The Impacts of Grain Subterminals on Rural Highways
Volume I

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THE IMPACTS OF GRAIN SUBTERMINALS ON RURAL HIGHWAYS

VOLUME I

BY

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FORWARD

This report represents a condensed version of the RTAP Devils Lake Highway Impact Study. The purpose of the report is to present a synopsis of the methods and data employed and to highlight the findings.

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INTRODUCTION

Grain subterminal-satellite elevator systems are changing traditional patterns of traffic flow in rural North Dakota. Prior to 1981, most grain was shipped from elevators directly to terminal market or processing center. Much of it originated by rail. The portion which did move by truck utilized the principal arterial and interstate highway networks. Farm-to-elevator flows were characterized by single-unit farm truck shipments to nearby country elevators.[1]

Much has changed since 1981. Many elevators have formed cooperative systems and have constructed large, centrally located "subterminals." Many previously independent elevators have become "satellites", transshipping grain to the subterminal rather than shipping directly to terminal market. These transshipments occur primarily in heavy combination five-axle (CO-5AX) trucks. The problem is compounded by the fact that many transshipments occur over rural collector or minor arterial highways rather than on the interstate system. The objective of the RTAP Devils Lake Highway Impact Study is to project the

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[1] The average loaded farm truck trip in 1981 was approximately 12 miles.

likely effects of subterminal development on future highway costs.

PROJECT OVERVIEW

The Devils Lake Highway Impact Study evolved through three stages:

1. Initial data collection,
2. HPMS analysis,
3. Model development and supplementary data collection.

In the initial phase of the project, the NDHWD collected weigh-in-motion (WIM) and vehicle classification data for thirty monitoring sites in the region (primarily on the rural arterial network). In the second phase of the study, the Highway Performance Monitoring System (HPMS) was used in an effort to determine the incremental funding requirements for the sample sections over a twenty year period. HPMS was run twice, once for a "base-case" analysis and again for an "impact scenario."[2] The HPMS analysis showed no incremental funding requirements over the 20-year period. The model simulated large-scale replacement or reconstruction improvements in the early years of the base-case

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[2] The ESAL factors, percent truck, and other variables were modified during both runs to reflect the base-case and impact case data.

analysis. This tended to obscure the impacts of incremental traffic under the impact scenario.

At the conclusion of the second phase of the project, it was felt that additional research was needed. An independent modeling process was deemed desireable, one which was specifically designed to gauge incremental pavement impacts. In addition, a second problem or shortcoming needed to be addressed. The NDHWD data collection effort covered much of the arterial network in the area, but provided only limited coverage of the major collector network. Furthermore, minor rural collectors were not addressed at all.

It was hypothesized that much of the impact might actually occur on the collector network. Heavy grain trucks tend to follow the most direct routes between satellite elevators and the subterminal regardless of the type of highway. Since "short-cuts" across collector highways (not designed for such heavy traffic) were felt to be a potential problem, additional highway attributes and traffic data for collectors needed to be gathered. In addition, these data were felt to be necessary in order to adequately assess changes in farm-to-elevator shipments, which may also be altered by the presence of a subterminal elevator.

The third phase of the project focused on the development of a system of models (independent of HPMS), and upon the expansion and improvement of the data base. An overview of the methods and data which were developed is presented later in the report.

PROBLEM SETTING

Chapter 1 of the full report presents a typology of the flow-types which occur within a subterminal-satellite elevator system, and discusses the major dimensions of the problem. Highlights of that discussion are presented in the following paragraphs of this report.

Problem Dimensions

The subterminal traffic problem entails three dimensions or facets:

1. grain flows,
2. highway equipment,
3. highway attributes.

Each dimension is important, both individually and collectively.

Grain Flows

Subterminal-satellite systems generate five classes or types of grain flows:

1. Farm-to-satellite elevator,
2. Farm-to-subterminal elevator,
3. Satellite elevator-to-market,
4. Satellite elevator-to-subterminal,
5. Subterminal elevator-to-market.

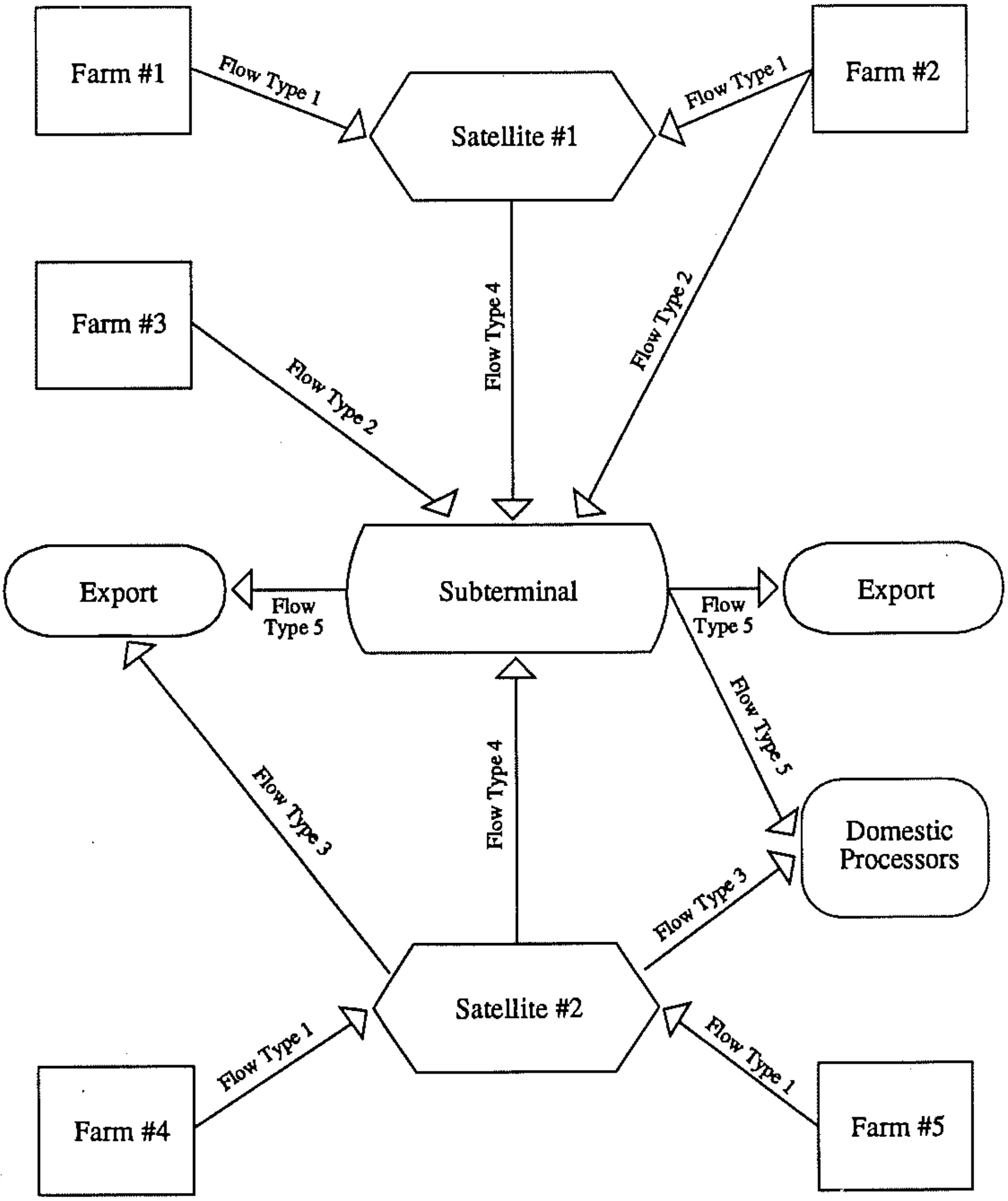
Figure 1 graphically depicts the marketing channels within a subterminal-satellite system and the traffic flows which they create.

Prior to 1981, only two types of grain flows existed in North Dakota: farm-to-local (satellite) elevator and local (satellite) elevator-to-market. With the reorganization of the grain elevator industry, many of the local, previously independent elevators in the state have become "satellites." As part of a subterminal-satellite system, they generate a new type of traffic flow: transshipment.

An important point should be made here regarding transshipments. When a transshipment occurs it represents the **second** truck movement within the subterminal-satellite market area. The first movement is the farm truck trip to the satellite elevator (flow-type 1).

Although most of the concern has been expressed over transshipments, subterminal-satellite systems have created two additional traffic flows as well. Direct farm-to-subterminal shipments are prevalent in some cooperatives today. Subterminal-to-market shipments (flow-type 5) are important in all systems, but move primarily by rail, engendering little if any highway concern. However, flow-type 5 is important in the aggregate

Figure 1. Logistics of Grain Flow Within a Subterminal-Satellite Elevator System



equation because truck trips to terminal market may have been reduced by the development of satellite-subterminal systems[3].

Truck-types

Three types of vehicles are used extensively in the highway transportation of grain in North Dakota:

1. The single-unit, two-axle farm truck (SU-2AX),
2. The single-unit, three-axle farm truck (SU-3AX),
3. The combination, five-axle truck (CO-5AX).

The three classes of vehicles have different tare weights, capacities, and axle configurations. Consequently, the axle loads applied to the pavement by each type of vehicle will differ. Furthermore (since the capacities differ among vehicle types), the annual number of trips required to haul a fixed level of volume or payload will vary.

The commodity plays a role in determining the axle weights and annual trips. Certain grains and oilseeds are denser than others. As a result, higher axle weights may be achieved, and

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[3] An argument might be made that subterminals actually remove truck traffic from the highways in the aggregate, and that the traffic effects balance-out. Normally where subterminals have been developed, considerable truck traffic has been removed from principal arterial and interstate highways, as outbound shipments from subterminals typically utilize rail service. However, these traffic changes may not be a complete "wash." Interstate and principal arterial highways have generally been designed for heavy truck traffic whereas collector and local roads have not.

fewer trips required. The reverse is true of less-dense, light-loading commodities[4].

Highway Attributes

The impacts of a fully loaded truck of a given type carrying a given commodity are determined in part by the axle weights. But they are also governed by the type and characteristics of the highways used.

The principal highway attributes which will determine the effects of truck shipments for a given climatic zone are:

1. The thickness of the surface course, the base course, and the subbase course of flexible pavements;
2. The thickness of the concrete slab for rigid or Portland Concrete Cement pavements;
3. The composition, characteristics, and strength of the materials used;
4. The composition and character of the supporting soil;
5. The age of the highway section; and
6. The present condition or serviceability.

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[4] The commodity plays its most important role with respect to the single-unit, two-axle truck. Because of the axle configuration, the SU-2AX may reach legal axle load limitations (e.g. 20,000 pounds) before the payload capacity is reached. This is particularly true with light-loading commodities such as barley and sunflowers.

The chain of cause-and-effect in highway deterioration is as follows. The truck-type and the commodity determine the axle weights or loads. The axle weights, in combination with the attributes of a highway section, determine the amount of damage that each truck pass will inflict. The number of annual trips required to haul a given level of commodity will decide the number of axle passes which will occur during a year. The accumulation of axle passes over time will eventually result in the rehabilitation or reconstruction of the highway section. Grain flows constitute mixed traffic flows; that is they consist of different types of vehicles with different axle weights. In pavement damage analysis, a mixed traffic stream is analyzed through the use of a "reference axle." Using the reference axle, all other axle weights are translated into equivalent axle loads. If the reference axle is a single axle, then the term "equivalent single axle load" or ESAL is used[5].

The damage that a particular axle configuration and load will cause is evaluated by first converting the axle to ESALs. For example, on a typical low-volume road a 22,000 pound single axle load is expressed as 2.35 ESALs[6]. Once the ESALs are

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[5] In almost all instances, the reference axle is the 18,000 pound single axle. In this study, the term "ESAL" refers exclusively to the 18,000 single axle.

[6] This example assumes the following conditions: (1) a flexible pavement, (2) a structural number or strength rating of

determined, the truck trips can be related to pavement decay through means of a damage model.

Table 1 gives the average tare (empty) weight, net weight, and gross vehicle weight for grain trucks operating over low-volume roads. Note that while the CO-5AX operates at higher gross weights, it carries substantially more payload than the SU-3AX or SU-2AX truck.

Table 1 illustrates the difference in ESALs and resulting pavement damage which could result from different patterns of vehicle use. The CO-5AX has by far the highest number of ESALs per loaded vehicle mile of travel (VMT),

TABLE 1. TYPICAL VEHICLE WEIGHTS AND LOADED ESALS FOR GRAIN TRUCK-TYPES.

Truck Types	Tare Weight	Net Weight	Gross Weight	Loaded ESALs
SU-2AX	12,407	15,412	27,819	1.58
SU-3AX	16,671	27,435	44,106	1.37
CO-5AX	26,650	53,350	80,000	2.37

3.0, and (3) a terminal pavement serviceability rating of 2.0. The structural number (SN) is an abstract index which reflects the composite strength of the layers of a flexible pavement section. In computing the SN, .44 of a point is typically added to the index for each inch of surface course, .14 for each inch of granular base and .11 for each inch of granular sub-base. The pavement serviceability rating (PSR) is a composite measure of a highway's condition at a given interval in time. The terminal PSR is the condition rating which prevails at the time the highway section reaches functional failure. Usually, at this point in a pavement's life cycle, the section is either replaced or upgraded.

followed by the SU-2AX farm truck[7]. Consequently, shifts in grain flows which result in a higher frequency of CO-5AX trucks within the impact area will result in greater highway damage per VMT.

Subterminal Effects

The manner in which a given subterminal-satellite system will impact a highway section depends on the extent to which the dimensions of the problem are altered or affected by the development of the subterminal.

Impacts on Grain Flows

In general, subterminal-satellite systems impact grain flows in two ways: (1) they create new types of flows (flow-types 2, 4, and 5), and (2) they alter the level of existing flows. But how a particular subterminal-satellite system impacts grain flows within a region depends on the organization of the business, its operating strategy, and the relationship between grain prices at the subterminal and its satellites. If the organizational

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[7] Note that the SU-3AX farm truck has lower ESALs per loaded VMT than does the SU-2AX truck. The reason for this lies with the axle configuration of the vehicles. The SU-3AX has a tandem rear axle, typically with eight tires. Thus the load per wheel which is transmitted to the pavement is less than that for the SU-2AX.

structure and price relationships favor direct farm-to-subterminal shipments, then flow-types 1 and 4 will be of secondary importance. On the other hand, if the strategy favors transshipment via satellites, then both will be quite prominent.

Flow-type 3 (the traditional elevator-to-market flow) will almost always be deemphasized. However, if satellites possess multiple-car load-out capabilities, or perform specialized functions, they might still ship directly to terminal market or processing center.

Zink (1988) surveyed 9 major grain cooperatives in the Upper Great Plains region, 7 of which were located in North Dakota. Some of the unpublished survey data obtained in the study shed light on the shipping patterns of subterminal-satellite systems. On the average, 61 percent of the inbound grains and oilseeds handled by the organizations which were surveyed constituted transshipments from satellite elevators to the subterminal (Table 2). The remaining 39 percent was drawn directly from farms to the subterminal. On the average, only 11 percent of total elevator-to-terminal market volume was shipped from satellite elevators. The remaining 89 percent of outbound shipments originated at the subterminal.

TABLE 2. REPRESENTATIVE SUBTERMINAL-SATELLITE ELEVATOR TRAFFIC FLOWS AS A PERCENT OF INBOUND AND OUTBOUND VOLUMES.

Flow-Type	Mean	Median	Low Value	High Value	Range
Transshipment (# 4)	61%	65%	25%	99%	74%
Direct Market (# 3)	11%	7%	0%	40%	40%

SOURCE: Unpublished UGPTI survey data.

Table 2 conveys some general expectations regarding the effects of subterminal-satellite systems on grain flows. These expectations are supported by the statewide traffic trends detailed in Appendix B of the full report. However, Table 2 also points-out an important consideration: considerable variations exist across systems. As a result, the traffic effects of subterminals could vary from region-to-region.

Impacts on Truck Use

As the grain flows change within a subterminal-satellite system, so do the relative frequencies of grain truck use. Prior to 1981, the majority of farm-to-elevator shipments occurred in single-unit, two axle trucks over relatively short distances. The average farm truck trip in 1980 covered 12 miles (Griffin, 1984). Now, direct farm-to-subterminal shipments are occurring over considerable distances. Zink (1988) found that the average distance from farms to the subterminal elevator within the seven North Dakota systems surveyed ranged from 10.5 to 37.2 miles, with a grand mean of 23 miles. Furthermore, it is not unusual for farmers on the periphery of a trade area (which constitute the extreme cases in a distribution) to truck up to 50 miles in order to reach the subterminal. Over such distances, farmers are more apt to use SU-3AX or CO-5AX trucks because of their greater payload capacity.

The second trend in truck usage attributable to subterminal-satellite systems is that of transshipment. An increase in transshipments implies a shift towards greater utilization of CO-5AX trucks within the subterminal market area. This has important implications for pavement damage, as illustrated by Table 1.

Impacts on Highway Use

As grain flows change, so do the highways utilized. Prior to 1981, the majority of CO-5AX truck miles were accumulated on interstate and principal arterial highways. These highways were specifically designed to accommodate heavy truck traffic. Today, the pattern has changed. The frequency of CO-5AX truck use has risen within the subterminal market area. Consequently, the majority of CO-5AX truck miles are now being accumulated on **low-volume roads.**

In many areas of the state, the highways which connect the subterminal to its satellites are minor rural arterials or local roads. Unlike the interstate and principal arterial network, these highways were not designed to accommodate heavy truck traffic. Furthermore, the rural minor arterial system in North Dakota is aging and in deteriorated condition. Much of it needs to be replaced. The bottom line is that the effect of a CO-5AX truck-mile on an old, deteriorated road which is designed for low volumes is much different than an interstate truck-mile over high design pavements.

ANALYTIC METHODS AND DATA

An integrated set of computer models is presented in this study which forecasts grain flows from farms-to-elevators in the region, as well as predicts outbound elevator shipments. The following submodels are included in the set:

1. Land Use Model
2. Grain Flow Generation Model,
3. Shipment Distribution Model,
4. Truck Distribution Model
5. Network Assignment Model,
6. Truck Weight Model,
7. Pavement Damage Model,
8. Highway Cost Model.

Collectively, these submodels simulate grain traffic flows and their associated highway costs from the time the grain leaves the farm until the outbound elevator shipments have left the impact region. Each submodel is described in detail in the full report. Only highlights will be presented here.

Two types of highway costs are modeled: (1) accelerated replacement costs ("build-sooner costs") and (2) upgrading costs. If incremental truck traffic is substantial, then some highway sections may have to be replaced earlier than previously anticipated. The shortening of the replacement cycle means that funds will have to be expended sooner than otherwise would have been the case. When the time value of money is considered, this leads to a real economic cost.

The capacity of a highway section to absorb ESALs remains fixed in the short-run (the period between replacement activities). The acceleration of replacement cycles due to incremental heavy truck traffic may be thought of as the short-run incremental cost of grain subterminals. In the long-run, the capacity of a highway section may be freely adjusted. The thickness of the surface layer of flexible pavements may have to be increased in response to the additional traffic in order to maintain the same service life (in terms of years) as before. This upgrading cost (which may occur at the end of the current replacement cycle) may be thought of as the long-run incremental cost of heavy truck traffic.

Short-run incremental costs (SRIC) were estimated in the study via a multi-step process:

1. the life of each sample section in ESALs (equivalent single axle loads) was estimated,
2. the annual ESALs in the base-case (for all traffic) were determined from NDHWD or survey data,[8]
3. annual baseline grain truck ESALs were projected by the system of models described in the full report,
4. annual grain ESALs for the impact case were similarly modeled,
5. the service life of each highway section was determined under both scenarios by dividing the ESAL life by the annual ESALs,
6. replacement costs were modeled for each section under both the base and altered traffic streams,
7. each projected outlay was discounted to present value,
8. the difference (if any) in the present value of future replacement costs was calculated.

Long-run incremental costs (LRIC) were estimated by computing the increase in asphalt surface thickness which would be required (if any) to maintain the service life of the highway as before. Any incremental thickness was multiplied by the

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[8] These data were adjusted for seasonal variations in grain shipments as well as for variations in other traffic classes. The process of computing average annual daily ESALs from the raw data is detailed in Chapter 4.

average cost per inch of overlay as experienced by the NDHWD on various functional highway systems in 1986 and 1987. Together, the SRIC and LRIC represent the change in future pavement outlays facing highway officials.

As detailed in the full report, farm-to-elevator grain flows were modeled with a spatial interaction model. Outbound elevator flows (within the subterminal-satellite system) were simulated through means of a transshipment model, a mathematical programming procedure which minimizes the logistical cost for the system of elevators as a whole. Both models are explained in detail in Chapter 3 and 4 and Appendix D of Volume II.

The deterioration of highway sections in the region was simulated with a pavement damage function developed by the Texas Transportation Institute (TTI) for the FHWA. Altogether, five flexible pavement damage models were evaluated in the study. Of the five, the TTI model was felt to be the most accurate and versatile. The TTI model predicted ESAL lifetimes fairly close to those predicted by the HPMS damage function when the tire-type and pressure parameters of the TTI model were set to values which prevailed at the AASHO Road Test.

SCENARIOS

The environment of grain transportation is subject to considerable uncertainty. A variety of forces acting in isolation or in concert can affect the setting for grain marketing and transportation. The basic impact solution in the Devils Lake study is built upon several fundamental assumptions regarding the future structure of the elevator industry and the broader transportation/regulatory environment. The major sources of uncertainty which stem from these basic assumptions are reflected in four major forces or variables which may shape the problem setting or otherwise present alternatives to the impact model. These are:

1. Rationalization of the grain elevator system,
2. Changes in truck utilization patterns,
3. Variation in organizational structure and management practices in the elevator industry,
4. The outcome of railroad rationalization.

The impact solution (or scenario) assumes that the subterminal-satellite elevator system will remain essentially intact ("as is") throughout the impact period. The assumption implies that the price relationships between the subterminal and the satellite elevators will remain the same, and that all satellites (substations) will remain operative. This is a valid assumption. However, it is not a certain one. There are alternative points of view on the matter. Cobia (1986) feels that many substations will be shut-down in the future. On page 86, he states: "Satellite stations will, with few exceptions, decline in use and will in many cases be eliminated as receiving stations."

Elevator rationalization is not the only element of uncertainty which exists. Future truck use (by truck-type) is also unknown. With more direct farm-to-subterminal shipments, increased use of CO-5AX trucks on the farm-to-elevator leg of the journey is a distinct possibility. One possible scenario is that a fleet of for-hire or leased combination trucks will be operating between the subterminal and area farms in the future.

The cooperative elevator model used in the impact case is felt to be realistic in most situations (but not all). A private, train-loading elevator may function in similar fashion to a subterminal in a cooperative system, purchasing grain from smaller, nearby elevators. However, there are important marketing differences between the two which may affect grain flows. Under a private subterminal model, the local elevators do not function as satellites. Instead, each elevator manager makes an independent decision regarding the marketing of his or her grain. If the price offered by the subterminal elevator is higher than the net market price, then the local elevator manager can maximize profits by selling grain to the subterminal. If the reverse is true, then the local elevator's net price will be optimized by selling directly in terminal markets. The key difference between this arrangement and the cooperative model is that under the latter, the general manager is assumed to act in a optimizing manner for the system of elevators as a whole. Thus, the local autonomy and independent action assumed under the private subterminal model could produce different flow patterns that a cooperative organizational structure.

Last (but not least) the future course of railroad rationalization presents a major uncertainty for the analysis. At one extreme, all of the light-density branch lines in the area could be abandoned in the future. Alternatively, the light-density lines could be operated by independent short-line railroads, providing elevator-to-elevator rail service (which is currently done in certain areas).

The future of the light-density branch-line system in rural North Dakota is uncertain. None of the lines serving the satellite elevators are currently being considered for abandonment. But as the process of rail rationalization proceeds, many light-density branch lines may be dropped. If the branch-line network in the Devils Lake area is abandoned, the solution derived in Scenario Four will no longer be valid. The objective of Scenario Five is to determine the change in flow patterns and highway costs which occur under the "all-or-nothing" assignment procedure employed in Scenario Four.

In all, seven scenarios were analyzed:

1. The impact scenario (based on a cooperative elevator model and static truck utilization patterns),
2. A CO-5AX farm-to-elevator scenario (where increased utilization of CO-5AX trucks is simulated),
3. An elevator rationalization scenario, in which four of the seven satellite elevators are assumed to be closed in the future,
4. An alternative organizational scenario (which simulates the flow generated by a private train-loading facility),
5. An abandonment scenario,
6. A short-line scenario,
7. A scenario which entails the combined effects of scenarios 2 and 5 (high CO-5AX farm-to-elevator truck use plus branch line abandonment).

A wide range of data inputs were required for the study. Most items were collected via survey or were derived from secondary sources. A partial list of the data items which were compiled for the study includes:

1. The grain produced during the base-year in each of 54 supply zones,
2. Production forecasts for the impact area (obtained from a Delphi study),
3. Highway routes and distances,
4. Highway attributes,

5. Elevator prices,
6. Historic grain shipments (by mode),
7. Rail freight rates,
8. Grain trucking rates and costs,
9. Grain truck weight and axle load factors,
10. Truck distribution factors.

Elevator prices, transportation costs, and routing data were developed for all 26 elevators in the region (both cooperative and noncooperative elevators). This was necessary so that impacts could be evaluated for all traffic streams in the impact region (not just within the subterminal-satellite system). This is important because subterminals may actually reduce traffic on some highways (due to an increased market share and a higher percentage of outbound shipments going by rail).

The baseline traffic/highway data base was developed from two sources. The NDHWD collected WIM and traffic data for 30 sections in the Devils Lake region, covering almost all of the heavily-impacted arterial highways. The raw data were adjusted for seasonal variance and turned-into average annual daily ESALs (AADE) via the process described in Chapter 4 of the main report. This data file was supplemented by information for an additional 23 highways on the collector network. Using the network/routing model described in the main report, the impacted sections on each collector highway were identified. Baseline AADE and highway attributes were then obtained for these sections through surveys with district and county engineers, or were estimated using average ESAL factors published by the NDHWD for similar highways. Collectively, the data base covers almost all of the impacted highways and sections in the region.

Drawing from the earlier discussion regarding problem dimensions and major forces, a more concise definition of the analytic dimensions of the subterminal problem is presented in the next section of the report.

ANALYSIS DIMENSIONS

Grain subterminals can potentially generate a fairly intricate set of impacts and cross impacts. The major effects (considered singularly) consist of potential impacts on:

1. Market share,
2. Grain flows,
3. Truck utilization/distribution,
4. Highway utilization.

There are some important cross-effects as well. The allocation of grain among flow-types will impact the distribution of shipments among truck-types, as well as the types of highways which are utilized.

In the analysis which follows, grain flow effects are evaluated by contrasting the allocation of grain among the five types of flows within the cooperative system between the "base case" and the "impact scenario." Truck-type effects are modeled in a similar fashion using the three truck classes introduced earlier. Highway class effects are simulated by compiling data at the functional class level.

In the Devils Lake study, five rural functional classifications were used to analyze highway effects:

1. Other principal arterials,
2. Minor arterials,
3. Major collectors,
4. Minor collectors,
5. Local roads.

Because the concept of functional classes is important to an understanding of the problem, a brief discussion of the major rural classes is presented next.

Functional Classes

The primary function of local roads is to provide access to land. Beyond that, they support travel over relatively short distances only. In the rural highway network, local roads serve individual farms and other rural land uses. Some general characteristics of local rural roads are:

1. They have very light traffic densities,
2. They generally have low-type surfaces,
3. They are discontinuous and limited in distant,
4. They are typically designed for low speeds (30 MPH for roads with less that 200 ADT).

Collectors (in contrast to local roads) directly serve small towns, connecting rural communities to the arterial network.[9] They are primarily characterized by intracounty travel (as opposed to statewide or interstate travel). Rural major collectors serve traffic generators of relatively major proportions on the intracounty level (such as major shippers, rural mines or other extractive industries, schools, etc.). Minor rural collectors serve smaller communities and connect localized traffic generators with farms and other outlying rural areas.

Rural arterials typically provide direct service between cities and larger rural towns. The trip distance on rural arterials is generally much longer that it is on collectors, some of it being statewide (or even interstate) in nature.

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[9] The discussion of functional classes presented in this section has been abstracted from AASHTO (1984).

Rural arterials are categorized as either principal or minor arterials. Principal arterials are further differentiated between "freeways" and "other principal arterials."[10]

Principal arterials are typically (but not always) multi-lane rural highways connecting major cities. They usually constitute the most heavily traveled routes in the rural network. Rural minor arterials are generally not as heavily traveled as the principal arterials, and provide for a shorter trip length and lower traffic densities. Rural minor arterials essentially allow for intercounty travel and tie the principal arterial network into the collector and local road system.

A typical farm-to-satellite (local) elevator trip will involve the use of the local, minor collector, major collector and/or minor arterials systems. The trip generally begins with a short journey (typically 5 miles or less) over a local road which leads to a minor or major collector. The length of the journey on the collector network is generally greater than on local roads, sometimes approaching (or even exceeding) 20 miles but more likely falling in the neighborhood of 5 to 10 miles. The loaded journey may conclude at this point (as many grain elevators are connected to the rural hinterland by major or minor

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[10] The primary difference is that freeways provide full control of access while other principal arterials do not.

collectors). Or, the trip may proceed on a rural minor arterial (or in some instances a rural principal arterial).

Elevator-to-market shipments generally entail a different combination of road use. Elevators are major rural traffic-generators, which are typically located on major collectors or minor arterials. Some are even situated on principal rural arterials. A truck journey from elevator-to-terminal market (flow-type 3) may begin on a major collector (or a minor arterial). But the traffic is quickly funneled onto a principal rural arterial or interstate highway where the majority of the trip miles occur.

Subterminal elevators are typically located on or near arterial highways.[11] So the outbound truck traffic which is generated usually travels on the principal arterial and interstate system. The satellite elevator-to-subterminal traffic (flow-type 4) may occur largely on the arterial network. Such a truck journey might begin on a major collector or minor arterial and conclude on a principal arterial. However, this is not always so. Sometimes the most direct route between the satellite and subterminal involves a "short-cut" across minor rural collectors (or even portions of local roads).

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[11] This is not always the case, as subterminals are sited according to rail rather than highway access.

Each component of the rural highway system is designed to serve a particular function. Each class is designed for a certain level of traffic (ADT) and traffic mix (percent trucks). The perceived traffic mix will determine the design strength (structural number or slab thickness) which in turn determines the ESAL-life. As depicted in Table 6 of the full report, the average ESAL life for a typical rural arterial is 1.5 million, while an average ESAL lifetime is roughly 400 thousand for rural collectors and 80 thousand for local roads respectively.

Although rural functional classes are not completely homogenous in nature, the highways which comprise the classes are generally quite similar in design. In short, rural functional classes generally reflect (at an aggregate level) the traffic and pavement design characteristics of the individual highways.

Major Cross Effects

There are three major cross-effects which determine (in large part) the extent of highway impacts. These are:

1. flow-types and truck-types,
2. flow-types and functional classes,
3. truck-types and functional classes,

They constitute the major analytic dimensions of the research methodology.

DIMENSIONAL ANALYSIS

This section of the report focuses on changes in the analytic dimensions outlined above. The objective of the discussion is to explain the forces underlying the projected replacement and upgrading cost estimates presented later.

Table 3 (which depicts mean annual shipments for the analysis period) illustrates the potential effects of the subterminal on grain flows in the region. As Table 3 shows, the eight elevators which comprise the cooperative collectively drew 6 million hundred-pounds (cwts) during 1985 (when the subterminal was operational for only five months of the year).[12] This amounted to 28 percent of total production. In contrast, the subterminal-satellite system is projected to draw over 16 million bushels (collectively) from the impact area in the horizon year.[13] This amounts to over 40 percent of the grain produced. The reason for this market domination lies with the transportation rate advantage and the size economies of the subterminal. Since the price at the satellite elevator is

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[12] This figure is based on actual grain shipment data.

[13] Horizon-year estimates take into account: (1) increased production, (2) changes in elevator relationships, and (3) increased market penetration by the subterminal.

assumed to be the price at the subterminal minus the grain trucking cost, all of the elevators in the system will enjoy a price advantage.

TABLE 3. MARKET SHARE ANALYSIS	SCENARIO	
	0	1
	CWTS	CWTS
	(000)	(000)
ELEVATOR STATUS		
NONCOOP ELEVATORS	15,280	13,484
COOP ELEVATORS	6,070	9,184
TOTAL	21,350	22,678

Impacts on market share are important. However, it is the aggregate change in grain flows brought about by the subterminal-satellite system which constitute the first major link in the chain of cause-and-effect which results in highway impacts. Table 4 shows the "before" and "after" patterns of flow in the impact area.[14] The table graphically illustrates the projected change in flow patterns predicted by the model. As the subterminal moves toward its long-run market and operating position, transshipments will increase dramatically. This points out the potential fallacy of focusing on early volume and shipment patterns only.

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[14] The 1985 figures reflect farm shipments to the existing Devils Lake elevator in the first half of the year, and farm-to-subterminal shipments during the last half of the year.

TABLE 4. GRAIN FLOW ANALYSIS	SCENARIO	
	0	1
	CWTS	CWTS
	(000)	(000)
FLOW TYPE		
FARM-TO-SATELLITE	14,550	18,052
FARM-TO-SUBTERMINAL	4,823	2,385
SATELLITE-TO-MARKET	1,977	1,397
TRANSSHIPMENT	.	11,913
SUBTERMINAL-TO-MARKET	.	834

Tables 5 and 6 depict the distribution of traffic among truck-types during the base-case and the impact scenario. As Table 6 shows, CO-5AX truck trips increased from 4 percent of annual truck trips in the base-case to 21 percent under the impact scenario. Meanwhile, both SU-2AX and SU-3AX truck-use fell dropping 7 and 10 percentage points respectively.

TABLE 5. TRUCK DISTRIBUTION	SCENARIO	
	ANNUAL	ANNUAL
	TRIPS	TRIPS
TRUCK-TYPE		
CO_5AX	7,774	53,174
SU_2AX	115,590	135,252
SU_3AX	67,792	64,256
TOTAL	191,156	252,682

TABLE 6. PERCENTAGE TRUCK DISTRIBUTION	SCENARIO	
	0	1
	ANNUAL	ANNUAL
	TRIPS	TRIPS
TRUCK-TYPE		
CO_5AX	4	21
SU_2AX	61	54
SU_3AX	35	25

Tables 7 and 8 present a similar display concerning highway use. As Table 7 shows, the number of annual trips increased within all functional classes. But in particular, there were large increases within the minor and principal arterial classes. This is the result of transshipments between satellite elevators and the subterminal.

TABLE 7. FUNCTIONAL CLASS ANALYSIS	SCENARIO	
	0	1
	ANNUAL TRIPS	ANNUAL TRIPS
FUNCTIONAL CLASS		
MAJ. ART.	120,262	184,030
MIN. ART.	186,690	235,508
MAJ. COL.	59,422	79,064
MIN. COL.	24,764	34,274
TOTAL	391,138	532,876

TABLE 8. % FUNCTIONAL CLASS DISTRIBUTION	SCENARIO	
	0	1
	ANNUAL TRIPS	ANNUAL TRIPS
FUNCTIONAL CLASS		
MAJ. ART.	31	35
MIN. ART.	48	44
MAJ. COL.	15	15
MIN. COL.	6	6

Changes in truck distribution and highway use are translated into incremental highway costs through changes in ESALs. Table 9 shows the incremental average annual daily ESALs (AADE) by road and functional class for the impact scenario. As Table 9 portrays, the major arterial in the region (Highway 2) shows substantial increases, as well as Highway 20 north and south of Devils Lake. Three major collectors (3618, 3627, and 3630) were also impacted, as were three minor collectors.

Several items are particularly noteworthy regarding Table 9. First, the highway on which the subterminal is located (2W) shows a substantial increase in grain AADE. This is to be expected, as both direct farm-to-subterminal shipments as well as transshipments will traverse parts of the highway. Second, Highway 20 (on which three of the satellite elevators are located) also experiences significant impacts. Again, these are due primarily to transshipments. One of the major satellite elevators in the system is located on Highway 3627 (a major collector). Consequently, this highway is also expected to experience a major increase in AADE.

TABLE 9. INCREMENTAL GRAIN AADE	FUNCTIONAL CLASS				
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	TOTAL
	GRAIN	GRAIN	GRAIN	GRAIN	GRAIN
	AADE	AADE	AADE	AADE	AADE
ROAD					
1	.	-4	.	.	-4
15	.	-10	.	.	-10
19	.	0	.	.	0
2E	9	.	.	.	9
2W	135	.	.	.	135
66	.	-16	.	.	-16
17E	.	0	.	.	0
17W	.	-4	.	.	-4
20N	.	47	.	.	47
20S	.	17	.	.	17
3604	.	.	.	8	8
3607	.	.	.	2	2
3614	.	.	0	.	0
3617	.	.	.	5	5
3618	.	.	4	.	4
3627	.	.	16	.	16
3630	.	.	6	.	6
3633	.	.	1	.	1
4819	.	.	.	-12	-12
TOTAL	144	30	27	3	204

It should be noted that negative or decremental values are possible in Table 9. As the subterminal exerts its influence over the market region, traffic will be diverted from some highways actually reducing impacts. However, as Table 9 shows, a net gain of 204 incremental grain AADE are forecast under the impact scenario.

Table 10 brings the potential financial impacts into sharper focus, displaying the projected replacement costs for the analysis period, by functional class and road. The projected replacement costs are not incremental costs. Before short-run incremental costs can be evaluated, the "build-sooner" costs must be computed. This is the topic of the following section.

TABLE 10 REPLACEMENT COST	FUNCTIONAL CLASS				
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	TOTAL
	REPLACEMENT COST	REPLACEMENT COST	REPLACEMENT COST	REPLACEMENT COST	REPLACEMENT COST
	(000)$	(000)$	(000)$	(000)$	(000)$
ROAD					
1	.	$5,712	.	.	$5,712
15	.	$3,927	.	.	$3,927
19	.	$834	.	.	$834
2E	$5,054	.	.	.	$5,054
2W	$4,118	.	.	.	$4,118
66	.	$3,927	.	.	$3,927
17E	.	$595	.	.	$595
17W	.	$476	.	.	$476
20N	.	$3,453	.	.	$3,453
20S	.	$2,536	.	.	$2,536
3604	.	.	.	$4,988	$4,988
3607	.	.	.	$3,248	$3,248
3614	.	.	$580	.	$580
3617	.	.	.	$3,248	$3,248
3618	.	.	$580	.	$580
3627	.	.	$4,408	.	$4,408
3630	.	.	$1,044	.	$1,044
3633	.	.	$4,408	.	$4,408
4819	.	.	.	$4,988	$4,988
TOTAL	$9,172	$21,460	$11,020	$16,472	$58,124

INCREMENTAL COST ANALYSIS

Eighty-two of the 126 highway sections in the Devils Lake study had some grain truck traffic routed over them during either the base case or the impact scenario. As Table 10 depicts, over $58 million in replacement costs were forecast for the 82 sections (which collectively comprise 452 miles of highway). The accelerated replacement cost (or build-sooner cost) totals $1.14 million. Much of it is concentrated on the major collector system and two minor rural arterials subject to the heaviest transshipments.

Table 11 shows the projected short-run incremental or build-sooner cost for the analysis period, while Table 12 depicts the long-run incremental or upgrading costs. Two major conclusions may be drawn from Table 11. First, the collector and minor arterial system is likely to be most heavily impacted by future subterminal operations. Second, while the magnitude of the replacement cost is substantial, the accelerated replacement costs do not appear to pose a significant financial burden. This is not to say that there might not be significant, even catastrophic localized problems. This is born-out by an analysis of the projected costs for heavily-impacted highways such as 3627 and 20S.[15]

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[15] Highway 3627 provides access to one of the satellites which has train-loading capabilities. As the table depicts it is perhaps the most-heavily impacted of all roads. This is because: (1) the facility both receives and transships grain on the same highway, and (2) the highway is not designed to arterial standards.

TABLE 11. SHORT RUN COST	FUNCTIONAL CLASS				
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	TOTAL
	SRIC	SRIC	SRIC	SRIC	SRIC
	(000)$	(000)$	(000)$	(000)$	(000)$
ROAD					
1	.	$0	.	.	$0
15	.	$0	.	.	$0
19	.	$0	.	.	$0
2E	$11	.	.	.	$11
2W	$75	.	.	.	$75
66	.	$0	.	.	$0
17E	.	$0	.	.	$0
17W	.	$0	.	.	$0
20N	.	$124	.	.	$124
20S	.	$286	.	.	$286
3604	.	.	.	$82	$82
3607	.	.	.	$22	$22
3614	.	.	$0	.	$0
3617	.	.	.	$49	$49
3618	.	.	$51	.	$51
3627	.	.	$345	.	$345
3630	.	.	$64	.	$64
3633	.	.	$29	.	$29
4819	.	.	.	$0	$0
TOTAL	$86	$410	$489	$153	$1,138

TABLE 12. LONG RUN COST	FUNCTIONAL CLASS				
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	TOTAL
	LRIC	LRIC	LRIC	LRIC	LRIC
	(000)$	(000)$	(000)$	(000)$	(000)$
ROAD					
1	.	$0	.	.	$0
15	.	$0	.	.	$0
19	.	$0	.	.	$0
2E	$63	.	.	.	$63
2W	$111	.	.	.	$111
66	.	$0	.	.	$0
17E	.	$0	.	.	$0
17W	.	$0	.	.	$0
20N	.	$249	.	.	$249
20S	.	$800	.	.	$800
3604	.	.	.	$1,213	$1,213
3607	.	.	.	$2,104	$2,104
3614	.	.	$0	.	$0
3617	.	.	.	$1,133	$1,133
3618	.	.	$283	.	$283
3627	.	.	$1,416	.	$1,416
3630	.	.	$218	.	$218
3633	.	.	$729	.	$729
4819	.	.	.	$0	$0
TOTAL	$174	$1,049	$2,646	$4,450	$8,319

The build-sooner costs represent only the short-run impacts of subterminal traffic incurred during the current replacement cycle. The upgrading or LRIC were also computed for each highway section (where applicable).

Not all highways in the impact region will have to be strengthened (see Table 12). With the exception of Highway 20 (and 2W in the vicinity of the subterminal) the arterial network in the region appears to be sufficient to support future changes in truck traffic generated by the subterminal. However, the collector system is under-designed in terms of the level and mix of future traffic which it will be required to bear. Certain major impact highways (such as 3627) are likely to incur significant long-run costs because of low structural numbers and old pavements.

SENSITIVITY ANALYSIS

Tables 13 and 14 summarize the SRIC and LRIC under each of five alternative scenarios. A detailed discussion of the scenarios is provided in the full report. As Table 14 indicates, the greatest LRIC would occur under Scenarios 2 and 7. Both entail heavy combination five-axle truck-use: Scenario 2 on the farm-to-elevator leg of the truck journey and Scenario 7 on the outbound leg.

TABLE 13. SHORT RUN INCREMENTAL COST

SCENARIO	FUNCTIONAL CLASS				TOTAL
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	
	SRIC	SRIC	SRIC	SRIC	SRIC
	(000)$	(000)$	(000)$	(000)$	(000)$
Scenario 2	$85	$383	$391	$141	$1,000
Scenario 3	$64	$410	$420	$0	$894
Scenario 4	$29	$410	$489	$153	$1,081
Scenario 5	$73	$410	$489	$153	$1,125
Scenario 6	$5	$410	$489	$153	$1,057
Scenario 7	$80	$383	$391	$141	$995

TABLE 14. LONG RUN INCREMENTAL COST

SCENARIO	FUNCTIONAL CLASS				TOTAL
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	
	LRIC	LRIC	LRIC	LRIC	LRIC
	(000)$	(000)$	(000)$	(000)$	(000)$
Scenario 2	$185	$913	$2,700	$6,473	$10,271
Scenario 3	$102	$1,071	$2,846	$0	$4,019
Scenario 4	$137	$1,049	$2,646	$4,450	$8,282
Scenario 5	$193	$1,049	$2,646	$4,450	$8,338
Scenario 6	$137	$1,049	$2,646	$4,450	$8,282
Scenario 7	$197	$913	$2,700	$6,473	$10,283

As the Table 13 displays, the SRIC costs show little fluctuation from the values forecast under the impact scenario. Scenario 3 (the elevator rationalization scenario) actually shows the lowest cost. There are three possible reasons for this. First, as substations are eliminated, fewer transshipments will occur. Second, since the subterminal elevator is located on a principal arterial, a different mix of highway utilization will materialize.

Third, only one trip is required to position the grain at the subterminal under a direct shipment scenario, whereas two truck trips are required in many instances under the impact scenario.

CONCLUSIONS

The siting of a grain subterminal elevator at Devils Lake may cause localized short-run impacts, but the network-wide effects will be minimal, totaling 1.14 million dollars in accelerated replacement costs. The LRIC will be more substantial if a "transshipment scenario" is realized (totaling $8.4 million). The probability of this occurring is unknown. However, as pointed out earlier, transshipment appears to the industry norm or model.

Scenario 3 (in which the elevator system is rationalized) shows the lowest projected SRIC and LRIC. This points out the potentially large reductions in highway costs brought about by the elimination of transshipments. Scenario Two (which entails high CO-5AX farm truck use) could result in relatively high incremental cost. However, the greatest SRIC would be generated under an abandonment scenario. The greatest LRIC would be generated under Scenario 7, which entails both increased CO-5AX farm truck shipments and branch line abandonment.

The difference between a private subterminal and a cooperative facility does not appear to be significant in this instance. Approximately the same SRIC and LRIC were generated under both scenarios. Since most of the other elevators in the region are single-car shippers, the price advantage offered by a private subterminal would tend to generate similar traffic flows and highway costs.

Under Scenario Six, the presence of a short-line carrier in the region was simulated. Short-line elevator-to-elevator rail rates were estimated from a previously published mileage scale. These rates were compared with short-haul truck rates from satellites to the subterminal. Because the distances from the satellites to the subterminal are less than 25 miles (in most instances), a short-line carrier is unlikely to have a significant impact on truck transshipment levels in the region. A conservative market share of 10 percent was estimated for the short-line on elevator-to-elevator shipments. As Tables 13 and 14 point-out, this would not cause a major change in the forecasted impacts.

Less than two percent of the rural minor arterial and collector highway mileage in North Dakota is represented in the Devils Lake study. If the region is a microcosm of rural North Dakota, the statewide accelerated replacement and upgrading costs could be in the vicinity of $57 million and $420 million respectively[16].

The conclusions of the study are consistent with common engineering and economic logic. Changes in traffic patterns caused by the subterminal are likely to generate increased CO-5AX trips and annual miles, much of which will be concentrated on collector highways that have not been designed for heavy truck traffic. This mismatch between traffic and highway classes will result in localized short-run impacts, as well as significant long-run costs on the collector network.

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[16] Regional variations within the state may result in either higher or lower per-mile costs for a given elevator system than those found in the Devils Lake region. Many parts of the state do not have the extensive coverage and quality of service provided by the arterial and collector network in the Devils Lake region. In these areas, the impacts may be much greater than in the case study.