of container traffic through these two ports obviously indicates that operating their present container ships on the St. Lawrence River between Montreal and the Atlantic is more attractive to several ocean carriers than putting in at Halifax and shipping containers between Halifax and inland points via land transport modes (rail or truck, or both).

With (a) third, fourth, and successive generations of container ships entering service, (b) navigation on the St. Lawrence impeded by winter conditions, (c) draft limitations at the Port of Montreal of increasing concern to some, and (d) a 1,000-mi round-trip voyage (on what is essentially an inland waterway) inherent to the service, the ability of the steamship lines now serving Montreal directly to compete with mega-ship service between Halifax and Europe and alternate land or water feeder service between Halifax and Montreal will come increasingly into question.

NY-NJ Versus Philadelphia, Baltimore, and Hampton Roads

Competition for load center status between the U.S. North Atlantic ports of NY-NJ, Philadelphia, Baltimore, and Hampton Roads (Norfolk-Newport News) is sharpened by the declining share as well as total tonnage of U.S. foreign trade moving through these and Great Lakes ports. This declining share stems from shifts in U.S. population and industry from the Northeast and Midwest to the South and the West as well as from shifts in U.S. trade from Europe to Asia. Between 1970 and 1983, the total volume of international cargo moved through all U.S. North Atlantic ports declined from 258.1 million tons to 202.0 million tons. The 1970 level accounted for approximately 46 percent of the total U.S. market, whereas the 1983 tonnage represented only about 28 percent of the U.S. total. During the same period, changes in U.S. market shares of ports in other U.S. regions included increases for the Gulf Region of from 22 to 41 percent and for the Pacific Region of from 14 to 17 percent while the South Atlantic Region held in the 7 to 8 percent range and the Great Lakes Region share dropped from 11 to 7 percent (2).

In terms of total tonnage, NY-NJ, Philadelphia, and Hampton Roads each handled volume in the 28 to 30 percent range of the 1983 total for the four U.S. North Atlantic ports while 12 percent passed through Baltimore. In terms of general cargo tonnage, however, NY-NJ handled 54.1 percent, Philadelphia 19.0 percent, Baltimore 17.2 percent, and Hampton Roads 9.7 percent of the 1983 total for these four ports. In container traffic alone, NY-NJ is even more outstanding, as indicated by the data in Table 3 (1).

TABLE 3 Container Traffic Through Four U.S. North Atlantic Ports, 1984 *(1)*

Port	Thousand TEUs	Percentage
New York-New Jersey	2,235.00	67.0
Baltimore	627.00	18.8
Hampton Roads	313.76	9.4
Philadelphia	162.00	4.8
Total	3,337.76	100.0

Although shifts in U.S. trade from Europe to Asia took tonnage away from Atlantic Coast ports, they stimulated the advent of container trains in which containers are stacked two high (double stacked) on well-type rail cars. These trains generally consist of 20 cars, each containing five platforms. Two 20-ft or one 40-ft container is loaded on the lower tier of each platform and a 40-, 45-, or 48-ft container may be loaded on the second tier provided the longer boxes are equipped with locking features at 40-ft locations. Several of these trains are now operating between such points as Los Angeles, Chicago, and New York; Los Angeles and Atlanta; Oakland and Chicago; Oakland, Houston, and New Orleans; Seattle, Chicago, and New York; Tacoma, Chicago, and New York; Baltimore and Chicago; and New York and Chicago. Cars operating on some of these trains are owned or leased by steamship lines and on others are owned or leased by the railroads.

The high cost of new-generation container ships operating up the Delaware Bay to call at Philadelphia and up Chesapeake Bay or using the Chesapeake and Delaware Canal to serve Baltimore puts these ports at a disadvantage, over which they will have no control but which will need to be offset, compared with NY-NJ and Hampton Roads, which have direct ocean access. With equal ocean accessibility, competitive inland transportation to the Midwest, and shifts in population and industry from the Northeast and Midwest to the South, it appears that Hampton Roads will be in good position to attract container traffic from NY-NJ.

Halifax Versus NY-NJ

With Halifax standing to gain from the uneconomic aspects of a voyage by large container ships up the St. Lawrence River to Montreal, it may appear that the future of Halifax is secure: it need only be patient and prepare for attractive increases in container business. Unfortunately for Halifax, NY-NJ is lurking in the background. Given the sheer size of NY-NJ's container traffic market, its ocean accessibility, and its proximity to primary Canadian markets, NY-NJ is the obvious U.S. port against which Halifax should direct its future container traffic strategy.

Faced with declining volume, some of which has been diverted to Montreal, it is certain that NY-NJ would be quick to seize an opportunity to recapture lost business. For several years U.S. ports have been losing traffic to Montreal and on several occasions have petitioned Congress to intervene, but Congress has not acted to block the diversions and is not likely to do so. More than 60 percent of container traffic handled by the Port of Montreal is estimated to originate or terminate in the United States, primarily in the Midwest. Even in the absence of megaship service, Montreal will remain a formidable competitor. The past success of that port in competing for container traffic is proof enough that it will strive to offset any disadvantage flowing from increased use of big container ships. The Port of Montreal's 5-year plan includes expenditures of about $260 million (Canadian) for improvements in container terminals, grain elevators, and the port's own railway facilities; and its marketing department reportedly will soon be strengthened.

Halifax must not only address the possibility that NY-NJ may capture Montreal traffic, which would otherwise be diverted to Halifax, but, more important, it must be concerned that whatever tactics NY-NJ may find successful in diverting Montreal traffic could possibly also be successful in capturing traffic now moving through Halifax to and from Montreal, Toronto, and points west.

STRATEGIES

In the continuous and ever more heated competition to maximize its portion of world trade, a port needs not only ocean accessibility and attractive inland transportation services but also a strong marketing structure, modern facilities to efficiently handle containers, and reasonable labor arrangements so that its own costs can be controlled. A deficiency in any one of these areas, which cannot be offset by other advantages, will reduce the competitive advantage inherent in geography.

Both Halifax and NY-NJ are investing heavily in port facilities. During the past 5 years, Halifax's expenditure on container facilities has totaled more than $60 million, and the second phase of an expansion project to increase capacity by 25 percent was recently completed (3). The 5-year plan proposed by the Port Authority of New York and New Jersey includes the following expenditures on container or related facilities (4):

- $110 million to $115 million for deepening channels leading to container terminals at Elizabeth, Newark, and Staten Island;
- $100 million to $110 million to improve Howland Hook Terminal on Staten Island; this terminal is used by United States Lines, which already operates its new 4,400-TEU container ships to NY-NJ as part of its round-the-world service;
- $35 million to $50 million on improvements at Port Elizabeth;
- $30 million to $35 million on improvements at Port Newark; and
- $5 million to $10 million on intermodal rail yard facilities.

NY-NJ's assessment on containerized cargo to fund longshoremen's fringe benefits and job security has always been higher than that of any other North American port. In May 1985, however, the New York Shipping Association and the International Longshoreman's Association agreed on a revised formula that reduced the assessment from $8.90 to $5.85 per ton. This will translate into an estimated saving of about $100 per 40-ft container moving to or from inland points located 260 or more miles from the port. Even with the attractive 34 percent reduction, NY-NJ's assessment is still more than twice Canadian rates, which were reduced 40 percent in 1984 and may soon be adjusted downward again.

Another move made by NY-NJ as part of its strategy to compete with other North American ports is direct involvement in minibridge service, which diverts some of its Far Eastern traffic to West Coast ports. In July 1985 the port began serving as an agent for Conrail's double-stack container trains operating between New York and Chicago. To operate these trains over the former Erie Lackawanna Railroad, clearances had to be increased at two points. Even this was deemed an inadequate competitive response. Conrail, in 1985, budgeted $10 million to raise bridge clearances on the superior route of the former New York Central Railroad (5).

CN Rail built and experimented with a double-stack container car as far back as 1971, but the many heavier-than-average 20-ft containers moving westward out of Halifax would overload that car if it were fully double stacked. Although CN Rail recently has been experimenting again with double-stack container cars, it has contended that shipper needs for competitive prices and service can be met with single-stack cars. CN Rail concedes, however, that some eastern Canadian traffic already has been diverted to U.S. double-stack rail service.

Of more fundamental concern to the Port of Halifax is the monopoly position of CN Rail on container traffic movements to and from its inland markets. Although CP Rail now reaches Halifax, that carrier's route is so circuitous and restrictive (ferry service between Digby, Nova Scotia, and St. John, New Brunswick) as to render the service ineffective.

As a major part of its strategy to stay in the container traffic hunt, the Port of Halifax is proposing that the federal government, by amendment of the Railway Act, provide for shared use of the CN Rail line between Halifax and Montreal, thus allowing CP Rail to also operate on it. Arguments advanced in support of this proposal include

- The line is in good condition and has considerable excess capacity;
- Additional utilization of the line by CP Rail will reduce the unit fixed cost that must be borne by shippers in rates charged; and
- Head-to-head competition between CN Rail and CP Rail would be expected to induce improvements in rates and service in the Halifax-Montreal corridor and, possibly, in the adjoining Montreal-Toronto or Montreal-Chicago corridors as well.

Although this proposal is worthy of pursuit by the Port of Halifax, extensive private interests and regional political concerns suggest that considerable time and some degree of compromise may be required before the issue is resolved. In the interim, Halifax will need to continue working with CN Rail on developing services and rates that meet the competitive requirements of the port.

The competition between Halifax and NY-NJ is not envisioned as a winner-take-all battle. It can reasonably be expected that many steamship lines will select NY-NJ as a load center, others will choose Halifax, and still others may serve both ports. The battle for comparative port advantage, which in former times was concerned only with attracting steamship lines and with inland rail rates, has now, as has been shown, widened to encompass inland rail service as well, especially for container traffic.

In the final analysis, the success of a port will be directly proportional to its ability not only to conceive and implement programs to provide quality port service at reasonable cost but also to consummate and orchestrate arrangements with and between steamship lines and inland transport carriers, which will minimize the total costs of moving containers in a timely fashion between the hinterlands and the high seas. In a world increasingly sensitive to marketing strategies, such arrangements will be increasingly important because they are customer responsive--they enhance shipper satisfaction.

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REFERENCES

1. J.M. Pisani. U.S. Ports: Meeting the Intermodal Challenge. Traffic World, The Traffic Service Corporation, Washington, D.C., Sept. 23, 1985.
2. T. Crane. Changing Tides for North Atlantic Ports. Business Review, Federal Reserve Bank of Philadelphia, Jan.-Feb. 1985.
3. F. Malone. Container Ports: The Race Is On. Intermodal Age, Simmons-Boardman Publishing Company, New York, June 1985.
4. C. Dupin. NY Port Vital to Area's Economy. Journal of Commerce, Sept. 16, 1985, p. 3D.
5. Rail News Update. Association of American Railroads, Washington, D.C., Jan. 8, 1986.

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Rationalization of Regional Distribution Systems for Containerized Freight

JOAN AL-KAZILY

ABSTRACT

The economic importance of the containerized freight trade is known to increase competition between ports. Since the advent of containerization some ports have increased the tonnage of general cargo handled and others have lost almost all of this trade. In areas of the world where load center ports have not yet developed there is competition to retain the general cargo trade that has traditionally been handled at each port. The economics of load center systems with waterborne feeder service and the economics of direct service (multiport itineraries) for containerized shipping to the Persian Gulf are examined. Total system costs are compared. Two alternative container ship sizes are used for each of three alternative route structures. Six design stage levels, defined by the number of 20-ft containers inbound to the Gulf per year, are considered. These range from 100,000 to 600,000 20-ft equivalent units (TEUs). Cost models take into account the effect of vessel size and number of containers handled on container-handling rates. Total costs are found to be lowest with a load center located at the port that handles the most containers. Because competition between ports in the Persian Gulf is likely to lead to the continuation of direct service, this competition will impose excess costs on the system. The total cost, in dollars per TEU slot, for the direct service alternative exceeds that for load center service by 12 percent at the lowest design stage level considered and by 4 percent at the highest design stage level.

The advent of containerized transportation in the 1960s has clearly revolutionized waterborne transportation of general cargo and has brought about changes for many ports around the world. In North America, Europe, Japan, and many other well-developed regions, load center ports have emerged and most general cargo freight is channeled through these load centers. Although this has streamlined the transportation system and produced "economies in ship operation, port handling, and connecting inland transportation" (1), it has also had an adverse effect on those ports that lost business because their general cargo trade was diverted to the load center ports.

In terms of port revenues per ton, general cargo represents the most valuable freight passing through a port. According to Marcus et al. (2) a ton of general cargo brings $25 to $30 in revenues to the surrounding community, compared with $4 to $8 per ton for bulk cargo. It is not surprising, therefore, that in the United States many port authorities at non-load center ports are striving to reclaim some of the trade they have lost in recent decades and that port authorities in developing countries are acquiring the capability of handling containerized cargo, often without regard for optimal regional planning.

Many factors have played a part in the development of load center ports in the United States. These include port location; volume of general cargo handled before containerization; availability of the large land areas required for container terminals; good planning; availability of funds to put the plans into practice; and the adequacy of the feeder distribution system, which usually means freeway or rail access, or both, in the United States. The success of the Port of New York is based on a combination of these factors. At Oakland all but the second factor have played a part. Lack of available land, as in the case of the Port of San Francisco, has been the most detrimental factor for some older ports because finger piers are not easily adapted to container terminals.

During the period of growth of containerized marine transportation, feeder distribution systems have also been developing. In North America these systems utilize the highways and railroads. This is due partly to the continental nature of the United States and Canada, but, even where waterborne alternatives could exist, they do not. For example, waterborne transportation of containers between Sacramento and Oakland, California, and between Providence, Rhode Island, and New York, New York, has been attempted. The Sacramento service was terminated because it was financially unsuccessful and the Providence service has not been doing well either. In Europe and Australia waterborne feeder service has proved to be more successful. In Europe this is referred to as short sea service and most frequently uses roll-on/roll-off vessels rather than lift-on/lift-off vessels, which dominate containerized transportation on longer (far sea) routes.

Load center ports compete with each other in terms of the geographic area from which they attract business. Their hinterland boundaries are not necessarily clearly defined, may overlap, and may change with time. In North America competition for hinterlands is influenced to a large degree by factors (including government regulations and labor contracts) that affect inland or feeder transportation costs. Load center ports may also experience competition from smaller ports striving to recapture some of their general cargo trade.

In regions of the world where containerized transportation is not yet highly developed, load

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centers do not exist. Competition between ports therefore can be categorized as competition to become load center ports or competition to retain the general cargo trade they have traditionally handled.

If the load center concept were fully implemented, far sea vessels would operate on two port itineraries that might be expected to optimize containerized transportation; however, some argue that "the multiport itinerary is an efficient method of providing transport capacity" (3). The study presented in this paper explores several alternative distribution systems for the Arab ports in the Persian Gulf in order to identify the most rational system for the region and to quantify the cost (if any) that is incurred if port competition interferes with optimal system development.

SETTING

The Persian Gulf (Figure 1) is a narrow body of water bordered on one side by Iran, which has three ports handling general cargo, and on the other side by several Arab countries, which together have a total of 10 ports handling general cargo. Of the Arab ports there are two in Saudi Arabia, four in the United Arab Emirates, one in Qatar, one in Bahrain, one in Kuwait, and one in Iraq. Each port receives calls from oceangoing vessels carrying general cargo, some of which is in containers. The flow of general cargo is almost entirely inbound.

The Gulf ports are now faced with important decisions about the size and type of container-carrying vessels they should be prepared to handle. Existing water depths at most ports are around 9.0 m; Dammam in Saudi Arabia, however, has 11.0 m and Khor Fakhan, a new facility in the United Arab Emirates (but actually located outside the Persian Gulf), has a water depth of 12.2 m (4). Container vessel drafts range from 8.4 m for 400-TEU (20-ft equivalent unit) vessels to 13.9 m for 3,000-TEU vessels. Thus only the latter two ports can accept fully loaded vessels with carrying capacity greater than 800 TEUs.

In response to the needs of shippers and shipping companies, most ports have begun to develop container-handling capabilities. Some have installed onshore container cranes. The port at Khor Fakhan was actually built with the intent that it should serve as a load center port (5). To date, development has been fragmented with little evidence of coordinated regional development.

To quantify the economic advantage (if any) of a load center distribution system for the Arab Gulf ports, this study compares the economics of direct service and load center service under various scenarios. Some of the major factors that influence the choice of scenarios are

1. Khor Fakhan and Dammam offer the most appropriate choices for load center ports because Khor Fakhan has a favorable location and Dammam handles the most general cargo. In addition, these ports have the greatest water depths. These two ports were therefore chosen as alternative load center locations.
2. A waterborne feeder system is more a viable than an overland system because of the existence of political boundaries, the distances involved, the lack of development of land transportation, and the desirability of perpetuating the existence of the other ports. Costs were therefore calculated with waterborne feeder service.
3. If direct service is continued, vessels are not likely to call at all 10 Arab ports on the same voyage. Five ports were therefore selected for development to receive direct service (one for each Arab country). All freight destined for each country was assumed to enter through the selected port. The five ports are Port Rashid in the United Arab Emirates, Doha in Qatar, Dammam in Saudi Arabia, Shuwaikh in Kuwait, and Basra in Iraq.
4. The volume of containerized cargo destined for the Arab Gulf ports is expected to grow quite rapidly as more potentially containerizable cargo is containerized. Six design stage levels were established with 100,000 to 600,000 TEUs inbound per year in intervals of 100,000 TEUs. These figures were obtained by extrapolation of the growth of containerizable cargo entering the port of Shuwaikh, Kuwait, during the years 1970 to 1975. (Containerizable cargo destined for Kuwait represents 20 percent of the total containerizable cargo destined for the Arab ports in the Persian Gulf.) For comparison, the northeastern Atlantic Coast ports of the United States received approximately 1,200,000 TEUs in 1980, and in the same year the southeastern Atlantic Coast ports received approximately 300,000 TEUs.
5. The number of ports of call on each voyage will actually vary. For simplicity, however, two origin and five destination ports of call were assumed for direct service and one origin and one destination for load center service and for feeder service.
6. Europe, North America, and the Far East are the main origins of containerizable cargo destined

FIGURE 1 Ports of the Persian Gulf.

for the region. The proportion of containerizable freight from each of these origins was estimated to be 33, 16, and 51 percent, respectively.

With these factors in mind, the following scenarios were developed for the study:

- Case A--Direct service to five Arab ports with vessel sizes ranging from 1,200 TEUs to 2,000 TEUs.
- Case B--Load center service through Khor Fakhan with vessel sizes ranging from 2,000 TEUs to 3,000 TEUs and with 400-TEU feeder vessels.
- Case C--Load center service through Dammam with vessels of the same sizes as used in Case B.

Actual round-trip distances from Europe, Japan, and the United States were used for all scenarios. The six design stage levels described earlier were applied to each scenario.

METHODOLOGY

Total costs in dollars per TEU of system carrying capacity were calculated for each scenario using the engineering cost models. The voyage cost model is

$$\begin{aligned} Vt = {} & f\, s^{2.07}\, cf\, d/3200\, C^{0.5} \\ & + [(Cm\, cv + w/C + cr)\,(d/24s + C/6hp) + Ti\, cr] \\ & + 4cg\, nc/hb + r\, ce/C \end{aligned}$$

where

Vt = total voyage cost (\$ per TEU),
f = vessel-specific fuel consumption (pounds per SHP-hr),
s = vessel speed (knots),
C = vessel container-carrying capacity (TEUs),
Cm = modified daily capital recovery factor,
d = round-trip distance (nautical miles),
r = number of ports of call on a round-trip voyage,
Ti = time that containers spend inland (days),
nc = number of cranes used on the vessel,
hb = container discharge and loading rate (TEUs per berth hour),
hp = container discharge and loading rate (TEUs per port hour),
cf = fuel cost (\$ per long ton),
cv = vessel construction cost (\$ per TEU of vessel size),
w = crew wages and housekeeping cost (\$ per day),
cr = container rental cost (\$ per TEU),
cg = cost for one gang working one crane (\$ per hour), and
ce = cost for tugs and pilot for port entry and exit (\$).

The first term of the voyage cost model covers fuel costs and is based on Gilman's model (3) for shaft horsepower (SHP). The second term in this model includes vessel construction and operation costs (excluding propulsion fuel) while at sea and in port and container rental costs. The third and fourth terms are container-handling and port entry costs, respectively.

The terminal cost model is a simple linear model for the storage yard, berths, cranes, and dredging:

$$Ct = S\, cs + Lb\, cb + Nc\, cc + Vd\, cd$$

where

Ct = total terminal costs for the system (\$ per year),
S = total number of TEU storage slots,
Lb = total length of berth space (m),
Nc = total number of cranes,
Vd = total volume of dredging (m^3),
cs = annualized cost for storage yard (\$ per TEU slot per year),
cb = annualized cost for berths (\$ per meter per year),
cc = annualized cost for cranes (\$ per crane per year), and
cd = annualized cost for dredging (\$ per m^3 per year).

The application of these models, which is fully described in earlier work by the author (6), takes into account the interaction between vessels and ports. Container-handling rates (hb and hp), for examples, are a function of vessel size, number of containers discharged and loaded, and facilities available at the ports. The number of cranes available to any vessel was assumed to be two for vessels with more than 300-TEU carrying capacity, three for vessels with more than 1,000-TEU capacity, and four for vessels with more than 2,400-TEU capacity. The number of containers discharged and loaded at a port is a function of the number of ports of call on the vessel's itinerary. The container-handling rates based on these factors and used in this study are shown in Figure 2. The two graphs show container-handling (discharge and loading) rates per hour of vessel time at berth (hb) and per hour of vessel time in port (hp).

Certain other assumptions were necessary in order to develop the graphs in Figure 2:

1. The time to enter and leave port was assumed to be 2 hr for feeder vessels and 4 hr for other vessels.
2. The percentages of container moves that are nonproductive were assumed to be zero for two-port itineraries and 15 percent for seven-port itineraries.

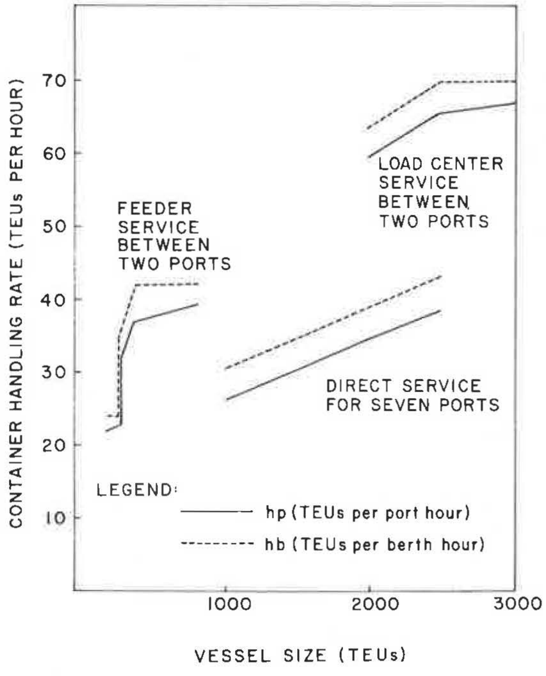

FIGURE 2 Container-handling rates *(7)*.

3. The percentages of containers exchanged at each port were assumed to be 100 percent for two-port itineraries and 50 percent at each of the two origin ports and 20 percent at each of the five destination ports for seven-port itineraries.

4. Each full container unloaded at a destination was assumed to be replaced by a container (loaded or empty) heading for the origin ports, and a 100 percent load factor was used.

5. The ratio of the number of 20-ft to 40-ft containers was assumed to be 3:2 (other sizes were not considered).

6. The base crane efficiency (containers per hour that can be handled by one crane working alone with no lost time) was assumed to be 25.

7. The crane interference factor, which accounts for the reduced effectiveness of each crane when more than one is used on a vessel, was assumed to be 0.85 for two cranes, 0.75 for three cranes, and 0.70 for four cranes.

8. The working-time-to-berth-time ratio was assumed to be 0.80.

To calculate berth capacities in TEUs per year, the container-handling rate (hb) was obtained from Figure 2 and berth occupancies ranging from 0.15 to 0.60 were assumed. Lower values were used for the direct service scenarios because of the reduced control over vessel arrival times. The numbers of berths and cranes required for each scenario at each design state level, based on the calculated berth capacities, are given in Table 1. The ratio of berths to cranes is not a whole number because it is assumed that cranes can be shared by adjacent berths. The number of cranes appears low for the same reason: when one berth is empty the cranes are assigned to an adjacent berth.

The numbers of TEU storage slots required for each design stage level (Table 2) were calculated based on a peaking factor of 2 and on an average dwell time of 6 days for direct service and 4 days for load center service.

TABLE 1 Numbers of Berths and Cranes

Service	Design Stage Level 1	2	3	4	5	6
Direct						
Vessel size 1,200 TEUs						
No. of berths	7	10	10	13	14	15
No. of cranes	15	22	22	28	29	32
Vessel size 2,200 TEUs						
No. of berths	6	9	10	11	13	15
No. of cranes	13	19	22	24	26	32
Load Center						
Vessel size 2,000-3,000 TEUs						
No. of berths	2	3	4	5	5	6
No. of cranes	4	8	8	12	12	12
Vessel size 400 TEUs						
No. of berths	5	6	8 (6)	8 (6)	9 (8)	11 (10)[a]
No. of cranes	10	12	16	16	18	22

[a] Numbers in parentheses are for service through Dammam; other numbers are the same for Cases B and C.

TABLE 2 Number of TEU Storage Slots Required

Design Stage Level	Case A	Case B	Case C
1	6,575	7,979	6,971
2	13,194	15,958	13,941
3	19,724	23,937	20,912
4	26,298	31,916	27,883
5	32,873	39,895	34,853
6	39,448	47,874	41,824

Volumes of dredging (Table 3) were based on dredged areas four times the area required for berthed vessels plus a nominal channel length of 4 km and a width of 150 m. Values used for cost are

cf = $90 per long ton,
cv = $20,000 to $30,000 per TEU (varies with vessel size),
w = $2,000 per day if C > 1,000 TEUs,
= $500 per day if C < 1,000 TEUs,
cr = $2 per day per TEU,
cg = $200 per gang-hour,
ce = $10,000 per entry if c > 2,000 TEUs,
= $5,000 per entry if C > 1,000 TEUs,
= $2,000 per entry if C < 1,000 TEUs,
cs = $750 per TEU slot per year,
cb = $2,000 per linear meter per year,
cd = $2.50 per cubic meter of initial volume per year,
cc = $360,000 per crane if C < 1,000 TEUs,
= $400,000 per crane if C < 2,000 TEUs, and
= $440,000 per crane if C > 2,000 TEUs.

TABLE 3 Volumes of Dredging (millions of m^3)

Design Stage Level	Vessel Size (TEUs) Case A 1,200	Case A 2,200	Case B 2,000	Case B 3,000	Case C 2,000	Case C 3,000
1	1.505	7.487	2.642	4.275	2.289	4.217
2	1.515	7.679	2.642	4.381	2.336	4.399
3	1.515	7.740	2.642	4.381	2.336	4.390
4	1.527	7.847	2.642	4.487	2.383	4.579
5	1.571	7.955	2.680	4.525	2.400	4.597
6	1.571	8.105	2.680	4.525	2.400	4.627

Note that port costs were annualized at 10 percent with lives of 20 years for storage yard, 30 years for berth, 50 years for dredging, and 15 years for cranes. Initial costs were $4,000 per TEU slot, $16,200 per linear meter, $10 per cubic yard, and $2.34 million to $2.86 million for cranes, respectively. Ten percent was added for maintenance and insurance of berths and storage yard and 15 percent for cranes. Maintenance dredging was assumed to be 15 percent of critical dredged volume. Storage yard operating cost was assumed to be $235 per TEU slot.

Values used for vessel, container, and voyage parameters are

C = 1,200 TEUs and 2,200 TEUs for direct service,
= 2,000 TEUs and 3,000 TEUs for load center service,
= 400 TEUs for feeder service,
s = 17 knots for 400-TEU vessels,
= 18 knots for 1,200-TEU vessels,
= 19 knots for 2,000-TEU vessels,
= 20 knots for 2,200- and 3,000-TEU vessels,
f = 0.40 lb/SHP-hr,
Cm = 0.000347,
d = 21,300 nautical miles (nm) (Khor Fakhan/USA),
= 13,700 nm (Khor Fakhan/Europe),
= 13,100 nm (Khor Fakhan/Japan),
r = 7 for direct service,
= 2 for load center service and for feeder service, and
Ti = 27 days.

Values for nc vary with vessel size, and hb and hp are as shown in Figure 2. Note that Cm is the daily capital recovery factor based on 10 percent compounded annually with a vessel life of 25 years and zero salvage, assuming vessels are in use 350 days in a year. Ten percent is added for annual maintenance and insurance.

RESULTS AND CONCLUSIONS

The results of the voyage cost model in dollars per TEU and the port cost model in dollars per year are given in Table 4. All costs are converted to dollars per TEU and plotted in Figures 3-5. Capital expenditures for each new design stage level are assumed to be introduced when the previous design stage level is reached. It should also be noted that the costs assume a load factor of 100 percent.

As can be seen from the graphs, Case C, load center service through Dammam, is optimum for all design stage levels. Using the least cost vessel sizes, costs for Cases A and B exceed those for Case C. Costs for Case A exceed those for Case C by 12 percent at design stage level 1 and 4 percent at design stage level 6. Costs for Case B exceed those for Case C by 1 percent at design stage level 1 and 4 percent at design stage level 6.

TABLE 4 Total Costs

	Vessel Size (TEUs)					
	Case A		Case B		Case C	
	1,200	2,200	2,000	3,000	2,000	3,000
Voyage cost ($ per TEU)	838	709	758	714	733	686
Port costs ($ million per year) for design stage level						
1	18.256	32.839	16.090	20.348	17.716	22.740
2	27.532	42.709	25.553	30.206	27.579	32.042
3	32.463	49.615	35.652	40.404	34.167	39.782
4	41.356	56.281	44.401	49.523	41.891	47.920
5	47.304	64.416	51.467	55.589	49.380	55.835
6	53.944	72.157	61.936	67.158	59.282	65.737

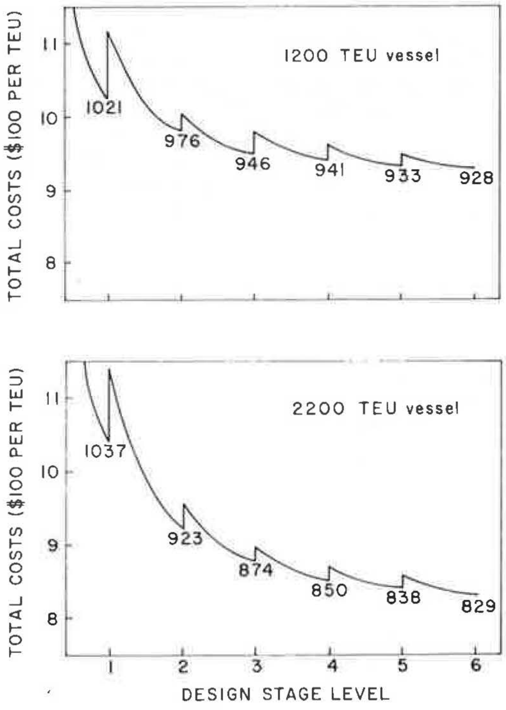

FIGURE 3 Total costs for Case A—direct service.

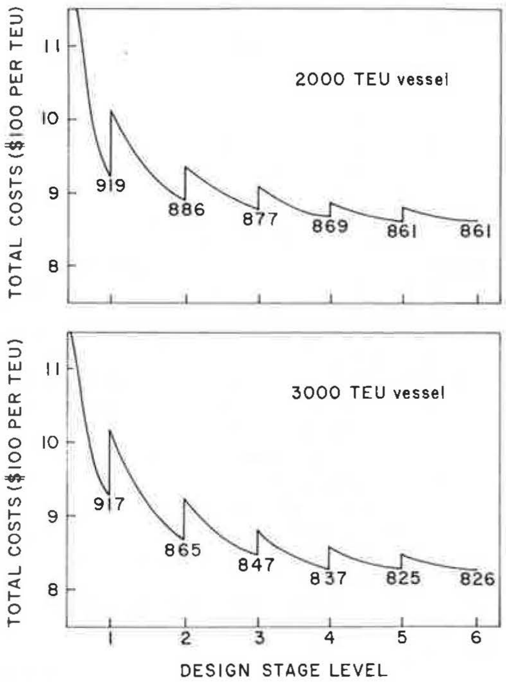

FIGURE 4 Total costs for Case B—load center at Khor Fakhan.

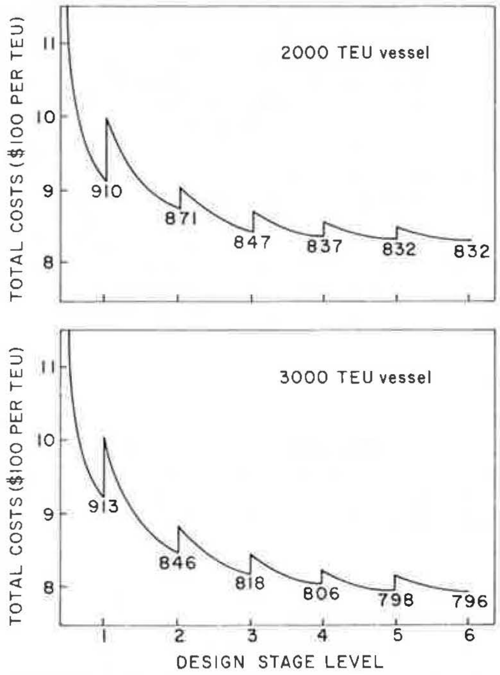

FIGURE 5 Total costs for Case C—load center at Dammam.

Two conclusions can be drawn from this. First, load center service provides optimality with greater economic advantage occurring at lower design stage levels and, second, the optimum load center port is the port that handles the most containerized freight.

These observations have been based on a comparison of the least-cost vessel sizes for the three cases. In each case the least-cost vessel size is seen to be the smaller vessel at design stage level 1 and the larger vessel at design stage levels 2 through 6. This indicates that smaller vessel sizes have a slight advantage over larger vessel sizes at low design stage levels. However, at higher design stage levels the economic advantage of larger vessels is clear.

Several comments must be made about the interpretation of these results. First, the number of vessel sizes used in this paper was limited for clarity. Optimum vessel size was found to vary with design stage level. In addition, optimum vessel size varies with the round-trip distance and in reality vessels of different sizes will be used on different routes. This work was based on the use of the same vessel size on all routes considered.

Another important point is that calculation of dredging was standardized for this analysis by applying the same channel dimensions and unit cost for dredging throughout the study. In addition, the need for extensive harbor improvements was not considered. The results should therefore be interpreted with this in mind. If the introduction of larger vessels results in unusually high costs at one of the load center ports or at any of the ports on the direct service route, the relative system costs could be changed significantly.

Two further comments are appropriate. Although large economies of scale are observed as system throughput grows from design stage level 1 through design stage level 4, system costs do not decrease significantly at higher design stage levels. This suggests that there is an upper limit for the size of load center systems, beyond which costs cannot be reduced significantly. When this is combined with the inevitable congestion that occurs in connection with large systems, it may be conjectured that load center systems that handle more than 300,000 TEUs inbound per year may not be economically efficient.

Finally, the sensitivity of the conclusion to the costs used in this analysis may be questioned. In retrospect the value used for fuel costs was low and estimates made for volume of dredging and number of berths also appear low. Although this means that the total cost estimates may be low and that relative costs for larger vessels compared with smaller vessels may also be low, it does not change the conclusion regarding the optimality of Case C. The conclusions are therefore considered to be reasonable.

DISCUSSION OF RESULTS

This study has been based on the premise that all facilities are available to all vessels. Such common user terminals are more prevalent in Europe than in the United States where major shipping companies have their own terminals and where each shipping company therefore operates its own separate system. However, it is of interest to compare the conclusions of the previous section with the situation in the United States. Table 5 gives a summary of statistics for the North Atlantic, South Atlantic, Gulf, South Pacific, and North Pacific coastlines of the United States. It can be seen that where inbound TEUs are below 400,000 there are one or two major load center ports but that on the North Atlantic and South Pacific coastlines, where inbound container flow is more than 800,000 TEUs, there are three major load center ports.

The development that has taken place in the United States was not driven by a conscious attempt to minimize total shipping costs. Shipping companies were seeking to minimize their costs, and certain ports, able to take advantage of the situation, developed or made possible the development of the facilities needed by the shipping companies. The same forces are at play in other parts of the world.

As can be seen from Table 4, the minimum voyage cost ($686 per TEU) occurs for Case C with 3,000-TEU vessels, and this is independent of design stage level. This is also the system level optimum for design stage level 6. At design stage level 1, however, the system optimum is Case C with 2,000-TEU vessels. This indicates that, although there is no conflict between shipping company and system optimum at high design stage levels, there is a conflict at low design stage levels.

For quite different reasons there are two obstacles to the development of the optimum (load center) system in the Persian Gulf region. One is the political boundaries that exist there and the desire of each country to continue to receive port calls from ocean vessels rather than feeder vessels. This is the case in many regions of the world where neighboring ports belong to sovereign countries that are relatively small.

The other obstacle to the development of the load center system is the difficulty of setting up and operating a feeder service common to all shipping companies. Theoretically a separate company could be established, but this would require that the shipping lines relinquish control over the movement of freight before it reaches its final destination. Each shipping company would probably prefer to operate its own feeder service, which would lead to duplication of facilities. In any case there is no existing agency or company that is likely to take responsibility for a common user feeder service.

In the face of these obstacles, development is more likely to continue in a fragmented manner. Ports in the region will undoubtedly realize the need for

TABLE 5 TEUs per Year at Load Center Ports in the United States

Coast	Total TEUs Inbound (000s)	Major Load Centers	TEUs (000s)	Minor Load Centers	TEUs (000s)
North Pacific	299	Seattle	224	Portland	56
				Tacoma	19
South Pacific	898	Los Angeles	366	San Francisco	96
		Oakland	265		
		Long Beach	171		
Gulf	285	Houston	139	Gulfport	16
		New Orleans	116	Galveston	14
South Atlantic	335	Charleston	127	Miami	98
				Savannah	56
				Jacksonville	28
				Wilmington	36
North Atlantic	1,238	New York	696	Philadelphia	79
		Baltimore	247	Boston	36
		Hampton Roads	180		

Note: Numbers of TEUs are approximate: they are derived by Al-Kazily *(8)* from the Maritime Administration's report of tonnage of containerized freight for 1979 *(9)*.

deeper channels to permit service by larger, more economical container vessels. In the long run, if container traffic grows rapidly to more than 400,000 TEUs, the total system costs will be less than 6 percent more than the optimum case. In the short run, however, if container traffic does not exceed 200,000 TEUs inbound and if ports in the region provide water depths for vessels up to only 1,200 TEUs, costs per TEU will be more than 12 percent greater than the optimum case.

In the short to medium term, therefore, port competition in this and other regions of the world is likely to prohibit the development of a rationalized system, thus resulting in costs that are higher than the optimum. In the long term, if container traffic bound for a region of the geographic size of the Persian Gulf reaches a level of 400,000 TEUs, shipping systems with multiport itineraries will be fairly efficient and come close in total cost to the optimum case.

REFERENCES

1. Port Development in the United States. Maritime Research Board, National Research Council, Washington, D.C., 1976.
2. H.S. Marcus, J.E Short, J.C. Kuypers, and P.O. Roberts. Federal Port Policy in the United States. Massachusetts Institute of Technology Press, Cambridge, 1976.
3. S. Gilman, R.P. Maggs and S.C. Ryder. Containers on the North Atlantic. Marine Transport Center, University of Liverpool, England, 1977.
4. C. Pielow. Guide to Port Entry. Pielow Shipping Guides Ltd., Riegato, England, 1977.
5. Proceedings of the Arab-Japan Port and Harbor Joint Conference. Japan Cooperation Center for the Middle East, Tokyo, June 1977.
6. J. Al-Kazily. Modelling Containerized Shipping for Developing Countries. Transportation Research, Part A General, Vol.16A, No. 9, July 1982.
7. J. Al-Kazily. Choice of Technology for Containerized Shipping: A Study of Interaction Between Vessels and Ports. University of California, Berkeley, Dec. 1979.
8. J. Al-Kazily. Role of United States Medium Sized Ports. Journal of the Waterway, Port, Coastal, and Ocean Engineering Division, ASCE, Vol. 110, No. 1, Feb. 1984.
9. Containerized Cargo Statistics, Calendar Yar 1979. Maritime Administration, U.S. Department of Commerce, 1981.

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Economics of Coal Transportation: Implications for Railroad and Shipper Strategies

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ABSTRACT

The importance of coal to the railroad industry is explored in this paper. By drawing from Interstate Commerce Commission waybill sample and quarterly commodity statistics it is shown that coal accounts for more than 20 percent of total railroad revenues while individual railroads' coal-derived revenues ranged from less than 1 percent to 67 percent in 1983. Coal is also instrumental in achieving economies of density. Using the FRA network model, it is shown that traffic densities on lines over which coal moves far exceed those on lines that handle no coal traffic. Finally, implications for shipper and railroad strategies, including shippers' actions to limit coal rates and railroads' investment and disinvestment policies, are explored.

In 1973 the Oil Producing and Exporting Countries (OPEC) formed a cartel and substantially reduced oil supplies to the industralized countries of the West. Although the original motive for the curtailment of oil supplies was political in nature, the ultimate result of the OPEC alliance was a sharp increase in the price of oil and the end of the era of "cheap" energy. The United States, heavily dependent on foreign oil, responded to the escalation of oil prices by tapping its own huge supplies of coal. In addition, the 1973 oil embargo and subsequent energy legislation of 1974 and 1975, which requires that new electric generating plants be designed to burn coal unless exempted on environmental grounds, substantially increased the demand for coal and the ancillary need for transportation by rail.

Dependence on coal as a fuel source is expected to grow in the foreseeable future. In a 1983 study, the Department of Energy (1,p.24) reported that it expects total U.S. coal consumption to increase by 42 percent between 1985 and 1995. Continued reliance on coal is attributable to the high cost and perceived dangers of nuclear power--the only recognized broad-based alternative for generating electricity. In addition, despite recent declines in the price of oil, the uncertainty of future prices and supplies as well as legislation discouraging its use renders oil a weak competitor to coal.

The sharp rise in demand for coal has brought forth an extensive literature on coal transportation systems. Several studies, including those by the Maritime Transportation Research Board (2), Desai and Anderson (3), and Elmes (4), have examined the adequacy of existing coal transportation systems. Other authors have explored the impact coal has had on rail transportation. Heller (5) and Beier (6) have examined the complex interaction between rail transportation of coal and the rate structure for this commodity.

The importance of transporting coal to railroads and utilities is brought into sharp focus by the recent efforts of the Interstate Commerce Commission (ICC) to develop a maximum rate methodology for coal. The public record in Ex Parte No. 347 (sub-1) (7) is replete with data that point to the importance of coal to consumers of energy and to the railroads as a source of revenues and traffic densities. Groups such as the National Coal Association, Edison Electric Institute, Consumer Federation of America, and the Association of American Railroads have documented the dominance of coal as an energy source. Similarly, they all recognize the economic significance of coal to the railroad industry. After 7 years of experimenting with varying cost-base maximum rate formulas, the ICC adopted a flexible maximum rate guideline called constrained market pricing (CMP) in Ex Parte No. 347 (sub-1). CMP requires consideration of both supply and demand in determining the reasonableness of rates. The approach places four constraints on coal rates. First, railroad earnings can generally not exceed a competitive return (revenue adequacy). Second, railroads must be efficient; the cost of inefficiencies is deducted from a carrier's revenue need to ensure that revenue adequacy is based on an efficient operation. Third, rates cannot exceed those of an efficient competitor [the stand-alone cost (SAC) test], and finally, disruptive rate increases are to be phased in so as to prevent economic dislocations.

Despite the intense scrutiny of railroad coal transport, there remain several unanswered questions about the relationship among economies of density, the cost of transporting coal, and the overall importance of coal to the financial health of the railroad industry. The importance of coal to the railroad industry is examined here. The more traditional demand aspects of coal are reviewed, and the supply aspects of coal transportation are quantified. In the second section the importance of coal demand to railroads in terms of the revenues it provides is demonstrated. In the third section coal is viewed from the supply side. Relying on both aggregate industry data and specific carrier data, it is shown that coal is largely responsible for economies of density for railroads. The close link between coal and economies of density has important policy implications for railroad management and for shippers applying the SAC test. These implications are explored in the fourth section of the paper.

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IMPORTANCE OF COAL

Gross and Net Revenue Contribution

By virtually every measure coal is the most important commodity transported by the railroad industry. When viewed from the perspective of an individual carrier, its importance to the major rail systems is even more striking.

Tables 1-3 give data from ICC Form QCS, Quarterly Report on Commodity Statistics, for all major commodity groups for the years 1978 through 1984. As can be seen in Table 1, coal is the leading revenue source in each year followed by (in 1984) chemicals, transportation equipment, farm products, and food and kindred products. More important, coal shows the greatest growth in revenues of all commodities. In 1978 coal accounted for 13.8 percent of total railroad revenues; by 1984 this percentage had grown to 23.3 percent. This growth is even more dramatically shown through comparisons with other major rail commodities. Taking the next major revenue producer as an illustration, in 1978 coal revenues were 123 percent of chemical revenues; by 1984 coal revenues were 207 percent of chemical revenues. Finally, comparison of Table 1 with Tables 2 and 3 further emphasizes the significance of coal as a revenue producer. The data in these tables indicate that coal volumes (as measured by cars and tons originated) increased through 1981, declined somewhat in 1982 and 1983, then increased dramatically in 1984. Revenues continued to rise throughout this period, with the exception of 1983. If revenue per car and revenue per ton are calculated from the tables, average coal rates have increased for all years with the exception of revenue per ton in 1983. Revenues for many other commodities, on the other hand, followed the pattern of tons and carloads and declined in 1982 and 1983.

The importance of coal varies sharply by railroad. This is illustrated by Table 4, which gives the number of coal cars as a percentage of total cars for 1982. Coal cars represented more than 50 percent of movements for six railroads: Bessemer and Lake Erie, Chesapeake and Ohio, Clinchfield, Norfolk and Western, Pittsburgh and Lake Erie, and Western Maryland. In addition, coal represented 33 to 50 percent of traffic for five railroads: Baltimore & Ohio; Burlington Northern; Denver & Rio Grande; Elgin, Joliet & Eastern, and Louisville & Nashville. On the other hand, coal represented less than 10 percent of carloads for nine railroads: Boston & Maine; Delaware & Hudson; Duluth, Missabe & Iron Range; Florida East Coast; Grand Trunk Western; Soo; Southern Pacific; St. Louis Southwestern; and Western Pacific.

Another perspective on coal's importance as a commodity can be obtained from costed waybill data. The waybill is a stratified sample of railroad movements [for a further description of the data collected and statistical properties of the ICC waybill sample, see Fine and Owen (8)]. Because the waybill contains specific information on the characteristics of each movement, it is possible to develop estimates of movement costs that can be compared with recorded revenue information. The costs used for the purposes of this study are variable costs based on the Rail Form A (RFA) methodology (9) with standard adjustments for multiple-car and trainload movements. These adjustments include reduction of switching costs by 50 and 75 percent for multiple-car and trainload, respectively; reduction of station clerical cost by 25 percent for both types of movements; reduction of variable freight train car costs by 25 and 50 percent, respectively; elimination of inter- and intra-train switching for trainload movements; reduction of interchange switching costs by 50 percent for trainload movements; and elimination of way train costs for trainload movements. There is no adjustment for density, which, as discussed later, is also an important determinant of cost levels.

Tables 5-7 focus on the differential between revenues and variable costs. This differential is termed net revenue contribution. The present analysis will use two measures of rail output, car-miles and ton-miles, in evaluating net contribution. These tables provide revenues, costs, and contribution on a car-mile basis and total contribution on a commodity basis. They indicate that coal ranks ninth in average revenue per car-mile for commodities generating at least 1 percent of total car-miles. This suggests that coal rates are not disproportionate compared with those of other commodities. On the other hand, these tables also indicate that the cost of transporting coal is among the lowest of all commodities. The primary cost efficiencies recognized in the analysis are those associated with multiple-car and unit-train operations. In addition, a significant amount of coal moves in privately owned equipment, which relieves the railroads of the associated costs of car ownership. Because of these low costs, the contribution per car-mile for coal is among the highest of all commodities. Because the purpose here is to compare RFA costs across different commodities, inaccuracies in the method, which is invariant across commodities, will not affect the results. Moreover, the importance of coal's total net revenue contribution is robust with respect to subsequent changes in estimated costs.

Contribution on a ton-mile basis yields sharply different results. Tables 8-10 give revenues, costs, volumes, net contribution per ton-mile, and total contribution for the years 1981, 1982, and 1983. Of those commodities generating at least 1 percent of total ton-miles, coal yields the lowest average revenues per ton-mile. It also ranks last in every year in terms of average cost per ton-mile. As a consequence, contribution per ton-mile is close to the median.

When looking at revenue contribution it is important to consider volume as well as contribution per ton-mile. Coal ranks first in ton-miles transported. When ton-miles are multiplied by the contribution per ton-mile, coal yields the largest total revenue contribution of all commodities. It is noteworthy that coal's total revenue contribution grew by 29 percent from 1981 to 1982 and remained at approximately 1982 levels in 1983. Thus, despite coal's low average revenue per ton-mile, its importance to the railroads is apparent when viewed in the context of the heavy loadings per car, low cost per ton-mile, and large volumes transported.

In sum, coal is the most important commodity transported by the rail industry. Even in the economic downturn of 1982, coal's overall revenue rose 5 percent from 1981 levels, and cars and tons originated decreased 3 and 1 percent, respectively. In 1983 revenues returned to approximately 1981 levels, and cars and tons dropped by 9 and 6 percent, respectively, from 1981 levels. A more striking picture is presented by looking at total revenue contribution. This figure rose 29 percent from 1981 to 1982, and car-miles and ton-miles increased 9 to 11 percent. Data for 1983 show total contribution declined by 1 percent from 1982 to 1983, and car-miles and ton-miles decreased 5 and 3 percent, respectively. When these figures are contrasted with the decreased revenues and total revenue contribution for most other commodities, it becomes clear that coal is the most important source of revenues for the railroads.

TABLE 1 Yearly Statistics on Revenues by Major Commodity Group for All Class I U.S. Railroads

Commodity	1978		1979		1980	
	Total Revenues ($000s)	Percentage of Total	Total Revenues ($000s)	Percentage of Total	Total Revenues ($000s)	Percentage of Total
Farm products	1,523,576	7.98	1,946,182	8.67	2,717,673	10.57
Forest products	14,925	0.08	16,486	0.07	14,707	0.06
Fresh fish or other marine products	1,474	0.01	1,394	0.01	1,284	0.00
Metallic ores	532,370	2.79	594,938	2.65	569,577	2.22
Coal	2,642,691	13.84	3,664,103	16.33	4,696,443	18.27
Crude petroleum, natural gas, and gasoline	16,940	0.09	15,129	0.07	17,394	0.07
Nonmetallic minerals	649,593	3.40	752,112	3.35	877,482	3.41
Ordinance or accessories	26,025	0.14	31,727	0.14	30,281	0.12
Food and kindred products	1,995,069	10.45	2,252,435	10.04	2,673,527	10.40
Tobacco products	19,002	0.10	22,604	0.10	24,107	0.09
Textile mill products	41,368	0.22	37,154	0.17	30,262	0.12
Apparel–finished textile products	7,844	0.04	9,353	0.04	8,803	0.03
Lumber and wood (except furniture)	1,341,751	7.03	1,417,743	6.32	1,414,572	5.50
Furniture and fixtures	96,745	0.51	99,952	0.45	92,223	0.36
Pulp, paper, and allied products	1,117,114	5.85	1,281,428	5.71	1,486,123	5.78
Printed matter	11,849	0.06	11,414	0.05	9,819	0.04
Chemicals	2,142,938	11.22	2,512,767	11.20	2,737,306	10.65
Petroleum or coal products	657,087	3.44	782,345	3.49	831,268	3.23
Rubber and miscellaneous plastics	132,694	0.69	151,144	0.67	141,130	0.55
Leather or leather products	2,175	0.01	2,633	0.01	2,513	0.01
Stone, clay, and glass products	775,918	4.06	875.833	3.90	881,152	3.43
Primary metal products	1,026,099	5.37	1,201,169	5.35	1,253,352	4.88
Fabricated metal products	103,712	0.54	105,701	0.47	101,778	0.40
Machinery except electrical	150,780	0.79	159,433	0.71	167,624	0.65
Other 36 categories	169,293	0.89	178,437	0.80	165,691	0.64
Transportation equipment	1,957,049	10.25	2,055,258	9.16	1,813,842	7.06
Instruments or photographic goods	2,972	0.02	3,684	0.02	3,173	0.01
Miscellaneous products of manufacturing	17,723	0.09	19,368	0.09	18,393	0.07
Waste or scrap materials	396,561	2.08	439,426	1.96	477,893	1.86
Miscellaneous freight shipments	37,800	0.20	47,022	0.21	48,343	0.19
Containers returned empty	52,460	0.27	58,848	0.26	47,916	0.19
Freight forwarder traffic	225,762	1.18	233,005	1.04	205,612	0.80
Shipper association traffic	406,510	2.13	501,656	2.24	520,804	2.03
Miscellaneous mixed shipments except forward	798,344	4.18	958,952	4.27	1,159,212	4.51
Less than carload traffic	23,222	0.12	23,649	0.11	14,590	0.06
Total	19,094,209	100.00	22,440,836	100.00	25,703,391	100.00

Source: Interstate Commerce Commission Quarterly Commodity Statistics Reports.

TABLE 2 Yearly Statistics on Tons Originated by Major Commodity Group for All Class I U.S. Railroads

Commodity	1978		1979		1980	
	Total Tons (000s)	Percentage of Total	Total Tons (000s)	Percentage of Total	Total Tons (000s)	Percentage of Total
Farm products	114,899	9.12	125,917	9.20	151,038	10.30
Forest products	593	0.05	596	0.04	485	0.03
Fresh fish or other marine products	68	0.01	56	0.00	49	0.00
Metallic ores	110,565	8.78	117,688	8.60	103,507	7.06
Coal	354,040	28.11	439,521	32.12	482,603	32.93
Crude petroleum, natural gas, and gasoline	1,650	0.13	1,190	0.09	1,156	0.08
Nonmetallic minerals	118,467	9.41	118,019	8.62	113,900	7.77
Ordinance or accessories	415	0.03	450	0.03	372	0.03
Food and kindred products	85,779	6.81	84,047	6.14	84,428	5.76
Tobacco products	282	0.02	325	0.02	285	0.02
Textile mill products	657	0.05	467	0.03	307	0.02
Apparel–finished textile products	130	0.01	130	0.01	93	0.01
Lumber and wood (except furniture)	79,646	6.32	77,409	5.66	70,802	4.83
Furniture and fixtures	851	0.07	752	0.05	579	0.04
Pulp, paper, and allied products	34,002	2.70	34,480	2.52	34,712	2.37
Printed matter	253	0.02	219	0.02	158	0.01
Chemicals	98,353	7.81	103,314	7.55	100,366	6.85
Petroleum or coal products	41,301	3.28	41,445	3.03	36,937	2.52
Rubber and miscellaneous plastics	2,522	0.20	2,532	0.18	1,992	0.14
Leather or leather products	55	0.00	47	0.00	45	0.00
Stone, clay, and glass products	49,737	3.95	51,087	3.73	44,619	3.04
Primary metal products	57,351	4.55	60,743	4.44	50,543	3.45
Fabricated metal products	2,194	0.17	1,945	0.14	1,841	0.13
Machinery except electrical	2,266	0.18	2,055	0.15	1,942	0.13
Other 36 categories	2,229	0.18	2,101	0.15	1,719	0.12
Transportation equipment	29,498	2.34	27,939	2.04	22,194	1.51
Instruments or photographic goods	46	0.00	48	0.00	34	0.00
Miscellaneous products of manufacturing	207	0.02	212	0.02	179	0.01
Waste or scrap materials	34,670	2.75	35,243	2.58	31,655	2.16
Miscellaneous freight shipments	772	0.06	923	0.07	966	0.07
Containers returned empty	1,302	0.10	1,265	0.09	988	0.07
Freight forwarder traffic	4,037	0.32	3,925	0.29	3,066	0.21
Shipper association traffic	8,423	0.67	9,248	0.68	8,262	0.56
Miscellaneous mixed shipments except forward	22,126	1.76	23,170	1.69	23,786	1.62
Less than carload traffic	549	0.04	450	0.03	258	0.02
Total	1,259,385	100.00	1,368,507	100.00	1,465,704	100.00

Source: Interstate Commerce Commission Quarterly Commodity Statistics Reports.

1981		1982		1983		1984	
Total Revenues ($000s)	Percentage of Total	Total Revenues ($000s)	Percentage of Total	Total Revenues ($000s)	Percentage of Total	Total Revenues ($000s)	Percentage of Total
2,616,539	8.89	2,298,161	8.73	2,371,460	8.90	2,482,893	8.32
17,242	0.06	13,469	0.05	15,253	0.06	18,830	0.06
1,460	0.00	1,110	0.00	895	0.00	925	0.00
721,600	2.45	402,891	1.53	449,319	1.69	567,475	1.90
5,955,637	20.24	6,280,465	23.85	5,932,516	22.26	6,965,499	23.33
20,895	0.07	16,171	0.06	19,425	0.07	22,925	0.08
1,023,252	3.48	840,155	3.19	831,140	3.12	997,073	3.34
34,234	0.12	26,430	0.10	21,039	0.08	27,721	0.09
2,909,385	9.89	2,582,462	9.81	2,347,806	8.81	2,309,000	7.73
37,580	0.13	26,895	0.10	15,626	0.06	13,259	0.04
38,561	0.13	30,186	0.11	36,221	0.14	38,566	0.13
11,403	0.04	9,114	0.03	10,789	0.04	13,028	0.04
1,544,108	5.25	1,289,950	4.90	1,526,615	5.73	1,610,564	5.39
106,534	0.36	75,526	0.29	74,145	0.28	78,090	0.26
1,829,449	6.22	1,699,200	6.45	1,669,464	6.27	1,761,559	5.90
9,701	0.03	7,369	0.03	8,184	0.03	1,761,559	0.03
3,273,292	11.12	2,924,115	11.10	3,076,504	11.55	3,359,670	11.25
1,016,153	3.45	883,509	3.36	843,391	3.17	912,539	3.06
156,619	0.53	123,442	0.47	102,776	0.39	107,442	0.36
1,629	0.01	1,747	0.01	2,676	0.01	3,667	0.01
1,105,740	3.76	880,900	3.35	906,007	3.40	1,023,705	3.43
1,555,198	5.28	973,480	3.70	815,924	3.06	955,016	3.20
104,511	0.36	71,226	0.27	52,203	0.20	56,715	0.19
175,719	0.60	114,757	0.44	75,287	0.28	80,735	0.27
174,424	0.59	127,861	0.49	131,363	0.49	147,184	0.49
2,116,406	7.19	1,956,632	7.43	2,291,888	8.60	2,859,473	9.58
3,545	0.01	3,232	0.01	2,760	0.01	3,506	0.01
18,541	0.06	12,807	0.05	10,657	0.04	11,697	0.04
569,579	1.94	414,950	1.58	423,273	1.59	495,751	1.66
73,167	0.25	75,691	0.29	82,596	0.31	118,944	0.40
37,385	0.13	38,996	0.15	43,661	0.16	66,979	0.22
196,812	0.67	127,985	0.49	101,578	0.38	90,384	0.30
642,237	2.18	588,995	2.24	552,023	2.07	436,547	1.46
1,329,610	4.52	1,413,891	5.37	1,802,519	6.76	2,206,655	7.37
17,685	0.06		0.00		0.00	13,055	0.04
29,428,148	100.00	26,333,773	100.00	26,646,985	100.00	29,853,259	100.00

1981		1982		1983		1984	
Total Tons (000s)	Percentage of Total	Total Tons (000s)	Percentage of Total	Total Tons (000s)	Percentage of Total	Total Tons (000s)	Percentage of Total
138,056	9.63	131,532	10.54	142,204	11.05	151,128	10.57
485	0.03	352	0.03	434	0.03	547	0.04
49	0.00	36	0.00	28	0.00	27	0.00
113,719	7.94	62,576	5.01	68,413	5.32	85,503	5.98
518,472	36.18	513,891	41.17	489,243	38.01	566,647	39.65
1,208	0.08	1,035	0.08	1,405	0.11	2,082	0.15
108,953	7.60	83,786	6.71	96,145	7.47	108,188	7.57
360	0.03	276	0.02	312	0.02	430	0.03
81,429	5.68	75,630	6.06	75,198	5.84	72,058	5.04
532	0.04	364	0.03	251	0.02	191	0.01
498	0.03	328	0.03	391	0.03	421	0.03
123	0.01	80	0.01	109	0.01	148	0.01
79,399	5.54	65,017	5.21	71,641	5.57	69,823	4.89
689	0.05	478	0.04	510	0.04	541	0.04
40,073	2.80	34,939	2.80	36,524	2.84	37,654	2.63
134	0.01	129	0.01	185	0.01	217	0.02
103,695	7.24	89,043	7.13	99,333	7.72	107,424	7.52
38,926	2.72	31,553	2.53	33,606	2.61	35,301	2.47
1,974	0.14	1,539	0.12	1,505	0.12	1,538	0.11
29	0.00	35	0.00	49	0.00	54	0.00
48,590	3.39	37,693	3.02	41,239	3.20	44,745	3.13
53,106	3.71	31,815	2.55	32,026	2.49	36,130	2.53
1,700	0.12	965	0.08	828	0.06	901	0.06
1,755	0.12	1,165	0.09	876	0.07	985	0.07
1,717	0.12	1,200	0.10	1,348	0.10	1,493	0.10
22,165	1.55	18,737	1.50	22,200	1.72	26,134	1.83
35	0.00	30	0.00	50	0.00	62	0.00
158	0.01	124	0.01	120	0.01	139	0.01
33,875	2.36	22,529	1.81	24,414	1.90	28,803	2.02
1,238	0.09	1,357	0.11	1,286	0.10	1,433	0.10
1,095	0.08	1,074	0.09	1,140	0.09	1,934	0.14
2,887	0.20	1,756	0.14	1,293	0.10	1,051	0.07
9,894	0.69	8,812	0.71	7,951	0.62	5,853	0.41
25,958	1.81	28,218	2.26	34,751	2.70	39,578	2.77
298	0.02	226	0.02	192	0.01	224	0.02
1,432,977	100.00	1,248,096	100.00	1,287,010	100.00	1,429,164	100.00

TABLE 3 Yearly Statistics on Cars Originated by Major Commodity Group for All Class I U.S. Railroads

	1978		1979		1980	
Commodity	Total Cars (000s)	Percentage of Total	Total Cars (000s)	Percentage of Total	Total Cars (000s)	Percentage of Total
Farm products	1,437,547	6.63	1,574,042	6.94	1,804,502	8.27
Forest products	10,850	0.05	11,086	0.05	8,814	0.04
Fresh fish or other marine products	1,506	0.01	1,190	0.01	1,052	0.00
Metallic ores	1,383,143	6.38	1,455,320	6.42	1,237,414	5.67
Coal	4,052,965	18.68	4,960,061	21.87	5,371,780	24.62
Crude petroleum, natural gas, and gasoline	21,098	0.10	14,099	0.06	13,659	0.06
Nonmetallic minerals	1,457,749	6.72	1,430,951	6.31	1,356,463	6.22
Ordinance or accessories	7,541	0.03	7,854	0.03	6,879	0.03
Food and kindred products	1,725,755	7.96	1,666,891	7.35	1,631,606	7.48
Tobacco products	9,823	0.05	10,896	0.05	9,405	0.04
Textile mill products	39,053	0.18	25,865	0.11	16,896	0.08
Apparel–finished textile products	7,293	0.03	7,644	0.03	5,336	0.02
Lumber and wood (except furniture)	1,417,204	6.53	1,352,324	5.96	1,192,355	5.46
Furniture and fixtures	88,955	0.41	73,739	0.33	55,355	0.25
Pulp, paper, and allied products	828,225	3.82	823,187	3.63	812,989	3.73
Printed matter	7,897	0.04	6,957	0.03	5,059	0.02
Chemicals	1,309,323	6.04	1,351,519	5.96	1,283,165	5.88
Petroleum or coal products	687,959	3.17	679,436	3.00	578,700	2.65
Rubber and miscellaneous plastics	143,044	0.66	142,095	0.63	108,240	0.50
Leather or leather products	2,805	0.01	2,520	0.01	2,219	0.01
Stone, clay, and glass products	766,613	3.53	774,654	3.42	652,353	2.99
Primary metal products	832,286	3.84	864,810	3.81	722,121	3.31
Fabricated metal products	86,377	0.40	77,368	0.34	65,678	0.30
Machinery except electrical	93,835	0.43	80,458	0.35	74,564	0.34
Other 36 categories	133,477	0.62	124,513	0.55	96,063	0.44
Transportation equipment	1,242,638	5.73	1,174,618	5.18	934,422	4.28
Instruments or photographic goods	2,391	0.01	2,479	0.01	1,697	0.01
Miscellaneous products of manufacturing	14,656	0.07	14,014	0.06	11,124	0.05
Waste or scrap materials	638,465	2.94	644,417	2.84	576,563	2.64
Miscellaneous freight shipments	40,965	0.19	47,128	0.21	45,000	0.21
Containers returned empty	100,228	0.46	97,936	0.43	80,325	0.37
Freight forwarder traffic	231,947	1.07	207,705	0.92	164,845	0.76
Shipper association traffic	497,690	2.29	518,895	2.29	460,957	2.11
Miscellaneous mixed shipments except forward	1,072,597	4.94	1,119,088	4.93	1,130,297	5.18
Less than carload traffic	56	0.00	1,127	0.00	10	0.00
Total	21,693,812	100.00	22,681,783	100.00	21,819,054	100.00

Source: Interstate Commerce Commission Quarterly Commodity Statistics Reports.

TABLE 4 Summary of Coal Car Loads as a Percentage of Total Car Loads by Railroad

Railroad	1979	1980	1981	1982	1983
Baltimore & Ohio Railroad Company	32	37	40	42	35
Bessemer & Lake Erie Railroad Company	35	35	36	73	61
Boston & Maine Corporation	4	6	5	9	8
Chesapeake & Ohio Railway Company	48	57	58	65	60
Consolidated Rail Corporation	19	22	22	24	22
Delaware & Hudson Railway Company	1	2	1	2	3
Elgin, Joliet & Eastern Railway Company	30	31	32	39	38
Grand Trunk Western Railway Company	4	6	4	6	5
Norfolk & Western Railway Company	43	49	51	53	46
Pittsburgh & Lake Erie Railroad	30	33	25	50	46
Western Maryland Railway	45	52	60	67	N/A
Clinchfield Railroad Company	64	71	74	80	N/A
Florida East Coast Railway Company	0	0	0	0	1
Illinois Central Gulf Railroad	16	18	19	24	23
Louisville & Nashville Railroad Company	35	37	40	39	N/A
Seaboard Coast Line Railroad	9	11	12	14	24
Atchison, Topeka & Santa Fe Railway Company	10	11	15	15	16
Burlington Northern, Inc.	29	41	40	41	42
Chicago & North Western Transportation Company	11	14	14	15	13
Chicago, Milwaukee, St. Paul & Pacific Railroad	16	18	18	17	14
Denver & Rio Grande Western Railroad Company	36	37	41	46	41
Duluth, Missabe & Iron Range Railway Company	1	1	0	0	0
Kansas City Southern Railway Company	16	21	22	29	29
Missouri-Kansas-Texas Railroad Company	8	13	19	22	20
Missouri Pacific Railroad Company	13	16	17	22	24
St. Louis Southwestern Railway Company	0	0	0	0	0
Soo Line Railroad Company	2	2	1	2	2
Southern Pacific Transportation Company	2	4	4	5	5
Union Pacific Railroad	14	17	21	21	19
Western Pacific Railroad Company	1	0	2	5	6
Detroit, Toledo & Ironton Railroad Company	19	22	10	12	8
Southern System	19	22	22	25	23

1981		1982		1983		1984	
Total Cars (000s)	Percentage of Total	Total Cars (000s)	Percentage of Total	Total Cars (000s)	Percentage of Total	Total Cars (000s)	Percentage of Total
1,617,079	7.68	1,543,595	8.44	1,641,763	8.67	1,756,742	8.39
8,565	0.04	6,324	0.03	8,053	0.04	10,371	0.05
1,143	0.01	912	0.00	677	0.00	658	0.00
1,354,342	6.43	760,315	4.16	812,219	4.29	1,001,003	4.78
5,728,491	27.20	5,603,304	30.63	5,216,878	27.54	6,061,046	28.94
15,131	0.07	12,356	0.07	17,160	0.09	25,514	0.12
1,261,644	5.99	948,684	5.19	1,075,447	5.68	1,203,562	5.75
6,410	0.03	4,902	0.03	5,252	0.03	7,481	0.04
1,529,726	7.26	1,358,974	7.43	1,315,498	6.95	1,233,632	5.89
16,887	0.08	12,096	0.07	8,349	0.04	6,645	0.03
23,667	0.11	15,939	0.09	19,119	0.10	20,801	0.10
7,100	0.03	4,886	0.03	6,309	0.03	8,447	0.04
1,242,608	5.90	991,461	5.42	1,074,081	5.67	1,050,586	5.02
65,545	0.31	44,933	0.25	47,664	0.25	46,935	0.22
866,419	4.11	733,765	4.01	744,084	3.93	740,583	3.54
4,132	0.02	4,743	0.03	8,009	0.04	9,451	0.05
1,298,154	6.16	1,096,703	6.00	1,215,703	6.42	1,311,795	6.26
605,546	2.88	465,513	2.54	494,576	2.61	529,289	2.53
104,476	0.50	80,097	0.44	77,211	0.41	78,615	0.38
1,453	0.01	2,089	0.01	3,405	0.02	3,620	0.02
682,119	3.24	509,777	2.79	538,281	2.84	576,022	2.75
756,895	3.59	456,212	2.49	440,384	2.33	487,400	2.33
54,749	0.26	34,885	0.19	33,405	0.18	36,559	0.17
66,456	0.32	43,434	0.24	38,057	0.20	40,457	0.19
86,686	0.41	66,162	0.36	80,369	0.42	88,859	0.42
938,023	4.45	799,829	4.37	954,066	5.04	1,140,979	5.45
1,835	0.01	1,555	0.01	2,704	0.01	3,341	0.02
9,716	0.05	7,693	0.04	8,917	0.05	10,001	0.05
604,413	2.87	405,210	2.22	416,281	2.20	479,537	2.29
58,176	0.28	63,272	0.35	63,602	0.34	73,183	0.35
68,680	0.33	83,455	0.46	105,148	0.56	204,237	0.98
162,071	0.77	109,965	0.60	82,524	0.44	67,231	0.32
540,191	2.56	512,628	2.80	443,003	2.34	326,397	1.56
1,273,499	6.05	1,507,526	8.24	1,942,634	10.26	2,304,554	11.00
1	0.00		0.00		0.00		0.00
21,062,027	100.00	18,293,194	100.00	18,940,832	100.00	20,945,536	100.00

TABLE 5 Summary of Car-Mile Statistics Arrayed by Commodity Group Extracted from the 1981 ICC Waybill Sample

Commodity	Total Car-Miles (000s)	Percentage of Total	Average Revenue per Car-Mile (cents)	Average Cost per Car-Mile (cents)	Average Contribution per Car-Mile (cents)	Total Contribution ($)
Farm products	1,110,747	8.74	201.14	175.23	25.91	287,777,910
Forest products	9,818	0.08	178.96	141.43	37.53	3,684,526
Fresh fish or other marine products	1,163	0.01	137.81	129.19	8.63	100,331
Metallic ores	248,642	1.96	288.63	190.46	98.16	244,079,258
Coal	2,444,294	19.24	214.11	154.07	60.05	1,467,700,385
Crude petroleum, natural gas, and gasoline	6,297	0.05	269.90	215.63	54.27	3,417,460
Nonmetallic minerals	360,029	2.83	243.44	217.76	25.69	92,487,285
Ordinance or accessories	4,202	0.03	473.07	131.64	341.43	14,346,467
Food and kindred products	1,310,333	10.32	205.94	172.90	33.04	432,980,083
Tobacco products	25,189	0.20	142.46	125.39	17.07	4,299,961
Textile mill products	21,731	0.17	136.78	111.51	25.27	5,491,628
Apparel–finished textile products	6,578	0.05	141.95	115.67	26.28	1,728,772
Lumber and wood (except furniture)	673,825	5.30	191.29	169.40	21.89	147,466,697
Furniture and fixtures	79,757	0.63	118.33	100.21	18.12	14,451,069
Pulp, paper, and allied products	895,577	7.05	178.68	147.51	31.17	279,128,370
Printed matter	6,239	0.05	157.17	139.02	18.15	1,132,196
Chemicals	952,994	7.50	289.16	193.80	95.36	908,782,596
Petroleum or coal products	300,225	2.36	275.29	195.58	79.71	239,303,416
Rubber and miscellaneous plastics	100,971	0.79	144.44	121.08	23.36	23,590,412
Leather or leather products	1,169	0.01	77.13	68.79	8.34	97,482
Stone, clay, and glass products	406,432	3.20	229.54	172.47	57.06	231,929,226
Primary metal products	531,255	4.18	260.87	170.90	89.97	477,994,363
Fabricated metal products	52,184	0.41	186.25	126.58	59.67	31,137,371
Machinery except electrical	74,957	0.59	189.46	117.87	71.59	53,658,928
Other 36 categories	79,845	0.63	187.67	123.98	63.69	50,852,402
Transportation equipment	767,174	6.04	233.22	144.87	88.35	677,795,284
Instruments or photographic goods	1,587	0.01	159.95	119.33	40.62	644,554
Miscellaneous products of manufacturing	9,283	0.07	150.12	106.62	43.51	4,038,879
Waste or scrap materials	208,503	1.64	250.95	207.87	43.09	89,836,727
Miscellaneous freight shipments	24,018	0.19	199.82	134.80	65.03	15,618,178
Containers returned empty	51,123	0.40	62.07	112.64	–50.57	–25,852,992
Freight forwarder traffic	191,076	1.50	83.22	58.90	24.31	46,451,591
Shipper association traffic	320,889	2.53	81.86	66.54	15.32	49,156,593
Miscellaneous mixed shipments except forward	1,422,962	11.20	77.50	72.72	4.78	68,003,078
All other categories	1,221	0.01	279.16	153.72	125.44	1,530,984
Total	12,702,697	100.00	198.84	152.04	46.80	5,944,841,470

TABLE 6 Summary of Car-Mile Statistics Arrayed by Commodity Group Extracted from the 1982 ICC Waybill Sample

Commodity	Total Car-Miles (000s)	Percentage of Total	Average Revenue per Car-Mile (cents)	Average Cost per Car-Mile (cents)	Average Contribution per Car-Mile (cents)	Total Contribution ($)
Farm products	1,040,470	8.52	198.59	184.21	14.38	149,596,477
Forest products	8,519	0.07	182.80	146.91	35.89	3,057,230
Fresh fish or other marine products	539	0.00	140.00	131.69	8.32	44,856
Metallic ores	121,209	0.99	318.37	218.03	100.34	121,626,660
Coal	2,672,043	21.88	226.10	155.29	70.82	1,892,269,469
Crude petroleum, natural gas, and gasoline	4,940	0.04	270.63	241.51	29.12	1,438,234
Nonmetallic minerals	274,694	2.25	267.71	235.56	32.15	88,304,419
Ordinance or accessories	3,345	0.03	449.53	150.44	299.08	10,004,644
Food and kindred products	1,189,263	9.74	207.69	180.73	26.96	320,577,133
Tobacco products	20,778	0.17	144.27	150.64	–6.37	–1,323,364
Textile mill products	19,265	0.16	129.16	108.34	20.82	4,010,769
Apparel–finished textile products	3,086	0.03	203.22	139.76	63.46	1,958,177
Lumber and wood (except furniture)	579,654	4.75	200.71	189.15	11.56	67,011,005
Furniture and fixtures	58,822	0.48	116.36	106.51	9.85	5,793,071
Pulp, paper, and allied products	810,136	6.64	195.65	161.07	34.58	280,158,865
Printed matter	4,693	0.04	151.24	126.26	24.98	1,172,283
Chemicals	867,353	7.10	312.10	216.97	95.13	825,079,352
Petroleum or coal products	258,952	2.12	299.61	223.77	75.83	196,374,962
Rubber and miscellaneous plastics	78,404	0.64	147.79	129.55	18.24	14,297,234
Leather or leather products	1,845	0.02	65.32	65.01	0.32	5,821
Stone, clay, and glass products	320,115	2.62	252.02	198.31	53.71	171,937,084
Primary metal products	340,889	2.79	270.40	185.33	85.07	289,995,162
Fabricated metal products	36,363	0.30	176.60	125.27	51.33	18,664,823
Machinery except electrical	39,399	0.32	217.31	129.84	87.47	34,463,306
Other 36 categories	63,250	0.52	171.78	117.69	54.09	34,212,101
Transportation equipment	721,666	5.91	237.41	152.33	85.08	613,969,536
Instruments or photographic goods	2,523	0.02	114.44	102.00	12.44	313,748
Miscellaneous products of manufacturing	8,765	0.07	148.40	114.51	33.89	2,970,378
Waste or scrap materials	164,429	1.35	254.44	216.92	37.52	61,689,574
Miscellaneous freight shipments	30,159	0.25	195.06	134.75	60.31	18,188,448
Containers returned empty	45,635	0.37	67.06	119.83	–52.77	–24,083,277
Freight forwarder traffic	152,220	1.25	72.37	60.77	11.60	17,662,219
Shipper association traffic	359,136	2.94	70.82	63.06	7.76	27,870,598
Miscellaneous mixed shipments except forward	1,905,129	15.60	68.70	68.77	–0.06	–1,219,230
Less than carload traffic	132	0.00	67.39	122.67	–55.27	–73,190
All other categories	1,722	0.01	242.60	192.50	50.10	862,872
Total	12,209,983	100.00	197.63	154.64	42.99	5,248,881,449

TABLE 7 Summary of Car-Mile Statistics Arrayed by Commodity Group Extracted from the 1983 ICC Waybill Sample

Commodity	Total Car-Miles (000s)	Percentage of Total	Average Revenue per Car-Mile (cents)	Average Cost per Car-Mile (cents)	Average Contribution per Car-Mile (cents)	Total Contribution ($)
Farm products	1,178,057	8.95	190.25	155.99	34.26	403,544,958
Forest products	8,925	0.07	171.45	141.83	29.62	2,643,552
Fresh fish or other marine products	650	0.00	116.00	114.10	1.91	12,396
Metallic ores	137,472	1.04	311.76	206.43	105.33	144,795,138
Coal	2,538,934	19.29	224.77	150.88	73.90	1,876,209,351
Crude petroleum, natural gas, and gasoline	6,459	0.05	265.40	224.34	41.06	2,652,246
Nonmetallic minerals	269,319	2.05	268.52	229.61	38.90	104,772,613
Ordinance or accessories	4,215	0.03	296.41	144.63	151.78	6,397,486
Food and kindred products	1,163,582	8.84	195.09	163.57	31.52	366,727,617
Tobacco products	10,821	0.08	124.04	108.82	15.22	1,646,857
Textile mill products	26,743	0.20	117.78	94.71	23.07	6,170,270
Apparel–finished textile products	6,194	0.05	147.16	106.16	40.99	2,539,311
Lumber and wood (except furniture)	637,082	4.84	199.45	184.42	15.03	95,725,245
Furniture and fixtures	62,868	0.48	104.96	95.67	9.29	5,840,405
Pulp, paper, and allied products	798,685	6.07	189.16	150.98	38.18	304,934,895
Printed matter	9,280	0.07	102.67	90.87	11.81	1,095,583
Chemicals	911,226	6.92	301.01	189.38	111.64	1,017,288,252
Petroleum or coal products	255,763	1.94	295.23	209.65	85.57	218,868,326
Rubber and miscellaneous plastics	74,794	0.57	128.20	109.47	18.73	14,006,262
Leather or leather products	3,136	0.02	70.95	65.27	5.69	178,327
Stone, clay, and glass products	328,356	2.49	255.22	191.14	64.08	210,409,124
Primary metal products	288,397	2.19	260.55	181.82	78.73	227,061,658
Fabricated metal products	32,143	0.24	148.22	120.96	27.26	8,760,753
Machinery except electrical	25,837	0.20	168.77	110.53	58.24	15,046,750
Other 36 categories	82,382	0.63	168.15	113.70	54.45	44,855,647
Transportation equipment	817,441	6.21	241.94	123.63	118.32	967,168,935
Instruments or photographic goods	2,245	0.02	97.65	81.67	15.99	358,981
Miscellaneous products of manufacturing	9,140	0.07	97.67	85.47	12.20	1,115,492
Waste or scrap materials	156,719	1.19	258.81	212.45	46.35	72,641,476
Miscellaneous freight shipments	26,998	0.21	216.55	132.53	84.02	22,683,511
Containers returned empty	66,005	0.50	55.31	110.06	–54.75	–36,137,226
Freight forwarder traffic	131,637	1.00	67.48	61.48	6.00	7,901,354
Shipper association traffic	350,789	2.67	64.31	63.89	0.42	1,462,291
Miscellaneous mixed shipments except forward	2,733,718	20.77	62.85	69.94	–7.08	–193,587,903
All other categories	5,757	0.04	176.44	158.79	17.65	1,015,978
Total	13,162,289	100.00	184.42	139.39	45.03	5,926,805,911

TABLE 8 Summary of Ton-Mile Statistics Arrayed by Commodity Group Extracted from the 1981 ICC Waybill Sample

Commodity	Total Ton-Miles (000s)	Percentage of Total	Average Revenue per Ton-Mile (cents)	Average Cost per Ton-Mile (cents)	Average Contribution per Ton-Mile (cents)	Total Contribution ($)
Farm products	89,133,133	11.90	2.51	2.18	0.32	287,777,910
Forest products	532,488	0.07	3.30	2.61	0.69	3,684,526
Fresh fish or other marine products	49,709	0.01	3.22	3.02	0.20	100,331
Metallic ores	21,415,879	2.86	3.35	2.21	1.14	244,079,258
Coal	223,403,486	29.83	2.34	1.69	0.66	1,467,700,385
Crude petroleum, natural gas, and gasoline	515,826	0.07	3.29	2.63	0.66	3,417,460
Nonmetallic minerals	30,280,191	4.04	2.89	2.59	0.31	92,487,285
Ordinance or accessories	214,751	0.03	9.26	2.58	6.68	14,346,467
Food and kindred products	70,903,523	9.47	3.81	3.20	0.61	432,980,083
Tobacco products	788,674	0.11	4.55	4.00	0.55	4,299,961
Textile mill products	467,105	0.06	6.36	5.19	1.18	5,491,628
Apparel—finished textile products	100,480	0.01	9.29	7.57	1.72	1,728,772
Lumber and wood (except furniture)	35,885,049	4.79	3.59	3.18	0.41	147,466,697
Furniture and fixtures	900,352	0.12	10.48	8.88	1.61	14,451,069
Pulp, paper, and allied products	41,992,093	5.61	3.81	3.15	0.66	279,128,370
Printed matter	261,084	0.03	3.76	3.32	0.43	1,132,196
Chemicals	76,750,293	10.25	3.59	2.41	1.18	908,782,596
Petroleum or coal products	19,767,786	2.64	4.18	2.97	1.21	239,303,416
Rubber and miscellaneous plastics	2,005,746	0.27	7.27	6.10	1.18	23,590,412
Leather or leather products	23,566	0.00	3.83	3.41	0.41	97,482
Stone, clay, and glass products	25,953,514	3.47	3.59	2.70	0.89	231,929,226
Primary metal products	35,287,315	4.71	3.93	2.57	1.35	477,994,363
Fabricated metal products	1,565,388	0.21	6.21	4.22	1.99	31,137,371
Machinery except electrical	2,026,527	0.27	7.01	4.36	2.65	53,658,928
Other 36 categories	1,638,846	0.22	9.14	6.04	3.10	50,852,402
Transportation equipment	17,925,160	2.39	9.98	6.20	3.78	677,795,284
Instruments or photographic goods	31,670	0.00	8.01	5.98	2.04	644,554
Miscellaneous products of manufacturing	156,045	0.02	8.93	6.34	2.59	4,038,879
Waste or scrap materials	11,067,307	1.48	4.73	3.92	0.81	89,836,727
Miscellaneous freight shipments	444,396	0.06	10.80	7.29	3.51	15,618,178
Containers returned empty	900,684	0.12	3.52	6.39	−2.87	−25,852,992
Freight forwarder traffic	3,629,687	0.48	4.38	3.10	1.28	46,451,591
Shipper association traffic	5,748,369	0.77	4.57	3.71	0.86	49,156,593
Miscellaneous mixed shipments except forward	27,174,719	3.63	4.06	3.81	0.25	68,003,078
All other categories	63,041	0.01	5.40	2.98	2.43	1,530,984
Total	749,003,744	100.00	3.37	2.58	0.79	5,944,841,470

TABLE 9 Summary of Ton-Mile Statistics Arrayed by Commodity Group Extracted from the 1982 ICC Waybill Sample

Commodity	Total Ton-Miles (000s)	Percentage of Total	Average Revenue per Ton-Mile (cents)	Average Cost per Ton-Mile (cents)	Average Contribution per Ton-Mile (cents)	Total Contribution ($)
Farm products	82,622,436	11.61	2.50	2.32	0.18	149,596,477
Forest products	461,129	0.06	3.38	2.71	0.66	3,057,230
Fresh fish or other marine products	26,708	0.00	2.83	2.66	0.17	44,856
Metallic ores	10,754,366	1.51	3.59	2.46	1.13	121,626,660
Coal	249,118,104	35.01	2.43	1.67	0.76	1,892,269,469
Crude petroleum, natural gas, and gasoline	400,337	0.06	3.34	2.98	0.36	1,438,234
Nonmetallic minerals	23,661,257	3.33	3.11	2.73	0.37	88,304,419
Ordinance or accessories	182,914	0.03	8.22	2.75	5.47	10,004,644
Food and kindred products	64,406,806	9.05	3.83	3.34	0.50	320,577,133
Tobacco products	633,152	0.09	4.73	4.94	−0.21	−1,323,364
Textile mill products	401,550	0.06	6.20	5.20	1.00	4,010,769
Apparel—finished textile products	58,444	0.01	10.73	7.38	3.35	1,958,177
Lumber and wood (except furniture)	32,339,378	4.54	3.60	3.39	0.21	67,011,005
Furniture and fixtures	635,988	0.09	10.76	9.85	0.91	5,793,071
Pulp, paper, and allied products	39,422,567	5.54	4.02	3.31	0.71	280,158,865
Printed matter	160,111	0.02	4.43	3.70	0.73	1,172,283
Chemicals	71,223,982	10.01	3.80	2.64	1.16	825,079,352
Petroleum or coal products	17,816,645	2.50	4.35	3.25	1.10	196,374,962
Rubber and miscellaneous plastics	1,612,144	0.23	7.19	6.30	0.89	14,297,234
Leather or leather products	32,423	0.00	3.72	3.70	0.02	5,821
Stone, clay, and glass products	21,888,894	3.08	3.69	2.90	0.79	171,937,084
Primary metal products	23,155,410	3.25	3.98	2.73	1.25	289,995,162
Fabricated metal products	1,005,844	0.14	6.38	4.53	1.86	18,664,823
Machinery except electrical	1,100,588	0.15	7.78	4.65	3.13	34,463,306
Other 36 categories	1,112,067	0.16	9.77	6.69	3.08	34,212,101
Transportation equipment	16,702,848	2.35	10.26	6.58	3.68	613,969,536
Instruments or photographic goods	49,401	0.01	5.84	5.21	0.64	313,748
Miscellaneous products of manufacturing	182,450	0.03	7.13	5.50	1.63	2,970,378
Waste or scrap materials	8,421,390	1.18	4.97	4.24	0.78	61,689,574
Miscellaneous freight shipments	542,256	0.08	10.85	7.49	3.35	18,188,448
Containers returned empty	714,694	0.10	4.28	7.65	−3.37	−24,083,277
Freight forwarder traffic	2,328,486	0.33	4.73	3.97	0.76	17,662,219
Shipper association traffic	5,585,327	0.78	4.55	4.05	0.50	27,870,598
Miscellaneous mixed shipments except forward	32,702,322	4.60	4.00	4.01	0.00	−1,219,230
Less than carload traffic	1,798	0.00	4.96	9.04	−4.07	−73,190
All other categories	93,095	0.01	4.49	3.56	0.93	862,872
Total	711,558,072	100.00	3.39	2.65	0.74	5,248,881,449

TABLE 10 Summary of Ton-Mile Statistics Arrayed by Commodity Group Extracted from the 1983 ICC Waybill Sample

Commodity	Total Ton-Miles (000s)	Percentage of Total	Average Revenue per Ton-Mile (cents)	Average Cost per Ton-Mile (cents)	Average Contribution per Ton-Mile (cents)	Total Contribution ($)
Farm products	94,162,829	12.82	2.38	1.95	0.43	403,544,958
Forest products	485,831	0.07	3.15	2.61	0.54	2,643,552
Fresh fish or other marine products	25,497	0.00	2.96	2.91	0.05	12,396
Metallic ores	12,437,075	1.69	3.45	2.28	1.16	144,795,138
Coal	241,934,082	32.95	2.36	1.58	0.78	1,876,209,351
Crude petroleum, natural gas, and gasoline	547,157	0.07	3.13	2.65	0.48	2,652,246
Nonmetallic minerals	23,475,699	3.20	3.08	2.63	0.45	104,772,613
Ordinance or accessories	242,410	0.03	5.15	2.51	2.64	6,397,486
Food and kindred products	63,096,478	8.59	3.60	3.02	0.58	366,727,617
Tobacco products	296,296	0.04	4.53	3.97	0.56	1,646,857
Textile mill products	544,041	0.07	5.79	4.66	1.13	6,170,270
Apparel–finished textile products	108,876	0.01	8.37	6.04	2.33	2,539,311
Lumber and wood (except furniture)	36,543,457	4.98	3.48	3.22	0.26	95,725,245
Furniture and fixtures	711,827	0.10	9.27	8.45	0.82	5,840,405
Pulp, paper, and allied products	39,261,129	5.35	3.85	3.07	0.78	304,934,895
Printed matter	246,660	0.03	3.86	3.42	0.44	1,095,583
Chemicals	74,364,484	10.13	3.69	2.32	1.37	1,017,288,252
Petroleum or coal products	17,697,867	2.41	4.27	3.03	1.24	218,868,326
Rubber and miscellaneous plastics	1,437,702	0.20	6.67	5.70	0.97	14,006,262
Leather or leather products	41,532	0.01	5.36	4.93	0.43	178,327
Stone, clay, and glass products	23,476,194	3.20	3.57	2.67	0.90	210,409,124
Primary metal products	19,812,997	2.70	3.79	2.65	1.15	227,061,658
Fabricated metal products	882,926	0.12	5.40	4.40	0.99	8,760,753
Machinery except electrical	573,312	0.08	7.61	4.98	2.62	15,046,750
Other 36 categories	1,570,113	0.21	8.82	5.97	2.86	44,855,647
Transportation equipment	18,948,679	2.58	10.44	5.33	5.10	967,168,935
Instruments or photographic goods	48,763	0.01	4.50	3.76	0.74	358,981
Miscellaneous products of manufacturing	147,846	0.02	6.04	5.28	0.75	1,115,492
Waste or scrap materials	8,562,373	1.17	4.74	3.89	0.85	72,641,476
Miscellaneous freight shipments	487,906	0.07	11.98	7.33	4.65	22,683,511
Containers returned empty	824,782	0.11	4.43	8.81	–4.38	–36,137,226
Freight forwarder traffic	1,905,088	0.26	4.66	4.25	0.41	7,901,354
Shipper association traffic	5,228,777	0.71	4.31	4.29	0.03	1,462,291
Miscellaneous mixed shipments except forward	43,968,058	5.99	3.91	4.35	–0.44	-193,587,903
All other categories	253,949	0.03	4.00	3.60	0.40	1,015,978
Total	734,354,056	100.00	3.31	2.50	0.81	5,926,805,911

Economies of Density

There is considerable literature on the cost structure of the railroad industry. Economists have generally used regression analysis of cross-sectional cost data, with each firm constituting an observation, to estimate industry cost curves. Keeler (10) has made a detailed review of this literature. He finds a general consensus in recent studies that have correctly distinguished returns to firm size from returns to traffic density. These studies, which include Harris (11) and Friedlaender and Spady (12), "give strong evidence of increasing returns, up to a rather high traffic density relative to tonnages moving over most route-mileage in the United States" (10,p.54).

More specifically, Keeler (10,p.54) states: "While the exact density at which railroad costs flatten out completely is not known, it is known that the cost curve for freight services becomes almost flat at around 7 million to 10 million net ton-miles per route-mile (NTM/RM), depending on commodity type and other circumstances." Keeler's conclusions are illustrated in Figure 1, which shows the average cost declines sharply with increases in volume up to about 7 million NTM/RM, at which point the curve becomes more horizontal; further increases in volume do not substantially reduce average costs. However, railroads typically have large differences in traffic densities among their lines.

Based on 1981-1982 waybill data, Class I railroads' aggregate traffic densities range between 1 million and 6 million net ton-miles per route-mile. However, railroads typically have large differences in traffic densities among their lines.

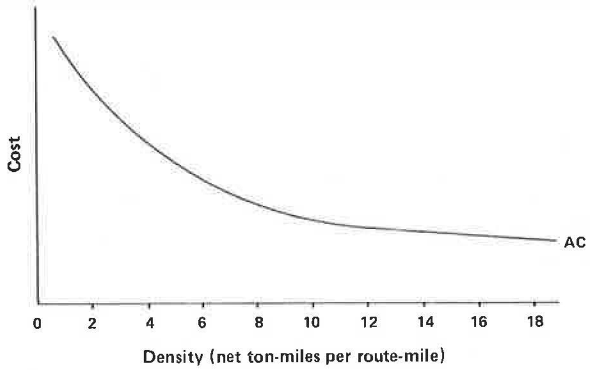

FIGURE 1 Economics of density in the rail industry.

To address the importance of coal to railroad economies of density, lines were dichotomized into those with and those without coal traffic. Thus coal route-miles were isolated from noncoal route-miles. The tools used for this section of the study were the 1981 and 1982 ICC waybill sample flowed over the Federal Railroad Administration's network model. Table 11 gives results for the U.S. railroad system as a whole. First it is necessary to clarify the meaning of the data in the table and then the implications will be explored.

Column 1 provides statistics on route-miles over which coal traffic flowed in the 1981 or 1982 waybill sample. Approximately 96,000 route-miles, out of a total of approximately 200,000 mi, have coal traffic. Based on all traffic that moved over these lines in 1981 and 1982, the 96,000 mi are divided into the six FRA density classes based on gross ton-miles per route-mile (GTM/RM). The average density (in net

TABLE 11 Statistics on Route-Miles by Density Class and Average Total Densities for the Total U.S. Railroad System

	(1) Route-Miles Handling Coal (all existing traffic)		(2) Route-Miles Not Handling Coal (all existing traffic)		(3) Route-Miles for Total System (all existing traffic)		(4) Route-Miles Handling Coal (coal traffic only)	
Density Class	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage
1	13,673	14.20	80,924	77.45	94,592	47.12	54,861	57.00
2	21,740	22.58	13,510	12.93	35,250	17.56	23,536	24.45
3	15,121	15.71	3,669	3.51	18,785	9.36	8,304	8.63
4	17,825	18.52	3,098	2.97	20,924	10.42	4,694	4.88
5	13,392	13.91	1,760	1.68	15,153	7.55	2,992	3.11
6	14,512	15.08	1,523	1.46	16,034	7.99	1,858	1.93
Total	96,263	100.00	104,484	100.00	200,738	100.00	96,245	100.00
Average density (NTM/RM)	6,853,898		1,093,902		3,675,439		2,227,779	

Note: Class 1 < 1 million GTM/RM, Class 2 < 1-5 million GTM/RM, Class 3 < 5-10 million GTM/RM, Class 4 < 10-20 million GTM/RM, Class 5 < 20-30 million GTM/RM, and Class 6 > 30 million GTM/RM.

Source: 1981 and 1982 ICC waybill sample flowed over the FRA network model.

ton-miles per route-mile) for the 96,000 route-miles, again based on all traffic flowing over these miles, is also given.

Column 2 provides statistics on route-miles that did not have coal traffic in the 1981 or 1982 waybill sample. Approximately 104,000 route-miles, out of a total of 200,000 mi, did not have coal traffic. The 104,000 route-miles are divided into density classes based on all traffic moving over these lines.

Column 3 is the sum of Columns 1 and 2. It provides statistics on all route-miles, dividing these miles into density classes. Column 4 provides additional information on the 96,000 route-miles that had coal traffic in the 1981 or 1982 waybill sample. In this column, the 96,000 mi are divided into density classes on the basis of coal traffic only. The average density for these lines is also given.

An example will clarify the difference between Columns 1 and 4. Assume a given route-mile carried a total of 7 million gross tons, of which 3 million gross tons were coal traffic. In Column 1, this route-mile of track would be included in density class 3 (5 to 10 GTM/RM). However, in Column 4, which measures the density based on only the coal traffic, the route-mile density could be classified in density class 2. Tables 12-15 give identical statistics for the Chessie System, Burlington Northern (BN) and the Norfolk and Western (N&W) railroads, and Consolidated Rail Corporation, the four largest coal-hauling railroads by total coal revenue (ranking based on 1983 commodity statistics from ICC Form QCS).

These tables clearly illustrate the importance of coal in achieving economies of density. The addition of coal traffic density to the line density created by all other traffic raises the U.S. average line density from 4.6 million NTM/RM to 6.8 million NTM/RM. A comparison of Column 1 with Column 2 shows that densities in the corridors that handle coal traffic are substantially higher than densities in those that do not have coal traffic. Column 1 for the N&W and BN show average density in the range in which Keeler found that the cost curve for freight services flattens out, and densities for noncoal lines are well below the minimum optimal level. BN's and N&W's average density for route-miles that handle coal only (Column 4) is significantly above the U.S. average. This illustrates the impact that coal has on these railroads' route-mile densities. In the following section, implications for both shippers and railroads will be discussed.

IMPLICATIONS FOR CARRIER AND SHIPPER STRATEGIES

The foregoing analysis has important policy implications for both railroads and shippers. First, the superior revenue contribution and the high volume of coal place it in a pivotal position for determining the future financial well-being of the railroad industry. Coal has revitalized the railroads in two ways. First, it produces substantial revenues; as shown previously, coal traffic generates approximately 22 percent of total railroad revenues and as much as 62 percent for some of the major coal-hauling

TABLE 12 Statistics on Route-Miles by Density Class and Average Total Densities for the Chessie System

	(1) Route-Miles Handling Coal (all existing traffic)		(2) Route-Miles Not Handling Coal (all existing traffic)		(3) Route-Miles for Total System (all existing traffic)		(4) Route-Miles Handling Coal (coal traffic only)	
Density Class	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage
1	2,031	26.69	3,207	89.28	5,237	46.76	3,260	42.83
2	2,077	27.29	279	7.77	2,355	21.03	2,397	31.49
3	903	11.87	16	.45	919	8.21	726	9.54
4	481	6.32	52	1.45	533	4.76	420	5.52
5	1,142	15.01	5	.14	1,147	10.24	762	10.01
6	976	12.83	33	.92	1,009	9.01	46	.60
Total	7,610	100.00	3,592	100.00	11,200	100.00	7,611	100.00
Average density (NTM/RM)	5,693,402		562,660		4,048,791		3,037,351	

Note: Class 1 < 1 million GTM/RM, Class 2 < 1-5 million GTM/RM, Class 3 < 5-10 million GTM/RM, Class 4 < 10-20 million GTM/RM, Class 5 < 20-30 million GTM/RM, and Class 6 > 30 million GTM/RM.

Source: 1981 and 1982 ICC waybill sample flowed over the FRA network model.

TABLE 13 Statistics on Route-Miles by Density Class and Average Total Densities for the Norfolk & Western Railway Company

	(1) Route-Miles Handling Coal (all existing traffic)		(2) Route-Miles Not Handling Coal (all existing traffic)		(3) Route-Miles for Total System (all existing traffic)		(4) Route-Miles Handling Coal (coal traffic only)	
Density Class	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage
1	684	13.28	3,036	87.72	3,719	43.18	2,649	51.40
2	1,103	21.41	217	6.27	1,320	15.33	899	17.44
3	1,187	23.04	165	4.77	1,352	15.70	589	11.43
4	1,027	19.93	4	.12	1,031	11.97	228	4.42
5	310	6.02	4	.12	314	3.65	251	4.87
6	841	16.32	35	1.01	876	10.17	538	10.44
Total	5,152	100.00	3,461	100.00	8,612	100.00	5,154	100.00
Average density (NTM/RM)	8,692,639		724,795		5,510,080		5,233,973	

Note: Class 1 < 1 million GTM/RM, Class 2 < 1-5 million GTM/RM, Class 3 < 5-10 million GTM/RM, Class 4 < 10-20 million GTM/RM, Class 5 < 20-30 million GTM/RM, and Class 6 > 30 million GTM/RM.

Source: 1981 and 1982 ICC waybill sample flowed over the FRA network model.

TABLE 14 Statistics on Route-Miles by Density Class and Average Total Densities for the Burlington Northern, Inc.

	(1) Route-Miles Handling Coal (all existing traffic)		(2) Route-Miles Not Handling Coal (all existing traffic)		(3) Route-Miles for Total System (all existing traffic)		(4) Route-Miles Handling Coal (coal traffic only)	
Density Class	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage
1	1,525	10.43	14,010	83.85	15,535	49.58	8,073	55.20
2	3,155	21.58	1,761	10.54	4,917	15.69	2,065	14.12
3	1,648	11.27	572	3.42	2,220	7.09	1,318	9.01
4	3,325	22.74	135	.81	3,460	11.04	1,133	7.75
5	2,715	18.57	169	1.01	2,884	9.20	1,086	7.43
6	2,254	15.42	62	.37	2,316	7.39	950	6.50
Total	14,622	100.00	16,709	100.00	31,332	100.00	14,625	100.00
Average density (NTM/RM)	9,433,966		671,782		4,790,393		5,038,578	

Note: Class 1 < 1 million GTM/RM, Class 2 < 1-5 million GTM/RM, Class 3 < 5-10 million GTM/RM, Class 4 < 10-20 million GTM/RM, Class 5 < 20-30 million GTM/RM, and Class 6 > 30 million GTM/RM.

Source: 1981 and 1982 ICC waybill sample flowed over the FRA network model.

railroads. Complementing this revenue-producing capability is the impact of coal on the cost structure of the railroads. Because railroads exhibit important economies of density, high coal volumes can improve profitability by reducing average costs.

Second, the study has important implications for actual railroad investment and disinvestment policies. Referring again to Table 11, route-miles with coal traffic have substantially higher traffic-densities than do lines without coal traffic. A vast majority of low-density lines do not carry coal. These lines represent 81,000 route-miles out of 95,000, or 85 percent of the lines classified as having traffic densities of 1 million GTM/RM or less (Class I). On the other hand, 63 percent of the lines with coal are in the highest four density classes, and only 10 percent of the non-coal-carrying lines are in these four classes.

Moreover, average traffic densities are six times higher for lines with coal traffic than for lines

TABLE 15 Statistics on Route-Miles by Density Class and Average Total Densities for the Consolidated Rail Corporation

	(1) Route-Miles Handling Coal (all existing traffic)		(2) Route-Miles Not Handling Coal (all existing traffic)		(3) Route-Miles for Total System (all existing traffic)		(4) Route-Miles Handling Coal (coal traffic only)	
Density Class	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage	Route-Miles	Percentage
1	1,908	21.87	11,793	92.31	13,700	63.72	4,635	53.10
2	2,549	29.21	684	5.35	3,233	15.04	2,935	33.63
3	871	9.98	182	1.42	1,053	4.90	704	8.07
4	1,016	11.64	34	.27	1,050	4.88	377	4.32
5	529	6.06	54	.42	583	2.71	77	.88
6	1,853	21.24	29	.23	1,882	8.75		.00
Total	8,726	100.00	12,776	100.00	21,501	100.00	8,728	100.00
Average density (NTM/RM)	6,774,088		315,802		2,896,784		1,402,474	

Note: Class 1 < 1 million GTM/RM, Class 2 < 1-5 million GTM/RM, Class 3 < 5-10 million GTM/RM, Class 4 < 10-20 million GTM/RM, Class 5 < 20-30 million GTM/RM, and Class 6 > 30 million GTM/RM.

Source: 1981 and 1982 ICC waybill sample flowed over the FRA network model.

without and almost twice that of the system as a whole. The comparison is even more striking for the major coal-hauling railroads. For example, BN's system average traffic density is 4.79 million NTM/RM (Table 14) compared with a U.S. railroad average of 3.67 million. Furthermore, BN's average density for lines with coal is 14 times higher than for route-miles without coal.

Given the importance of economies of density, rail management has strong incentives to build its plant around high-volume core routes, which for many railroads are largely synonymous with their coal routes. At the same time it is recognized that noncoal traffic can and has historically yielded high densities. These core routes in most cases represent the best maintained and engineered corridors. However, management also has strong incentives to invest in facilities that handle noncoal traffic as long as this traffic relies heavily on the coal core. Such a multiproduct service approach allows for a larger, more diverse traffic base, which can ensure greater utilization of the fixed plants. It also reduces the vulnerability of the railroads to minor shifts in coal or other traffic. Comparing Columns 1 and 4 of Table 11, it can be seen that the addition of noncoal traffic to coal lines more than triples average traffic density and significantly reduces the percentage of lines operating below minimal efficient density. This is also true of the four coal-carrying railroads in Tables 12-15.

Coal may also be expected to influence railroad management's decisions on abandonment. Most of the low-density noncoal lines may ultimately be in danger of abandonment. Such abandonment will not occur immediately because many of these lines may yield a higher return as going concerns than they would if abandoned and sold. However, as these lines deteriorate, maintenance may be reduced to minimal levels until the lines are no longer serviceable. Thus abandonment may likely be stretched out over time as railroads focus on their high-density corridors.

The investment implications of this study also relate to shippers of captive coal. As discussed previously, the ICC's coal rate guidelines prescribe SAC as a basis for determining maximum reasonable rates. The analysis presented in this paper demonstrates that publicly available data such as the waybill sample can be used to develop first-order approximations of route-mile densities and the SAC of serving that system. Such preliminary analyses are relatively inexpensive and can yield information on important questions such as (a) How would densities on the proposed stand-alone system compare with current system densities? (b) How would stand-alone costs compare with system average costs to the extent that traffic densities influence cost? (c) How much grouping of traffic is necessary to achieve minimum efficient density and the accompanying low costs? The results of such a preliminary analysis would be useful in determining whether a full-blown stand-alone analysis is justified and in identifying cost and traffic data that can be used in the detailed study.

This study clearly demonstrates the importance of grouping in computing SAC. A comparison of Columns 1 and 4 of Table 11 shows the importance of including noncoal traffic in the stand-alone system. These data can be viewed as representative of a stand-alone coal system for the U.S. rail system as a whole, with extremes on retention and exclusion of noncoal traffic. In other words, Column 1 assumes 100 percent traffic retention, and Column 4 assumes a coal-only system. As can be seen, the addition of noncoal traffic to coal lines more than triples average density, significantly reducing the percentage of lines operating below minimal optimal scale. This means that issue traffic's share of SAC in a rate proceeding will be substantially reduced by grouping coal and noncoal traffic.

Depending on the retention of noncoal traffic, a coal system's density would be within the 2.2 to 6.6 million NTM/RM range shown in Columns 1 and 4. This suggests that typical densities on stand-alone systems would be comparable with the average density on the current system (3.6 million NTM/RM for the United States) or even above that level. To illustrate, if half of the traffic were retained, the stand-alone system density would be 4.5 million NTM/RM.

For the major coal-hauling railroads, stand-alone densities are likely to be higher than the national system average. For example, BN's traffic density would range from 5.0 million NTM/RM with no noncoal traffic to 9.4 million NTM/RM with total traffic retention. Furthermore, under the coal rate guidelines, shippers could select the least cost and highest density system that carries their coal.

Clearly, stand-alone systems would be selected on the basis of traffic densities instead of on the basis of coal-only lines. There is evidence that traffic densities of lines that carry coal would generally be greater than current system densities and that SAC, to the extent densities are a factor, would be below current system average costs.

In summary, the results of the analysis have similar implications for both railroads and shippers. By rationalizing their systems, concentrating on high-density lines over which coal travels, railroads can lower the cost of providing service to the extent that increased traffic densities produce cost economies. Shippers, in developing stand-alone systems, also have every incentive to maximize cost economies by grouping traffic and raising the stand-alone systems' density. Finally, the analysis points to a readily available procedure and data base for determining line segment densities. These estimates can be used by the railroads in formulating their investment policies and by the shippers in fabricating their stand-alone systems.

CONCLUSION

The importance of coal to the rail industry has been established. The prominence of coal in total revenue contribution leaves no doubt as to the role it plays in the financial health of the industry. The impact that coal has on line segment densities is also pronounced. Lines that carry coal have approximately three times the average density of those lines that do not carry coal.

The implications of coal revenue contributions and traffic densities for railroad and shipper strategies have also been explored. Given that costs are a function of density, line segment densities will have a substantial impact on railroad investment decisions. With the adoption of ICC maximum rate guidelines and the SAC constraint contained therein, shippers should choose their stand-alone systems on the basis of traffic densities.

REFERENCES

1. Railroad Deregulation: Impact on Coal. Energy Information Administration, U.S. Department of Energy, 1983.
2. Critical Issues in Coal Transportation Systems. Maritime Transportation Research Board, National Research Council, Washington, D.C., 1979.
3. S.A. Desai and J. Anderson. Rail Transportation Requirements for Coal Movements in 1980. U.S. Department of Transportation, April 1976.

4. G. Elmes. Coal Transportation: An Undervalued Aspect of Energy Modeling? Transportation Research, Vol. 18A, No. 1, 1984.
5. J.N. Heller. Coal Transportation and Deregulation. The Energy Bureau and Serif Press, 1983.
6. F.J. Beier. Electric Utilities and the Movement of Coal. Transportation Journal, Vol. 21, No. 4, Summer 1982.
7. Coal Rate Guidelines--Nationwide. ICC interim decision issued Feb. 1983, final decision issued Sept. 1983.
8. S. Fine and R. Owen. Documentation of the ICC Waybill Sample. Office of Policy and Analysis, Interstate Commerce Commission, Nov. 1981.
9. Z. Griliches. Cost Allocation in Railroad Regulation. Bell Journal of Economics, Vol. 3, Spring 1972.
10. T.E. Keeler. Railroads, Freight and Public Policy. Brookings Institution, Washington, D.C., 1983.
11. R.G. Harris. Economics of Traffic Density in the Rail Freight Industry. Bell Journal of Economics, Vol. 8, No. 2, Autumn 1977.
12. A.F. Friedlaender and R.H. Spady. Equity, Efficiency and Resource Rationalization in the Rail and Regulated Trucking Industries. Massachusetts Institute of Technology Press, Cambridge, 1980.

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Factors That Determine Mode Choice in the Transportation of General Freight

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ABSTRACT

This study examines the factors that influence the mode choice decisions of shippers of general freight commodities in the Atlantic provinces of Canada. The study employed a mail-response questionnaire directed to randomly selected manufacturers to determine the basis of each firm's decision to ship by its regular mode. Respondents were required to identify the product shipped most frequently by the firm and the most regular origin-destination link. They were then required to provide pertinent details, such as transit time, shipping costs, and frequency of shipments, relating to the shipment of that product on the identified origin-destination link. Linear logit models were used to determine the variables that influence the selection of various modes for goods shipments and the relationship between the utility of each mode and the explanatory variables. The models obtained were as intuitively expected. It is concluded that logit analysis using survey data represents a valid and potentially more useful methodology than the use of waybill data. It is recommended that further research using the suggested model forms and data obtained from personal interviews of shippers would improve the quality of the results and provide a greater understanding of the shipper mode choice decision process.

Freight transport carriers in Canada face two serious challenges. One is the slowdown in growth of the freight transport market over the next two decades, as predicted in a paper published by Transport Canada (1, p.i). It is stated in the paper, however, that during the 1980s this growth rate is expected to drop to about 3 percent annually. The reasons given for this lower rate of growth include "a slower pace of economic growth, higher energy costs, higher labor income relative to productivity increases, and relatively fewer technological gains, which could otherwise reduce prices and lower costs."

The other challenge is deregulation of the freight transport market. These challenges will take the form of increasing competition for a slow-growing market. The major problem facing carriers, therefore, under the twin threats of economic and regulatory instability, is the determination of the combinations of service and price that specified categories of shippers would find acceptable for the shipment of their goods.

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The objectives of this research are

1. To determine the factors that affect the mode choice decisions of shippers of general freight commodities and the relationship between the service attributes offered by a mode and the utility of that mode to shippers and
2. To determine if survey rather than waybill data can be used to study the mode choice decisions of shippers of general freight commodities.

DATA

Previous studies of modal choice in freight transportation have used the data recorded on freight waybills or the same data compiled in data banks. The advantage of using this type of data is that much of the information, such as freight rate and transit time, is precisely recorded and the explanatory variables, therefore, do not have appreciable measurement errors. Unfortunately, however, there are a number of problems with waybill data, some of which are

1. Waybills usually record only a few system variables and supply no information about the level of service attributes and the way shippers view those service attributes. The data are therefore unsuitable for a behavioral analysis of all the probable factors affecting mode choice.
2. Many of the data items recorded on waybills are difficult to integrate and use because of differences in recordkeeping among the various modes with respect to commodity classification, units of measurement, and so forth.
3. Shippers generally consider the information on their waybills sensitive and tend to refuse to release their waybills for research purposes.

The alternative to using waybill data is to carry out a survey of shippers. There are two main problems with this method. First, the survey procedure itself is subject to a number of errors. The errors that generally occur in surveys are discussed in detail by Deming (2). Sources of error in surveys conducted in the area of behavioral travel research are treated by Wermuth et al. (3). Second, it is argued that the variables obtained in a survey are imprecise because there are sometimes differences between the actual values of the variables and the values perceived by shippers.

The advantage of surveys is that it is possible to obtain the views of the shippers about as many choice-influencing variables as are considered appropriate for the study in question. The errors inherent in the survey procedure can be minimized by careful attention to the questionnaire design and sampling techniques. Even the difference between perceived and actual values of the variables on the part of shippers need not be a disadvantage. It is argued that because shippers base their decisions on their perceptions of the attributes of the various modes, the perceived variables are the correct ones to use.

For these reasons, it was decided to use a survey to obtain information on individual shipments from a sample large enough to be representative of the shipping population in the Atlantic provinces. A mail-response survey was selected over personal and telephone interviews as the most realistic means of collecting data for this research given the financial, time, and accuracy constraints. The survey was conducted in September 1984. A sample of randomly selected manufacturing industries based in the Atlantic provinces was surveyed to determine the basis of each shipper's decision to use its preferred mode for goods shipments. Respondents were required to identify their main product and their most important origin-destination (O-D) link and then to answer a number of questions about the shipment of that commodity on the listed O-D link. The main product was defined in this research as the product that the company ships most frequently. The breakdown of returns into mode choices is as follows:

Mode	Number	Percentage
Hired trucks	66	51.56
Private trucks	41	32.03
Rail	10	7.81
Mail	6	4.69
Air	4	3.12
Ship	1	0.78

ANALYSIS

The factors that influence the mode choice decisions of shippers may be roughly classified into four groups: characteristics of the transportation system, characteristics of the shipment, characteristics of the local carriers, and characteristics of the shipper. The variables introduced into some or all of the models calibrated are given in the following subsections.

Characteristics of the Transportation System

C = shipping cost per pound of the commodity on the defined O-D link;
T = transit time in days from departure at origin to arrival at destination;
D = in-transit damage or loss in cents per pound of commodity shipped; and
R = reliability of transit time delivery, defined as the percentage of time that shipments are judged to have arrived at the destination early or on time.

Characteristics of the Shipment

F = frequency of shipment of commodity on specified O-D link,
V = market value per pound of the commodity, and
S = shipment size in pounds.

Characteristics of the Carriers

A = 1 if the shipment tracing capability of the carrier is considered important in the choice of the mode and
= 0 otherwise,
P = 1 if cooperation between shipper and carrier personnel is considered important in the choice of the mode and
= 0 otherwise,
G = 1 if the geographic coverage offered by the carrier is considered important in the choice of the mode and
= 0 otherwise, and
K = 1 if pickup services are provided by the carrier and
= 0 otherwise.

Characteristics of the Shipper

W = 1 if the shipper has reviewed the mode of transportation of the commodity within the past 12 months and
= 0 otherwise, and
E = experience of the shipper in years.

Derived Variables

C_m = shipping cost/commodity value derived from the hypothesis that the degree of importance of shipping cost to a shipper has an inverse relationship with the value of the commodity;

T_m = frequency of shipment times transit time, derived from the hypothesis that the perception of the importance of transit time is related to the frequency of shipment; and

R_m = frequency of shipment times reliability, derived from the hypothesis that the perception of the importance of reliability of transit time delivery is directly related to the frequency of shipment of the commodity.

Models

The analysis was performed using linear logit models of the form

$$P_m = \exp U_m / \Sigma_N \exp U_n \qquad n = 1, \ldots, N \qquad (1)$$

where

P_m = probability of choice of mode m,
U_m = utility of mode m, and
N = number of modes.

Therefore,

$$P_H = \exp U_H / (\exp U_H + \exp U_P + \exp U_R) \qquad (2)$$

$$= 1/[1 + \exp(U_P - U_H) + \exp(U_R - U_H)] \qquad (3)$$

Similarly,

$$P_P = 1/[1 + \exp(U_H - U_P) + \exp(U_R - U_P)] \qquad (4)$$

and

$$P_R = 1/[1 + \exp(U_P - U_H) + \exp(U_R - U_H)] \qquad (5)$$

U_H, U_P, and U_R are utility functions determined using maximum likelihood estimation procedures and are expressed as

$$U_m = \alpha_0 + \sum_{j=1}^{n} \alpha_j X_j \qquad (6)$$

where

α_0, α_j = parameters determined by maximum likelihood estimation procedures and
X_j = explanatory variables.

It was noted that in-transit damage and commodity value are highly correlated and may not be used in the same model because of multicollinearity problems. Two alternative forms of a model that contains the direct explanatory variables are therefore tested; the only difference between the two models is the alternative specifications of in-transit damage and commodity value. A third model is specified using the derived variables instead of the corresponding direct variables. The three model specifications are as follows:

Model 1a

$$\begin{aligned} U_m = {} & \alpha_0 + \alpha_1 C + \alpha_2 T + \alpha_3 D + \alpha_4 R \\ & + \alpha_5 S + \alpha_{16} F + \alpha_6 E + \alpha_7 A \\ & + \alpha_8 G + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \end{aligned} \qquad (7)$$

Model 1b

$$\begin{aligned} U_m = {} & \alpha_0 + \alpha_1 C + \alpha_2 T + \alpha_{12} V + \alpha_4 R + \alpha_5 S \\ & + \alpha_{16} F + \alpha_6 E + \alpha_7 A + \alpha_8 G \\ & + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \end{aligned} \qquad (8)$$

Model 2

$$\begin{aligned} U_m = {} & \alpha_0 + \alpha_{13} C_m + \alpha_{14} T_m + \alpha_{15} R_m + \alpha_3 D \\ & + \alpha_5 S + \alpha_6 E + \alpha_7 A + \alpha_8 G \\ & + \alpha_9 P + \alpha_{10} K + \alpha_{11} W \end{aligned} \qquad (9)$$

Three sets of computations of P_M are made; in each set the three alternative specifications of U_M are used. The statistical properties of each set of computations and comparisons of the signs of parameter coefficients with expected shipper behavior are used to determine which factors best explain the choice of each mode.

RESULTS

The results of the model calibrations are presented in this section. For each model specification, the variables found to be significant in influencing the choice of that mode and associated statistics are presented. In all cases, the two alternative specifications of Model 1 produced identical results because neither in-transit damage in Model 1a nor commodity value in Model 1b was found to be significant.

Hired Truck

The variables that are significant for the choice of hired truck and model statistics are given in Tables 1 and 2. The results of the model calibrations for the hired truck mode are

1. For Model 1, the signs of the parameters for those variables significant in explaining the choice of the hired truck mode are as expected. The parameter estimates for transit time and frequency have negative values, confirming that the utility of the mode decreases with increasing transit time and with increasing frequency of shipment. Similarly, the positive signs for the parameter estimates of pickup and cooperation indicate as expected that the utility of the hired truck mode increases with greater cooperation between shipper and carrier personnel and

TABLE 1 Variables That Are Significant for Choice of Hired Truck

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	0.115	0.277	0.17	
Frequency	α_{16}	-1.006	0.469	4.61	-0.121
Transit time	α_2	-1.142	0.338	11.41	-0.231
Cooperation	α_9	0.682	0.303	5.08	0.132
Pickup	α_{10}	1.845	0.334	30.59	0.402
Model 2					
Intercept	α_0	0.379	0.300	1.59	
Frequency x time	α_{14}	-1.271	0.355	12.82	-0.247
Tracing	α_7	-0.594	0.320	3.44	-0.090
Cooperation	α_9	1.029	0.353	8.51	0.192
Pickup	α_{10}	1.911	0.343	30.96	0.405

TABLE 2 Model Statistics for Hired Truck

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	89.53	4	0.000	0.670	All signs correct
2	85.31	4	0.000	0.687	One sign incorrect

also when pickup services are provided by the carrier.

2. For Model 2, the signs of the parameters of most significant variables are as expected, except for the parameter for the variable tracing. The negative sign for the parameter appears to indicate that the greater the shipment-tracing capability of the carriers, the lower the utility of the mode to shippers. This is contrary to expected shipper behavior.
3. The P-values indicate that the hypothesis of independence between the probability of choice of the hired truck mode and the explanatory variables of the model may be safely rejected. The t-values and partial R-values are higher for most of the variables in Model 2 than for the corresponding values for Model 1, which indicates that the parameter estimates for Model 2 are slightly better.
4. The R-value for Model 2 is slightly higher than the corresponding value for Model 1, but statistically there is not much difference in goodness-of-fit between Model 1 and Model 2.

All the statistics associated with the variables and with the two models indicate that Model 2 is slightly better than Model 1 at explaining the factors that influence the choice of the hired truck mode. However, the dominant feature in the validity of the two models is the incorrect sign of the parameter for the tracing variable in Model 2, which leads to conclusions that are contrary to expected shipper behavior. Therefore, better statistics notwithstanding, Model 2 is on the whole less satisfactory than Model 1 in explaining the factors that influence the choice of the hired truck mode and is rejected. The model that explains the variables that influence the choice of the hired truck mode is, therefore, given by

$$U_H = 0.277 - 1.006\ F - 1.142\ T + 0.682\ P = + 1.845\ K$$

Private Truck

The variables that are significant for the choice of private truck and model statistics are given in Tables 3 and 4. The results of the model calibrations for the private truck mode are

1. For both Model 1 and Model 2 the signs of the parameters of the variables that influence the choice of private truck are as intuitively expected. The negative sign for transit time indicates that the attractiveness of the private truck mode decreases with increasing transit time, and the positive sign for frequency indicates that the utility of the mode increases with increasing frequency of shipment. The signs of the parameters for derived transit time and derived reliability are also as expected.
2. The P-values indicate that the hypothesis of independence between the choice of private truck and the explanatory variables of the model can be safely rejected.

TABLE 3 Variables That Are Significant for Choice of Private Truck

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	-1.032	0.255	16.32	
Frequency	α_{16}	0.642	0.318	4.09	0.114
Transit time	α_2	-1.219	0.426	8.20	-0.196
Model 2					
Intercept	α_0	-0.839	0.221	14.43	
Frequency x time	α_{14}	-0.973	0.395	6.08	-0.159
Frequency x rely	α_{15}	1.253	0.391	10.25	0.227

TABLE 4 Model Statistics for Private Truck

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	137.43	2	0.000	0.345	All signs correct
2	141.31	2	0.001	0.308	All signs correct

Statistically, Model 1 performed slightly better than Model 2 in explaining the variables that influence the choice of private truck as the preferred freight transport mode. However, on an intuitive level, it may be noted that Model 2 demonstrates the influence of one additional variable the effect of which is not shown by Model 1: reliability of transit time. For the purposes of this research, therefore, Model 2 has a greater explanatory power than does Model 1 and is selected as the model better capable of indicating the factors that influence the choice of the private truck mode. Model 2 is presented as

$$U_P = -0.839 - 0.973\ T_m + 1.253\ R_m$$

Rail

The variables that are significant for the choice of rail and model statistics are given in Tables 5 and 6. The results of the model calibrations for the rail mode are

1. It is observed from Model 1 that the signs of all of the parameters of the variables that influence the choice of the rail mode are as intuitively expected. The parameters for the variables pickup and

TABLE 5 Variables That Are Significant for Choice of Rail

Variable	Parameter	Estimate	Standard Error	t-Value	R-Value
Model 1					
Intercept	α_0	-3.602	0.708	25.87	
Time	α_2	1.038	0.330	9.91	0.336
Tracing	α_7	0.590	0.334	3.13	0.127
Pickup	α_{10}	1.036	0.588	3.11	0.126
Model 2					
Intercept	α_0	-3.120	0.507	37.92	
Frequency x time	α_{14}	0.811	0.258	9.91	0.336
Tracing	α_7	0.894	0.340	6.92	0.265

TABLE 6 Model Statistics for Rail

Model	-2 Log L	Degrees of Freedom	P	R-Value	Signs
1	49.48	3	0.001	0.458	All signs correct
2	54.11	2	0.003	0.415	All signs correct

tracing are both positive, which indicates that these variables have a positive effect on the probability of choice of the rail mode. The positive parameter for transit time implies that as shipping distances (for which transit time is serving as a proxy) increase, the attractiveness of the rail mode increases. This result is consistent with the observed shipper behavior. Similarly, the signs of the parameters of derived transit time and shipment tracing capability in Model 2 are consistent with expected shipper behavior.

2. The P-values indicate that the hypothesis of independence between the probability of choice of the rail mode and the values of the explanatory variables in the models may be safely rejected.

The statistics associated with Model 1 and Model 2 indicate that the two models have approximately equal power to explain the factors that influence the choice of the rail mode. However, Model 1 has one more degree of freedom than does Model 2 and is considered the better model. The model that best explains the factors that affect the choice of the rail mode, therefore is

$$U_R = -3.602 + 1.038\ T + 0.590\ A + 1.036\ K$$

Discussion of Results

The results from the research show that the variables that influence the choice of the hired truck mode are frequency of shipment, transit time, provision of pickup services, and cooperation between shippers' and carriers' personnel. The partial R-values for the variables indicate that the single most important factor, which accounts for almost half of the explanatory power of the model, is the provision of pickup services. The other significant variables in order of decreasing importance are transit time, cooperation, and frequency.

The factors that influence the decision to use private truck are the derived variables for transit time and reliability of transit time. The t-values of the significant variables indicate that the intercept term makes the highest contribution to the explanatory power of the model, followed in order by derived reliability and derived transit time.

It is pertinent in this context to discuss the significance of the intercept term. The intercept term accounts for other nonquantifiable variables (such as personal biases and prestige value) that affect the mode choice decision but that are not included in the model. Hence the intercept term approaches zero as more of the significant factors are included in the model and reduces to zero when all factors that affect the mode choice decision are accounted for in the model. That the intercept term in the private truck model makes the highest contribution to the explanatory power of the model implies that the most important factors influencing the decision to use private truck have not been identified in this research and may, indeed, not be quantifiable. Of the quantifiable factors, the importance of the derived variables for reliability and transit time in the mode choice decision are exactly as intuitively expected.

The important factors that influence the choice of the rail mode are transit time, shipment tracing capability of the carriers, and provision of pickup services. The t-values indicate that the highest contribution to the explanatory power of the model defining the utility of the rail mode is provided by the intercept term, followed in order by transit time, shipment tracing capability, and provision of pickup services. Again, the implication here is that factors other than those included in the model heavily influence the decision to use rail. The signs of the parameters of all of the significant variables are as intuitively expected.

In most cases statistics associated with the two model forms tested were within the same value ranges. On an intuitive level, Model 1 is the better specification because it shows the correct signs on all parameters of significant variables for all modes whereas Model 2 produces an incorrect sign for the shipment tracing variable for the hired truck mode. However, Model 2 better demonstrates the importance of frequency of shipment and reliability of transit time in the decision to use private truck. It may be recalled that the derived variables were obtained from the hypothesis that shippers' perceptions of the importance of transit time and reliability are influenced by the frequency of shipment of the commodity. The results appear to indicate that this hypothesis may be valid. It is observed from the results for the private truck mode that, although reliability by itself was not significant in explaining the choice of the mode, the derived variable frequency times reliability was the more important of the two significant quantifiable factors.

Shipping cost was not found to significantly influence the choice of any mode. This result is somewhat unexpected. The lack of significance of the cost variable may be attributed to one or more of the following factors:

1. The commodities in the survey are not sensitive to transportation cost.
2. There are measurement errors in the cost variable because of lack of precision in the cost information supplied by respondents to the questionnaire.
3. The cost variable is improperly specified. It has been suggested that an alternative specification of the cost variable (such as cost per ton-mile rather than the cost per pound used in this study) might have produced different results. This is a valid point and should be considered by subsequent researchers in this area.

In-transit damage was found to be not significant in all the models. This result is not entirely unexpected. Examination of the data shows that a majority of respondents (68 percent) indicated that no damage or loss occur to their commodities while in transit. Of those who indicated some commodity damage, a large number provided damage estimates that were comparatively small.

Commodity value was rejected in most models because it had limited dispersion. This effect also caused the relative cost derived variable to be rejected in all models. It is not obvious from the data why commodity value has limited dispersion because a large variety of commodities is included in the sample. A possible explanation of this result could be the lack of precision in the values of the variable supplied by respondents.

In many previous surveys of shippers, reliability of transit time was ranked near the top of the list of factors that influence mode choice. The results of this research show reliability to be especially significant in the decision to use private truck, but it does not appear to influence the choice of any other mode.

Meaningful models could not be produced for the air and mail modes because of limited observations of these modes in the sample.

CONCLUSIONS

The conclusions of this research and some recommendations for further research are

1. Shippers choose different modes for different reasons. The single factor that appears to affect the choice of all modes is transit time, which showed an inverse relationship with the utility of the truck modes and a direct relationship with the utility of the rail mode. This indicates that, as length of haul increases, shippers would, ceteris paribus, tend to move away from the use of truck and toward the use of rail. This result is consistent with observed shipper behavior.
2. Frequency of shipment showed an inverse relationship with the utility of the hired truck mode and a direct relationship with the utility of the private truck mode. This implies that as frequency of shipment increases shippers would, ceteris paribus, tend to move away from the use of hired truck and toward the choice of private truck. This result is as intuitively expected.
3. Reliability proved important only in influencing the decision to use private truck. This implies that for-hire carriers may be able to influence the private versus for-hire decision of shippers by reorganizing their operations to emphasize reliability of transit time delivery and providing greater frequency of service.
4. Shipping cost was not found to be significant in influencing the choice of any of the modes. This unexpected result may be true, or it may have been caused by lack of precision in the cost data supplied by respondents or by an improper specification of the cost variable. Further research on this point is needed.
5. In-transit damage and commodity value were found to have limited dispersion and proved to be not significant in influencing the choice of any mode. This result for in-transit damage is borne out by an examination of the data, but it is not immediately apparent for commodity value.
6. Several level-of-service variables significantly affect the mode choice decision. Provision of pickup services appears to be the most important factor influencing the choice of hired truck, cooperation between shipper and carrier personnel has some influence in the decision to use hired truck, and the shipment-tracing capability of carriers is one of the important factors influencing the choice of rail.
7. Factors that do not appear to have any influence on mode choice include the shipper's experience, the extent of the geographic coverage offered by the carrier, and whether the shipper has reviewed the mode of transportation within the past 12 months.
8. The perceptions of the importance of reliability and transit time by shippers are influenced by the frequency of shipments. Investigations of the mode choice decision should therefore employ the derived variables rather than the direct variables if frequency of shipment is not itself a direct variable in the model.
9. For both the private truck and rail modes the intercept terms had the highest explanatory power, which implies that factors not identified in the research have significant influence on the choice of these modes. It is not immediately apparent whether these unknown factors are purely unquantifiable ones or whether they also include the effects of those variables that were rejected because of either lack of precision in the data or incorrect specification.
10. Disaggregate models of freight transport modal choice can be calibrated using survey data. However, this research indicates that a mail-response questionnaire may not be a good data collection method because of lack of response from shippers and possible lack of precision in the values of the variables.
11. It is recommended that the freight transport modal choice decision be modeled along the lines suggested in this research but using personal interview data, which, in addition to ensuring adequate sample sizes, provide a higher level of accuracy in the measurable factors. Personal interviews would also make possible the exploration of unknown factors that appear to significantly affect the decision to use private truck and the decision to use rail.

REFERENCES

1. Canadian Freight Transportation System Performance and Issues: A Discussion Paper. Transport Canada, Ottawa, Ontario, Vol. 1, 1981.
2. W.E. Deming. Some Theory of Sampling. Dover Publications, New York, 1980.
3. P. Stopher, A. Meyburg, and W. Brög, eds. New Horizons in Travel Behavior Research. Lexington Books, Lexington, Mass., 1981.

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Distributing Nonstorable Items Without Transshipments

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ABSTRACT

The research reported in this paper attempted to find optimal strategies for distributing items from one depot to many demand points without transshipments and within a limited amount of time. The objective was to find a near optimal partition of the region supplied by the depot into districts (the zones containing the points visited by one delivery route) and corresponding shipment sizes and costs. Initially, the average distribution cost per demand point on a single delivery route was studied using expressions that relate route length to the dimensions of a delivery district. Two routing strategies were considered: one that generates tours with nearly minimal local distance per point and another that generates tours with nearly minimal line-haul distance per point. Formulas were derived to estimate the optimal shipment size, district shape, and cost when the strategy yielding the least cost per point is used. Finally, the results were applied to develop guidelines for partitioning a whole supply region into nearly optimal districts; an example is given. For a constant demand density, an optimal district partition of the supply region should have bigger and fatter districts near the depot and smaller and thinner ones along the boundary of the region.

This research focuses on minimizing the cost of distributing nonstorable items (goods that must be delivered within a limited amount of time) from one depot to many demand points without transshipments. The distribution costs considered include driver wages, vehicle depreciation, and operating cost. Examples include not only perishable goods (fruits, vegetables, etc.) but also newspapers and parcels delivered through express mail or other express services.

One-to-many distribution problems with multiple tours (routes) are usually known as "single depot vehicle routing" problems. Substantial literature exists on minimizing transportation costs for vehicle routing problems [see Turner, Ghare, and Fourds (1) and Golden, Magnanti, and Nguyen (2) for a review]. Existing vehicle routing methods include the savings algorithm developed by Clarke and Wright (3), the "cluster first, route second" method by Tyagi (4), the sweep algorithm by Gillett and Miller (5), and the "seed first, route second" algorithm by Fisher and Jaikumar (6). These earlier works, however, are not concerned with the time required for delivery; they do not apply to the distribution of nonstorable items.

This analysis starts with a single delivery district (i.e., the area containing all demand points served by a single vehicle route). The district is assumed to be rectangular. The spatial density of demand points rather than their exact locations is considered. This eliminates the need to specify a network and allows detailed routing arrangements to be ignored.

The dual-strip strategy, a routing strategy that can generate tours of nearly minimal distances (7), is considered first. For this routing strategy, the district dimensions and shipment size that minimize the average distribution cost per point are derived. The optimal cost per point consists of three components: first, the per stop cost; second, the average local operating cost, which depends on the local distance traveled per point; and third, the average fixed-plus-line-haul cost, which depends mainly on the distance from the district to the depot and on the shipment size (or the number of points served by the vehicle). Because the dual-strip routing strategy yields a nearly minimal average local distance per point, it is appropriate for use when the local operating cost is the major component of the total delivery cost.

An alternative routing strategy, the single-strip strategy, is also considered. Although this strategy yields longer distances, it allows a nearly maximal number of points to be served within a given amount of time and reduces the line-haul cost per point. Thus it is preferred when the average fixed-plus-line-haul cost is the major component of the total delivery cost.

Comparison of the delivery costs of the two routing strategies shows that dual-strip routing should be applied when the delivery district is close to the depot (or, more precisely, if the local operating cost is larger than one-half of the fixed-plus-line-haul cost). Otherwise, single-strip routing is preferred. Then the overall optimum shipment size, district shape, and cost for the best of the two routing strategies in any given situation are derived.

The results are applied to develop guidelines for partitioning a large region supplied by one depot into nearly optimal districts. An example, in which a circular region that contains more than 1,000 points is partitioned into more than 100 districts, is given to demonstrate how the guidelines can be used.

The formulas developed in this paper can be used for sensitivity analysis. This is illustrated in the final section in which the cost impacts of changes in available delivery time, vehicle speed, and vehicle capacity are analyzed and discussed.

SINGLE DELIVERY DISTRICT

Assume that on any given day items must be delivered to demand points (customers) that are independently

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and randomly scattered in a region. On the next day (or after any other operation cycle), whether or not the number and location of the customers stay the same, service must be provided again. Distribution strategies are derived for one day; the strategies may or may not change daily.

Situations in which the density of customers (δ) varies spatially but is nearly constant within each delivery district are considered. Furthermore, it is assumed that the same number of items is required at all demand points and that the items to be distributed on a given day become available simultaneously at the depot. At that time the locations of all the customers (for that day) are known and distribution begins. Each vehicle must visit all customers in its district within a limited amount of time (τ_0) after the beginning of distribution. It is also assumed that vehicles are large enough to hold all the items that can be delivered in time τ_0. Note that, although these assumptions appear to be restrictive, the results of this paper can be applied to situations that are more general than those described here. This will be discussed in the last section of the paper.

Consider a rectangular district of sides ℓ and ℓ' ($\ell' > \ell$), as shown in Figure 1, where the distance between the depot and the gravity center of the district is $\rho[\rho > (\ell'/2)]$. Let

C_0 = fixed cost (per day) of the delivery vehicle;
C_d = delivery vehicle operating cost per unit distance;
L = average route length (i.e., average total distance traveled per day by the delivery vehicle);
D = average distance traveled from the depot to the last delivery point;
S = time consumed at each demand point;
U = average speed of the delivery vehicle;
χ = average number of demand points contained in a square with sides equal to ℓ, $\chi = \delta\ell^2$; and
N = shipment size of the delivery vehicle in terms of the number of demand points visited, $N = \delta\ell\ell'$.

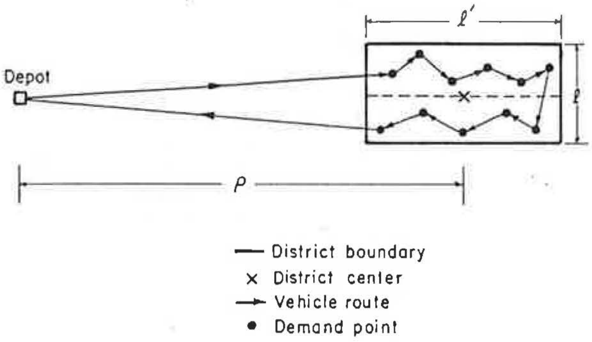


FIGURE 1 Delivery district with dual-strip route.

For the time being, it is assumed that vehicles are large enough that N can be as large as desired. Note that the district dimensions, ℓ and ℓ', can be expressed in terms of N and χ [i.e., $\ell = (\chi/\delta)^{1/2}$ and $\ell' = N/(\delta\chi)^{1/2}$]. N and χ can be thought of as dimensionless indicators of district width and district area. The use of such dimensionless variables, as it will be shown later, allows the development of numerical figures or tables that are applicable to different situations.

The design of the shortest route is not of concern; an attempt is made to find a near optimal partition of the region supplied by the depot into districts (the zones containing the points visited by one delivery route) and the corresponding shipment sizes and costs. Therefore expressions that relate route lengths (i.e., L and D) to district dimensions (in terms of N and χ) will be used when nearly optimal routes are used. Unless otherwise specified, the Euclidean distance will be used throughout this paper.

Early shortest tour length formulas (8,9) did not take district dimensions into account. Expressions that are sensitive to district shape have only been developed recently (7,10).

The routing strategy used by Daganzo (7), termed the "dual-strip strategy" in this paper, yields tours such as the ones shown in Figure 1 in which the rectangular district is divided into two equally wide strips. In each strip the delivery vehicle visits demand points from one end to another without backtracking. Daganzo (7) has shown that the average route length (L) can be expressed as a function of N and χ:

$$L(N, \chi) \cong 2\rho + N\delta^{-1/2}\,\phi(\chi) \qquad \rho > \ell'/2 \tag{1}$$

where

$$\phi(\chi) = (\chi^{1/2}/6) + (1/\chi^{1/2})\left(4/(\chi/4)^2\left\{[(1 + (\chi/4)]\log[1 + (\chi/4)] - (\chi/4)\right\} - 1\right) \tag{2}$$

The two terms in Equation 1 represent the line-haul distance and the local delivery distance, respectively.

Because the last demand point in the delivery district must be covered in time τ_0, the average distance (D) from the depot to the last delivery point has to be derived for the analysis. The difference between D and the whole route length (L), the back-haul distance, is approximately $\rho - \ell'/2 = \rho - N/[2(\delta\chi)^{1/2}]$. Thus,

$$\begin{aligned} D(N, \chi) &\cong L(N, \chi) - \rho + N/[2(\delta\chi)^{1/2}] \qquad \rho > \ell'/2 \\ &= \rho + N\delta^{-1/2}\,\psi(\chi) \qquad \rho > \ell'/2 \end{aligned} \tag{3}$$

where

$$\psi(\chi) = \phi(\chi) + 1/(2\chi^{1/2}) \tag{4}$$

The object now is to minimize the average cost of serving one demand point, that is,

$$c(N, \chi) = [C_0 + C_d L(N, \chi)]/N \tag{5}$$

Because this expression decreases with N, N should be chosen to be as large as possible. It has been assumed that vehicle capacity does not restrict N; however, the time constraint does. The number of stops should satisfy the following delivery time constraint:

$$NS + [D(N, \chi)]/U \leqslant \tau_0 \tag{6}$$

The left side of this inequality increases with N. Consequently, the optimum (minimum) cost (c*) is obtained when N is so large that no more demand points can be visited within time τ_0. If N is approximated by a continuous variable, it should satisfy Equation 6 strictly:

$$NS + [D(N, \chi)]/U = \tau_0 \tag{7}$$

Thus substituting Equation 3 for $D(N,\chi)$ in Equation 7, and solving for N, the optimal shipment size (N) is obtained for a given zone width (χ):

$$N(\chi) = (\tau_0 - \rho/U)/[S + \delta^{-1/2}\ \psi(\chi)/U] \qquad \rho < U\tau_0 \tag{8}$$

In this expression the numerator and the denominator can be interpreted, respectively, as the time available for local delivery and the average time required to cover one demand point.

Before expressing the cost (c) as a function of χ, let us define the following dimensionless constant:

$$g = (C_0 + 2\rho C_d)/[(U\tau_0 - \rho)\ C_d] \qquad \rho < U\tau_0 \tag{9}$$

The term $U\tau_0 - \rho$ can be visualized as the maximum local distance that can be traveled within time τ_0; it will be called the local range. The parameter g thus can be interpreted as a ratio between the fixed-plus-line-haul cost and the operating cost required to cover the local range. If the fixed cost is considered a part of the line-haul expenses, g can legitimately be called the line-haul-to-local cost ratio. Note that g increases to infinity as ρ approaches $U\tau_0$ because then the local range (and the local cost) goes to zero. The line-haul-to-local cost ratio thus also indicates the district's distance from the depot.

The optimal cost per item [$c(\chi)$] is obtained by replacing N in Equation 5 by Equation 8. It can be written as

$$c(\chi) = C_d USg + C_d\delta^{-1/2}\ [\phi(\chi) + g\psi(\chi)] \tag{10}$$

As shown by this equation, the average cost per item has three components. The first, C_dUgS, is the portion of fixed-plus-line-haul cost per item associated with the time lost at one stop; fewer items can be carried in the time allowed because of this lost time. The second component, $C_d\delta^{-1/2}\phi(\chi)$, is the local vehicle operating cost per point and is proportional to the local distance traveled per point, $\delta^{-1/2}\phi(\chi)$. The third cost term, $C_d\delta^{-1/2}g\psi(\chi)$, is similar to the first; it is the portion of fixed-plus-line-haul cost per point that arises because vehicles do not travel infinitely fast and can only carry a finite number of items.

The problem now becomes one that has a single decision variable, χ. The optimal width, χ^*, is the one that minimizes $c(\chi)$ in Equation 10 or, simply, $f(\chi) = \phi(\chi) + g\psi(\chi)$. Let χ_1 and χ_2 be the solutions that minimize $\phi(\chi)$ and $\psi(\chi)$, respectively: $\chi_1 = 6.7$ and $\chi_2 = 9.2$.

Although a delivery district with width $\ell = 6.7^{1/2}\delta^{-1/2}$ yields a nearly minimal local distance traveled per point (as well as a nearly minimal local vehicle operating cost per point), a slightly wider district with $\ell = 9.2^{1/2}\delta^{-1/2}$ allows a nearly maximal number of points to be covered within time τ_0; it yields approximately the lowest average fixed-plus-line-haul cost per point. For districts near the depot, χ^* would be expected to be closer to χ_1; and for remote districts, χ^* should be close to χ_2. The following analysis confirms this expectation. Because both $\phi(\chi)$ and $\psi(\chi)$ are convex, $\chi^* \varepsilon [6.7, 9.2]$ for $0 < g < \infty$. As the aggregate line-haul-to-local cost ratio, g (i.e., the distance from the depot), increases, χ^* moves from the left to the right in [6.7, 9.2]. As the district distance from the depot increases, the optimal district becomes gradually wider, allowing more demand points to share the aggregate line-haul cost, although yielding a somewhat longer local distance traveled per point. These adjustments to district width are not very substantial; when $g \to \infty$, ℓ is only 17 percent larger than when $g \to 0$. The impact on cost of departures from the optimal ℓ is examined in the next section.

Because dual-strip routing can yield tours with nearly minimal local distances per point, it is appropriate for use when q is small and cost per point depends primarily on the local distance traveled. When g is large, radically different routing strategies may be better.

ALTERNATIVE ROUTING STRATEGY

Let us now consider the single-strip routing strategy shown in Figure 2. This strategy allows the delivery vehicle to serve more demand points within a given amount of time and thus reduces the average fixed-plus-line-haul cost per point. [To see this, simply consider a district half as wide but twice as long as for dual-strip routing and with the same center of gravity. The distance traveled between points is the same (on average) in both cases, but for single-strip routing the distribution stage begins and ends sooner. Additional points can thus be served.] Single-strip routing can be appropriate when the line-haul-to-local cost ratio is high. A recent study (11) also shows that, for distributing valuable goods, the single-strip strategy is better than the dual-strip strategy; these authors used an L_1 metric for their calculations.

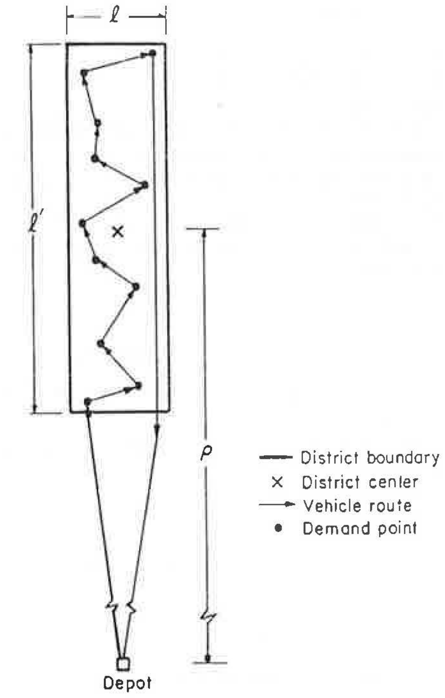


FIGURE 2 Single-strip routing.

Expressions for tour lengths, shipment size, and cost can also be derived for single-strip routing with a Euclidean metric (see the Appendix). An additional subscript (s) is used to denote single-strip variables and functions. All have a form similar to that given previously. For example, when the zone width (χ) is given, shipment size [$N_s(\chi)$] and cost [$c_s(\chi)$] are

$$N_s(\chi) = (U\tau_0 - \rho)/[US + \psi_s(\chi)\delta^{-1/2}] \qquad \rho < U\tau_0 \tag{11}$$

and

$$c_s(\chi) = C_d \left\{ USg + \delta^{-1/2} \left[\phi_s(\chi) + g\psi_s(\chi)\right] \right\} \tag{12}$$

where

$$\phi_s(\chi) = (\chi^{1/2}/3) + (1/\chi^{1/2}) \left\{ (2/\chi^2) \left[(1+\chi)\log(1+\chi) - \chi\right] \right\}$$

and

$$\psi_s(\chi) = \phi_s(\chi) - 1/(2\chi^{1/2})$$

Note that $c_s(\chi)$, like $c(\chi)$ as given by Equation 10, also has three cost components: the cost per stop, the average local operating cost, and the cost of time constraint.

Unlike dual-strip routing, however, the minimum of $\psi_s(\chi)$, 1.9, is smaller than the minimum of $\phi_s(\chi)$, 2.7. This happens because $\psi_s(\chi)$ is obtained from $\phi_s(\chi)$ by subtracting a decreasing function. Thus with single-strip routing an optimal district becomes narrower instead of wider as the distance from the depot (g) increases.

Figure 3 shows how χ_s^* moves from 2.7 to 1.9 as g is increased; it compares χ_s^* and χ^* as well. The figure also reveals that, when $g \sim 2$, $\chi^* = 4\chi_s^*$. That is, single-strip districts should be half as wide as dual-strip districts; both routing schemes should use equally wide strips. This is approximately true for all the g's that can occur in practice. Even in extreme cases, when $g \to 0$ or $g \to \infty$, the optimal strip widths of the two routing strategies differ by less than 30 percent.

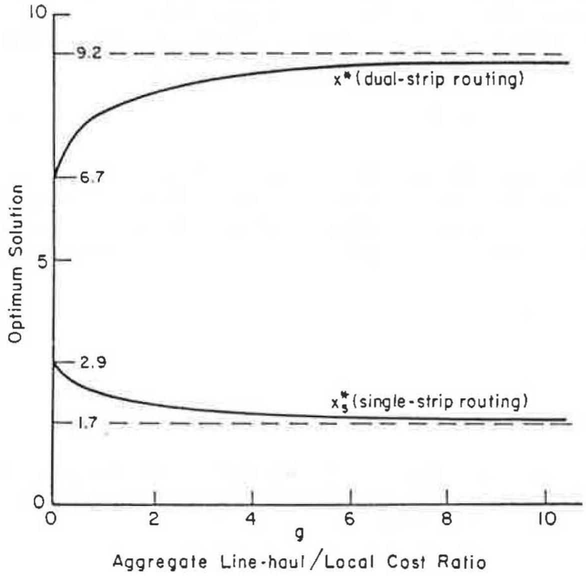


FIGURE 3 Optimum solutions of two routing strategies.

To compare the cost of the two routing strategies, f^* and f_s^* are plotted in Figure 4; they cross each other at the critical point $g_c \simeq 2$ (this is exact for the L_1 metric). Thus the single-strip strategy should be applied when the aggregate line-haul-to-local ratio (g) is larger than 2 (this also implies that the strategy with the narrowest optimal strip is best). The farther g is from g_c, the more important it is to choose the proper strategy. For example, if the per stop cost is ignored, single-strip routing can reduce the delivery cost of dual-strip routing by about 10 percent when g = 4 and by about 24 percent when $g \geq 100$. For road transportation, g is most likely in the range of $0 < g < 50$ (12).

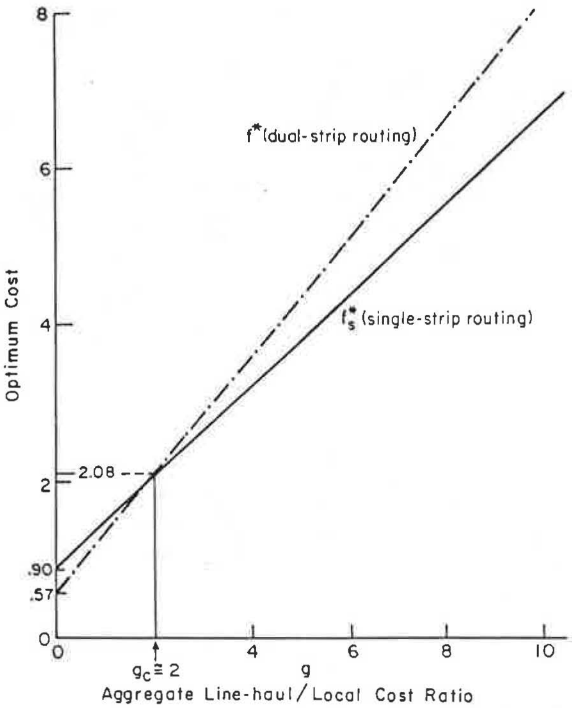


FIGURE 4 Optimum costs of two routing strategies.

According to Equation 9, a switch should be made from dual to single-strip with dual-strip routing when the (critical) distance between the depot and the district center of gravity (ρ_c) is

$$\rho_c = (2\,U\tau_0 - C_0/C_d)/4 \qquad \rho_c \geqslant 0 \tag{13}$$

Note that ρ_c does not depend on S. For $0 < \rho < \rho_c$, dual-strip routing should be used; beyond this range, single-strip routing is best. When the fixed cost (C_0) is zero, $\rho_c = 0.5U\tau_0$ (i.e., the critical distance is half the distance that can be traveled in time τ_0). As C_0 increases, ρ_c decreases; the application region of dual-strip routing shrinks. When $C_0 > 2U\tau_0 C_d$, only single-strip routing should be used. Figure 5 illustrates these phenomena.

OPTIMAL COST, SHIPMENT SIZE, AND DISTRICT DIMENSIONS

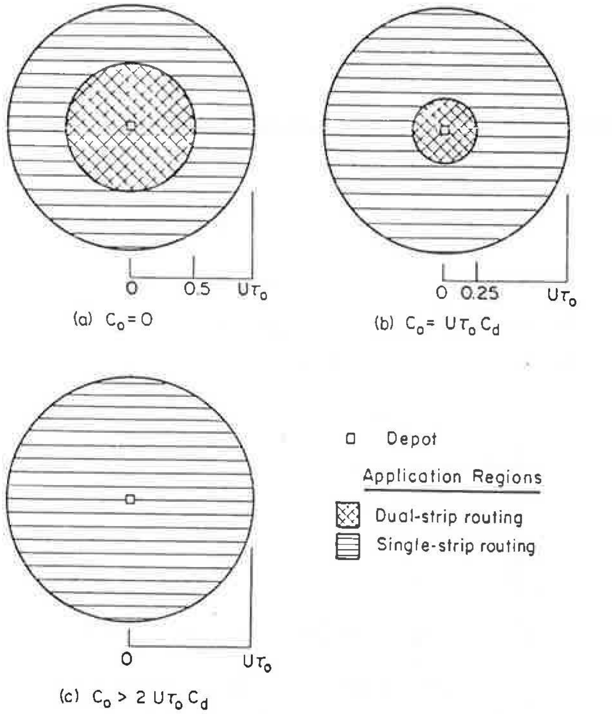
Let us now examine in more detail the properties of the optimal solution. Let us first define the overall optimum cost $\hat{c} = \min[c^*, c_s^*]$, which results from the best use of the two routing strategies considered. [Although hybrid strategies have dual-strips for only part of the way and strips of variable length can reduce the cost below $\hat{c}$, these reductions appear to be insignificant (11); hybrid strategies are not considered in this paper.] The circumflex is placed above any variable corresponding to $\hat{c}$. Let

$\hat{f} = \min[f^*, f_s]$; that is,

$$\hat{f} = f^* = f(\chi^*) \qquad \text{if } g < 2 \text{ (or } \rho < \rho_c)$$

and

$$\hat{f} = f_s^* = f_s(\chi_s^*) \qquad \text{if } g > 2 \text{ (or } \rho > \rho_c) \tag{14}$$



(a) $C_0 = 0$ (b) $C_0 = U\tau_0 C_d$ (c) $C_0 > 2U\tau_0 C_d$

FIGURE 5 Application regions of two routing strategies.

For any g, the functions $f(\chi)$ and $f_s(\chi)$ are very flat around their minima. Thus χ^* and χ_s^* do not need to be chosen very precisely (as in Figure 3); simpler rules can be followed. For example, if dual-strip routing with $\chi^* = 8.0$ is chosen when $g < 2$ and single-strip routing with $\chi_s^* = 1.9$ is chosen when when $g > 2$, the resulting values of $f(\chi)$ and $f_s(\chi_s)$ only deviate from $f(\chi^*)$ and $f_s(\chi_s^*)$ by less than 0.5 percent (see Table 1). These approximations ($\chi^* \sim 8.0$ and $\chi_s^* \sim 1.9$) are reasonable; they will be used from now on. The $\hat{f}$ can be approximated as

$$\hat{f} \cong f(8.0) = 0.576 + 0.753g \quad \text{if } g < 2$$

$$\cong f_s(1.9) = 0.937 + 0.574g \quad \text{if } g > 2 \qquad (15)$$

and $\hat{c}$ can be written as follows

$$\hat{c}(\rho) \cong \left\{ [\alpha_1(C_0 + 2\rho C_d)] / (U\tau_0 - \rho) \right\} + 0.576\delta^{-1/2} C_d \quad \text{if } \rho < \rho_c$$

$$\cong \left\{ [\alpha_2(C_0 + 2\rho C_d)] / (U\tau_0 - \rho) \right\} + 0.937\delta^{-1/2} C_d \quad \text{if } \rho > \rho_c \qquad (16)$$

where

$$\alpha_1 = US + 0.753\delta^{-1/2} \qquad (17)$$

and

$$\alpha_2 = US + 0.574\delta^{-1/2} \qquad (18)$$

Note that α_1 and α_2 are the distances that the vehicle can cover during the time it takes to serve one point (US plus the local distance per point). Figure 6 (bottom) shows how $\hat{c}$ depends on distance; except at the critical point, where $\rho = \rho_c$, the optimum cost ($\hat{c}$) increases at an increasing rate. This phenomenon does not occur for storable items; the cost of distributing storable items increases at a decreasing rate with distance (13). With storable items, inventory-plus-transportation cost is minimized when the largest loads are dispatched to the remotest districts. This cannot be done with non-storable items; when ρ increases, the local range decreases and fewer points can be covered.

The overall optimum shipment size ($\hat{N}$) becomes

$$\hat{N}(\rho) \cong (U\tau_0 - \rho)/\alpha_1 \quad \text{if } \rho < \rho_c$$

and

$$\cong (U\tau_0 - \rho)/\alpha_2 \quad \text{if } \rho > \rho_c \qquad (19)$$

These expressions are reasonable; both represent the ratio of the local range to the distance spent per point. Figure 6 (top) shows plots of $\hat{N}(\rho)$. As was just discussed, $\hat{N}(\rho)$ decreases (linearly) with ρ, except at the point of discontinuity ($\rho = \rho_c$). The vehicle load can be increased at this point because the switch from dual- to single-strip routing advances the time of the last delivery.

The variables V_d and V_s, defined in Figure 6 (top), represent the largest load that is carried with either routing strategy. There is no guarantee that $V_s > V_d$ (as in the figure).

The optimal size and district dimensions as functions of the distance ρ can also be derived. Such expressions, as it will be shown later, are useful for partitioning a region into nearly optimal districts. The optimal district size ($\hat{A}$) is

$$\hat{A}(\rho) = \hat{N}(\rho)/\delta \quad \rho < U\tau_0 \qquad (20)$$

$\hat{A}$ exhibits the same properties as $\hat{N}(\rho)$.

The width of a delivery district is given by $\ell = (\chi/\delta)^{1/2}$. Thus similar to χ^* and χ_s^*, $\hat{\ell}$ remains constant when $\rho < \rho_c$ and when $\rho > \rho_c$. The expressions are

$$\hat{\ell} = 2.83\delta^{-1/2} \quad \text{if } \rho < \rho_c$$

and

$$= 1.38\delta^{-1/2} \quad \text{if } \rho_c < \rho < U\tau_0 \qquad (21)$$

Districts are about half as wide when single-strip routing is used. In both cases the strip should be about $1.4\delta^{-1/2}$ distance units wide.

TABLE 1 Percentage Errors in Optimum Cost

$0 \leqslant g \leqslant 2$

g	① f(8)	② f^*	$\frac{① - ②}{②} \times 100\%$ Δ%
0	0.57599	0.57522	0.66
1	1.3287	1.3287	0
2	2.0815	2.0803	0.06

$g \geqslant 2$

g	$f_s(1.9)$	f_s^*	Δ%
2	2.0849	2.0803	0.22
4	3.2331	3.2331	0
10	6.6776	6.6733	0.06
100	58.345	58.178	0.28
1,000	575.02	573.19	0.32

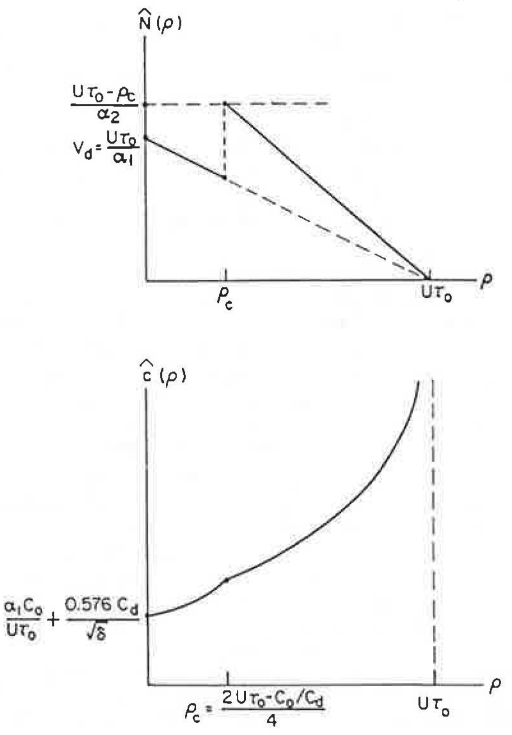


FIGURE 6 Optimal shipment size and cost.

The length of a delivery district is given by $\ell' = A/\ell$. Thus

$$\tilde{\ell}' = (0.35)\,[(U\tau_0 - \rho)/\alpha_1]\,\delta^{-1/2} \quad \text{if } \rho < \rho_c$$

and

$$= (0.73)\,[(U\tau_0 - \rho)/\alpha_2]\,\delta^{-1/2} \quad \text{if } \rho_c < \rho < U\tau_0 \tag{22}$$

These expressions follow the same pattern as $\hat{N}(\rho)$. They decrease linearly with ρ, except for a jump when $\rho = \rho_c$. For a given distance, single-strip districts are 2.1 (α_1/α_2) times as long as dual-strip districts.

The shape of a rectangular district can be represented by the ratio of its width and length, $\beta = \ell/\ell'$. This ratio was called the slenderness factor by Daganzo (7). From Equations 21 and 22

$$\tilde{\beta}(\rho) \cong 8.0\alpha_1/(U\tau_0 - \rho) \quad \text{if } \rho < \rho_c$$

and

$$\cong 1.9\alpha_2/(U\tau_0 - \rho) \quad \text{if } \rho_c < \rho < U\tau_0 \tag{23}$$

For storable items, β remained constant with distance. Now, however, $\hat{\beta}(\rho)$ increases with ρ except, of course, when $\rho = \rho_c$.

SERVING A REGION: AN EXAMPLE

Consider now a region that contains many delivery districts and define the optimal district partition of the region as that which yields the minimum cost of serving the whole region. Although such a partition is difficult to derive, its desirable properties can be explored. Imagine an ideal district partition that is characterized by the following two properties:

- P1. It is feasible; all districts pack well, cover the whole region, and each can be covered within time τ_0.
- P2. For each district, both the size (A) and the slenderness factor (β) are optimal (i.e., $A = \hat{A}$ and $\beta = \hat{\beta}$).

Although such an ideal partition usually does not exist, a district partition that closely follows its properties should yield a cost that is not much larger than the minimum. [Problems involving the determination of the location of, or the spacing between, a set of points (depots, warehouses, bus stops, scheduled headways, etc.) usually have cost functions that are very flat near their optima (8, 14, 15).] Therefore, in designing a desirable district partition, an attempt is made to follow P1 and P2 as much as possible. The following example shows how these guidelines can be applied.

Consider a circular region with a radius R and the depot located at its center. For such a region, P2 can be approximated with a ring-and-radial partition that satisfies P1. Let m be the number of equally big districts in the ring defined by two concentric circles with radii r_0 and r_1 that are such that $r_1 > r_o > 0$ (Figure 7). Given r_0 or r_1, the other radius and $\hat{A}$ can be determined from the previously developed formulas. Specifically,

$$r_1 = r_0 + \tilde{\ell}' \tag{24}$$

and

$$\tilde{A} = [U\tau_0 - (r_0 + r_1)/2]/(\alpha_1\delta) \quad \text{if } r_0 + r_1 < 2\rho_c$$

and

$$= [U\tau_0 - (r_0 + r_1)/2]/(\alpha_2\delta) \quad \text{if } r_0 + r_1 > 2\rho_c \tag{25}$$

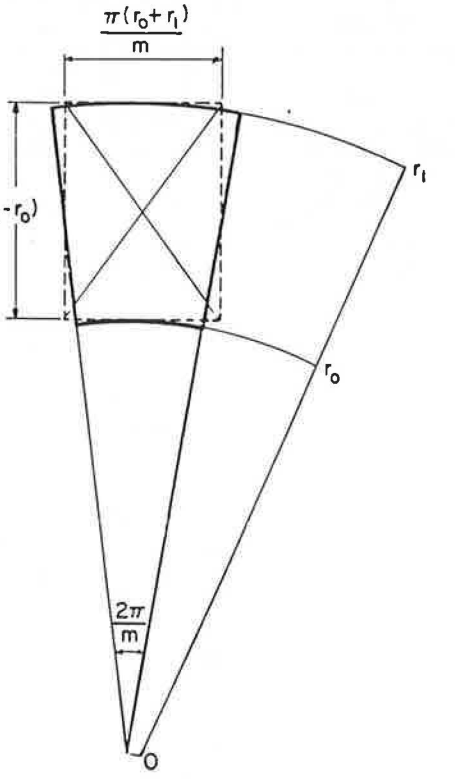


FIGURE 7 Partition sector.

The number of zones in a ring is

$$\hat{m} = \pi(r_1^2 - r_0^2)/\hat{A} \qquad (26)$$

When the values $\hat{\ell}$ and $\hat{\ell}'$ are calculated for $\rho = (r_0 + r_1)/2$, Equation 24 yields

$$r_1 = r_0 + (U\tau_0 - r_0)k \qquad (27a)$$

or

$$r_0 = (r_1 - U\tau_0 k)/(1 - k) \qquad (27b)$$

where

$$k = (0.5 + 2.83\alpha_1\delta^{1/2})^{-1} \quad \text{if } r_0 + r_1 < 2\rho_c$$

and

$$k = (0.5 + 1.38\alpha_2\delta^{1/2})^{-1} \quad \text{if } r_0 + r_1 > 2\rho_c \qquad (28)$$

These expressions are reasonable if the districts that result are approximately rectangular. For the first ring of districts, however, this is not the case. For storable items, first-ring districts should be approximately 40 percent longer than predicted for rectangular shapes (11); other rings do not need a correction. A similar phenomenon should occur now; it appears reasonable to increase $r_1 = kU\tau_0$ (see Equation 27a with $r_0 = 0$) by 40 percent while simultaneously maintaining $\hat{N}(\rho)$ and $\hat{A}(\rho)$ at the previous level (with $\rho = kU\tau_0/2$) for the first ring of districts. The optimal radius of the first ring thus should be approximately $1.4kU\tau_0$.

Suppose that customers and vehicles have the following characteristics: $U\tau_0 = 15$, $\delta = 4$, and $C_0/C_d = 10$ and consider two cases for US = 0 and US = 1. For a circle of radius R = 13, there are more than 2,000 customers.

Table 2 gives numerical results that show how (starting with $r_1 = 13$ and proceeding inwards) the sequence of ring radii can be obtained for both cases by repeated use of Equation 27b. Usually, as in the example, one of the innermost dual-strip rings will have $r_1 \sim 1.4kU\tau_0$. Any rings inside this ring should be eliminated. The resulting partition should be nearly optimal, even when the first radius is significantly different from $1.4kU\tau_0$; the first ring usually does not contain a large portion of all the customers, nor does it account for a large fraction of the vehicle-miles. Still, if desired, the boundary between the first and second rings can be shifted a little so that the inaccuracy in zone lengths is spread over two rings; Newell and Daganzo (11) discuss this for storable items. Table 2 also gives the (unrounded) $\hat{N}$, $\hat{A}$, and $\hat{m}$ corresponding to each ring.

Figures 8 and 9 show the districting patterns that result. Figure 10 shows the two typical routing patterns for $\rho < \rho_c (\rho_c = 5)$ and $\rho > \rho_c$ when US = 0. For US = 0, districts are larger and more elongated than for US = 1. Vehicles also make more stops. When US = 1, more rings are needed to cover the same area than when US = 0.

In cases in which the average number of stops per district calculated for a ring ($\hat{N}$) is not large (as with the outer rings for US = 1), the boundaries of the ring should be modified so that the resulting N is an integer. [Note in particular that an $\hat{N}$ smaller than 1 cannot be used. In some instances, the farthest customers may receive individual service.] A similar modification is needed to make the number of districts in a ring ($\hat{m}$) an integer when $\hat{m}$ is small. These modifications can be made as the calculations for Table 2 are being done or can be left to experienced judgment. Human intervention is hard to avoid in any case (7). For example, when customer locations change daily, the most cost-effective way of defining the final routes is often through human dispatching. The dispatcher can follow the guidelines, but he must ensure that districts pack, that the time constraint is not likely to be violated, and that routes are network feasible and balanced.

DISCUSSION

The example in the previous section illustrated how the formulas developed in this paper can be used for operational planning purposes. Although the example was idealized, it is not difficult to see how realistic cases should be addressed. If the customer demand density varies, the district dimensions should change with it; a districting pattern that follows these dimensions closely, and yet fits within the irregular boundaries of a service region, can usually be found. [See Newell (14), Clarens and Hurdle (15), Daganzo (7), and Daganzo and Newell (16) for additional discussion of this issue and several examples.]

Seven properties of a near-optimal operations plan are

1. Districts should be elongated toward the depot.
2. Vehicles should cover districts near the depot with two laps (dual-strip routing) and districts far

TABLE 2 Numerical Results

r_1	r_0	$\rho = (r_1 + r_0)/2$	$\hat{N}(\rho)$	$\hat{A}(\rho)$	$\hat{m}$	Routing
US = 0 ($1.4kU\tau_0 = 8.2$)						
13	6.2	9.6	18.9	4.7	87.2	Single-strip
6.2	0.8	3.5	30.6	7.6	15.5	Dual-strip
0.8	NA[a]					Dual-strip
US = 1 ($1.4kU\tau_0 = 2.5$)						
13	12.3	12.7	1.8	0.5	115.5	Single-strip
12.3	11.4	11.9	2.4	0.6	108.1	Single-strip
11.4	10.2	10.8	3.3	0.8	98.5	Single-strip
10.2	8.6	9.4	4.3	1.1	85.8	Single-strip
8.6	6.5	7.6	5.8	1.4	68.8	Single-strip
6.5	3.7	5.1	7.7	1.9	46.5	Single-strip
3.7	2.1	2.9	8.8	2.2	13.0	Dual-strip
2.1	0.3	1.2	10.0	2.5	5.4	Dual-strip
0.3	NA[a]					Dual-strip

[a] NA = not applicable ($r_0 < 0$).

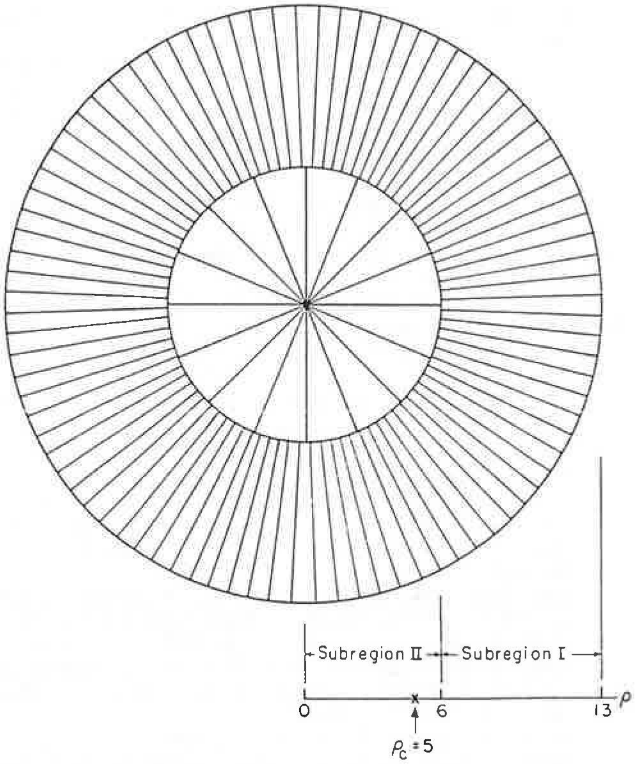


FIGURE 8 District partition, US = 0.

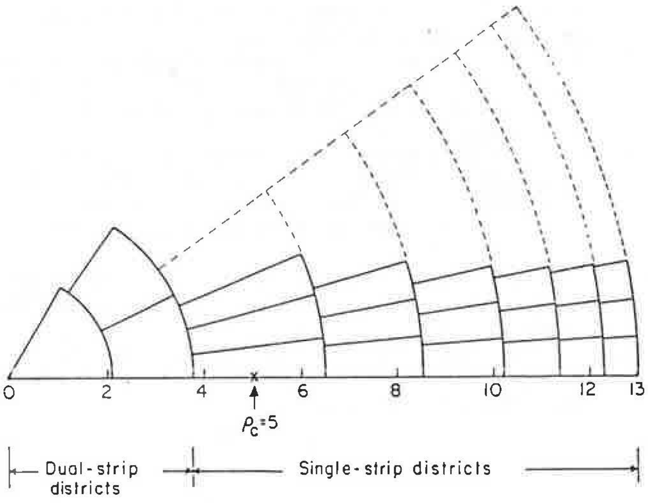


FIGURE 9 District partition, US = 1.

from the depot with only one outbound lap (single-strip routing).

3. If the fixed-plus-operating cost of a vehicle is proportional to distance, dual-strip routing should be used for districts the center of which can be reached in less than one-half the time available for delivery.

4. All districts of a given type, regardless of their locations relative to the depot, should have approximately the same width. Dual-strip districts should be about twice as wide as single-strip districts.

5. The number of stops, length, and size of both single- and dual-strip districts, however, should decline with the distance from the depot.

6. All else equal, an increase in the time needed per stop diminishes the size of the district that can be covered but does not change either its width or the type of routing that should be used.

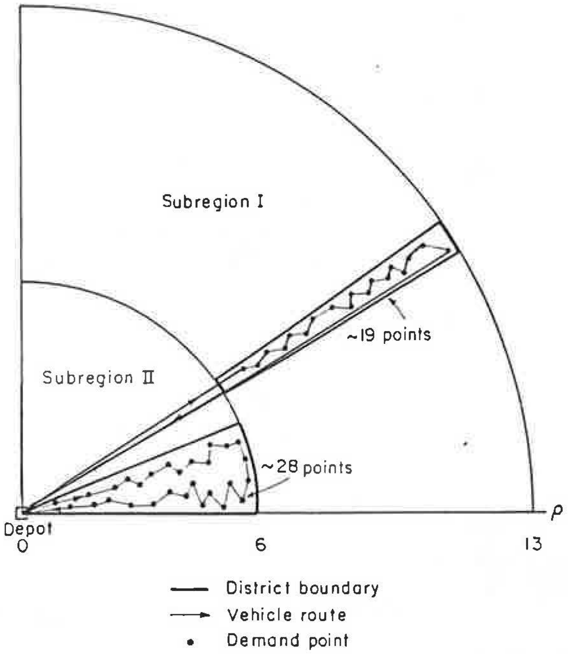


FIGURE 10 Two typical routing patterns.

7. The cost per item increases at an increasing rate with distance.

For land transportation problems, where the Euclidean metric with constant speed everywhere is not reasonable, these principles still apply, albeit in a somewhat modified fashion. For example, "elongation toward the depot" should be interpreted to read "perpendicular to the equi-travel time contours." Newell and Daganzo (11) refined the principles and formulas for the case of storable items; a similar refinement can and should be sought for nonstorable items.

The formulas in this paper also quantify conveniently the cost impact of changes in demand, vehicle operating characteristics, and the service standard of a time-constrained distribution system. Therefore, they can be used for strategic planning purposes. For example, take the available delivery time (τ_0). Figure 11 shows how the entire cost curve shifts to the lower right when the available time increases from τ_0 to τ_0'. Vehicle speed (U) has a similar effect on optimum cost.

The capacity of the vehicles is another operating characteristic that affects cost. In this paper it was assumed that vehicles are large enough to hold all the items that can be delivered in time τ_0. When this is not reasonable, the expressions should be modified (12). Then, as the number of stops that can be made by a vehicle is reduced, the size of the region where dual-strip routing is preferred and the cost both increase. This is logical. The attractive feature of single-strip routing--that more stops can be made--is negated when vehicles are not large enough to make all the stops.

The results in this paper can be applied to scenarios more general than those described at the outset. For example, problems in which all the items distributed in one day are not produced simultaneously can be studied. If the items are not destination specific, loads can be made as soon as batches of the right size become available; there is no need for inventories at the depot. When the items

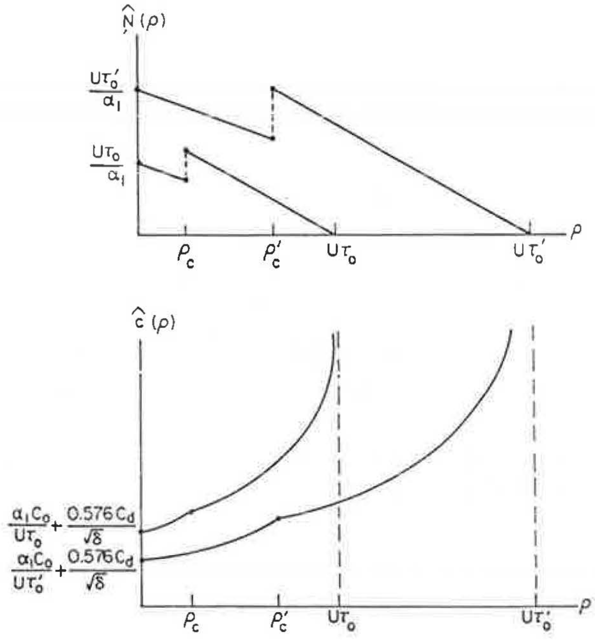


FIGURE 11 Influence of available delivery time.

shipped are perishable, the available delivery time for an item is measured from its time of production. Because all batches should be delivered in about the same amount of time, the strategies described in this paper apply verbatim. On the other hand, when the items have to be distributed to beat a deadline (e.g., newspapers and magazines as well as items taken to businesses that open and close at fixed hours), less time is available for the last batches that become available. In such cases the first batches should be sent to the remotest districts and the last loads to the nearest customers. To apply the results of this paper, the time available for delivery to each ring of the service area should first be determined. This is possible because the production schedule is known, each ring has a known demand, and rings are served from the outside in. The formulas presented in this paper can then be used to determine the best way of supplying each ring.

The research reported in this paper can be used as a building block for analyzing more complicated time-constrained distribution problems. Among possible applications are

- Determining either the optimal spacing between two adjacent depots (production plants or transshipment terminals) or the optimal location of additional depots, given the cost of setting up a depot, and
- Identifying optimal ways of distributing nonstorable items through transfer points.

ACKNOWLEDGMENT

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REFERENCES

1. W. Turner, P. Ghare, and L. Fourds. Transportation Routing Problem--A Survey. AIIE Transactions, Vol. 6, No. 4, 1974, pp. 228-301.
2. B. Golden, T. Magnanti, and H. Nguyen. Implementing Vehicle Routing Algorithms. Networks, Vol. 7, 1977, pp. 113-148.
3. G. Clarke and J.W. Wright. Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. Operations Research, Vol. 4, 1964, pp. 568-581.
4. M. Tyagi. A Practical Method for the Truck Dispatching Problem. Journal of the Operations Research Society of Japan, Vol. 10, 1968, pp. 76-92.
5. B. Gillett and L. Miller. A Heuristic Algorithm for the Vehicle Dispatch Problem. Operations Research, Vol. 22, 1974.
6. M.L. Fisher and R. Jaikumar. A Generalized Assignment Heuristic for Vehicle Routing. Networks, Vol. 11, 1981, pp. 109-124.
7. C.F. Daganzo. Distance Traveled to Visit N Points with a Maximum of C Stops per Vehicle: An Analytic Model and an Application. Transportation Science, Vol. 18, 1984, pp. 331-350.
8. S. Eilon, C.D.T. Waston-Gandy, and N. Christofides. Distribution Management: Mathematical Modeling and Practical Analysis. Hafner Press, New York, 1971.
9. D.M. Stein. An Asymptotic, Probabilistic Analysis of a Routing Problem. Mathematics of Operations Research, Vol. 3, No. 2, 1978, pp. 89-101.
10. C.F. Daganzo. The Lengths of Tours in Zones of Different Shapes. Transportation Research, Vol. 18B, 1984, pp. 135-145.
11. G. Newell and C.F. Daganzo. Design of Multiple Vehicle Delivery Tours. Transportation Research B (in press).
12. A. Han. One-to-Many Distribution of Nonstorable Items: Approximate Analytic Models. Ph.D. dissertation, Dissertation Series 84-3. University of California, Berkeley, 1984.
13. C.F. Daganzo and G.F. Newell. Physical Distribution from a Warehouse: Vehicle Coverage and Inventory Levels. Transportation Research, Vol. 19B, 1985, pp. 397-408.
14. G.F. Newell. Scheduling, Location, Transportation and Continuum Mechanics: Some Simple Approximations to Optimization Problems. SIAM Journal of Applied Mathematics, Vol. 25, No. 3, 1973, pp. 346-360.
15. G. Clarens and V.F. Hurdle. An Operating Strategy for a Commuter Bus System. Transportation Science, Vol. 9, 1975, pp. 1-20.
16. C.F. Daganzo and G.F. Newell. Configuration of Physical Distribution Networks. Networks, Vol. 16, 1986, pp. 113-132.

APPENDIX--Derivations Associated with Single-Strip Routing

Let d be the average Euclidean distance traveled between two succeeding points in the district. This distance is a function of strip width, which for single-strip routing is also the district width, ℓ (10).

$$d \cong (\ell/3) + (\delta\ell)^{-1} h(\delta\ell^2) \qquad \text{(A1)}$$

where

$$h(\chi) = (2/\chi^2)\,[(1+\chi)\ln(1+\chi) - \chi] \qquad (\chi = \delta\ell^2 \text{ as defined in the text})$$

If the distances between the district boundary and the first and last points in the district are ignored,

$$L_s \cong N_s d + 2\rho \qquad \text{(A2)}$$

and

$$D_s \cong N_s d + \rho - (\ell'/2) \qquad \text{(A3)}$$

Substituting d in Equations A2 and A3 by Equation A1, and remembering that $\ell' = N_s/(\delta\chi)^{1/2}$ and $\ell = (\chi/\delta)^{1/2}$ yields

$$L_s \cong 2\rho + N_s \delta^{-1/2} \phi_s(\chi) \qquad \text{(A4)}$$

and

$$D_s \cong \rho + N_s \delta^{-1/2} \psi_s(\chi) \qquad \text{(A5)}$$

where

$$\phi_s(\chi) = (\chi^{1/2}/3) + (1/\chi^{1/2}) \left\{(2/\chi^2)\ [(1+\chi)\ln(1+\chi) - \chi]\right\}$$

and

$$\psi_s(\chi) = \phi_s(\chi) - 1/(2\chi^{1/2})$$

For single-strip routing, the time constraint is

$$N_s S + (D_s/U) = \tau_0 \qquad \text{(A6)}$$

Substituting D_s in Equation A6 by Equation A5 gives

$$N_s(\chi) = (U\tau_0 - \rho)/[US + \psi_s(\chi)\delta^{-1/2}] \quad \rho < U\tau_0 \qquad \text{(A7)}$$

Replacing L and N in Equation 5 with L_s and N_s, Equations A4 and A5, respectively, yield

$$c_s(\chi) = C_d \left\{USg + \delta^{-1/2}[\phi_s(\chi) + g\psi_s(\chi)]\right\} \qquad \text{(A8)}$$

where g, as defined in Equation 9, is the line-haul-to-local-cost ratio.

Equations A7 and A8 are the same as Equations 11 and 12, respectively.

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Effects of Weight and Dimension Regulations: Evidence from Canada

ALAN M. CLAYTON and FRED P. NIX

ABSTRACT

In this paper the following questions are examined: (a) How has the makeup and use of Canada's fleet of large trucks been affected by differences in and changes to weight and dimension regulations? (b) Has the use of larger trucks led to increases in shipment sizes? (c) How and to what extent has the for-hire trucking industry passed on productivity gains to shippers in the form of reduced rates? Information sources include registration data, roadside survey data, Statistics Canada's survey of shipments, and actual industry tariffs. The conclusions are that, as expected, different regulations in different jurisdictions and changing regulations do have an impact on fleet characteristics, shipment size, and trucking rates. However, the precise nature and extent of these impacts is complex and not readily predictable. For example, the evidence indicates that relaxing weight and dimension regulations in the western provinces led to the steady introduction of double-trailer combinations in the trucking fleet but that the rate of introduction varied significantly between intraprovincial and extraprovincial operations, among different provinces, and between for-hire and private carriers. Similarly, the evidence suggests that there were highly varied impacts on shipment sizes and for-hire trucking rates. There have been rate savings of up to 33 percent directly attributable to the use of larger vehicles for certain commodity movements; in other cases there have been little or no savings.

Canada is an ideal laboratory for analyzing the effects of weight and dimension regulations: first, cross-sectionally, each of Canada's 12 provinces and territories is responsible for and has promulgated its own, sometimes quite distinct, regulations and, second, the regulatory situation has been significantly relaxed over the last 15 years. In this paper a number of different data sources are used to examine the effect of these regulations on the characteristics of the trucking fleet, the average size of truck shipments, and trucking rates. Although there are few simple answers to the questions that may be posed, some partial evidence is beginning to emerge in Canada as a result of an on-going research effort.

REGULATORY SETTING

The regulatory setting for vehicle weights and dimensions in Canada is complex. This has resulted from a division of jurisdictional responsibility among federal, provincial, and local governments; different transportation problems and requirements in various regions; and different engineering problems and practices. In this paper only key aspects of the current "basic" regulations and recent changes to these regulations can be summarized. The term "basic" refers to the weight and dimension regulations applicable to major highways during the summer season (no spring reductions or winter weight premiums) and to most trucks (excluding trucks operating under exemptions or special permits).

In 1970 maximum dimensions were more or less uniform across the country: 102-in. widths, 13.5-ft heights, 35- or 40-ft lengths for single vehicles and 65-ft combination lengths. With one major exception, maximum axle weights and gross vehicle weights (GVWs) were also relatively uniform: The general standard was 18, 32, and 74 kips for single axles, tandem axles, and GVWs, respectively. The major exception was in Ontario where triple axles were allowed a load of 40 kips and GVWs of 116 kips were permitted.

In 1971 Ontario moved even further away from the relatively uniformity in the rest of the country by adopting the Ontario bridge formula as the basis for regulating vehicle weights and dimensions. In its original form, this new approach permitted 20, 35, and 44 kips on single, tandem, and triple axles and a maximum GVW of 135.5 kips (1). The Ontario bridge formula introduced a greater degree of flexibility into the design of large truck combinations, which permits an almost infinite variety of configurations, axle spacings, and load-distribution options. In addition, the introduction of the bridge formula spurred a rapid period of adjustment and "catch-up" in other regions: between 1971 and 1973 Newfoundland, New Brunswick (major highways), Quebec, British Columbia, and the Yukon all increased allowable axle and gross vehicle weights significantly.

The next major change was the Western Canada Highway Strengthening Program. As a result of this program, in 1974 the three prairie provinces replaced their single, tandem, and GVW limits of 18, 32, and 74 kips with 20, 35, and 110 kips on primary highways. This permitted standard five-axle tractor-semitrailers to operate on major routes at 80 kips (assuming 10-kip steering axles); increased payload capacity by 6 kips; and permitted double-trailer combinations (doubles) with six or seven (sometimes eight) axles to be used effectively on major routes

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at GVWs of up to 110 kips, thus handling weight-out payloads of up to 80 kips or nearly double the previous maximum of 45 kips.

In 1978, as a result of another highway strengthening program, the Atlantic provinces adopted as minimum 20-, 40-, and 110-kip single, tandem, and GVW limits (37.5 kips on tandem-drive axles) for all major highways. An important aspect of this change was the adoption of the 110-kip GVW limit in Nova Scotia (it had previously had the most restrictive limits) permitting the effective use of doubles throughout the region.

In 1982 the prairie provinces further increased GVW limits on primary highways to 118 kips in Alberta and Saskatchewan and 125 kips in Manitoba. In addition, GVW limits on most secondary highways were increased to 108 kips (from 74). This change permitted doubles on primary highways to register at the full GVW limits obtained by summing allowable axle weights (seven axles in Saskatchewan and Alberta and eight in Manitoba) and increased payload capacity by 8 kips (15 in Manitoba). It also permitted doubles to be used effectively off the primary highway network. This use of doubles on secondary roads was significant in that much of the region's bulk commodity movements (grain, fertilizer, lumber) originate or terminate, or both, off the primary system (2).

Throughout this period important increases in allowable combination lengths were introduced in most jurisdictions, replacing the 65-ft limit with limits of up to 75.5 ft (given certain further conditions depending on the jurisdiction). These changes were made to facilitate the use of long wheelbase tractors in the double-trailer combinations that were emerging.

Given these changes, Canada's current basic regulations can be summarized as follows: (a) Doubles can now be used effectively across the country, albeit at GVW limits that range from a low of 110 kips in Nova Scotia (seven axles) to a high of 140 kips in Ontario, British Columbia, and the Yukon (eight and sometimes nine axles); (b) there are no meaningful variations in height (13.5 ft) or width (8.5 ft) limits; (c) overall combination length limits vary considerably, but doubles of 75.5 ft can now be operated in all provinces and territories from Quebec to the West; (d) steering-axle weight limits vary from 12 to 20 kips; (e) nonsteering, single-axle weight limits vary from 18 to 22 kips; (f) tandem-axle limits vary from 35 to 44 kips; (g) western Canada prohibits the effective use of triple axles (restricting them to tandem-axle limits) whereas central and eastern Canada permit their use at load levels greater than tandem-axle limits; and (h) western Canada generally prohibits the effective use of "belly" axles (nonsteering single axles in the middle of trailer units, generally capable of being raised when not needed) whereas these can be used effectively in Ontario and several other eastern provinces.

This is a highly condensed description of Canada's weight and dimension regulations, but it provides sufficient background against which some of their effects can be described. Further details on these regulations are provided elsewhere (3-5). In addition to these basic limits, and the road-class and seasonal variations on them, all provinces allow overdimension or overweight trucks, or both, under exemptions or special permits. These trucks are a growing component of Canadian trucking but are not considered here.

TRUCK FLEET CHARACTERISTICS

There is no complete information base that can be used to characterize Canada's fleet of large trucks. Three regional and partial sources have been used here: registration data for the prairie provinces, on-road survey data, and a survey of industry officials. Although these sources do not provide directly compatible information, together they provide strong indications of how trucking operations have adapted to various regulatory regimes and changes in those regimes.

Western Canada

Registration Data

The 1974 regulatory changes permitted higher GVW levels on existing five-axle combinations by increasing axle weights on primary highways. Further, six- to eight-axle doubles could be used effectively on primary highways in place of the then standard (typically five-axle) tractor-semitrailer units. The 1982 change, which increased GVW limits on the region's secondary highway system, extended the opportunity to use doubles in most trucking activities on the prairies.

The information given in Table 1 is the proportion of nonresident private, for-hire, and total (private plus for-hire) tractors registered in each of the three prairie provinces from 1973 to 1984 at GVW levels that imply the use of configurations of six or more axles (doubles). On the basis of the information presented in this table and other data (6), there are a number of observations that can be made about the effects of the 1974 and 1982 regulatory changes.

First, trucking operators steadily introduced six- to eight-axle doubles (compared with a sudden large increase). For example, for the fleet represented in Table 1 (extraprovincial nonresident vehicles), in 1974 there were no six- to eight-axle doubles in the three prairie provinces. Two years later, 2 to 3 percent of the fleet had been registered at double-trailer weight levels; 10 years after the change, 30 to 38 percent of the nonresident tractor registrations in the three provinces were at weight levels that imply double-trailers. Considering intraprovincial vehicles and data provided elsewhere (6), the rate of introduction of doubles in the region varied from a level roughly similar to that for extraprovincial operations (Manitoba) to half that rate (Saskatchewan). There are several possible explanations for these different rates of introduction of doubles into the fleet: (a) differences in the extent and nature of secondary highways in each of the three provinces, (b) differences in local demand conditions, and (c) differences in the trucking industry within each province.

Second, for-hire carriers have introduced doubles more rapidly than private truck operators. Referencing the nonresident fleet information given in Table 1, in the early years of the relaxed weight regulations there was not much difference in the proportion of doubles introduced into the for-hire and private extraprovincial fleets. By 1980-1981, however, one of every five (nonresident) for-hire tractors was registered at double-trailer weight levels versus one in ten private tractors. By 1983-1984, these ratios had changed to (roughly) two of every five for-hire tractors versus one of five private tractors.

Third, the majority of the new doubles registered in the region required a minimum of seven axles; they were 3-S2-2(3) or 3-S1(S2)-3 A-trains or 3-S2-S2 B-trains. The remainder were registered at weight levels that require only six axles and were typically 3-S1-2 A-trains. ("3-S2-2" indicates vehicle combinations and number of axles; "S" indicates a fifth wheel; an A-train consists of a semitrailer and a

TABLE 1 Proportion of Nonresident Private (P), For-Hire (F), and Total (T) Tractors Registered at GVW Levels Implying Double Trailer Operation in Manitoba, Saskatchewan, and Alberta, 1973-1984

	Manitoba			Saskatchewan			Alberta		
	P	F	T	P	F	T	P	F	T
1973-1974	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
1975-1976	5	2	3	1	2	3	–	–	–
1977-1978	6	7	6	–	–	–	–	–	–
1978-1979	8	14	12	–	–	–	–	–	–
1979-1980	11	15	14	–	–	–	–	–	–
1980-1981	12	20	18	10	21	20	–	–	–
1982-1983	17	29	25	18	34	29	17	32	28
1983-1984	20	34	30	20	40	34	21	42	38

Note: Dashes = no data.
[a] Effective use of doubles was prohibited.

full trailer; a B-train consists of two semitrailers.) In 1983-1984, 85 percent of the doubles registered in all three provinces for extraprovincial operations were registered at weights that require seven or more axles.

On-Road Surveys

On-road truck surveys measure actual vehicle characteristics on the road as distinct from registered fleet characteristics. There are important differences between these two indicators of fleet characteristics. For example, a carrier might register a tractor at 118 kips for use in a seven-axle A-train configuration but operate it in both this configuration and as a standard five-axle tractor-semitrailer (by dropping the pup trailer) depending on the available payload.

The information given in Table 2 is based on an unpublished vehicle classification analysis of on-road surveys conducted at three of Manitoba's permanent weigh scales for the years 1974 to 1984. There are four observations concerning the effect of the 1974 and 1982 changes in regulations. First, three- and four-axle tractor-semitrailers (single-drive axle tractors) have been virtually eliminated as of 1984 at all scale sites, including the international border crossing at Emerson.

Second, at two scale sites along the Trans-Canada Highway (Westhawk and Headingly), doubles began to appear soon after the 1974 regulatory adjustment. Such units accounted for 1 to 2 percent of all tractor-trailer combinations in 1974 and steadily increased to 12 to 13 percent by 1981 to 1982. As of 1984 they accounted for 17 percent of the combinations observed at Westhawk. This is approximately one-half of the proportion of doubles that would have been expected on the basis of vehicle registration data.

Third, fleet changes at the Emerson scale site (international border) have been limited to the disappearance of three- and four-axle tractor-semitrailers and the introduction of a small proportion of doubles. The small employment of seven- and eight-axle doubles through this site is to be expected because they could not be used effectively in the United States (given an 80-kip GVW limit in Minnesota). A relaxation of the GVW limit in the United States could lead to a fairly rapid adoption of seven- and eight-axle doubles on this international route because such units are now well established in the Manitoba fleet and the traffic lane is dominated by the movement of weight-out bulk commodities (grain, potash, lumber, etc.) (7).

Fourth, A-train configurations have dominated the double-trailer units in Manitoba, and the nature of these A-trains has changed over time. Initially, they were primarily five- and six-axle units, which suggests that cube-out rather than weight-out operations were the first to take advantage of the relaxed regulations. This was followed by a shift to a more or less equal proportion of six- and seven-axle units, coupled with the demise of single-drive-axle tractors and increased opportunities for using doubles in handling weight-out commodities. Finally, there has been a more recent shift to seven- and

TABLE 2 Classification of Observed Laden Tractor-Trailer Configurations at Permanent Weigh Scale Sites in Manitoba (shown as % of all such combinations observed)

Vehicle Type	Westhawk Scale					Headingly Scale				Emerson Scale			
	1974	1975	1978	1981	1984	1974	1975	1978	1982	1974	1975	1978	1981
2-S1	1	*	*	*	*	2	1	*	*	*	*	*	*
2-S2	5	8	6	5	1	9	6	4	3	4	2	*	*
2-S3	*	0	*	0	*	0	*	0	0	0	0	0	0
3-S1	*	*	*	0	0	0	*	*	*	0	0	0	0
3-S2	90	86	85	79	80	86	89	87	84	95	96	99	96
3-S3	2	2	1	2	*	*	*	*	1	*	*	0	0
2-S1-2	*	1	*	*	*	2	1	*	*	*	*	0	*
2-S2-2	*	*	*	0	0	0	0	0	0	0	0	0	0
3-S1-2	*	1	3	5	5	*	*	3	3	0	*	0	0
3-S1-3	0	0	*	2	4	0	0	1	*	0	0	0	0
3-S2-2	0	*	2	3	4	0	*	3	4	0	0	0	3
3-S2-3	0	*	*	2	4	*	*	*	1	0	0	0	0
3-S2-S2	0	0	*	*	1	0	0	*	3	0	0	0	*
Observations	559	726	831	812	545	1,181	1,012	996	994	686	458	670	482

Note: * signifies this vehicle type accounted for > 0% but < 1% of observations. Westhawk scale, Trans-Canada Highway, Manitoba-Ontario border, observed interprovincial trucking; Headingly scale, Trans-Canada Highway, west of Winnipeg, local and long-distance trucking; and Emerson scale, located at the Manitoba and North Dakota/Minnesota border [see Clayton and Sem (7)].
Source: Manitoba Department of Highways and Transportation, unpublished truck survey data.

eight-axle units (the effective use of eight-axle units was impossible before the 1982 relaxation of the GVW limit in Manitoba). B-train configurations were not observed in Manitoba until 1978, and today they appear to account for only about 5 percent of the doubles used in interprovincial movements between Manitoba and eastern Canada and about one-quarter of the doubles used west of Winnipeg. (The 1982 regulatory adjustment in Manitoba permitted A-trains to handle greater payloads than B-trains; as a result, the use of B-trains is discouraged.)

On-road survey data collected in Saskatchewan (8,9) and Alberta (10,11) from the early 1970s to the present show trends similar to those in Manitoba. Some minor differences in the trends and further observations based on these surveys include the following: (a) In Saskatchewan there is a higher proportion of doubles observed on the road than in Manitoba (nearly 30 percent versus the 17 percent on the Trans-Canada Highway in Manitoba) and this higher proportion in Saskatchewan is closer to the figures suggested by vehicle registration data; (b) in Alberta the evidence suggests that during the past 11 years the use of straight trucks has declined, the use of large configurations (doubles, truck-trailers, and triples) has increased, and the use of the standard five-axle tractor-semitrailers has remained relatively constant; (c) although the rate of introduction of doubles into the Saskatchewan and Alberta fleets was relatively steady (as in Manitoba), there was one sharp increase in Alberta 4 years after the regulatory change; and (d) by 1981 6.3 percent of all trucks observed in Alberta (including those weighed empty) had payloads of 60,000 lb or more.

Ontario: On-Road Surveys

Ontario's regulations (based on its bridge formula) have given rise to a variety of vehicle types quite unique to Ontario, and in particular six-or-more-axle single- and double-trailer combinations using various types of triple- and belly-axle arrangements. For example, Ontario is one of only two provinces where it is feasible to operate tractor-semitrailers up to 75.5 ft long, and it is one of the few places where tractor-semitrailers with as many as nine axles can be seen on a regular basis (no special permit is required).

On-road surveys provide some indication of how Ontario's truck fleet developed between 1978 and 1983 (12). In 1978 only 2 percent of the tractor-trailers observed on Ontario's highways were doubles; 98 percent were single semitrailers. In 1983 doubles accounted for (at least) 5.5 percent of observed tractor-trailers split more or less evenly between A- and B-trains; single-trailer units accounted for 93.3 percent of the observed tractor-trailer fleet; and the remaining 1.3 percent involved a mixture of combinations not easily classified.

Of more interest is the distribution of Ontario's tractor-trailers by number of axles, which illustrates some of the unique characteristics of this fleet. The standard 3-S2 configuration accounts for three-quarters of the tractor-semitrailer class; triple- and multiaxle semitrailer combinations (with six or more axles) account for another nearly 20 percent). About half of Ontario's doubles have eight or more axles, which suggests weight-out operations, and B-trains (typically 3-S3-S2) are somewhat more prevalent than A-trains [presumably 3-S2(S3)-3(2) arrangements]. The other half of the observed doubles had seven or fewer axles, which suggests cube-out operations.

Canada-Wide: Survey of Industry Officials

A survey of truck operators was carried out in 1984 to provide an indication of the relative popularity of different configurations operating in different regions across the country (13). In British Columbia, doubles account for 40 percent of tractor-trailer combinations. Four of every five of these are A-trains (dominated by 3-S1-2 and 3-S2-3 configurations); the remainder are B-trains (nearly always a 3-S2-S2 or a 3-S2-S3 with a belly axle). Doubles account for only 2 percent of the tractor-trailer fleet in New Brunswick. Tractor-semitrailers account for 98 percent of the fleet; four of every five of these are the 3-S2 configuration and 15 percent are six-axle units (most with a belly axle). Two regulatory considerations that have contributed to this low utilization of doubles in this region are the 65-ft combination length limits and the relatively recent (1978) increase in axle and GVW limits. In Quebec doubles account for 10 percent of the tractor-trailer fleet; four of every five are A-trains [essentially all are 3-S2-3(4) configurations], and the remainder are B-trains (nearly always a 3-S3-S2 arrangement). Tractor-semitrailers account for 90 percent of Quebec's tractor-trailer fleet; three-quarters of these are 3-S2 configurations and 20 percent have six axles and use either triple-axle or belly-axle arrangements. (This is only a partial summary of the survey.)

SHIPMENT SIZE

An analysis has been made of average shipment sizes based on the annual survey of for-hire shipping documents conducted by Statistics Canada (14). The object of this analysis was to determine if more relaxed weight and dimension regulations resulted in larger shipments. That is, the hypothesis being tested was that as the trucking industry adopted larger vehicles, some of the productivity savings would show up in the form of larger shipments at correspondingly lower rates per unit of weight. The analysis encountered a series of problems in trying to isolate the effects of weight and dimension regulations from those of the many other factors at work; nevertheless, on the basis of the findings of this work (4), some relevant observations have emerged.

The first attempt to analyze the data indicated that there was an apparent trend between 1976 and 1980 in Canada to larger truckload (TL) shipment sizes and that most of this trend was accounted for by intraprovincial shipments. In a second attempt, using data from 1976 to 1981 and based on a frequency distribution of shipment sizes in each province or territory, it appeared that the distribution of shipments within particular weight categories changed from year to year independent of any particular change in weight and dimension regulations. This is important (and probably intuitively obvious) because it emphasizes the point that not all the differences (in time or between jurisdictions) can be attributed to weight and dimension regulations.

Notwithstanding this observation, the frequency distribution of shipments by size did reveal a clear difference between the "high-weight" provinces (particularly Ontario and Quebec) and the "low-weight" provinces. For example, in 1976, less than 1 percent of shipments of crude materials (e.g., sand and gravel) in either Nova Scotia or Manitoba was in the "over 60 kip" category; in Ontario, 65 percent of these shipments were in the "over 60 kip" category. Clearly, there is a difference in shipment sizes in these provinces that is related to different allowable weight regulations (in 1976 the permitted maximum GVW in Nova Scotia was 80 kips; in Manitoba the new 110-kip limit on primary highways was only beginning to have an effect on shipment size; and in Ontario the 135-kip limit had been in effect for some time).

Considering the change in shipment sizes over time, there was a reasonably clear trend toward larger shipments in those provinces that adopted more permissive weight and dimension regulations in the 1970s. For example, in 1976 only 0.8 percent of crude materials in Manitoba were in the "over 60,000 lb" category; by 1981, 24.2 percent of these shipments were in this weight category. (The important change in weight regulations occurred in 1974.)

Further in the analysis (the definition of TL was changed slightly), it was determined that the average weight of intraprovincial TL shipments in the low-weight provinces was in the range of 42 to 46 kips, whereas the average weight in the high-weight provinces was in the range of 50 to 54 kips. There were, however, few clear trends over time (an exception was the case of Nova Scotia). Considering extraprovincial shipments, there was a general tendency toward larger shipments in all provinces. In the case of extraprovincial traffic, of course, regulations of several provinces have an influence, which makes it difficult to trace the causal links. Between 1976 and 1981 extraprovincial TL shipments in Canada increased in average size by 3,000 to 5,000 lb.

Although there was only a preliminary examination of revenues per ton-mile in the analysis, it was enough to show the large difference shippers paid for small TL shipments versus large TL shipments. For example, in 1980 TL shipments of lumber moving 320 to 360 mi cost a shipper 5.95 cents per ton-mile if the shipment weighed between 20 and 30 kips whereas the cost dropped to 2.15 cents per ton-mile if the shipment weighed between 70 and 100 kips.

Since this work [reported elsewhere (4)] was done, more recent data have been published by Statistics Canada (15). These new data permit the analysis to be extended to include 1982. Unfortunately the 1976 to 1980 data are published in imperial units and the 1981 to 1982 data are published in metric units; as a result the weight breaks used do not correspond, and only a rough idea of the increase in shipment sizes can be gleaned. The following figures show the proportion of large TL shipments in 1982 with the comparable 1976 figure shown in parentheses (large in 1976 is 50,000 lb or more out of all shipments weighing 20,000 lb or more; large in 1982 is 20 tonnes or more out of all shipments weighing 10 tonnes or more): Newfoundland and Prince Edward Island, 66.9 percent (versus 27.0 percent in 1976); Nova Scotia, 70.7 percent (38.9 percent); New Brunswick, 69.0 percent (50.0 percent); Quebec, 58.1 percent (42.2 percent); Ontario, 63.3 percent (46.6 percent); Manitoba, 61.6 percent (19.0 percent); Saskatchewan, 49.2 percent (29.5 percent); Alberta, 59.4 percent (29.3 percent); and British Columbia and the territories, 62.9 percent (48.5 percent). For all of Canada, 61.0 percent of TL shipments were large in 1982 versus 42.4 percent in 1976. Clearly, and overlooking the imperfections in the measurements, there has been a significant increase in the size of TL shipments.

TRUCK COSTS AND RATES

The purpose of relaxing weight and dimension regulations is to allow larger and heavier trucks to haul freight more efficiently (more payload per unit of input) thereby producing a lower cost service for shippers. The potential productivity advantages of larger vehicles have been extensively examined in the literature (16,17). In Canada it has been shown that moving freight in seven- or eight-axle doubles versus standard five-axle tractor-semitrailers provides per unit payload cost advantages of 7 percent for cube-out traffic and 15 to 42 percent (increasing with GVW) for weight-out traffic (18). However, knowing what advantages larger vehicles can potentially offer is one thing; knowing in fact what advantages result from permitting their use is another (e.g., are the savings actually realized and passed on to shippers?).

Comprehensive data on the actual effect of weight and dimension regulations on rates are difficult to obtain. In the preceding section information on revenue per ton-mile showed that larger shipments move at lower rates than smaller ones; this is close to demonstrating the effect of weight and dimension regulations, but it does not sort out all the factors. Some case study research has been done in Canada (3) and the results of this work plus some extensions made by the authors can be used to show the impact of the Western Canada Highway Strengthening Program. (There are problems using a case study approach; various qualifications to this work are being overlooked here.)

Saskatchewan: Petroleum Rates

Rates for the intraprovincial movement of bulk petroleum are regulated by the Saskatchewan Highway Traffic Board. Most movements take place in TL quantities from refineries or distribution centers to retail outlets. The following observations illustrate how Saskatchewan's weight and dimension regulations, and changes in these regulations since 1974, have been reflected in these rates. The specific numbers discussed are based on a case involving 100-mi hauls, assigned traffic, and carrier-provided equipment.

First, weight and dimension changes since 1974 have led to the progressive introduction of more and larger minimum-shipment-size lots with attendant relative decreases in rates. Before 1974 there was one TL rate for shipments of 40 to 45 kips handled at the then maximum allowable GVW of 74 kips. In February 1975 a 52-kip minimum shipment rate (relevant for the new 80-kip GVW limit for 3-S2 units on primary highways) was introduced that provided an 8 percent rate differential over the 46-kip minimum shipment rate (relevant for the same unit operating on secondary highways at a GVW of 74 kips). In December 1976 a 72-kip rate (relevant for seven-axle A- and B-trains on primary highways) was introduced that provided a 16 percent differential compared with the 46-kip minimum rate. In the spring of 1982 two additional shipment lots were introduced (69 and 78 kips) that are relevant for the new GVW limits for doubles on the secondary (108 kips) and primary (118 kips) highways, respectively.

Second, the size of the rate differentials has progressively increased, which suggests that the potential cost savings associated with larger shipments took time to be fully realized, understood, and passed on to the shipper. For example, the differential on a TL lot for a 3-S2 unit on a primary versus secondary highway in 1975 was 8 percent and rose to 12 percent by 1983. Similarly, the differential between a primary highway double-trailer lot versus a secondary highway 3-S2 unit lot was 16 percent in 1976 and rose to 23 percent in 1983.

Third, the size of the minimum shipments applicable to various types of units increased throughout the period, which indicates either progressive decreases in average tare weights or improved loading experience. For example, the minimum shipment size relevant for a standard 3-S2 unit operating on primary highways increased from 52.0 kips (1975) to 52.3 kips (1980) and then to 53.5 kips (1983).

Industry sources indicate that, today, 90 to 95 percent of all intraprovincial petroleum movements occur in double-trailer lots at the 75- or 78-kip rates. This suggests that shippers could be realizing a total saving of up to 25 percent in freight costs as a result of the 1974 and 1982 increases in weight limits. A number of institutional and industry considerations unique to this case have influenced the strong linkage between weight limit increases and rate decreases. First, the shippers involved (oil companies) are few in number, powerful in their dealings with the truckers, and more knowledgeable than most shippers about trucking costs. Second, the truckers in this business operate in a very competitive environment and regularly face the threat of the private carriage option. Third, the presence of an intermediary regulatory agency has created a continuous search for "logic" in the rate structure ("the rates must reflect the fact that larger trucks result in unit cost savings").

Manitoba: Petroleum Rates

Rates for the movement of petroleum products within and to or from Manitoba are set by the carriers. The 1975 to 1980 tariffs established by one of the major carriers involved in this business have been examined for evidence of change in response to the 1974 regulatory adjustment. For illustrative purposes, rates on two movements are considered in the following observations (an intraprovincial movement from Winnipeg to Brandon and an extraprovincial movement from Regina to Brandon).

Double-trailer lot rates for minimum payloads of 73.2 kips (implying a 110-kip GVW operation) were first introduced 4 years after the relaxed weight limits were implemented (and nearly 2 years after an equivalent rate was introduced in Saskatchewan). The differential between the 74- and the 80-kip GVW rates is on the order of 5 to 6 percent compared with the Saskatchewan differential of nearly 10 percent. The differential between the 110-kip GVW double-trailer lot rates and the 80-kip GVW single-trailer lot rates is very similar to that implemented in Saskatchewan during the same time period. As happened in Saskatchewan, this differential increased with time from 8 to 10 percent to nearly 14 percent in 1980.

Central-Western Canada: General Freight Rates

This section is a report on an analysis of rates published by the Canadian Transport Tariff Bureau Association (CTTBA) from 1971 to the present for certain commodity movements between central and western Canada. This is an extension of results presented elsewhere (3). Such an analysis is open to error or misinterpretation, or both. Tracing problems occur because of changes over time in tariff numbers and in detailed commodity descriptions within a tariff. The mere existence of a rate under one item in one tariff is no assurance that the analyst is looking at an "important" transportation price. For example, rates for "Meat--Fresh, Hanging" may become less important as the rate for "Meat--Fresh, Boxed" becomes more important, or a rate in one tariff may be meaningless given the existence of "independent actions." These qualifications must be borne in mind in considering the following observations.

The first CTTBA rate considered is for "Brass, Bronze or Copper: Bars, Pipes, Sheets, Tubing." Rates have been analyzed on three lanes (Toronto to Calgary, Winnipeg, and Regina). Before October 1974, 40 kips was the largest minimum shipment size rate and was available on all three lanes. This rate would be relevant for a five-axle tractor-semitrailer operating at the old 74-kip GVW limit. In October 1974 a 50-kip minimum rate was introduced on the Toronto-Winnipeg lane only; this rate would be relevant for the same five-axle unit operating at the newly permitted 80-kip GVW limit. The 50-kip rate has been retained in the tariff for the Winnipeg movement to the present, whereas on the Regina and Calgary lanes the largest minimum shipment rates are still at 40 kips. No "train-lot" (75-kip) rate has been introduced into the tariff.

The October 1974 tariff established the following (approximate) relationships between different rates on the three lanes:

	Ratio of X-kip Rate to 40-kip Rate			
	20:40	30:40	40:40	50:40
Toronto to				
Calgary	1.21:1	1.07:1	1:1	n.a.
Regina	1.18:1	1.08:1	1:1	n.a.
Winnipeg	1.22:1	1.09:1	1:1	0.94:1

These ratios have remained stable through a series of rate adjustments, except for the 50:40-kip ratio on the Toronto-Winnipeg lane. This ratio has decreased from 0.942 (September 1977), to 0.903 (October 1977), to 0.871 (April 1979), to 0.855 (October 1979), to 0.784 (March 1980), to 0.720 (March 1981), and finally to 0.672 (April 1982). The extent to which the differential between the 50- and 40-kip rates has developed (now nearly 33 percent) is much greater than could be expected from unit cost savings comparing 3-S2 operations at 80 and 74 kips. This suggests that the 50-kip rate is typically used for much larger payloads, in particular payloads of maybe 75 to 80 kips, which are relevant to double-trailer operations at 110+-kip GVWs.

The second CTTBA rate considered, under a number of tariffs, is for "Iron and Steel" moving from southern Ontario to western Canada. From 1971 to the present, in the "all-member" tariff, the largest minimum shipment lot is 40 kips, which suggests no development in response to relaxed weight regulations. However, most westbound iron and steel moves under independent actions: individual carriers file their own rates, typically at levels substantially lower than the all-member rates. One of these filings has, at least since April 1983, provided rates for five minimum shipment lot sizes: 45, 60, 70, 80, and 100 kips. There is an important condition attached to the 100-kip lot rates requiring a volume commitment (essentially an agreed charge). The 45-kip rate suggests payloads that could be handled in standard 3-S2 units, and the 60-, 70-, and 80-kip rates suggest double-trailer operations not permitted before the 1974 weight change. The 80-kip rate is about 16 percent lower than the 45-kip rate.

The 100-kip rate is 28 percent lower than the 45-kip rate; however, it is a rate that requires a payload that cannot be handled on the Manitoba leg of the trip (where the maximum GVW is 125 kips). There are three possible explanations for the existence of this 100-kip rate: (a) the carrier may be "breaking" the double close to the Manitoba-Ontario border and using two tractors into Winnipeg, (b) the carrier may be operating overload in Manitoba, or (c) the carrier may break the load into two units at the origin and top-up with other traffic. Industry sources indicate that the third scenario is most likely, and this point helps to explain one of the realities of the impact of relaxed regulations on trucking in general. As suggested by these sources, the more permissive regulations have strengthened the competitive position of truck vis-à-vis rail, and this has been exercised by capturing "base" loads of heavy commodities, splitting them, and topping them up with more lucrative traffic. Such practices would be difficult to measure in the field and would have been difficult to predict before the regulatory change.

The third CTTBA rate considered is the new "Pup-Load Charge," a direct consequence of the increased weight limits. Rates are filed on a commodity-specific basis for the use of a pup independent of the payload (up to the pup's GVW potential). For example, as of April 1985, the rates for the movement of "synthetic resin articles" from Calgary to Toronto were $5.50 per hundredweight (20+ kips), $4.77 per hundredweight (40+ kips), and $1,378.00 for a pup load. Assuming a linear weight of 1,000 lb per foot and a 27-ft pup, the pup-load charge is equivalent to $5.10 per hundredweight. At 1,500 lb per foot, the equivalent rate is $3.40 per hundredweight. Thus, given a high-density payload, the use of doubles (two 27-ft pups, each with a payload of 40.5 kips) would offer a saving of about 29 percent.

Other CTTBA rates analyzed were for "Fresh Meat--Suspended" and "Seeds: Field, Grass, Mustard." In neither case could any evidence be found that the changing weight and dimension regulations had affected rates.

Saskatchewan: Intraprovincial General Merchandise Rates

Rates for intraprovincial movements of general merchandise [typically less-than-truckload (LTL) general freight] are regulated. At present the tariff is a prescribed maximum. The lowest rate in the tariff has been applied to a gradually increasing minimum shipment size over time as the regulations have permitted larger trucks. This relatively decreasing rate is irrelevant, however, because the evidence suggests that 99 percent of all shipments moving under this tariff are small shipments. In those isolated instances in which general merchandise is moved in large shipments (40+ kips), actual rates are undoubtedly less than the prescribed maximums.

The major impact of the relaxed regulatory environment on these intraprovincial general merchandise rates is associated with the total payload-handling capabilities of the larger vehicles rather than with the maximum shipment size that can be handled. To this effect, since 1979, the LTL general merchandise rates have been derived from a cost model that incorporates a payload parameter: the greater the payload, the lower the unit cost, the lower the unit rate. However, there is evidence to suggest that larger payloads and lower rates have not materialized simply because the underlying demand conditions cannot support larger payloads (given the same service frequency).

Western Canada: Selected Dry Bulk Commodity Rates

Cement, grain, and fertilizer are three significant dry bulk commodities handled by trucks within the prairie region. Each of these is a weight-out rather than a cube-out product and as such has been an obvious candidate for servicing at higher GVW limits. Several observations can be made about the impact of relaxed weight and dimension regulations on these movements.

Considering bulk cement movements, as of June 1974, TL rates from Winnipeg to points in Saskatchewan, Manitoba, and western Ontario were based on a 36-kip minimum shipment. In early 1977 the minimum shipment size was increased to 48 kips. In early 1982 a rate reduction of 10 percent from the 48-kip rate was introduced for double-trailer lots (110-kip GVW) with a minimum payload of (about) 73 kips. There has been no further differential introduced in response to the 1982 weight limit increases. Two factors have apparently discouraged more extensive use of double-trailer lot rates for the movement of this product: (a) storage capacity restrictions at the receiving points and (b) a reluctance on the part of the shippers to introduce pricing practices that would lead to differences in the delivered unit price between a consignee who accepted a single-trailer lot versus one who accepted a double-trailer lot.

Commercial grain-hauling rates in western Canada have generally been insensitive to shipment size (19). The industry thinks in terms of a 48-kip (plus or minus) "normal" minimum shipment size. Such a load can be handled by a standard five-axle unit, even at secondary highway axle weight limits. However, as of 1982, some truckers have introduced double-trailer lot rates that assume approximately 77-kip loads. These rates are typically 10 to 15 percent lower than the quoted semitrailer lot rates. Although this may appear to contradict the observation that rates have been insensitive to shipment size, the "discounted" double-trailer rates fall within the same range as those actually being paid to the competing semitrailer operators. The market is relatively unsophisticated (many small shippers and truckers), highly competitive, and very fluid. All rates, no matter what is quoted or what equipment is used, tend to normalize at certain levels.

Tariffs for fertilizer published by two major distributors indicate that, as of the fall of 1982, a 48-kip (plus or minus) minimum was the only minimum shipment lot rate provided (19). Possible explanations for this apparent insensitivity to the relaxed regulatory situation are (a) the highly peaked nature of the demand for fertilizer movements, with the result that trucking services are offered in a sellers' market and (b) the general reluctance of farmers to take delivery of fertilizer in double-trailer lots.

CONCLUSIONS

Clearly, different weight and dimension regulations and changing weight and dimension regulations affect the characteristics of the large truck fleet, the size of shipments, and the cost or rate of the trucking service. It is also clear that the precise nature of these impacts is complex. Given Canada's experience, it would be extremely simplistic to subscribe to the view that more permissive regulations instantaneously "cause" large trucks to appear on the roads with larger payloads, larger shipments, and lower rates.

The truth is that the exact consequences of different or changed weight and dimension regulations are difficult to predict:

- What segment of the trucking industry will respond (for-hire/private, bulk commodity/general freight)?
- What will the time lags be (instantaneous, several years as some of the evidence suggests, or longer)?
- What types of commodity or hauling situations

are more critical under different regulatory scenarios (dense weight-out or less dense cube-out commodities)?

- Why do changes in some jurisdictions appear to encourage A-trains instead of B-trains (or is this largely a matter of the type of operating condition or flexibility required by carriers)?
- Why do trucking rates for some commodity and hauling situations appear to respond relatively rapidly and significantly to changes in weight and dimension regulations while others do not?
- Why does the spread between the "old" TL rates and the "new" double-trailer rates appear to increase over time for some hauling situations but not for others?

Developing convincing assessments of alternative weight and dimension regulations will require answers to these and other questions. Although the evidence discussed in this paper obviously provides some partial answers, it also raises many more questions.

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REFERENCES

1. M.D. Armstrong, F.W. Jung, and W.A. Phang. A Proposed Method of Regulating Vehicle Weights in Ontario. Report RR166. Ontario Department of Highways, Toronto, Ontario, Canada, 1970.
2. G. Sparks, R. Courturier, and A.M. Clayton. Increasing Allowable Gross Vehicle Weights on Secondary Highways. Proc., Canadian Transportation Research Forum Annual Meeting, Regina, Saskatchewan, Canada, June 1983.
3. A.M. Clayton, G. Sparks, and R. Mak. Truck Industry Technological Response to the Western Canada Highway Strengthening Program. Roads and Transportation Association of Canada Annual Conference, Edmonton, Saskatchewan, Canada, 1983.
4. F.P. Nix and R. Schipizky. The Effect of Vehicle Weight and Dimension Regulations. Proc., Canadian Institute of Transportation Engineering Annual Conference, Ottawa, Ontario, Canada, June 4-6, 1984.
5. F.P. Nix, A.M. Clayton, and B.G. Bisson. Study of Vehicle Weight and Dimension Regulations and Canada's Trucking Industry. Background Paper 1: Description and Analysis of Vehicle Weight and Dimension Regulations. Transportation Development Centre, Montreal, Quebec, Canada, 1985.
6. A.M. Clayton and R. Mak. Selected Canadian Vehicle Registration Statistics for Large Trucks: Prairie Provinces, British Columbia and Ontario. The Transportation Group, Department of Civil Engineering, University of Manitoba, Winnipeg, Manitoba, Canada, 1985.
7. A.M. Clayton and J. Sem. Regulatory Issues in Transborder Trucking: A Case Study Referencing Trucking Between Manitoba and Minnesota. Proc., Canadian Transportation Research Forum Annual Meeting, Toronto, Ontario, Canada, 1985.
8. Commodity and Truck Weight Study. Saskatchewan Highways and Transportation, Regina, Saskatchewan, Canada, 1974, 1975, and 1978.
9. Truck Axle Weight and Commodity Study. Saskatchewan Highways and Transportation, Regina, Saskatchewan, Canada, 1979, 1981, and 1982.
10. J.T. Christison and I.V. Krumins. Truck Traffic Load Demand on Alberta Highways: 1970-1980. HTE 83/01. Alberta Research Council, Edmonton, Alberta, Canada, May 1983.
11. 1979, 1980, and 1981 Truck Origin-Destination Studies. Alberta Transportation Planning Services, Edmonton, Alberta, Canada, 1980, 1981, and 1982.
12. M.H. Parera and E.G. Corupe. Ontario Commerical Vehicle Survey--1983. Ontario Ministry of Transportation and Communications, Downsview, Ontario, Canada, 1984.
13. R.D. Ervin. A Survey of the Characteristics of Equipment in the Canadian Trucking Fleet. Roads and Transportation Association of Canada, Ottawa, Ontario, Canada, Nov. 1984.
14. For-Hire Trucking Survey. Cat. 53-224. Statistics Canada, Ottawa, Ontario, Canada, annual.
15. Service Bulletin: Road Transport. Cat. 53-006. Statistics Canada, Ottawa, Ontario, Canada, Vol. 14, No. 1, Jan. 1985 and Vol. 14, No. 2, Feb. 1985.
16. An Investigation of Truck Size and Weight Limits. U.S. Department of Transportation, 1981.
17. The Economic Consequences of Changed Weight Regulations for Trucks in Sweden. Report 1983:5E. Swedish Transport Research Commission, Stockholm, Sweden, 1983.
18. A.M. Clayton and G. Sparks. The Benefit Dimensions of Large Truck-Trailer Combinations: Canadian Experience. Proc., 10th International Road Federation World Meeting, Rio de Janeiro, Brazil, Oct. 1984.
19. A.M. Clayton, F. Nix, and G. Sparks. Aspects of Commercial Trucking of Grain in the Prairie Region. Research Report 1984/06E. Canadian Transport Commission, Hull, Quebec, Canada, May 1983.

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