Study of Impact of Rail Abandonment on Local Roads and Streets

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In the 1970s, 404 miles of Kansas rail line were abandoned. That figure rose to 745 miles in the 1980s. Railroad abandonment has had adverse consequences for Kansas farmers, rail shippers, and rural communities, including lower grain prices received by Kansas farmers, higher transportation costs and reduced profits for rail shippers; loss of market options for Kansas shippers, foreclosed economic development options in rural Kansas communities, higher road maintenance and reconstruction costs, and negative social impacts on rural Kansas communities. Kansas State University contracted to do a study of the adverse consequences for the Kansas Department of Transportation. Of the many objectives, this paper deals with the measurement of the public costs of rail abandonment in south central Kansas (e.g., increased road maintenance expenditures caused by larger truck volumes). The study area is a 10-county region in south central Kansas served by three Santa Fe branchlines that were placed in Category 1 abandonment status in June 1990. The principal findings of the project that relate to the impact on roads and streets are as follows. For the three branchlines as a group, the Santa Fe's share of wheat shipments (from study area grain elevators) fell from 74 percent in 1985 to about 60 percent in 1990. Most of the decline in market share occurred in 1990 and continued to fall in early 1991. The major 1990–1991 wheat markets for the grain elevators on study area branchlines are terminal elevators in Wichita and Hutchinson, Kansas, as well as Enid, Oklahoma. Substantial wheat volumes are sold to flour mills in Kansas and Oklahoma. Although abandonment of the Santa Fe branchlines resulted in only an 8 percent increase in commercial trucking of wheat, this additional trucking caused a 50 percent increase in road damage costs. The truck-attributable road damage costs resulting from abandonment of the three Santa Fe branchlines were slightly more than $1 million. Of this total, 27 percent was due to farm-to-country elevator truck movements, and 73 percent was attributable to shipments from country elevators to terminal elevators.

Maximum rail mileage in the United States was reached just before 1920 at approximately 253,000 rail miles and peaked in Kansas around 1930 at about 9,324 rail miles (*1*). Since that time, segments of the railroad system have gradually been abandoned. Some line segments that have been candidates for abandonment were built in an earlier period in anticipation of industrial or agricultural growth that did not occur, and still others were built to transport natural resources to factories whose resource deposits have since been depleted. Most commonly, however, a shift in the role of railroads in the total transportation system has so reduced the volume of traffic on some, mainly rural, lines that income is no longer sufficient to cover railroad operating and maintenance costs. Whatever the reason, the net effect of these actions has reduced total U.S. rail mileage by 55 percent to 113,056 mi and Kansas rail mileage by 31 percent to 6,393 mi in 1992 (*2*, pp. 44–45). The railroad that abandons the line benefits by avoiding further losses. However, abandonment decisions by privately owned railroads result in public costs, such as road damage from increased trucking following abandonment.

The reduction in rail traffic has a profound impact on all areas, both rural and urban; however, the effects of these abandonments are greatest in rural areas. Loss of rail service often has dire consequences in rural communities. Farmers are faced with an increase in trucking costs since they are forced to haul their grain farther to remaining grain elevators. Cutbacks in profit margins are necessary for grain elevators on abandoned lines in order to remain competitive with those elevators that have rail connections. Perhaps most important, abandonment means the hastened deterioration of rural highways and bridges from additional truck traffic and the accelerated maintenance costs that accompany deterioration of this kind.

There has been a trend lately toward low-density branchline rail abandonment. This trend is cause for great concern for the policy makers and planners of Kansas and other states. Abandonment of light-density rail lines constitutes a major change in the method for transporting grain in rural areas, not only at the local elevator level but also at the production level. Farmers, who generally sell their grain to elevators offering the highest bid, would probably be inclined to take their grain to elevators served directly by rail because of the tendency of these elevators to provide higher bids because of cheaper shipping costs. In addition, with discontinued rail service, elevators are forced to truck their grain to other elevators with rail service or to terminal elevators. The impacts of these changes cause increased truck mileage, which means additional use and damage to the state's roads.

Since highway pavements are structures with finite lives, they are designed to withstand a specific number of 18,000-lb equivalent single axle loads (ESALs). One railcar of grain or dry fertilizer is roughly equivalent to 3.7 tractor-trailers (*3*). Consequently, the truck traffic consumption of ESAL design life, and increased highway infrastructure costs associated with it, can increase rapidly where significant volumes of rail traffic diversions to trucks are involved. This phenomenon not only occurs on those highway segments that were designed for a high level of truck traffic but also occurs, perhaps with greater consequence, on rural highways that are often not designed to handle large truck volumes. If a road section was not designed for heavy axle loads, as many rural roads are not, it could be rendered inadequate in a matter of months or even weeks.

As an example, a section of road might be designed for 5,000,000 ESALs with a structural life expectancy of 25 years based on a truck projection of 200,000 ESALs per year. If a rail abandonment resulted in a highway traffic consisting of 500,000 ESALs per year, the structural capacity of the road would be used up in 10 years instead of 25 years. It would also be reasonable to assume that the road would require almost the same amount of maintenance over those 10 years as it would have required over 25 years to maintain the same ride comfort and quality.

Study Focus

The cost of a rail abandonment is a function of the proximity of alternate rail lines, the nature and volume of commondity flow, and the highway system itself. The focus of a study that was funded by the Kansas Department of Transportation (KDOT) and performed by Kansas State University (KSU) was on determining the cost of infrastructure maintenance or reconstruction due to the traffic diversion caused by selected railroad abandonments in south central Kansas, with emphasis on the existing network of county, city, and state roads (*4*).

The rail lines that were being considered for abandonment included 298 mi of the Atchison, Topeka & Santa Fe Railway Co. (Santa Fe) encompassing portions of 10 counties in south central Kansas. One of the major objectives of the KSU study was to estimate the impact on the Kansas road system of potential Santa Fe branchline abandonment and more specifically, the abandonment of three study area branchlines: (a) Rago to Englewood, (b) Wichita to Pratt, and (c) Hutchinson to Wellington. If rail service is withdrawn, additional trucking of wheat will occur, thus increasing damage to the area's road system.

Upon evaluation of several methods for completing an analysis of railroad abandonment effects on a given highway pavement system, the most appropriate method for this study was determined to be one developed by KDOT's Bureau of Rail Affairs. In its 1989 report, a methodology was developed and documented to provide a systematic procedure for estimating the incremental highway costs associated with branchline abandonment (*5*). The methodology was based on previous work by Tolliver (*3,6*).

Methodology Description

In this study, a transportation-estimating model for personal computers developed by Chow was used to generate wheat flow data relevant to determining the impacts of railroad abandonment (*7*). This model estimated likely minimum cost wheat flows over specific highway routes after the assumed abandonments occurred. A specified amount of grain was routed by the program from several simulated farms to its ultimate destination by way of local elevators and terminal destination transit points. The program required that the user provide several data elements from which the program develops minimum cost grain flow patterns.

Assumptions

If rail service is withdrawn, additional trucking of wheat will occur. Some farmers may continue to deliver wheat to elevators on these abandoned rail lines. After abandonment, these elevators are completely reliant on trucks for shipment of grain to markets. In other cases, farmers will transport their wheat over greater distances to elevators that offer higher prices due to the existence of rail service at that location. It is impossible to determine before the fact how much additional trucking will occur as a result of abandonment. The best that can be done is to make some assumption regarding the manner in which farmers and elevators react to abandonment. In this study, it is assumed that elevators and farmers use the transportation service that minimizes wheat transportation and handling costs. This will maximize farm price received and country elevator profit margins.

Description of the Model

Given the foregoing assumption, a model is required that describes the movement of wheat from study area farms to final markets at the least transportation and handling costs. To do this, it was decided to use a wheat logistics network model developed by Chow (7). The model is employed to measure truck and rail shipments of wheat assuming no rail abandonment in the study area. The model is then used to determine the additional trucking of wheat that would occur if the three Santa Fe branchlines in the study area were abandoned. The incremental trucking caused by abandonment is the difference in truck shipments measured by the two simulations.

The Chow network model minimizes transportation and handling costs of moving wheat from the farm to domestic and export markets via various transshipment points (country elevators, terminal elevators, etc.). The mathematical formulation is as follows:

$$Z \sum_{i=1}^{F} \sum_{j=1}^{C} a_{ij} WF_{ij} + \sum_{i=1}^{C} \sum_{j=1}^{I} (b_{ij} WC_{ij} + b'_{ij} WC'_{ij})$$

$$+ \sum_{i=1}^{I} \sum_{j=1}^{P+X} (c_{ij} WI_{ij} + c'_{ij} WI'_{ij})$$

where Z is minimized subject to the following constraints:

1. No stocks will remain at the farm or at transshipment points at the end of one year;

$$\sum_{i=1}^{F} WRF_i - \sum_{i=1}^{F} \sum_{j=1}^{C} WF_{ij} = 0 \;/\; \sum_{i=1}^{C} WRC_i$$

$$- \sum_{i=1}^{C} \sum_{j=1} (WC_{ij} + WC'_{ij}) = 0 \;/\; \sum_{i=1}^{I} WRI_i$$

$$- \sum_{i=1}^{I} \sum_{j=1}^{P+X} (WI_{ij} + WI'_{ij}) = 0$$

2. All coefficients $(a_{ij}, b_{ij}, c_{ij}, \ldots) > 0$; and
3. All endogenous variables $(WF_{ij}, WC_{ij}, WI_{ij}, \ldots) > 0$;

where

Z = total shipment and handling cost;
WF_{ij} = quantity of wheat shipped from farm i to its next destination j by farm truck;
WC_{ij}, WC'_{ij} = quantity of wheat shipped from country elevator i to its next destination j by commercial truck and by railroad, respectively;
WI_{ij}, WI'_{ij} = quantity of wheat shipped from inland terminal i to its next destination j by commercial truck and by railroad, respectively;
a_{ij} = unit shipping cost from farm i to its next destination j by farm truck;
b_{ij}, b'_{ij} = unit shipping cost from country elevator i to its next destination j by commercial truck and by railroad, respectively;
c_{ij}, c'_{ij} = unit shipping cost from inland terminal i to its next destination j by commercial truck and by railroad, respectively;
WRF_i = quantity of wheat received from farm i;
WRC_i = quantity of wheat received from country elevator i;
WRI_i = quantity of wheat received from inland terminal i;
F = number of farms;
C = number of country elevators;
I = number of inland terminal elevators;
P = number of domestic points; and
X = number of export port terminals.

The model assumes that both wheat production and the quantity of wheat demanded at final markets are predetermined. Furthermore, no wheat stocks remain on the farm or at various transshipment points at the end of one year.

The Chow model seeks to represent the wheat logistics system. Wheat is delivered to local elevators at harvest and is then shipped to various transshipment points on its way to final markets. The principal potential movements of the network model are displayed in Table 1. Wheat is delivered from the farm at harvest via farm truck to local elevators. Country elevators may ship wheat by railroad and commerical truck to terminal elevators. Wheat moves from terminal elevators by railroad or commerical truck to Gulf of Mexico ports or out-of-state milling locations.

The data requirements for the Chow network model are as follows (*4*):

1. Identification of production origins, country elevators, terminal elevators, export terminals, and out-of-state milling locations;
2. Quantity of wheat supplied from the study area and each production origin;
3. Quantity of wheat demanded at final markets;
4. Farm truck operating costs;
5. Distances between transshipment points;
6. Commerical truck wheat prices; and
7. Railroad wheat prices.

The study area includes 10 south central Kansas counties. The portions of these counties along the branchlines are divided into 400 wheat production origins, each equal to a 4.8- × 4.8-km (3- × 3-mi) area. The 400 production origins are located within the feasible market areas of the grain elevators on the three Santa Fe lines, and these 400 production origins supply 19.9 million bu of wheat. The model contains 75 country elevators located in the 10-county study area. Also included in the network are three terminal elevator locations (Hutchinson and Wichita, Kansas, and Enid, Oklahoma), out-of-state flour mills, and Gulf of Mexico ports (Houston and Galveston, Texas).

The amount of road damage due to abandonment depends partly on wheat production. Other things being equal, the larger the production level, the more wheat will be transported by truck after abandonment. The quantity of wheat selected for the network model is 90 percent of 1988 wheat production in the 10-county study area, or 56.4 million bu. The other 10 percent of the crop is used for feed and seed. The production origins served by the three Santa Fe lines supply 19.9 million bu of wheat. The remainder of the 10-county production (36.5 million bu) is supplied by production origins served by other railroads.

Since truck transportation is often more costly than rail transport, abandonment will reduce the price farmers receive for their wheat. A lower price should reduce the supply of wheat, reduce the demand for truck transportation, and mitigate road damage due to abandonment. However, this scenario is not very likely since the U.S. price elasticity of supply for winter wheat is estimated to be only 0.099. This means that a 10 percent decline in the price of winter wheat will produce less than a 1 percent reduction in winter wheat supply. Thus, it seems likely that about the same amount of winter wheat will have to be transported both before and after abandonment.

The 1988 wheat production of each county is divided by county area to obtain production per square mile. The per-square-mile output is aggregated into the 4.8- × 4.8-km (3- × 3-mi) production origins.

The quantity of wheat demanded at final markets (Gulf of Mexico ports and U.S. milling locations) is based on data in *Kansas Grain Marketing and Transportation* published by Kansas Agricultural Statistics (*8*). This publication contains the percentage of Kansas wheat shipped to various destinations. The quantity demanded at final markets is obtained by multiplying 1988 wheat production (56.4 million bu) by these percentages.

Farm truck operating costs were obtained by updating a farm truck cost model developed by Chow as part

TABLE 1 Network Model Transportation Movements (*4*)

Origin	Transportation Mode	Destination
Farm	Farm Truck	Country Elevator
Country Elevator	Railroad	Terminal Elevator
Country Elevator	Commercial Truck	Terminal Elevator
Terminal Elevator	Railroad	Gulf of Mexico Port
Terminal Elevator	Commercial Truck	Gulf of Mexico Port
Terminal Elevator	Railroad	Out-of-state Flour Mill
Terminal Elevator	Commercial Truck	Out-of-state Flour Mill

of his 1984 doctoral dissertation (9). The model yields mileage-based costs for single-unit, two-axle (SU-2AX) farm trucks.

Distances from production origins to country elevators were obtained from county road maps. A Kansas highway map was employed to determine distances from country elevators to terminal elevators. A Rand McNally road atlas provided the distances for wheat movements to out-of-state destinations. In all cases, the distances were for the shortest possible route, determined manually. Bridge load limits were obtained and taken into account. If a road segment had a bridge with a load limit below 8 tons, the road was not used.

The commercial truck wheat prices are regulated tariff rates published by the Kansas Motor Carrier Association (*11*). The trucks were assumed to be commercial five-axle (CO-5AX) trucks, the type usually employed by grain elevators to ship wheat. The rail prices for country elevator to terminal elevator movements were the car prices provided by the Santa Fe Railroad and the Kansas City Board of Trade (*12*). Contract railroad prices for movements from terminal elevators to export ports were provided by a consultant (J. J. Irlandi, President, Skill Transportation Consultant, Wichita, Kansas, personal communication).

The Chow network model was employed to generate two sets of wheat movement data. The first set simulated wheat flows assuming no abandonment of Santa Fe branchlines. The second set simulated least cost wheat movements assuming abandonment of the three study area Santa Fe branchlines (Rago to Englewood, Wichita to Pratt, and Hutchinson to Wellington).

For each simulation, two types of truck movements were identified. The first is farm to local elevator movements by farm trucks (SU-2AX) over a combination of county, municipal, and state roads. The second set involves commercial truck (CO-5AX) movements from country elevators to terminal elevators over various Kansas roads. In each case, bushels transported were converted to truck trips by road segment. This was done by dividing the wheat volume moved by truck on each road segment by truck capacity. Payload capacities were assumed to be 810 bu for commercial trucks and 256 bu for farm trucks. In the study area, some wheat is transported from the farm in larger trucks owned by custom cutting firms that harvest wheat. However, precise data on these movements are lacking. To the extent that this occurs, the model understates road damage due to abandonment.

Grain Flow Analysis Results

Using the methodology discussed briefly above, it was concluded that the abandonment of the selected Santa Fe branchlines could be expected to decrease the amount of wheat handled by the elevators on the lines to be abandoned from 77 precent of 19.9 million bu in the before-abandonment period to 67 percent in the after-abandonment period (*4*). The increase in the amount of wheat flowing to the elevators on competing, nearby rail lines in the after-abandonment scenario increases the distance farm trucks must travel to deliver their wheat to the elevators with rail service that offer higher bids for grain. The amount of grain diversion is limited to some extent, however, by producers who choose to deliver their wheat to elevators on the abandoned line regardless of the availability of rail service. The motive behind these actions stems from the fact that the distance traveled to elevators located on competing lines is too great to be considered feasible or convenient even though the bids for the grain may be somewhat higher at these elevators.

Upon completion of the farm-to-elevator grain flow analysis, it was determined that truck wheat bushels shipped from local elevators on the three Santa Fe lines to terminal elevators increased by 8 percent. These additional truck wheat shipments translate into an increase of the truck market share of total grain traffic from 80 percent in the before-abandonment period to 87 percent in the after-abandonment period (*4*).

A majority of the wheat diverted from rail to truck in the after-abandonment scenario is moved to elevators located a "long" distance from the terminal elevator transit points due, in part, to these elevators' becoming increasingly far apart. This forces producers located near elevators on the abandoned lines, who wish to deliver their grain to alternative lines with rail service and higher prices, to truck their commodity a great distance, which may be economically infeasible. In this case, the producers will deliver their grain to elevators on the abandoned line and those elevators will have to truck their wheat to the various inland terminals. Yet another reason for a majority of the diversion being located in areas a great distance from terminal destination transit points is that Chow's model is based on shipper cost minimization, and rail transportation becomes more economical (relative to truck cost) as the shipping distance increases. Therefore, in the before-abandonment scenario, most of the grain shipped from these distant locations is by railroad. After abandonment, most of the grain shipped from these elevators is diverted to truck.

Measurement of Road Consumption

Road damage techniques developed by Tolliver at the Upper Great Plains Transportation Institute (UGPTI) were followed (*5,6*). The techniques are basically

(AASHTO) pavement damage equations. Pavements have a limited useful life in terms of the passage of a finite number of ESALs (i.e., each passage uses up a portion of the pavement life). The life of a typical highway section that is maintained to acceptable standards comprises a series of cycles. Pavements are rehabilitated or reconstructed when the pavement becomes "unacceptable" for normal traffic use in terms of ride comfort (pavement serviceability rating or PSR) and is usually improved prior to the full expiration of structural pavement life.

The UGPTI procedures (adapted from AASHTO pavement damage functions) were developed in a dissertation by Tolliver (*6*). The consumption of pavement life constitutes an economic cost that occurs whenever a portion of the remaining useful life of a pavement is consumed. Two types of economic costs are associated with pavement consumption: marginal cost and incremental cost (*6*).

Each type may be either short run or long run in nature. In the context of pavement life cycles, the short run is the period of time for which a highway section's capacity to absorb ESALs is fixed. In other words, the short run is the cycle between replacement activities. The long run reflects the entire existence of a highway section from the time of initial construction to the time the road is abandoned.

Within the context of highway impact analysis, short-run marginal cost reflects the additional consumption of highway rideability (PSR) resulting from each additional ESAL applied to a highway section in its current condition. On the other hand, the long-run marginal cost (LRMC) has nothing to do with the current condition of a highway section and is instead the cost of an increase in pavement strength necessitated by the summation of ESALs over the life of the pavement (*6*).

To clarify LRMC, if pavement thickness were on a scale of zero to some maximum thickness, then the LRMC of an ESAL would be the additional layer of thickness required to maintain the service life of a highway as it was before the one ESAL addition. Although LRMC is not a practical concept in pavement impact analysis and is not considered a major part of this study, it does provide a better understanding of the relationship between traffic and pavement design (*6*).

The second type of cost, incremental cost, is a much more relevant concept to highway planners and policy makers than marginal costs. With many ESALs' passages over time, actual capital expenditures are required to maintain a highway section above an acceptable level. These costs arise from considering relatively large traffic increases as opposed to a single ESAL. Unlike the effects of a single ESAL, the impacts of a larger traffic volume are measureable on a more meaningful scale that can be translated to dollars. For example, "an additional 2 in. of pavement" is a much more relevant bit of information to highway officials than is the concept of 0.00022 in. per ESAL. Due to the more meaningful data provided by the reporting of incremental pavement costs, these are the costs that are most relevant in this study. It is important to keep in mind, however, that even though the incremental costs of pavement will be most important, the concept of short-run marginal costs will be used to obtain these values because there is a key linkage between marginal and incremental cost. The cost of an increment of traffic is roughly the sum of the marginal costs incurred by the individual vehicles (*6*).

As explained above, the concept of short-run marginal cost was used to reflect the additional consumption of highway capacity resulting from the addition of one or more axle loads to a highway section. The marginal cost of an axle pass depends on two factors: (a) age and serviceability of the highway section and (b) vehicle axle loads and configurations (*6*).

The decline in PSR is a nonlinear function of traffic over time. Logically then, the short-run marginal cost of an axle pass will vary with time, increasing with the age and serviceability of the highway section. For the reference axle [18 kips (8165 kg)], the marginal cost at any point on the PSR decay curve is given by the derivative of pavement serviceability with respect to cumulative axle passes. The manner in which the marginal cost of an axle pass is determined for vehicles of different axle loads and configurations involves the concept of ESALs. For an axle other than the reference axle, an equivalent rate of damage is determined by converting raw truck passes to ESALs (*6*).

The AASHTO traffic equivalency formulas were used to convert truck axle load passes to ESALs.

Flexible pavement, single axles:

$$\begin{aligned}\log10(NR/NX) = {} & 4.79 * \log10(10(LX + 1) \\ & - 4.79 * \log10(LR + 1) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{1}$$

Rigid pavement, single axles:

$$\begin{aligned}\log10(NR/NX) = {} & 4.62 * \log10(LX + 1) \\ & - 4.62 * \log10(LR + 1) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{2}$$

Flexible pavement, tandem axles:

$$\begin{aligned}\log10(NR/NX) = {} & 4.79 * \log10(LX + 2) \\ & - 4.79 * \log10(LR + 1) \\ & - 4.33 * \mathrm{LOG10}(2) \\ & + G/\beta R - G/\beta X \end{aligned} \tag{3}$$

Rigid pavement, tandem axles:

$$\log10(NR/NX) = 4.62 * \log10(LX + 2) - 4.62 * \log10(LR + 1) - 3.28 * \mathrm{LOG10}(2) + G/\beta R - G/\beta X \quad (4)$$

where

$\log10(NR/NX)$ = log of the traffic equivalency formula,
LR = reference axle weight (18 kips),
LX = axle weight (kips),
PSR = pavement serviceability rating,
$G = \mathrm{Log10}[(5 - PSR)/3.5]$, and
β = a damage function coefficient expressed below for the two pavement types:

Flexible pavement:

$$\beta = .40 + [.081 * (L1 + L2)\hat{}3.23]/[(SN + (6/SN)\hat{}.5)\hat{}5.19 * L2\hat{}3.23] \quad (5)$$

Rigid pavement:

$$\beta = 1 + [3.63 * (L1 + L2)\hat{}5.20]/[(D + 1)\hat{}8.46 * L2\hat{}3.62] \quad (6)$$

where

$L1$ = axle load (kips),
$L2$ = axle type (where 1 = single axle and 2 = tandem axle), and
D = depth of pavement (in.).

[NOTE: The damage function coefficient (β) is computed with respect to the reference axle (βR) and axle group (βX), that is, single or tandem axle.]

These equations had also been used by Eusebio and Tolliver (*5,6*). The average empty and loaded axle loads as obtained from statewide truck weight data and tabulated in Table 2 were converted into axle-specific marginal costs [in ESALs given the strength and condition rating of each highway section obtained from KDOT (*10*)]. The individual marginal costs for each axle group of a truck (in ESALs) were then summed to reflect a truck pass for the particular vehicle class. Total road damage attributable to a certain class of traffic is the sum of the cost of each individual truck trip for a particular class of traffic. It is assumed that SU-2AX trucks were used for truck movements from simulated farm to country elevator while CO-5AX trucks were used for country elevator to final destination transits.

An example of the use of the AASHTO axle equivalency formulas will help further illustrate the effects of axle passes on pavement damage at different levels of PSR. Assume that a 12,000-lb (5 437 kg) single-axle truck is to be considered and that the terminal serviceability rating of the affected flexible pavement highway is 2 and the strength value, expressed as an AASHTO structural number, is equal to 2 as well. The reduction in pavement life in terms of ESALs resulting from a single axle pass at different PSRs is shown in Table 3.

As shown in Table 3, the pavement life used and, therefore, marginal cost of an axle pass increase as the serviceability of a highway section decreases. In other words, as the PSR of a road segment decreases, the damage caused to the pavement due to one axle pass increases. These examples also illustrate that the incremental pavement cost of a particular class of truck will be at its greatest on an old, partially deteriorated highway. Consequently given the age and condition of many of the rural, minor arterial, and collector roads in south central Kansas, it is important to obtain the initial PSR for accurate, meaningful results. It also reinforces the theory that the roads most affected by a line abandonment are those rural roads that were not designed for heavy loads at the outset, especially rural roads (*6*). Stronger pavements have PSR decay curves that are "flatter"; therefore, the effects of line abandonments are not as great.

To summmarize, the ESALs for empty and loaded trucks for each axle group were calculated using the AASHTO formulas (Equations 1 through 6). These values were then subsequently summed for all axle groups to obtain the degree of road damage per round-trip vehicle mile traveled (VMT) for a given road segment. The number of annual truck trips for a given road segment (as derived using Chow's transportation network model) multiplied by the road damage (in ESALs) per round-trip VMT equals the total incremental annual damage for the road segment. These calculations were performed for the before- and after-abandonment scenarios.

SUMMARY OF PAVEMENT DAMAGE RESULTS

Using the grain flow data produced by Chow's transportation model and the applicable road data, the next step in the analysis of railroad abandonment effects on pavements was to acquire the truck-accountable road damage costs. This task was accomplished by using AASHTO pavement damage functions along with the Kansas road rehabilitation costs shown in Table 4.

Using the methods presented previously, truck-attributable road damage costs were calculated for the before-abandonment and after-abandonment scenarios. The difference between the two road damage estimates

TABLE 2 Loaded and Empty Axle Weights for Trucks Hauling Wheat

Axle Group	Tare Weight		Loaded Weight	
	SU-2AX (1000 lbs.)	CO-5AX (1000 lbs.)	SU-2AX (1000 lbs.)	CO-5AX (1000 lbs.)
1	4.9	8.6	9.9	11.4
2	6.4	11.6	20.0	32.4
3	---	8.1	---	33.3

Note: For the SU-2AX trucks, axle groups 1 and 2 are both single axles. For the CO-5AX trucks, axle group 1 is the single axle while axle groups 2 and 3 are the tandem axles.
(Source: Kansas Truck Weight and Volume Study for 1987.[10])

TABLE 3 Pavement Life Used at Various PSRs for 12,000-lb Single Axle Passage

PSR at time of passage	Pavement Life Used (ESAL's)
4.0	.067
3.0	.109
2.5	.128
2.1	.142

(Source: Calculated and compiled by Mauler.[14])

TABLE 4 Pavement Rehabilitation Costs in Thousands of Dollars by Road Type, 1988

Road Type	Per-mile cost of Surfacing and Shoulders	
	Rural	Urban
Interstate	568	1,217
Arterial		
Principal	424	963
Minor	248	563
Collector	161	462
Local	58	115

Source: (Interstate and Arterial) KDOT road surfacing and road rehabilitation projects from 1978-88. (Collectors and Local Roads) Federal Highway Administration, Final Report on the Federal Cost Allocation Study (1982). Figures in this report updated using the Federal aid maintenance cost index found in KDOT, 1989 Selected Statistics.

is the highway damage costs of abandonment. Table 5 contains these costs for farm-to-country elevator wheat movements. As the table indicates, before Santa Fe abandonment, total road damage costs are $638,613. After abandonment, these costs rise to $911,972, nearly a 43 percent increase. The total road damage cost due to the Santa Fe abandonment is $273,359. Of this amount, $261,699 (96 percent) in road damage costs occur on state-funded arterial and collector roads. The increase in road damage costs after abandonment is caused by farmers trucking their grain over longer distances to elevators with rail service. The 43 percent increase in costs indicates that the road system is not designed to accommodate a large increase in truck grain axle passes. This relatively large increase in costs may be understated to the extent that grain is transported

TABLE 5 Annual Pavement Damage Costs of Farm-to-Country-Elevator Truck Wheat Movements by Road Class Before and After Abandonment Scenarios

Road Class	(1) Before Abandonment	(2) After Abandonment	(2)-(1) Abandonment Costs
Interstate*	0	0	0
Arterial*	$169,678	$277,870	$108,192
Collector*	300,277	453,976	153,699
Local**	168,658	180,126	11,468
Total	$638,613	$911,972	$273,359

* State funded roads
** County funded roads

from the farm in large trucks owned by custom grain-cutting firms.

Table 6 contains road damage costs of truck wheat movements from study area country elevators to terminal elevators (i.e., intercity movements). Prior to Santa Fe abandonment, the total road damage cost attributable to trucks is $1,451,494. After abandonment, these costs rise to $2,182,725, a 50 percent increase. The truck-attributable road damage cost, resulting from abandonment, is the difference between the aforementioned two figures: $731,231. All of this cost occurs on state-funded arterial and collector roads. The increase in truck-attributable road damage cost is due to the diversion of wheat from railroads to trucks after abandonment occurs. The roads used by trucks in the intercity wheat movements are of higher quality than those used in the farm to country elevator movements. However, the much larger trucks (and ESALs) moving over greater distances more than offset higher road quality and inflict much more damage costs.

Summary

Total truck-attributable road damage cost due to abandonment is $1,004,590, a 48 percent increase from the before-abandonment cost. Of the total damage cost amount, 27 percent is due to farm to country elevator movements and 73 percent to country elevator to terminal market movements. The $1 million cost is probably conservative since the network model is unable to incorporate rail movements of wheat to local flour mills. After abandonment, some of this wheat would be diverted to commercial trucks.

TABLE 6 Annual Pavement Damage Costs of Country-Elevator-to-Terminal-Elevator Truck Wheat Movements by Road Class Before and After Abandonment Scenarios

Road Class	(1) Before Abandonment	(2) After Abandonment	(2)-(1) Abandonment Costs
Interstate*	$41,956	$41,956	0
Principal Arterial*	222,843	210,940	-11,903
Arterial*	544,288	1,093,018	548,730
Collector*	574,165	771,548	197,383
Local**	68,242	65,263	-2,979
Total	$1,451,494	$2,182,725	$731,231

* State funded roads
** County funded roads

Rail abandonment would precipitate many other costs that are not measured in this study. For example, the network model routed commercial trucks around bridges with a weight limit of 8 tons or less. In reality, some of these bridges, as well as those on other routes, would have to be repaired or replaced to accommodate the increase in truck traffic.

Given that rail abandonment will produce an increase in road damage cost, who will pay the additional cost? As trucking of wheat increases, motor carrier user taxes will also rise. If the additional motor carrier user fees are equal to the increment in truck-attributable road damage cost, then society and other highway users are no worse off. If additional truck user taxes exceed road damage costs, society and other highway users are actually better off. However, there is a third possibility: the additional truck user fees will be less than the increment in road damage cost. If this happens, the following consequences may occur:

- Diversion of highway funds from other road projects to cover the shortfall in resurfacing and replacement cost;
- Increased motor fuel taxes, registration fees, and personal property taxes for automobile owners; and
- A permanent decline in highway quality.

This study indicates that the third possibility is the most likely. The bushels of wheat trucked from country elevators to terminal elevators increases by 8 percent after abandonment. However, the truck-attributable road damage cost increases by 50 percent after abandonment. Thus, it is highly unlikely that additional truck user fees will cover the increase in road damage cost.

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