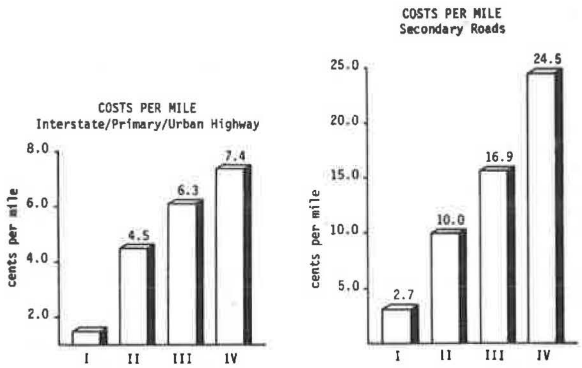
Figure 4. Costs per mile traveled.



The cost-per-mile responsibility is overwhelmingly greater for secondary roads. Even with a consistent methodology, the responsibilities are at least doubled for each class on the secondary roads. Also, the cost-per-mile produces the expected relationship among the truck classes (i.e., combinations have greater responsibility than single-unit trucks). This, of course, stems from removing the impact of the miles traveled on secondary roads.

In sum, determination of the cost responsibility for secondary roads was an important part of the overall study of cost responsibility in Virginia. The findings on secondary roads showed a different distribution of cost responsibility than on the other systems, as had been expected. The combination of secondary road allocations with the other road system allocations led to the conclusion that class 2 and 3 vehicles were underpaying. Inclusion of secondary road expenditures in the state's cost-responsibility analysis was therefore a key factor in influencing study results.

ACKNOWLEDGMENT

This paper reflects our positions and opinions and should not be construed to represent the position of the Joint Legislative Audit and Review Commission of the Virginia General Assembly.

REFERENCES

1. E.J. Mosbaek. Highway Finance: Assessing User and Non-User Shares. Jack Faucett Associates, Washington, DC, March 1981.
2. J.A. Dunn, Jr. The Importance of Being Earmarked: Transport Policy and Highway Finance in Great Britain and the United States. Comparative Studies in Sociology and History, Vol. 2, Jan. 1978.
3. D. Lee. Alternative Criteria for Highway Cost Allocation. U.S. Department of Transportation, March 1980.
4. D. Lee. Recent Advances in Highway Cost Allocation Analysis. TRB, Transportation Research Record 791, 1981, pp. 1-5.
5. Joint Legislative Audit and Review Commission of the Virginia General Assembly. Methodology for a Vehicle Cost Responsibility Study. Senate Document No. 12 of 1981 Session, Richmond, Jan. 1981.
6. Joint Legislative Audit and Review Commission of the Virginia General Assembly. Vehicle Class Cost Responsibility in Virginia. Senate Document No. 13 of 1982 Session, Richmond, Nov. 1981.

Publication of this paper sponsored by Committee on Low-Volume Roads.

Effect of Unit-Train Grain Shipments on Rural Nebraska Roads

DEAN LINSENMEYER

The unit-train concept has altered the rural pricing structure for grains and consequently encouraged longer-distance truck transportation in larger-sized lots by producers and rural elevators over the 1975-1980 period. Annual data on grain production, livestock consumption, and storage capacity were obtained from Nebraska Agricultural Statistics. Primary data on truck receipts were collected by interview with the managers of 86 unit-train shippers across the state. A computer model was developed to calculate the total ton miles of producer transport of grains within the elevator's trade area for each district as well as ton miles of interelevator transfer. Nebraska producers in 1980 transported 71 percent more ton miles delivering grain to commercial elevators than in 1975. Combined with the growth in interelevator grain transfers by truck, the annual ton miles of rural truck transport of grains in 1980 was nearly double the 1975 level. The investment required to maintain and upgrade the rural road system is not independent of changes in other sectors of the total U.S. transportation system. The increased use of unit-trains has precipitated an increase in the ton miles of grain hauled over low-volume roads as well as an increase in the weight per axle and a subsequent increase in stress on rural roads and ridges.

From 1975 through 1980, Nebraska's annual production of grains and oilseeds averaged more than 22 million metric tons. More than 71 percent of this, or approximately 16.5 million metric tons, moved over rural roads annually via farm vehicles to commercial elevators. The growth in total volume of rural grain traffic in recent years has placed increased demand on the rural road system. Nebraska grain production increased by 7 percent annually between 1975 and 1980, more than twice the growth rate of U.S. production. With no distinguishable trend in Nebraska's feed requirements during the 1975-1980 period, increased production resulted in an average annual increase of nearly 1.5 million metric tons of grain to be marketed commercially.

Historically, bid prices to farmers have differed only marginally between competitive elevators in a given area. Consequently, producers had little incentive to seek a market beyond their nearest elevator. However, in 1975 the unit-train concept was initiated in Nebraska and offered fares significantly lower than previous single-car rates. For most elevators, adjusting to the unit-train shipment meant making a sizable investment in fixed facilities sufficient to load the 25-, 50-, and 75-car trains in 24 h.

Many shippers needed to expand their trade area to assemble the bushel volume required to support a unit-train shipping program. This was accomplished by passing a portion of the rate advantage on to producers as higher bid prices. With this incentive, producers from outlying areas found it profitable to transport grain further to unit-train facilities. Some elevators that chose not to become unit-train shippers found their grain merchandizing advantage eroded and, in turn, transferred grain by truck to the unit shippers.

The result has been an increase in rural truck transportation of grains into fewer elevators that then ship directly to the export market and bypass the traditional terminals. As producers moved grain greater distances, it became profitable to increase truck size. The net effect has been to increase the ton miles hauled over low-volume roads as well as to increase the weight per axle with a subsequent increase in stress on rural roads and bridges.

OBJECTIVES

The purpose of this study was to estimate the magnitude of such changes for major grain-producing regions of the state over the 1975-1980 period. Specific objectives were to (a) describe the changes between 1975 and 1980 in variables that influence the rural transportation system such as the truck transportation costs, the number of single-car and unit-train elevators, and the annual volume of marketed Nebraska grain; (b) compare the producer ton miles of grain transportation by crop reporting district for 1975 and 1980; and (c) estimate the increase in ton miles of interelevator grain transfer by truck by crop reporting district from 1975 to 1980.

Methodology

The total ton miles of grain transportation required to serve the originating elevator depends on several variables. The quantity of nonfeed grain per square mile and the number and size of elevators within the crop reporting district are important considerations. The amount and distance of interelevator grain transfers by truck identify additional transportation necessary to position the grain for shipment out of the area. Secondary data were obtained for grain production, livestock numbers, and feed requirements as well as elevator size and numbers. Primary data were collected on elevator bid prices, interelevator grain transfers, and trucking costs.

A computer program was developed to calculate the difference in ton miles of rural truck transportation between 1975 and 1980. Equation 1 is the identity equation used to compare the two years of transportation needs in district K.

$$\Delta M_K = M_{K_{80}} - M_{K_{75}} \tag{1}$$

where M_K is ton miles of rural truck transport in district K.

Estimating Rural Truck Transport in 1975

The total ton miles of rural truck transport in 1975 ($M_{K_{75}}$, Equation 1) was attributed to producer transport since grain transfers from country elevators to terminals would probably not occur over rural roads and the country-terminal traffic was not included in either the 1975 or 1980 calculation. Equation 2 computes the ton miles of producer transport in 1975.

$$M_{K_{75}} = \sum_{J=1}^{J} \sum_{R=1}^{R} [(T_{J,K,R} - T_{J,K,R-1})\, 1.207 D_K R_M] \tag{2}$$

where

$T_{J,K,R} = (B_{J,K} / \sum_{J=1}^{J} B_{J,K})\,(A_K)$, the square mileage trade area of elevator J in district K with a radius of R in 1975;
A_K = total square mileage area of district K;
$B_{J,K}$ = licensed storage capacity of elevator J in district K;
D_K = density (metric tons per square mile) of marketed grain; and
$R_M = \sqrt{R^2 - R + 0.5}$, the radius to the midpoint of the trade area delineated by R and R - 1.

According to $B_{J,K}$, the total square mileage of the crop-reporting district was allocated among the elevators in proportion to their licensed grain storage capacity, thereby determining the trade areas for individual elevators. It was assumed that elevators that possess a large percentage of the district's total licensed storage capacity served a proportionately large trade area in 1975.

A circular configuration was imposed on each individual trade area even though it is recognized that this implies an equal amount of overlapped and nontraded area. Although other classical location models have assumed hexagonal or other polygonal patterns (1), the circular form allows trade areas to be of unequal size, which was crucial to the present study. Once an individual firm's trade area was determined, the elevator was assumed to be located at the central origin of a rectangular grid road system that extends over the entire area. Beginning with the outer rim portion of the trade area ($T_{J,K,R} - T_{J,K,R-1}$) the ton miles generated from each 1-mile-wide concentric area were summed for all radii R inwardly toward the epicenter. An average correction factor of 1.207 was calculated by using the Pythagorean theorem to convert direct radius distances into road distances to account for marketed grain originating off the main X or Y axis of the grid network. Marketed grain is defined as the annual production of all grains and oilseeds in a given district minus the annual livestock feed requirements in that district. The ton miles of transport were then summed for all firms J in district K.

Estimating Rural Truck Transport in 1980

By 1980, licensed storage capacity was not a relevant criteria for estimating elevator trade areas for the unit-train shippers. The volume of grain handled by single-car shippers was calculated by using estimated annual turnover rates on storage capacity. Because local livestock feed requirements were already deducted in determining marketable grain, the turnover rates of single-car elevators did not include the volume of grain handled by elevators to satisfy local feeders. Based on discussions with industry sources, the turnover rate of 1.0 times the total licensed storage capacity was applied against grains marketed through the single-car shipper into the interregional commerce.

The annual volume of direct producer deliveries of grain to unit shippers in 1980 was estimated to consist of the total marketed grain for that district minus the estimated grain receipts of single-car shippers. This remaining grain was distributed between the unit-train elevators in proportion to their car-loading capacity.

Equation 3 estimates the total ton miles of rural truck transport of grain in 1980. Its three major components are estimates of producer transport to single-car elevators, producer transport to unit-train elevators, and interelevator truck transport.

$$M_{K_{80}} = \sum_{N=1}^{N}\sum_{R=1}^{R}\left[(T_{N,K,R} - T_{N,K,R-1})\,1.207\,D_K R_M\right]$$

(producer transport to single-car elevators)

$$+ \sum_{U=1}^{U}\sum_{R=1}^{R}\left[(T_{U,K,R} - T_{U,K,R-1})\,1.207\,D_K R_M\right]$$

(producer transport to unit-train elevators)

$$+ 1.9375\,T_{U,K,R}\,D_K \qquad (3)$$

(interelevator transfer)

where

$T_{N,K,R} = B_{N,K}/D_K$, the square mileage trade area of single-car elevator N in district K with radius R in 1980;

$T_{U,K,R} = (L_{U,K}/\sum_{U=1}^{U} L_{U,K})\,(A_K - \sum_{N=1}^{N} T_{N,K,R})$, the square mileage trade area of unit-train elevator U in district K with radius R; and

$L_{U,K}$ = load-out capacity of unit-train elevator U in district K, specified as the number of hopper cars capable of being spotted on the elevator's siding.

The total ton miles of producer transport in 1980 within a given elevator's trade area was calculated in a similar manner as the 1975 computations. The amount of interelevator transfer was estimated as a percentage of total unit-elevator receipts, based on primary data collected from the operators of all 66 unit-train elevators in 1980.

RESULTS

The total quantity of marketed grain in 1980 was nearly 2.5 million metric tons or 19 percent larger than in 1975 according to Table 1. This growth was accomplished in spite of the fact that livestock feed requirements in 1980 were significantly above the 1975-1980 trend and a widespread drought reduced 1980 production significantly below the trend. Districts such as the Southeast and East experienced growth in livestock feed requirements that nearly offset increased grain production. Consequently, their volume of 1980 marketed grain was only 6 and 8 percent, respectively, larger than in 1975. In contrast, grain marketed over rural roads in the Central district increased by 25 percent, in the Northeast by 27 percent, in the Southeast by 31 percent, and in the South by 44 percent over the same period. Even if the average length of haul did not change from 1975 to 1980, one could expect ton miles of rural producer transport of Nebraska grains to increase approximately 19 percent due only to the greater volume of grain being marketed.

The total number of receiving elevators has remained relatively constant with less than 1 percent decline over the five years. However, the real change (as Figure 1 illustrates) has been in the upgrading of single-car elevators into unit-train facilities along with a small increase in newly constructed unit elevators. The number of single-car elevators declined by nearly 11 percent due to up-

Table 1. Changes in quantity of Nebraska's marketed grain, 1975-1980.

	Grain Production		Feed Requirements		Commodity Surplus	
Crop Reporting District	Absolute Increase (000s metric ton)	Increase (%)	Absolute Increase (000s metric ton)	Increase (%)	Absolute Increase (000s metric ton)	Increase (%)
Northeast	483	18	100	8	383	27
Central	333	15	-72	-12	405	25
East	547	11	231	24	316	8
Southwest	475	27	24	8	451	31
South	810	39	28	10	782	44
Southeast	307	10	166	27	141	6
State total[a]	2955	17	477	12	2478	19

[a]State total does not include Northwest and North districts.

Figure 1. Changes in Nebraska's grain elevators: 1975-1980.

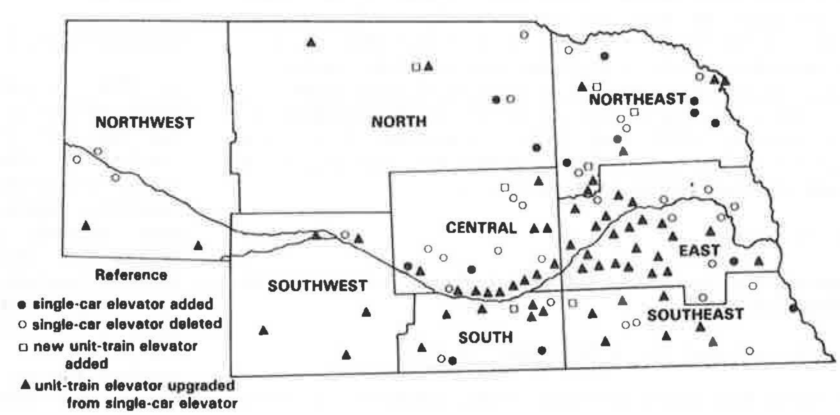


Table 2. Change in ton miles of rural Nebraska truck transportation of grains, 1975-1980.

Region	Producer to Elevator: Nonunit Shipper (000s ton mile)	Unit Shipper (000s ton mile)	Increase: Ton Miles (000s)	Increase: Percent	Interelevator Nonunit to Unit Transfer (000s ton mile)	Total Increase: Ton Miles (000s)	Total Increase: Percent
Northeast	-5 121	+16 214	+11 092	97	+2 940	+14 033	123
Central	-4 141	+12 882	+8 471	83	+3 215	+11 957	113
East	-10 244	+12 337	+2 093	9	+5 393	+7 486	32
Southwest	+223	+20 280	+20 503	165	+2 727	+23 230	189
South	-6 538	+14 229	+7 691	61	+3 878	+11 569	93
Southeast	-682	+8 797	+8 115	71	+2 424	+10 538	92
State total[a]	-26 503	+84 738	+58 235	71	+20 576	+70 812	96

[a]State total does not include Northwest and North Regions; assumes 1.0 turnovers per year on licensed storage capacity for nonunit shippers not including grain for local livestock feeding.

grading as well as closures. The number of rural train-load shippers increased by 66, not including the 19 terminal facilities.

The pricing structure has changed as well. Weekly cash bid prices collected over the last two years from six privately owned single-car and unit-train shippers in central Nebraska were compared. It was found that the prices offered to producers by unit-train shippers were approximately 8 cents/bushel higher than at nearby single-car elevators. Given this differential bid price between elevators, the extent to which the trade areas of unit-train elevators would likely expand is determined by the producer's cost of rural transport. Payne, Baumel, and Moser (2) calculated variable costs of trucking by using a 16-ft, 325-bushel grain box at approximately 0.06 cents/bushel per mile (1975 dollars), not including dead-haul labor costs. The pricing of identical items (2) by using 1980 prices revealed a variable cost per bushel per mile of about 0.16 cents for the 325-bushel load. This would indicate that it could be economically rational for a producer to increase a haul by more than 6 miles for a 1 cent differential in bid price. In addition, more producers are now using 18-ft, 425-bushel grain boxes for which the variable costs are estimated to be only 0.13 cents/bushel per mile.

Of additional importance is the seasonal difference in the demand for rural transport. Primary research of producer marketing practices in Nebraska in 1977 revealed that more than 72 percent of producer deliveries of wheat to local elevators occurred in June and July. Likewise, 50 percent of the 1977 corn and 75 percent of the milo harvest was delivered to commercial centers for sale or storage during the October-November period (3). Not only does the demand on the system appear extremely concentrated but maintenance of rural road conditions during the wet snowy late fall conditions requires a different investment than during the dry wheat harvest of early July. The high concentration of corn, sorghum, and soybean production in the Central, South, Southeast, and Northeast crop-reporting districts indicates that nearly half of all rural grain transport in those areas will occur in the late fall.

The combined impact of increases in marketed grain and the greater differential in bid prices relative to the costs of transport has meant more bushels that travel farther over rural roads. According to Table 2, the total ton miles transported by producers for all major grain districts was 71 percent greater in 1980 than in 1975. However, the increase in demand on rural roads was by no means consistent between districts. In the East, where the marketed grain increased only marginally in 1980 and a considerable number of single-car elevators were upgraded to unit-train capacity, total ton miles increased by 9 percent in five years. That growth occurred as deliveries to unit-train facilities more than offset an overall decrease in ton mileage incurred for delivery to nonunit elevators. On the high side, the Southwest district experienced a 165 percent increase in producer ton miles, primarily because of increases in marketed grain and a modest growth in unit-train facilities.

In addition to increased producer transportation, Table 2 indicates an increase in interelevator truck transfer from single-car to nearby unit-train elevators. Based on primary data collected from the 66 unit-train elevators in 1981, more than 6 percent of their total volume was received by truck from single-car shippers located an average of 31 miles away. Consequently, Nebraska's road system supported nearly 17 million additional ton miles of truck transportation due to interelevator transfers, from single-car to unit-train facilities.

In summary, Table 2 indicates that total ton miles of truck transport of grains over non-Interstate rural roads has nearly doubled over the 1975-1980 period. Nearly three-quarters of this increase has been due to changes in producer transportation patterns.

SUMMARY AND CONCLUSION

The investment required to maintain and upgrade the rural road system is not independent of change in other sectors of the total U.S. transportation industry. The introduction of the unit-train concept for on-rail transportation in the Great Plains has altered the rural pricing structure for grains and consequently encouraged longer distant truck transport of grains by producers in major production regions.

This study has indicated that the 19 percent growth rate over 1975-1980 in Nebraska's marketed grain has combined with longer distant hauls to increase total ton miles of rural truck transport at a rapid pace. It was found that, in 1980, Nebraska producers transported 71 percent more ton miles in delivering grain to commercial elevators than in 1975. Combined with the growth in interelevator grain transfers by truck, the annual ton miles of rural truck transport of grains in 1980 was nearly double the 1975 level.

Recognition of the interdependencies between transportation modes and the economies of unit-train transport will assist in anticipation of the demands placed on rural roads. A better understanding of the amount and type of demands on the rural road network will assist in making long-run public investments.

ACKNOWLEDGMENT

This paper was previously published as paper number 6880, Journal Series, Nebraska Agricultural Experiment Station.

REFERENCES

1. B.C. French. The Analysis of Productive Efficiency in Agricultural Marketing: Models, Methods, and Progress. A Survey of Agricultural Economics Literature, Vol. 1 (L. Martin, ed.), Univ. of Minnesota Press, Minneapolis, 1977.
2. D. Linsenmeyer. Analyses of Nebraska Wheat Flows. Department of Agricultural Economics, Univ. of Nebraska, Lincoln, 1981.
3. W.F. Payne, C.P. Baumel, and D. Moser. Estimating Truck Transport Costs for Grain and Fertilizer. College of Agriculture, Univ. of Missouri, Columbia, Res. Bull. 1027, June 1978.

Publication of this paper sponsored by Committee on Low-Volume Roads.

Development of a Computerized Technique to Identify Effective Forest Roadway Networks

DAVID C. SHUNK AND ROBERT D. LAYTON

Forest transportation planning is a complex task that involves many decisions. This paper presents an algorithm and computer program that will assist in effective transportation planning and decisionmaking in the national forests. This identification of an efficient arterial, collector, and local roadway network is a primary component in the transportation planning process. An earlier study by Kehr and Layton identified the primary factors and important decision criteria used to evaluate forest arterial and collector networks. This study employs these decision criteria in the development of a computerized comprehensive analytical framework, PLANET1 and PLANET2, to identify and evaluate forest arterial and collector networks. Two main computerized network algorithms have been used in transportation network evaluation: the shortest path algorithm and the minimum spanning tree algorithm. The shortest path algorithm provides the most direct route to each point, without direct consideration of construction costs. The minimum spanning tree algorithm emphasizes the least-cost connective network and ignores the travel times and operating costs. The computerized technique presented in this report combines the advantages of the shortest path algorithm with those of the minimum spanning tree algorithm to determine a more efficient roadway network than is provided by either approach used individually. Examples of the use of these new algorithms, PLANET1 and PLANET2, are presented and discussed.

As defined by the Forest Service Manual, the objective of transportation planning is (1) "to ensure that plans for the development and operation of the forest development transportation system are made, and that they are consistent with land-use planning policies and procedures, and will effectively achieve resource management objectives".

The identification of an efficient arterial, collector, and local roadway network is a primary component of the transportation planning process. A previous study by Kehr and Layton (2) identified the primary factors and important decision criteria used to evaluate forest arterial and collector networks. The study employs these decision criteria in the developing of a comprehensive analytical framework to identify and evaluate forest arterial and collector networks. The method developed in the report by Kehr and Layton, however, is a manual method that takes a great deal of time to use.

Two computerized network algorithms used extensively in forest transportation network analysis and evaluation are the shortest path algorithm and the minimum spanning tree algorithm. The shortest path algorithm provides the most direct route to each point, measured by time, distance, or cost, usually operating cost. The minimum spanning tree algorithm provides the least-cost connective network, which is usually measured by the length of links or link costs, typically construction and maintenance costs.

The method developed by Kehr and Layton (2) recommends the use of a method that employs both the shortest path and the minimum spanning tree algorithms. However, no computerized technique is presented in that study. A primary analysis technique for national forest planning is the timber transport model (TIMBRI), a computerized method to find the least-cost timber haul routes (3). This technique relies heavily on the shortest path algorithm together with a mixed integer linear programming routine. However, that technique focuses on identifying the most efficient network for timber haul alone. The PLANET1 and PLANET2 algorithms combine the advantages of a shortest path analysis, which minimizes time or operating cost, and the minimum spanning tree analysis, which minimizes construction costs and, if desired, maintenance costs, to determine an efficient roadway network.

SCOPE

This paper presents a computerized method to identify effective forest roadway networks. The decision criteria used to evaluate forest road networks are divided into four major groups: physical, analytical, quantitative, and qualitative. The important decision criteria in each group are given below in rank order.

1. Physical criteria--connection to regional mills and markets, connectivity with surrounding road networks, types of vehicles and users present, extent of access to forest area, interface conflicts and delays, and access to adjacent lands;
2. Analytical criteria--total cost for timber haul, timber traffic volume, recreational traffic volume, least-cost connective network, construction cost, operating cost, maintenance cost, safety cost, level of service, and capacity;
3. Quantitative criteria--size of area served, speed of travel, and road design standards; and
4. Qualitative criteria--compatibility with environment, comfort and convenience, and safety.