THE IMPACTS OF GRAIN SUBTERMINALS ON RURAL HIGHWAYS VOLUME II

by

Denver D. Tolliver

UGPTI Publication No. 75

March 1989

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DENVER D. TOLLIVER

UPPER GREAT PLAINS TRANSPORTATION INSTITUTE
NORTH DAKOTA STATE UNIVERSITY
P. O. BOX 5074
FARGO, NORTH DAKOTA 58105

MARCH 1989

The preparation of this report was financed in part through the United States Department of Transportation's Federal Highway Administration and the North Dakota State Highway Department in cooperation with the Upper Great Plains Transportation Institute.

Highlights

The problems associated with increased heavy grain truck traffic in rural regions were investigated. Both the short-run incremental costs of accelerated pavement replacement and the long-run incremental costs of upgrading low-volume highways were considered. A set of demand and traffic models was formulated which projects the annual flow of grain from each production zone in an impact region to each elevator, allocates the flows among truck-types, computes the annual trips, gross vehicle weights and axle weights, and assigns the truck trips to the highway network. A set of highway models was also formulated which computes the equivalent single axle loads for each highway section in an impact region and estimates the incremental costs associated with subterminal traffic.

The impacts of a newly-formed subterminal-satellite elevator system in rural North Dakota were investigated. The results of the case study indicate that rural collector highways are likely to experience substantial localized impacts from subterminal development but the effects on principal arterials may be minimal. Altogether, $1.14 million in short-run costs and $8.41 million in long-run costs were projected for the impact region. However, the case-study roads represent less than 2 percent of the rural arterial and collector highway mileage in the state. If the case-study network represents a microcosm of rural North Dakota, then the statewide short-run and long-run incremental costs may be in the vicinity of $57 million and $420 million respectively. However, regional variations within the state may result in either higher or lower costs for a given elevator system than those projected in the case study.

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CHAPTER 1
PROBLEM STATEMENT AND OBJECTIVES

The development of subterminal-satellite elevator systems has altered the traditional pattern of grain traffic in many rural areas of North Dakota and the Upper Great Plains. The impacts of these changes on the rural highway network have not previously been researched.

The purpose of this dissertation is twofold: (1) to quantify the impacts of subterminal development on pavement life-cycles and future highway financial needs, and (2) to develop a set of procedures which can be used elsewhere in the state or region to analyze similar problems in the future.

OVERVIEW

Prior to 1981, the predominant grain flows in rural North Dakota consisted of farm-to-country elevator and country elevator-to-market shipments. The majority of farm-to-elevator shipments were made by two-axle, single-unit farm trucks over relatively short distances.[1] Outbound elevator shipments originated primarily by rail. The

[1] A 1980 survey by the Upper Great Plains Transportation Institute found that 84% of the farm truck fleet in North Dakota consisted of two-axle, single unit trucks. The average length of haul in 1980 was 12 miles. Source: Griffin, Wilson and Casavant (1984).

remainder moved via long-haul commercial trucking services, which primarily utilized interstate and principal arterial highways.

Today, under a cooperative organizational structure, many of these small, previously independent elevators function as "satellites." As such, they are primarily used for the assembly and storage of grain which is reshipped to the subterminal at a later date. In several areas of the state, transshipments or elevator-to-subterminal shipments have largely supplanted the traditional country elevator-to-market flow. Consequently, rail or long-haul trucking services at the country elevator have been replaced by short-haul trucking to the grain subterminal.

As grain flows change, so do the types of highways used and the frequency of use. In certain parts of the state, minor arterials, collectors, and local roads are being utilized extensively to haul grains and oilseeds from satellites to subterminals. Most of these low-volume roads were designed for lighter, more infrequent loads than are now being applied. State and local transportation officials are concerned that the service lives of impacted highways will be reduced, and that some highways will have to be rebuilt to a higher design standard in order to accommodate heavy truck traffic.

The potential highway impacts of subterminal-generated traffic are particularly problematic when considered in light of the overall rural road problem. The changes in traffic patterns caused by subterminals are being acted out on an aging, deteriorating infrastructure. More than one-third of the rural minor arterial system, the backbone of the farm-to-market and rural access network in North Dakota, is over 25 years old (NDHWD, 1988). A recent highway needs assessment conducted by the North Dakota Highway Department using the Highway Performance Monitoring System (HPMS) projected that 2,937 miles of minor rural arterial highway will need rehabilitation, restoration, or reconstruction by the year 2000 at current funding levels (NDHWD, 1988)[2]. As will be detailed later, the introduction of incremental, heavy truck traffic onto an aging, deteriorated highway section accelerates pavement decay and shortens the effective life of the section.

The life-cycle pavement consequences of subterminal truck traffic may not be readily apparent from visual inspection over a relatively short period of time, except in

[2]The Highway Performance Monitoring System is an analytical package developed by the FHWA which describes the baseline condition of a state's highway network, forecasts future highway needs by functional classification of highway, and projects the condition and performance of the highway network under various funding alternatives.

the very worst of circumstances. Yet intuitively, it is known that each increment of grain truck traffic consumes some portion of the remaining life of a highway section. Years of experience will undoubtedly tell the tale, but by then the damage will be done and highway officials may be left with large, unforeseen rehabilitation or reconstruction needs.

The potential financial consequences necessitate that the problem be analyzed systematically and that a set of procedures be developed which can predict the impacts of subterminal-generated traffic on rural highways. This report represents an effort to fulfill those needs, and to provide a foundation for future highway impact analysis.

OBJECTIVES

The primary objectives of the report are:

1. To formulate a set of systematic procedures which can be used to simulate the incremental highway costs of subterminal-generated traffic;

2. To apply the procedures to a case study in an effort to identify potential changes in future highway needs attributable to subterminal development;

3. To document the analytical process and techniques which were used in sufficient detail so that they may be replicated by other analysts in the future;

4. To build a base of information from which future analysts may draw concerning the use of various analytical techniques in subterminal impact analysis.

It is further hoped that the set of computer models developed in the study may prove to be a starting point for the development of a microcomputer highway impact and planning model at some future time.

PROBLEM STATEMENT

The preceding discussion has painted a general picture of the problem of subterminal-generated traffic. The objective of the discussion was simply to overview the problem. In this section of the report, a more specific definition of the problem is presented. The objective is to pinpoint effects or impacts which can be systematically and quantitatively evaluated.

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

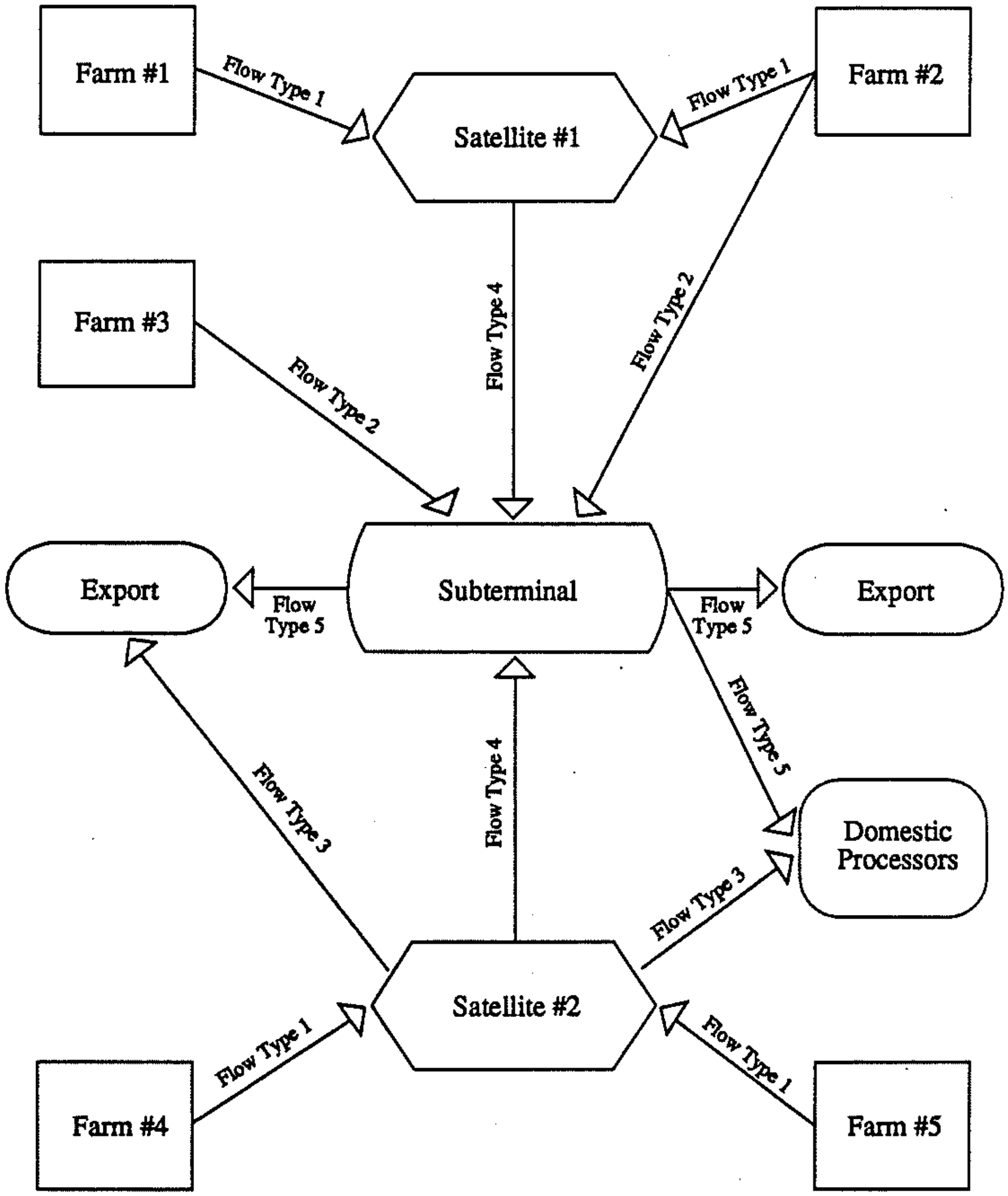

FIGURE 1. Logistics of Grain Flow Within a Subterminal-Satellite Elevator System

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

Truck Types

The classes of equipment used constitute the second dimension of the subterminal traffic problem. 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).

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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. Appendix B presents a synopsis of recent truck traffic trends in North Dakota.

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 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.

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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 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.

There are clearly other attributes which are of importance, but these are the principal ones of concern for this study.

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. In almost all instances, the reference axle is the 18,000 pound single axle[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

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[5] 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 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.

the ESALs are 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

followed by the SU-2AX farm truck[7]. Consequently, shifts in grain flows which result in a higher frequency of CO-5AX

[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.

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 management practices 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 flow-type 1 will be quite prominent. But under a transshipment scenario, flow-type 2 will be of only minor concern.

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.

While each subterminal-satellite system will affect grain flows in a unique manner, certain trends are evident in the North Dakota elevator industry that indicate what is happening in a general sense. Appendix B describes in detail recent trends in elevator size, volume, and truck traffic patterns in North Dakota. As Appendix B details, transshipments (as a percentage of total truck bushels shipped) have increased from 21.3 percent at the beginning of 1984, to 35.6 percent during the first half of 1987. In contrast, long-haul elevator-to-market trucking has declined precipitously over the years. Truck bushels constituted 38 percent of total bushels shipped in crop year 1979-1980, prior to the development of subterminals. By crop year 1983-84, truck share (excluding transshipments) had fallen to 24.7 percent of total volume. Since then, long-haul truck share has continued to decline, reaching a low of 19 percent in crop year 1986-87.

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. 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 collector 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.

To summarize Chapter 1, the subterminal traffic problem:

1. Is a complex, multi-dimensional problem;
2. Typically involves high levels of transshipments in CO-5AX trucks with high ESALs per VMT;
3. Sometimes involves significant direct farm-to-subterminal hauls over relatively long distances within the impact area;
4. Is exacerbated by the routing of heavy truck traffic over low-volume highways which were not designed for such use;
5. May vary from system-to-system, depending on management strategies, price relationships, and other variables.

The purpose of Chapter 1 has been to set forth the objectives of the report and to provide a working definition of the problem. The remainder of the study is organized as follows:

Chapter 2 outlines the research design and delineates the scope of the project;

Chapter 3 builds the theoretical groundwork for modeling subterminal highway impacts;

Chapter 4 describes the process of subterminal impact analysis in detail, and documents the procedures and data collection techniques which were used in the Devils Lake case study;

Chapter 5 presents the results of the case study and summarizes the major findings of the investigation.

CHAPTER 2
RESEARCH DESIGN

Subterminal traffic impacts pose a complex problem which cannot be evaluated using any single model. Instead, a battery of models or submodels is needed.

This chapter introduces the submodels required. But before the discussion turns to the topic of models, three items are addressed. First, the scope of the analysis is more clearly defined. Second, a set of research hypotheses is formulated. And third, the general approach or philosophy underlying the research design is made apparent.

SCOPE OF THE ANALYSIS

Changes in traffic patterns due to subterminal development may generate a wide range of impacts. These include:

1. highway capacity costs;
2. user costs;
3. safety impacts;
4. environmental consequences;
5. community impacts; and
6. pavement rehabilitation and reconstruction costs.

Increased heavy truck traffic on a highway section consumes a portion of the available capacity of the road (as measured in vehicles per lane per hour). In general, on a rural, two-lane highway over level terrain, a single-unit two-axle truck occupies 1.2 times the capacity of a standard passenger car in a stream of traffic (FHWA, 1984). The passenger car equivalents (PCE's) are even higher for single-unit three-axle trucks and combination trucks: 1.5 and 3.0, respectively. Furthermore, the PCE's increase considerably in areas of rolling terrain.

Operating speed on rural highways is a function of the design speed and the volume-to-capacity (V/C) ratio. As the V/C ratio of a highway section increases due to additional truck traffic, the costs of other users (as measured in travel time) will rise. If user costs rise substantially due to congestion, lanes may have to be widened or added.

In general, capacity constraints and increases in user cost due to congestion are unlikely to occur on a noticeable scale in rural North Dakota because the existing V/C ratios are typically low. However, congestion may be of some concern in and around the subterminal itself, particularly if the facility is located in or near an urban area.

Perhaps more important than capacity constraints, incremental truck traffic may have a serious impact on safety on rural highways of a lower design type. Narrow lanes and shoulders may pose both vehicle and pedestrian hazards. Inadequate vertical and/or horizontal alignment may reduce a driver's line of vision and impair operating safety. Furthermore, a basic increase in accident exposure at railroad grade crossings and other areas of potential hazard will occur due to an increase in truck vehicle miles of travel.

The environmental consequences of subterminal-generated traffic consist principally of noise, air pollution, and dust in the impact region. These externalities are particularly noticeable in instances where CO-5AX trucks are routed over gravel-surface, low-volume roads.

Community impacts consist of those effects experienced by non-users residing in the impact area. Community impacts can be environmental, such as increased noise, pollution, and dust on unpaved roads. However, community impacts can also be perceptual in nature. The obtrusiveness of transportation into the everyday lives of non-users can be exacerbated by additional truck traffic on low-volume highways.

While it is acknowledged that safety, environmental, and community-related impacts may exist, they are **not** addressed in this study. The report focuses exclusively on the pavement-related impacts of subterminal traffic. The justification for this research design is:

1. pavement costs represent direct monetary outlays which transportation agencies must face in future years, and are therefore felt to be the primary concern of decision-makers; and,

2. addressing safety, environmental, and community impacts would greatly expand the time-frame for the analysis and the resources required.

RESEARCH HYPOTHESES

Four major hypotheses were formulated and tested in the study.

1. Truck traffic generated by subterminal-satellite systems reduces the useful life of highway sections.

2. Subterminal grain truck traffic results in incremental capital costs arising from the need to increase the strength of pavements to handle a greater number of axle loads for a given design period (e.g., 20 years).

3. Subterminal-generated truck traffic alters the distribution of highway needs among functional classes of highways.

4. The highway impacts of subterminal-satellite systems varies significantly across management strategies and operating scenarios.

Hypothesis 1 implies that incremental heavy truck traffic reduces the effective life of pavements, thereby resulting in more rapid rehabilitation or restoration. As a result, monetary outlays will be encountered sooner than originally anticipated. Hypothesis 2 implies that certain highways do not possess adequate structural strength to handle heavy traffic. Thus, the existing pavement on a highway section will not only have to be replaced, but the road will have to be rebuilt to a higher standard[8].

Hypothesis 1 or 2 could be restated in terms of specific functional classes. For example: incremental grain truck traffic reduces the effective life of rural collectors. Logically, the pavement-related impacts of subterminals may vary across functional classes due to the design and present serviceability of highways. So minor collectors and local roads designed for low volumes of traffic may be impacted disproportionately by additional heavy axle loads.

The price relationships between subterminal and satellite elevators and the operating plan implemented by management can alter grain flows, affect the frequency of truck types used, and change highway routes. Certain price relationships and operating strategies will result in substantial levels of transshipments. Others will result in sizable farm-to-subterminal flows. Hypothesis 4 posits that highway impacts will vary significantly across the range of possible operating scenarios for a subterminal-satellite system.

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[8] For example, additional thickness in the asphaltic concrete surface layer on flexible pavements may be required if the incremental axle loads are sufficiently large. This added strength is a different effect than the accelerated replacement of pavements captured by Hypothesis 1.

RESEARCH APPROACH AND PHILOSOPHY

The basic philosophy underlying this research design is that the analysis of traffic data (in and of itself) cannot adequately describe the long-range impacts of subterminal traffic. Traffic data are important, but constitute one element of a broader analytical approach.

In the initial stage of the Devils Lake project, the NDHWD collected traffic and truck weight data in the impact region for two intervals in time: 1985 (the year during which the subterminal began operation) and 1986 (the year afterwards). An analysis of the "before" and "after" data failed to disclose any clear trends in traffic patterns. This is not a surprising conclusion given the fact that it may take several years for a new facility to reach its "normal" or long-run level of output[9]. However, it does raise an appropriate question regarding the approach which future studies should take.

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[9]Normal operations refer to the level of output and operating procedures which prevail over a relatively long period of time. Normal operations may be quite different than initial or start-up operations. During the initial phase of operations, the facility is unlikely to be operating at its long-term level of volume. Furthermore, management strategies or policies may not have completely crystallized at this point.

The Traffic Approach Versus Systems Analysis

There are several ways to conduct a highway impact assessment. In the traditional "traffic approach", the analyst collects traffic and truck weight data for a "before" and "after" period, and attempts to identify trends in the data which can be attributed to some external or environmental change (such as the opening of a grain subterminal).[10] This approach can provide some useful insights into changes in transportation patterns over time (if the data collection program is properly designed). However, there are problems and limitations associated with this strategy (both philosophical and practical). First, the traffic approach (as its name implies) focuses on traffic volume rather than on transportation demand. Traffic data collected at particular sites can show what is occurring (the results), but cannot explain why. The truck volume at any given monitoring site at any particular time is determined by the demand for the transportation of the commodities to and from specific locations. The traffic

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[10]Ideally, multiple years of "after" data should be collected. If only two years of data are collected, several problems may arise. First, the facility may not have entered the phase of normal or long-term operations by the conclusion of the impact year. Second, construction traffic may inflate base year traffic data, requiring that the data be "cleaned" (if possible). Third, one year of data may not reflect long-term trends.

approach treats the determinants of demand as exogenous forces which are reflected in trend lines and patterns. Because the traffic approach does not explicitly account for underlying casual relationships, it is subject to considerable uncertainty.[11] Furthermore, simulation and sensitivity analysis cannot be properly performed because the underlying demand relationships are unknown.

Second, the traffic approach typically deals with classes of vehicles or traffic, rather than with classes of commodities. For example, short-term changes in vehicle class 6 (SU-3AX trucks) may be captured by the data, but the farm truck movements which comprise a portion of these counts may not be specifically identified.

Third, the traffic approach does not identify origins and destinations for the traffic. The classification data tell how many vehicles of a particular type pass a monitoring site during a particular time interval, but do not say where the trips originated and where they will terminate. Again, this limits the simulative and analytical capabilities of the approach.

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[11]An important position which is advanced throughout this study is that uncertainty in traffic forecasting can only be adequately addressed if the underlying commodity transportation demand relationships are understood and utilized to forecast changes in commodity flows, which in turn cause changes in truck traffic volumes.

An alternative to the traffic approach is "transportation systems analysis." In transportation systems analysis (TSA), the transportation network and the economic landscape of a region (the "land-use system") are jointly modeled. Relationships between the location and level of economic activities (e.g. production, processing, and storage facilities) and the flow of commodities are established. This allows changes in transportation demand to be reflected in the estimation of highway traffic volumes.

Traffic data are important inputs to the TSA process. Traffic counts and weigh-in-motion (WIM) data, properly adjusted for seasonal variance, help paint a picture of the baseline traffic stream and its composition. But the overall approach is much broader in nature. A systems approach is usually adopted which explicitly models the location and level of economic activities in the impact region[12]. Commodity flows are simulated from originating to terminating zones on the basis of economic and spatial linkages. The abstract commodity flows are then translated

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[12] For grain subterminal analysis, this means that agricultural production zones (farms), conditioning and storage centers (elevators), and processing or market locations are explicitly defined in the models. Collectively, they comprise the land-use components of the system.

into traffic volumes, and assigned to the highway and rail networks.

The advantages of a systems approach over a traffic approach are:

1. In addition to vehicle class data, specific commodity flow data within each vehicle class are accounted for;

2. The origin and destination zones are explicitly defined;

3. Long-run subterminal operating strategies and effects may be accounted for;

4. The traffic effects of changes in demand due to exogenous economic, social, or political forces may be simulated;

5. Uncertainty and the dynamics of the agricultural transportation system may be better accounted for.

A great deal of uncertainty exists in forecasting future grain flows within a satellite-subterminal system. A variety of forces acting in isolation or in concert can affect and dramatically alter the patterns of commodity flows which exist.[13] In effect, a set of feasible

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[13]A range of global, national, and local factors and conditions will affect traffic flows, either directly or indirectly, within a subterminal-satellite system. **Aggregate** demand for grain transportation will be affected by: (1) global demand, (2) global production, (3) the level of reserves or storage, (4) climatic conditions, (5) the agricultural policy of foreign countries, (6) U.S. agricultural policy, (7) U.S. transportation policy, and (8) a host of related economic or political factors. **Localized** demand will be affected by: (1) local production, (2) competition from neighboring elevators and subterminal-satellite systems, and (3) the subterminal manager's strategies and operations plans. **Modal** demand will be

alternative futures exists, each with its own level and distribution of highway impacts. Such uncertainty lends itself to the use of scenario analysis.

Scenario Analysis Versus Forecasting

The use of future or scenario analysis has received greater attention lately in transportation and economic forecasting, as the capability to control for exogenous forces has become circumspect[14]. In scenario analysis, the

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impacted by: (1) transportation policy and regulation, (2) transportation technology, (3) the availability of transportation supply (e.g., freight cars), (4) the pace of railroad rationalization and branch line abandonment, and (5) other economic and political factors. Federal policy has been particularly important in the past in determining the allocation of freight among the modes of transport. For example, the transportation policy set forth by the Staggers Rail Act of 1980 altered (either directly or indirectly) the nature and scope of railroad pricing policy, service levels, and technology. Efforts currently underway in the U.S. Congress to amend, change, or replace the Staggers Act could conceivably affect the competitiveness of the modes in an analogous fashion, thus leading to future shifts in modal demand. The bottom line to this discussion is that considerable uncertainty exists with respect to the modeling of grain flows due to the number of affecting variables and forces which exist.

[14] For a recent example of the application of future or scenario analysis to public transportation see: Rutherford and Lattman (1988). In this study, an expert panel was assembled with a knowledge of "economics, demographics, social sciences, development, law, trade, and business", which provided technical input on national and regional trends. The panel was asked to assign probabilities to future regional scenarios and estimate the impacts of each scenario on the various jurisdictions involved.

analyst does not have to forecast the future. Instead, he or she forecasts a set of likely, alternative futures. This approach admits the incapability of analytical techniques to adequately control for all major economic, political, and environmental forces.

In lieu of a single deterministic forecast, scenario analysis yields a range of forecasts which might hold true under different assumptions. By looking at a range of impacts, the analyst can identify both the worst and the best possible cases. Furthermore, an "expected value" of future flows can be calculated simply by assigning probabilities to each scenario[15]. In the Devils Lake study, the technique of scenario analysis was used in conjunction with a Delphi survey to generate estimates of future commodity flows within the region[16]. Then, using the

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[15]The concept of scenario analysis lends itself to the formulation of contingency plans. Instead of developing a single financial strategy which is valid only if the underlying assumptions and forecasts hold true, transportation planners may formulate a set of alternative plans which might be implemented under various circumstances.

[16]The Delphi technique was originally developed by the Rand Corporation in the early 1960's as an alternative to committee forecasting. The Delphi procedure employs the concepts of anonymity and feedback to arrive at an approximate consensus within a panel of experts. Briefly, the Delphi technique works as follows. First, a panel of experts is identified. Second, a survey instrument is designed and administered to the panel. Third, the results are tabulated and used in a second round of questionnaires. In the second round, participants are allowed to compare

expected values of the scenarios, a range of possible highway impacts was identified.

OVERVIEW OF MODELS

A major part of this study involves the formulation of a "chain" of submodels which will collectively translate the demand for transportation (and the abstract traffic flows which it creates) into estimates of future highway costs. Four broad categories or types of models are included in the chain:

1. transportation demand models,
2. traffic models,
3. network models, and
4. highway impact models.

Transportation demand models relate the type, intensity, and location of economic activities to the demand for the movement of goods between various locations in space.[17] Intuitively, the demand for transportation is the

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their answers against those of other (anonymous) committee members, and adjust their initial response if appropriate. The iterations continue until there is no longer a great deal of convergence in the answers.

[17]Two points should be noted here concerning transportation demand analysis. First, as mentioned earlier, the demand for freight transportation is a derived demand, derived from the underlying demand for the use of a commodity at a particular point in space during a particular interval in time. Although the expressed demand may be for truck trips or ton-miles, the true underlying demand is for the commodity itself. Second, and following from the first point, transportation demand analysis is distinct from traffic forecasting. The two are obviously related, but

potential for traffic flow between spatially separated points or zones. A much more detailed recounting of this theory is provided in Chapter 3.

Traffic models translate abstract commodity flows into traffic volumes over space and time. Collectively, traffic models predict the distribution of shipments between zones, the mode taken, the classes of highway equipment utilized, and gross vehicle weights and axle loads.

Network models assign the predicted highway traffic flows between origins and destinations to specific highways and routes. Then, based on the attributes of the highway sections in each route, the ESALs per VMT are estimated.

The impact models utilize the ESALs and axle passes generated by the network models to simulate use-related pavement deterioration on highway sections. The highway needs model, the final link in the chain, estimates the absolute level and distribution of future highway needs among functional classes.

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traffic forecasting may involve the use of trending, extrapolation, or other techniques in an effort to forecast future volumes. Consequently, this process may be removed from underlying commodity demand relationships. Demand analysis, on the other hand, focuses on the relationships, linkages, and decision rules which give rise to the flow of commodities or people between zones. Demand analysis thus begins at the level of abstract commodity flow, and converts these flows into traffic volumes.

Table 3 summarizes the individual submodels needed for subterminal traffic analysis and their relationship to the general categories of models discussed above[18]. The submodels, in effect, represent a battery of models. The output of one submodel becomes the input to the next.

The purpose of this chapter has been to overview the research design of the report. In summation, it may be stated that:

1. The scope of the report is restricted to pavement-related impacts;

2. The research design incorporates a systems approach, which is broader than traffic analysis, and relies on scenario analysis;

3. A system or battery of submodels is required in order to effectively model the pavement impacts of subterminal-generated traffic.

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[18]This sequence represents a fusion of models from several different disciplines or schools of thought. Combinations of various submodels have been utilized in urban transportation planning, intercity passenger transportation analysis, and regional (intercity) freight transportation forecasting. The models are generic enough to provide a framework for the analysis of interregional or intraregional transportation problems, freight or passenger. In addition to the trip generation, trip distribution, and network assignment models which have found widespread application, the list above also includes truck distribution, truck weight, pavement damage, and highway needs models. These submodels translate abstract grain traffic flows into truck trips, axle passes, pavement deterioration, and future highway costs.

TABLE 3. SUBMODELS NEEDED FOR SUBTERMINAL TRAFFIC ANALYSIS.

Category	Submodels
Demand	Land-Use Flow Generation
Traffic	Shipment Distribution Modal Split Truck Distribution Truck Weight
Network	Route Assignment Highway Attribute Equivalent Axle Load
Impact	Pavement Damage Highway Needs

CHAPTER 3
THEORETICAL FRAMEWORK

This chapter of the dissertation lays the theoretical groundwork for the remainder of the study. In Part 1, a simple yet intuitive model of demand relationships within a subterminal-satellite system is formulated and the concept of spatial interaction modeling is introduced. In Part 2, some fundamental ideas in pavement life cycles and the economic analysis of highways are set forth. In Part 3, pavement deterioration or decay models (the analytical backbone of the impact assessment process) are reviewed and evaluated.

COMMODITY TRANSPORTATION DEMAND

Kananafi (1983) identified three basic approaches to commodity transportation demand analysis:

1. A microeconomic approach,
2. A spatial interaction approach,
3. A macroeconomic approach.

Both microeconomic theory and spatial interaction modeling play key roles in the commodity transportation demand models formulated in this study. This section of the dissertation introduces some relevant concepts in each, and formulates an applied transportation demand model which specifically addresses the relationships that exist within a satellite-subterminal system.

The Microeconomic Approach

Microeconomic commodity demand analysis is based on the theory of the firm, particularly its production processes and level of technology. In the theory of the firm, commodities constitute factors of production; that is, they are inputs to the production, sales or marketing processes of a firm. The firm requires (demands) the commodities, thus establishing economic linkages with producers or suppliers.

The discussion of demand theory begins with the formulation of some simple yet intuitive relationships[19]. Assume (for purposes of illustration) that a supplier in Zone "A" sells an input to a firm located in Zone "B." The demand for the commodity at B is a function of price.

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[19]Much of the discussion and formulation of basic relationships presented in this section draws from and expands on material found in Chapter 10 of Kanafani (1984). However, the responsibility for the correctness of the formulations and their subsequent translation into agricultural commodity transportation demand functions lies with the author.

Algebraically, this relationship is expressed by:[20]

$$Q_B = f(P_B) \tag{1}$$

where:

Q_B = Quantity demanded at B
P_B = Price at B

The price of a good at B is comprised of two components; the price at A (P_A) plus the transportation cost between A and B (TC_{AB}). Thus the quantity demanded at B may be restated as:

$$Q_B = f(P_A + TC_{AB}) \tag{2}$$

The demand for the transportation of a commodity between A and B results in a commodity flow or volume (V_{AB}). The volume of flow between A and B is a joint function of

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[20]This simple relationship assumes that all other factors or forces are held constant. The prices of complements and substitutes for the commodity are assumed fixed. Plus, competitive relationships or reactions (e.g., supply-point and demand-point competition) are assumed to be constant. The model is thus quite restrictive, and is useful mainly for providing an intuitive understanding of fundamental demand relationships.

the demand for the commodity and the level of transportation service (S):[21]

$$V_{AB} = f(Q_B, S) \tag{3}$$

Since the level of service affects operator costs, it implicitly has an effect on the cost of transportation between A and B (TC_{AB}). Therefore, with little loss of explanatory power, equation (3) may be condensed to:

$$V_{AB} = f(Q_B) \tag{4}$$

Alternatively (by substitution) the demand for transportation between A and B becomes:

$$V_{AB} = f(P_A + TC_{AB}) \tag{5}$$

Equations 1--5 make two important points concerning commodity transportation demand: (1) if the firm's demand for a good is known, then the demand for transportation of the commodity can be derived, and (2) the firm's demand for a given commodity is a function of its supply-point price and the transportation cost between A and B.

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[21]The level of service (as used in this study) is an abstract rating which defines the availability, capacity, congestion, and general condition and performance of the transportation network.

Spatial Interaction Modeling

The major problem with the simple demand model presented above is that it does not explicitly account for the competitive relationships and spatial linkages which exist within a particular market region. Only one commodity and firm were contemplated. But in reality, there are usually multiple commodities, purchasers and suppliers within a given geographic region. There is competition among firms (demand-point competition) and competition among suppliers (supply-point competition). When these competitive relationships are strong, they tend to distort the restrictive model presented in (5).

An alternative formulation of equation (5) can be derived by moving to a spatial interaction approach. Spatial interaction models are typically aggregate in nature, dealing with zones of excess supply and demand rather than with individual firms and suppliers.

Fairly large regions or zones have been used in the past. For example, Black (1972) modeled subnational, interregional commodity flows with a spatial interaction model. However, the level of aggregation does not necessarily have to be great. Russell (1981) modeled intercity commodity flows and Rimmer and Black (1982) modeled the flow of goods within a metropolitan region. In fact, the smaller the level of aggregation and the more concise the demand relationships, the more accurate the spatial interaction model will be.

Theory

Blunden and Black (1984) have extensively developed the theory behind spatial interaction modeling. In their 1984 study, they conceived of traffic flow as a "potential/flow problem" with analogies in physics. On page 21, they write:

> Interaction between land-use activities and transport facilities may be conceptualized as a potential/flow problem. The analogy in physics is a mass, electric charge, or a magnetic pole, setting up a gravitational, electric, or magnetic field which exerts a force or influence on a remote counterpart. Similarly, a zone of land-use activity creates a socioeconomic "field" which causes attraction forces among other complementary land-uses.... This force of attraction acts on people giving rise to the flow of person trips. Intuitively, the strength of attraction is directly proportional to the intensity of the land-use activity but diminishes as the effort of making the trip increases.

Although referring to person-trips in the quote, the basic concepts advanced by Blunden and Black (and others) are equally applicable to all modes and types of transportation, freight or passenger[22]. The central idea is

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[22]For a description of the land-use/transportation modeling process (particularly as it relates to urban transportation planning) see: Dickey (1983) and Mannhiem (1979).

that a land-use zone containing processing plants or industry will exert an economic attraction over complementary production or supply zones within a given geographic region[23]. The force of attraction will be directly proportional to the intensity of the land-use activity in the zone (as measured by the size, number, and output level of firms), and inversely proportional to the distance or cost of transport.

Laws

Spatial interaction is governed by three fundamental laws: (1) a law of attraction, (2) a law of flow, and (3) a law of interaction. Although originally stated in terms of person-trips, the laws are general enough so that they can be restated in terms of commodity flows.

The attractive force exerted over an origin (supply) zone "O" by a destination (demand) zone "D" is directly proportional to the level of the economic attractors at D and inversely proportional to the "impedance" to flow which exists between O and D. This relationship is given by:

[23]Land-use is a generic term referring to the type, intensity, and level of economic activity occurring at a particular location in space during a particular interval of time. In this study, agricultural production and processing are the two types of land-use which are of primary importance.

$$A_{OD} = X_D \ / \ Z_{OD} \tag{6}$$

where:

A_{OD} = the attractive force exerted over zone "O" by destination zone "d"

X_D = a measure of economic attraction

Z_{OD} = a variable representing the impedance to flow between zone "O" and zone "D"

X_D is typically some function of the bid price for the commodity at D, the number and size of firms, the amount of available storage, the adequacy of unloading and transloading facilities, and a range of related factors. The impedance factor (Z_{OD}) is typically some function of the distance between O and D, the level of transportation services, the travel time, and/or operator costs.

If the level of transportation services is low, the impedance to flow will be high. Conversely, if the distance is small and/or the travel time short, the impedance will be low.

Since the level of transportation services, the distance, and the travel time all affect operator costs, the cost of trucking between zones O and D is frequently used to represent the impedance function. Similarly, since the size and number of firms and their processing and handling capabilities are somewhat reflected in the bid price for the commodity, the price is typically taken as a measure of the economic attraction between supply and demand zones.

The law of attraction defines the intensity of the economic linkages which exist between complementary land-use zones within a region. The law of flow translates this attractive force into a potential volume or flow.

The law of flow is given by:

$$F_{OD} = S_O X_D \ / \ Z_{OD} \qquad (7)$$

where:

F_{od} = the potential volume of flow between O and D

S_o = the amount of commodity available (the supply) at O

The law of flow describes the **potential** volume between O and D given the level of supply at O, the intensity of the economic attraction at D, and the impedance to flow. But the law of flow does not actually say what the interzonal volume will be. This depends upon the attractiveness of D relative to all other destination zones in the region. In other words, the interzonal volume of flow will be determined (in part) by demand-point competition.

Demand-point competition is addressed in spatial interaction modeling through the law of interaction. Algebraically, this law states that:

$$V_{OD} = \frac{S_O X_D \ / \ Z_{OD}}{\sum_D X_D \ / \ Z_{OD}} \qquad (8)$$

where:

V_{OD} = the volume of flow between supply zone O and demand zone D

Recall from equation (6) that the term "X_D/Z_{OD}" is the attractive force exerted over zone "O" by destination zone "D" (A_{OD}). Thus by substitution, equation (8) becomes:

$$V_{OD} = \frac{S_O A_{OD}}{\sum_D A_{OD}} \qquad (9)$$

Intuitively, equation (9) states that the volume of flow between two land-use zones is a function of the attractiveness of the destination zone relative to the attractiveness of all other zones. Thus, the law of attraction might be more accurately termed the law of "relative attraction."

The discussion thus far has focused on commodity transportation demand in a broad, general sense. The objective has been to develop a framework for evaluating subterminal traffic flows. Having accomplished this, the chapter now turns to a more specific discussion of the demand relationships within a subterminal-satellite elevator system.

A Subterminal-Satellite Elevator Spatial Interaction Model

A subterminal market area constitutes a special case of a "land-use/transportation system." Within the system, three types of land-use are of particular importance:

1. Farms or production zones,
2. Satellite elevators,
3. The subterminal elevator.

Farms function solely as supply or origin zones within the system. They generate truck shipments headed for satellite or subterminal elevators. Satellite elevators function as both originating and terminating zones. On one hand, they receive inbound farm truck shipments. On the other hand, they generate outbound traffic to the subterminal or terminal market. In similar fashion, the subterminal constitutes both a receiving and a generating zone.

Rephrasing the law of attraction, it may be said that the attractive force exerted over a particular production zone by a given grain elevator is directly proportional to the bid price at the elevator, and inversely proportional to the cost of trucking from farm-to-elevator. Within a subterminal-satellite system, each elevator (including the subterminal) will establish a bid price. Producers within the region will react to the prices (and to the perceived farm truck costs involved), and make a decision regarding where to sell their grain.

Given this arrangement, the law of flow may be restated for subterminal-satellite systems as follows

$$F_{OD} = S_O P_D \ / \ FT_{OD} \tag{10}$$

where:

S_O = The amount of grain and oilseeds available for shipment (Production - Consumption - Storage - Loss) at zone O.

P_D = Elevator price at D

FT_{OD} = Farm truck cost from O to D

Within a subterminal-satellite elevator system, each elevator (theoretically) will exert some attractive force over each production zone (albeit weak over long distances). The effects of these attractive forces on grain flows can be modeled by restating the law of interaction so that it applies specifically to subterminal-satellite elevator systems. This is the purpose of equation (11).

$$V_{OD} = \frac{S_O P_D \ / \ FT_{OD}}{\sum_{D} P_D \ / \ FT_{OD}} \tag{11}$$

As equation (11) implies, the price relationships between elevators within a cooperative system will determine (in part) the relative attractiveness of each destination zone. Zink (1988) found that with few exceptions the price at a satellite elevator consists of the price at the subterminal elevator minus the trucking cost between the satellite and the subterminal. Given this pricing scheme, the attractiveness of a satellite elevator for a given production zone is a function of two items: (1) the farm truck cost to the satellite, and (2) the grain trucking cost from the satellite to the subterminal.

Assuming the price relationship described above holds true, P_D may be defined as follows.[24]

$$P_D = P_T - GT_D \qquad (12)$$

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[24]The bid price at the subterminal elevator may be a weighted-average of the bid prices for individual commodities handled at the facility. In this case, P_T is given by:

$$P_T = \sum_i Q_i * P_i \Big/ \sum_i Q_i$$

where:

Q_i = Quantity handled of commodity "i"
P_i = Price of commodity "i"

Individual commodity bid prices should ideally represent the average for the calendar year. Statewide calendar year averages (which are suitable proxies for the individual elevator prices) can normally be obtained from crop and livestock reporting statistics for the state where the analysis is taking place.

where:

P_T = Bid price at the subterminal

GT_D = Grain trucking cost between subterminal and satellite elevator (located at D)

The spatial interaction model presented in equation (11) is not the only alternative for modeling farm-to-elevator flows. In Chapter 4, an optimization model is presented which simulates grain flows in a manner that minimizes farmers' transportation costs, or which (alternatively) maximizes net farm prices. The advantage of the spatial interaction model (over the optimization approach) is that it explicitly considers the demand relationships and spatial linkages in a market area. However, it has disadvantages and practical limitations which are discussed in Chapter 4.

The end objective of Part 1 of this chapter has been to develop a theoretical model of commodity demand relationships within a system of elevators, and from that representation, to formulate an applied spatial interaction model which is directly relevant to subterminal-satellite systems. Having accomplished this objective, the chapter now turns to the topic of pavement life-cycles.

LIFE-CYCLE PAVEMENT CONCEPTS

In Chapter 2, a hypothesis was set forth regarding the effects of subterminal-generated traffic on pavement life. In order to evaluate this hypothesis, some fundamental concepts in pavement life-cycles must be introduced.

The objectives of this section of the report are:

1. To introduce some fundamental theoretical concepts in pavement life-cycle analysis;

2. To define marginal and incremental costs specifically within the context of pavement damage analysis;

3. To formulate a theoretical model which describes the impacts of subterminal traffic on pavement costs;

4. To specify equations for estimating the incremental cost of subterminal traffic.

A Theoretical Model of Pavement Life

A pavement, like any other asset or resource, has a useful life. Pavements deteriorate with time and axle loads, as illustrated by Figure 2.

The exact rate of decay and shape of the function will depend upon factors such as climate, the composition of the supporting soil, the strength of the pavement, and other design considerations. But for now, only the general nature of the relationship is important.

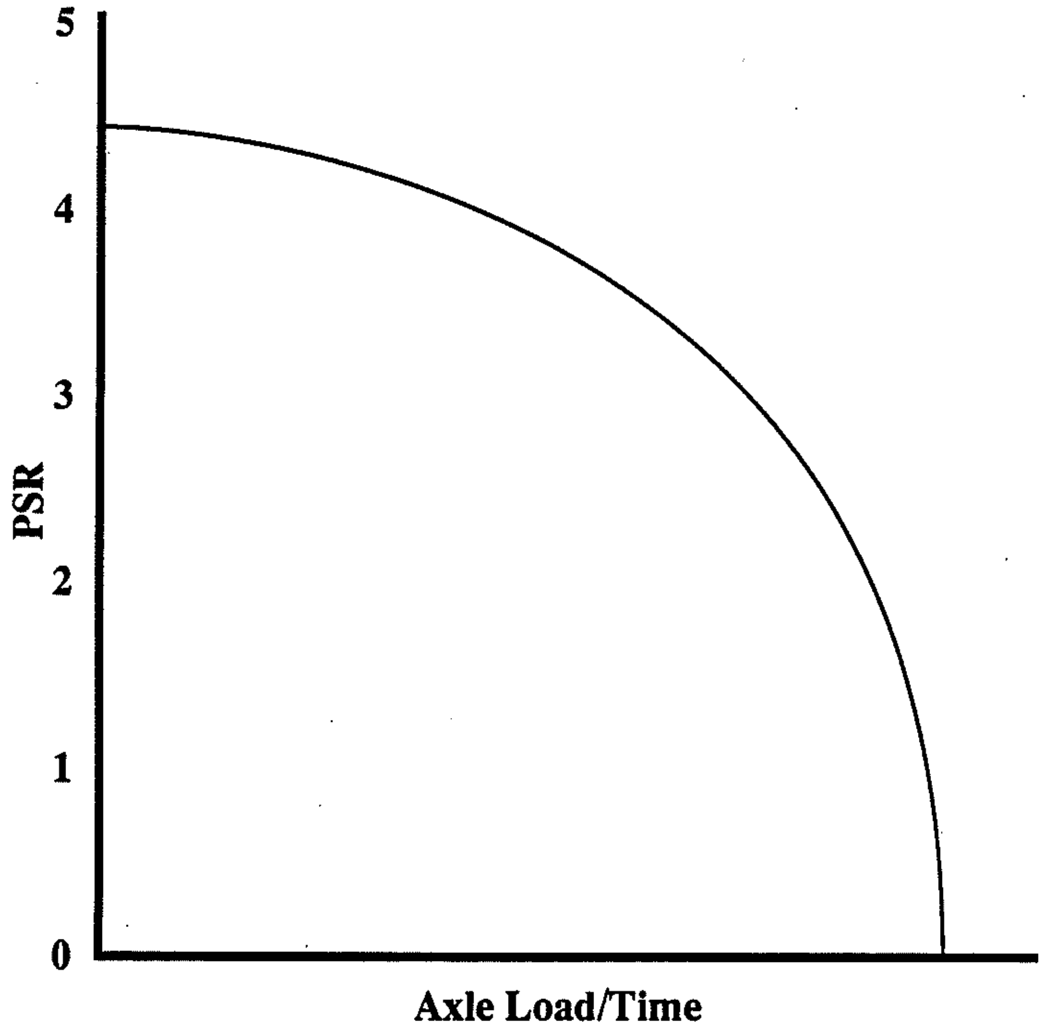

FIGURE 2. Theoretical Pavement Deterioration Function

PSR - Pavement Serviceability Rating (an index ranging from 0.0 to 5.0)

The effects of time and non-use related pavement decay are difficult to isolate and model. Theoretically, a pavement which has never been exposed to traffic may last up to 100 years (Balta and Markow, 1985). However, this has never been verified empirically. So while it is known that time is partially responsible for pavement decay, highway deterioration models are typically condensed to "damage models", wherein the decline in pavement serviceability is attributed solely to axle passes.

Assuming away the effects of time, pavement life is typically viewed as a function of the cumulative number of axle passes in a given climatic zone, the soil support factor, and the strength of the highway section. This fundamental relationship is depicted in equation (13).

$$PL = f\ (N,\ C,\ SSN,\ STR) \tag{13}$$

where:

PL = Pavement life

N = Cumulative passes of a given axle type and load

C = Climatic zone or regional factor

SSN = Soil support number or index

STR = Strength of the highway section (some function of D or SN, T1, and/or T2)

where:

D = Slab thickness (PCC pavements)

SN = Structural number (flexible pavements)

T1 = Thickness of asphaltic concrete layers

T2 = Thickness of the aggregate base

If values are defined for the soil support index and the regional factor, equation (13) can be simplified as follows:

$$PL = f\ (N,\ STR) \tag{14}$$

For a mixed traffic stream, the effects of different axle passes can be translated into ESALs. So if the strength of a pavement section is held constant, pavement life becomes a function of ESALs. Consequently, equation (14) may be simplified as follows.

$$PL = f\ (ESAL) \tag{15}$$

The life of a highway section is comprised of a sequence of cycles. Typically, pavements are rehabilitated or reconstructed prior to the full expiration of pavement life. When a pavement is replaced, the highway section enters a new phase or stage. As illustrated in Figure 3,

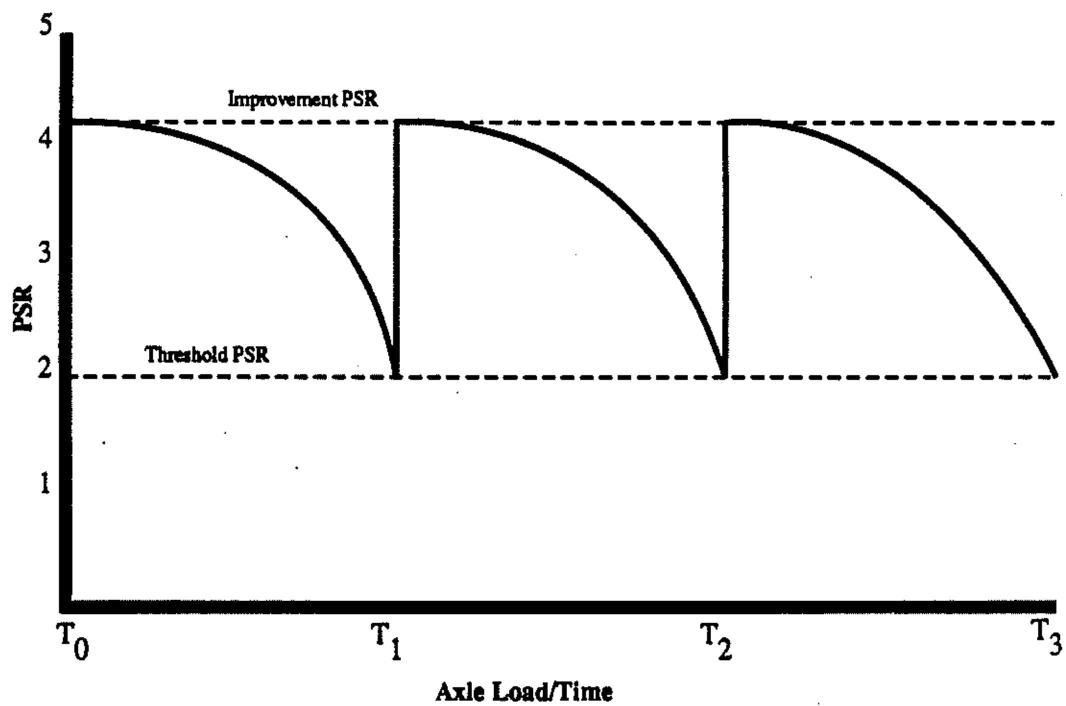

FIGURE 3. Pavement Replacement Cycles

PSR - Pavement Serviceability Rating
Improvement PSR - The condition rating of a newly built or replaced pavement.
Threshold PSR - The pavement condition rating at which replacement activities are "triggered".

the section is typically restored to some acceptable level of condition, from which the decay process starts all over again.

The cycles between replacement are of fundamental importance in evaluating the effects of subterminal-generated traffic. Intuitively, each cycle may be viewed as a discrete pavement life span in the overall existence of a highway section. An alternative way of stating Hypothesis 1 is that subterminal truck traffic reduces the length of the cycles between replacement. Thus, replacement costs are incurred sooner than originally anticipated.

To summarize thus far:

1. Each pavement section has a useful life, which expires with traffic over time.

2. The useful life a highway section may be expressed in ESALs.

3. A typical section moves through a series of pavement life cycles over its entire existence.

4. Subterminals are hypothesized to shorten the interval between rehabilitation or capital outlays.

Cost Concepts

The expiration or consumption of pavement life constitutes an economic cost which is different from (although usually followed by) a financial outlay or expenditure. Expenditures occur only at discrete time intervals, as illustrated by Figure 3 (e.g., at times T_1, T_2, and T_3). Costs occur whenever a portion of the remaining useful life of a pavement is consumed[25].

Two types of economic cost are of primary importance to this study: (1) marginal cost (MC), and (2) incremental cost (IC). Each type of cost 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 the capacity of a highway section to absorb ESALs is fixed. In other words, the short-run may be viewed as the cycle between replacement activities. At the end of each cycle, the pavement is replaced as before, or rebuilt to a higher standard. In either case, the capacity to handle traffic once again becomes fixed, and another short-run period ensues.

The long-run, on the other hand, reflects the entire existence of a highway section from the time of initial construction until the time the roadway is abandoned. In the long-run, the capacity to handle traffic may be freely adjusted.

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[25] Expenditures are related indirectly (albeit causally) to ESALs. Economic costs, on the other hand, are directly related to ESALs and may be expressed in terms of the pavement life expired or consumed.

Marginal Pavement Cost

Within the context of highway impact analysis, short-run marginal cost (SRMC) reflects the additional consumption of highway capacity resulting from the addition of one more ESAL to a highway section. SRMC depends on three factors: (1) the ESAL life of a section, (2) the replacement cost incurred at the end of the cycle, and (3) the current condition of the highway section.

Recall from Figure 2 that the decline in pavement serviceability (PSR) is a nonlinear function of traffic over time. Logically then, the short-run marginal cost of an axle pass will vary over time, increasing with age and accumulated passes. Mathematically, SRMC is the derivative of PSR with respect to axle passes.

Unlike SRMC, long-run marginal costs (LRMC) have nothing to do with the present serviceability of a highway section. LRMC are the result of an increase in pavement strength necessitated by the addition of one more ESAL to the existing traffic base. If pavement thickness were defined on a ratio scale from zero to some practical 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 before. However, in practical terms the addition of a single ESAL to a traffic stream does not require an overlay of existing pavement. It is only the accumulation of ESALS over time that leads to the upgrading of pavements.

Although long-run marginal cost is not a practical analytical concept in pavement impact analysis, it does provide a theoretical understanding of the relationship between traffic and pavement design. An important distinction to remember for this study is that LRMC is related to pavement thickness, not to current serviceability. Mathematically then, LRMC is the derivative of pavement thickness with respect to ESALs.

Incremental Pavement Cost

The addition of an ESAL to a traffic stream results in a real cost, however infinitesimally small. But it is only when many ESALs are combined over time that capital expenditures actually flow. For this reason, incremental cost is frequently a more relevant concept to highway planners than marginal cost.

Incremental pavement costs arise from considering the effects of classes of traffic (or relatively large traffic increases) as opposed to a single ESAL. Incremental costs are especially relevant in subterminal traffic analysis[26]. Here, highway planners are dealing with a potentially sizable class of traffic rather than with a single vehicle or operator. Therefore, incremental cost (rather than marginal cost) is the most relevant concept or measurement[27].

Replacement Versus Upgrading Costs

The previous discussion loosely introduced the concepts of replacement and upgrading costs. These classifications are crucial to the analysis of subterminal-generated traffic, and will be expounded upon here.

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[26]Unlike the effects of a single vehicle, the impacts of a class of traffic are usually measurable on some meaningful scale, and can be translated into dollars or resource costs. The statement "an additional 2 inches of pavement might be required in order to handle heavier vehicles" is a much more relevant bit of information to highway managers that the theoretical concept of .00011 inches per ESAL.

[27]There is a key linkage between marginal and incremental cost. The cost of an increment of traffic is roughly (although not precisely) the sum of the marginal costs occasioned by the individual units of traffic which comprise the class. For example, if 1,000 annual CO-5AX truck trips constitute the class of traffic under evaluation, then the incremental cost of the class is approximately equal to the sum of the cost of each individual truck trip.

Replacement cost, as the name implies, is the cost associated with the periodic "replacement" of pavements so that the highway section may continue to provide service at roughly the same functional level as before. Upgrading costs, on the other hand, are the capital expenses associated with increasing the capacity of a highway section to handle heavy traffic.

Pavement replacement encompasses a range of potential improvements usually referred to as resurfacing, rehabilitation, restoration, or reconstruction. Resurfacing and rehabilitation typically entail an overlay of existing pavement with a new asphaltic concrete surface layer. If a pavement has been allowed to deteriorate to a very low level of serviceability, an overlay is unlikely to restore the section to its intended functional use. In such cases, full-scale pavement reconstruction may be required wherein the existing pavement is completely removed and replaced. Regardless of the improvement type which is implemented, the idea is that the pavement is replaced essentially as before.

If the traffic and axle loads change appreciably during a given pavement cycle, replacing the pavement will not provide satisfactory service other than for a short period of time. As the intervals between replacement become increasingly short, the only economic solution is to strengthen the existing pavement.

There are several ways to strengthen an existing pavement. Yoder and Witczak (1975, page 73) state: "in order to reduce the subgrade stress (of flexible pavements) to some tolerable design value, one can either increase the base-course thickness and the surface thickness of the same layered material or replace the quality of the layered material with a more rigid material." Typically for low-volume rural roads, strength is added by increasing the thickness of the surface or asphaltic concrete layers rather than by increasing the rigidity of the materials.

In this study, the upgrading of impact highways is assumed to entail an asphaltic concrete overlay.

"Build-Sooner" Costs

Employing the concepts of incremental and replacement costs, a concept may be defined which allows the direct evaluation of Hypothesis 1. This term is "build-sooner" cost[28].

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[28]The term build-sooner cost was originally coined by Bisson, Brander, and Innes (1985) during their evaluation of the incremental effects of heavy truck traffic on New Brunswick highways. On page 10 they write: "Build-sooner cost is related to the hypothesis that loading a large increment of heavy traffic onto a link will cause two conditions to evolve. First, pavement life cycles are likely to become shorter, and, second, future capacity improvements will be needed sooner."

Build-sooner costs constitute the incremental highway impacts of increased heavy truck traffic arising from the timing of future replacement activities. More specifically, build-sooner costs are concerned with the shortening of replacement cycles as illustrated in Figure 4.

The logic of Figure 4 is as follows. Over the life of a highway section, the pavement is replaced periodically when the PSR or serviceability reaches some threshold or trigger level (e.g., 2.0). Upon restoration, the section is replaced essentially as before, and the condition rating is returned to its previous level (e.g., 4.2). This is called the improvement PSR, or PSR_I. Assume that in Stage 1 of the section's life, a significant increment of heavy truck traffic is added to the traffic stream. The baseline pavement deterioration curve P_{1a} is shifted to the left in response. This shift (represented by curve P_{1b}) reflects the accelerated rate of decay attributable to the new traffic stream. Build-Sooner Period 1 (BSP_1) may be thought of as the reduction in pavement life in Stage 1 due to incremental traffic.

A fundamental concept in the economic analysis of highways is the time value of money. Money has a different value to highway officials, users, and taxpayers over time.

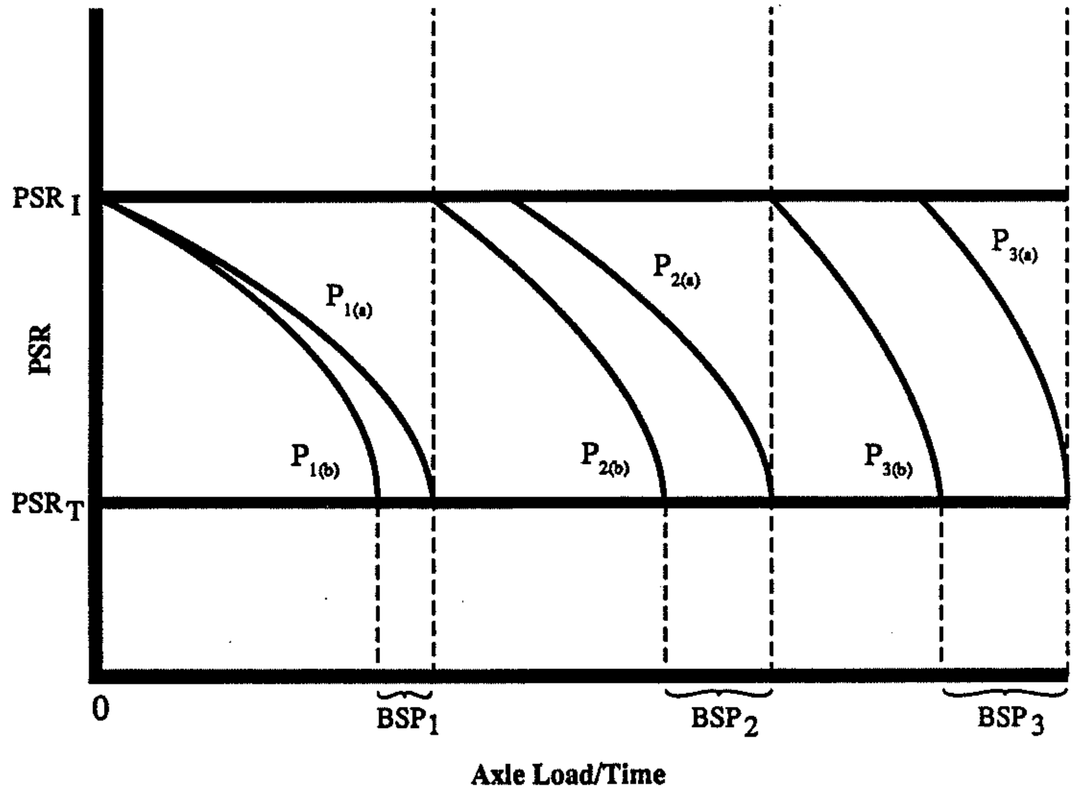

FIGURE 4. Pavement Deterioration and Build-Sooner Costs

PSR	-	Pavement Serviceability Rating (0.0 - 5.0)
PSR_T	-	Threshold PSR
PSR_I	-	PSR After Improvement
$P_{1(a)}$	-	Pavement Deterioration without Incremental Traffic: Stage 1
$P_{1(b)}$	-	Pavement Deterioration with Incremental Traffic: Stage 1
BSP_1	-	Build-Sooner Peroid #1

If given a free choice, everyone would prefer to receive a dollar today rather than 5 years from now; ceteris paribus. The same is true for capital outlays. Highway officials, given a free choice, would prefer to spend a dollar on highway improvements five years from now rather than today; ceteris paribus[29].

Differences in the value of money over time are accounted for by expressing all future outflows (or inflows) in present dollars. The present value of a dollar ten years in the future is calculated by "discounting" the dollar to reflect the fact that highway officials and users value it less than a dollar available today. Discount rates for transportation analysis are typically based on the opportunity cost of public sector capital.

Returning to the concept of build-sooner cost, if the capital outlays incurred at the end of the baseline replacement cycle (P_{1a}) and the altered replacement cycle (P_{1b}) are both discounted to present value, then the build-sooner costs in Stage 1 assume a real monetary value. They are equal to the difference between the present value (PV)

[29]This is only rational behavior. The retention of the dollar(s), all things being equal, provides highway officials with greater management flexibility, and allows funds to be used for some competing, alternative purpose. This preference, it should be noted, is independent of inflation.

of the capital outlay which would have occurred at the end of the baseline replacement cycle and the PV of the outlay which now occurs at the end of the altered replacement cycle. If acted out over stages 2, 3, and so forth, the accumulated difference in present value represents the build-sooner cost associated with a particular increment of heavy traffic over the life of a highway section.

To summarize this section, it may be said that build-sooner costs:

1. Constitute incremental, replacement costs;
2. Represent the reductions in pavement life-cycles attributable to incremental truck traffic;
3. Are concerned with the timing of future monetary outlays;
4. Are premised on the time value of money; and
5. Are expressed as the difference in the present value of the discounted capital outlays between the baseline and the altered traffic streams.

Upgrading Costs

Purnell (1976) developed a procedure for estimating the increased cost on Indiana highways due to rail branch line abandonment. The procedure entailed the estimation of the incremental pavement thickness required for an altered traffic stream which would (hypothetically) result from the abandonment of rail branch lines in an area.

According to Purnell, the incremental thickness of the asphaltic concrete (AC) layer for a flexible highway section can be calculated as follows:

$$IT_i = \frac{SNA_i - SN_i}{a_1} \tag{16}$$

where:

IT_i = incremental thickness for section "i"

SN_i = structural number of section "i" under conditions of "normal" traffic

SNA_i = structural number of section "i" under conditions of altered traffic

a_1 = layer coefficient of the surface AC (generally taken to be .44)

Purnell's procedure involves three basic steps. First, the SN required to handle the ESAL load under "normal" traffic conditions is determined using the AASHTO design equation for a given design period (e.g., 20 years). Second, a revised structural number is determined (again using the AASHTO design equation) based on the estimated ESAL load **after** the addition of the incremental traffic to the normal traffic stream. And third, the incremental dollar cost associated with the required thickness is estimated from unit costs for material and labor.

As noted previously, the introduction of incremental heavy truck traffic onto a highway section will reduce the interval of time between replacement cycles. Upgrading the section according to Purnell's formula essentially returns the replacement cycle to its previous duration (that which existed prior to the alteration of the traffic stream). For example, if the SN of a highway section provides for a 20-year life at current traffic levels, then the revised structural number (SNA) will similarly provide for a 20-year life at **higher** traffic levels.

In contrasting upgrading and replacement costs, it may be said that build-sooner costs represent the short-run incremental costs (SRIC) of additional truck traffic. That is, build-sooner costs are the costs incurred during a given replacement cycle, during which time the capacity of a highway section to absorb ESALs is fixed. In contrast, upgrading costs (as estimated via Purnell's method) represent the long-run incremental costs (LRIC) associated with the new traffic stream[30].

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[30]In the long-run, the capacity of a highway section to absorb ESALs can be freely adjusted. For practical purposes, the long-run period begins at the **end** of the current replacement cycle, and extends over all remaining cycles in the section's overall life.

The problem with Purnell's approach is that it does not consider the impacts of incremental truck traffic during the current replacement cycle. On page 2 he writes:

> Since the adopted procedure is concerned strictly with the incremental impact arising from increased truck traffic due to service elimination along a nearby rail line, the present condition of a pavement structure is not directly considered.

Although Purnell did not directly address the costs incurred during the current replacement cycle, he did acknowledge their existence and the need for evaluation. Later on page 2 he writes:

> Nevertheless, service discontinuance on railroad branch lines can alter the setting of priorities associated with upgrading and routine maintenance of a rural road. A rural highway which is forced to assume additional trucks transporting commodities previously moved by way of the railroad may have to be repaved earlier than had been specified in a state or county's maintenance program. Thus, the current condition of a facility's pavement structure must be considered via an analysis of the manner in which a study section's need for upgrading is escalated by the effects of railroad abandonment.

The procedure which has been adopted in this study attempts to measure both effects. The incremental cost of subterminal-generated traffic is defined as the sum of the SRIC incurred during the **current** replacement cycle (the build-sooner cost) and the LRIC incurred **if** the section must be upgraded at the end of the current cycle[31].

Measuring Short-Run Incremental Cost

Reductions in pavement life must eventually be translated into monetary terms in order to obtain a meaningful measure of cost. When this occurs, the timing of the expenditures must be considered.

As noted previously, the time value of money is accounted for by discounting expenditures occurring at different times in the future to present value, and

[31]This approach explicitly assumes that impacted highways will be upgraded at the end of the current replacement cycle. The alternative to upgrading is to continue to replace the section periodically at ever-shortening intervals throughout its life. Upgrading the section represents the most rational and economic course of action (in most instances) as the savings in life-cycle maintenance costs should more than offset the initial upgrading expenditure. However, upgrading will not always be necessary for each section. The occurrence of upgrading costs on a highway section will depend upon two factors. The first is the existing design of the section. A relatively strong rural section may be able to handle some additional truck traffic without the need for increasing the structural strength of the pavement. On the other hand, relatively weak or under-designed sections cannot accommodate additional ESALs without unduly increasing user costs and dramatically shortening the rehabilitation cycle. The second factor governing the occurrence of upgrading costs is the absolute level and composition of the incremental traffic. A large increase in ESALs even on a relatively well-built highway section may necessitate upgrading. In this study, highway sections which show little or no reduction in pavement life (as measured in years) are not upgraded.

comparing them. The present value of a future sum accruing at time "n" is given by:

$$PV = \frac{FS_n}{(1 + r)^n} \tag{17}$$

where:

PV = Present value of a future sum
FS_n = Future sum accruing at year "n"
r = Rate of interest or discount rate

As an illustration, consider the following hypothetical case. The replacement cycle for a principal rural arterial extends for 20 years under normal traffic conditions. Under an impact scenario, the cycle is reduced to 15 years. As a result, expenditures are encountered 5 years earlier than originally anticipated.

Assume that the replacement cost per mile is $288,000 and that the discount rate (r) is 10 percent. Using equation (17), the present value of replacement expenditures for a one-mile section of highway 15 years in the future is approximately 69 thousand dollars. In contrast, the present value of the same expenditure twenty years in the future is 43 thousand dollars. The build-sooner cost (the difference between the two) amounts to 26 thousand dollars.

The Marginal Cost of an Axle Pass

Recall from Figure 2 (and the surrounding discussion) that the marginal cost of an axle pass of a given type and load will vary with the age and serviceability of a highway section. Due to the concave nature of the damage function (Figure 2), the time at which the incremental traffic is introduced into the traffic stream will determine (in part) the extent to which the current replacement cycle is shortened.

The manner in which the marginal cost of an axle pass is determined for vehicles of different axle configurations and loads involves the concept of equivalent single axle loads. For the reference axle, the MC at any point on the decay curve is given by the derivative of pavement serviceability with respect to cumulative axle passes. For axles other than the reference axle, an equivalent rate of damage is determined by converting raw axle passes to ESALs.

Appendix C gives the AASHTO axle equivalency formulas for single and tandem axles. An example is presented in the following paragraph (using the AASHTO equations) which illustrates the effects of axle passes on pavement damage at different serviceability levels (or ages).

Assume that the 16,000 single axle is the axle of interest and that the terminal serviceability of the impacted highway is 2.0. Table 4 illustrates the change in ESALs resulting from a single axle pass at different PSR's as the pavement serviceability rating declines from 4.0 to 2.1.

TABLE 4. CHANGE IN ESALs WITH DECLINE IN PSR FOR A 16,000 POUND SINGLE AXLE

Pavement Serviceability Rating	ESALs
4.0	.47
2.5	.55
2.1	.79

As Table 4 illustrates, the marginal cost of an axle pass (expressed in ESALs) increases significantly with a decline in serviceability. Therefore, the SRIC of a particular class of heavy truck traffic (such as subterminal truck traffic) will be at its greatest on an old, deteriorated highway. Given the age and condition of North Dakota's rural minor arterial and collector system, the accurate assessment of incremental impacts during the current replacement cycle is an important consideration in the design of a highway impact methodology.

In summary, the highway impact procedure developed in this study measures both the SRIC incurred during the current replacement cycle (the "build-sooner costs") and the LRIC incurred if the highway section has to be upgraded at the end of the current cycle. In measuring the SRIC, the age and current serviceability of a given highway section (at the time the traffic changes occur) are directly accounted for in the cost calculation. Consequently, the SRIC reflects (approximately) the sum of the true marginal costs associated with each axle pass.

Having outlined the theory behind the highway impact submodel or procedure, the report now turns to the topic of pavement deterioration models: the analytical key to the measurement of short-run incremental and long-run incremental costs.

PAVEMENT DETERIORATION MODELS

Pavement deterioration or decay functions constitute an important element of the predictive methodology presented in this study. The purpose of this section of the report is to discuss the theory behind pavement deterioration models, and to introduce and evaluate some of the major pavement damage functions in existence today.

The discussion begins with some general background concepts in pavement damage analysis.

Pavement Damage Functions: Background

The deterioration of pavements is typically analyzed through means of a damage function which relates the decline in pavement serviceability to traffic or axle passes. Figure 2, it will be recalled, presented a theoretical pavement deterioration curve in which the pavement serviceability rating declined with axle passes over time. This general relationship is expressed by equation (18):

$$g = (N/\tau)^{\beta} \tag{18}$$

where:

- g = an index of damage or deterioration
- N = the number of passes of an axle group of specified weight and configuration (e.g. the 18-kip single axle)
- τ = the number of axle passes at which the section reaches failure
- β = a shape factor

At any time between construction (or replacement) and pavement failure, the value of g (the damage index) will range between 0.0 and 1.0. When N equals zero for a newly-constructed or rehabilitated section, g equals zero. On the other hand, when N (the number of cumulative axle passes) equals the life of a highway section (τ), g equals 1.0.

There are several ways to model the deterioration of pavements and the decision to rehabilitate or reconstruct. A "distress approach" may be taken in which the occurrence of specific distresses (such as rutting or fatigue cracking) is modeled. In this approach, a damage function is developed for each distress, and the decision to replace a pavement is modeled collectively from the occurrence of individual distresses.[32] The distress approach is preferable for highway cost allocation because different axle weights have different effects on pavement life within the context of different distresses. However, modeling individual distresses requires considerable data and is not practical for use in this study.

Alternatively, the traditional approach which has been taken in pavement deterioration analysis is to model the

[32] In this approach, the relative contribution of each distress in terms of the decision to rehabilitate is determined empirically. For example, rutting may account for 14 percent of the decision to replace a pavement. Consequently, 14 percent of the cost of replacement is assign to rutting. For a detailed discussion of this approach and the development of damage functions for individual distresses see: Rauhut, J.B., R.L. Lytton, and M.I. Darter. Pavement Damage Functions for Cost Allocation, FHWA Report No.: FHWA/RD-841018, Washington, D.C., 1984.

decline in pavement serviceability rating. A pavement serviceability rating (PSR or PSI) is a composite index which reflects the general serviceability of pavements at the time of evaluation. The verbal rating scheme used in determining the PSR (Figure 5), considers the smoothness of the ride as well as the extent of rutting and other distresses. Thus by modeling the decline in PSR, one is to a certain extent modeling the occurrence of individual distresses as well.

To return to the general damage function presented earlier, if the ratio of the decline in pavement serviceability relative to the total capacity of a highway section is used to represent the damage index, then equation (18) may be rewritten as follows:

$$\frac{P_i - P}{P_i - P_t} = (N/\tau)^{\beta} \qquad (19)$$

where:

P_i = Initial pavement serviceability rating

P_t = Terminal pavement serviceability rating

P = Current or present serviceability rating

The term "P_i - P" on the left-hand side of the equation represents the decline in pavement serviceability rating from the time the highway was initially constructed (or replaced) until the present. The numerator in the

Scale	Verbal Rating	Description
5–4	Very Good	Only new (or nearly new) pavements are likely to be smooth enough and sufficiently free of cracks and patches to qualify for this category. All pavements constructed or resurfaced recently should be rated very good.
4–3	Good	Pavements in this category, although not quite as smooth as those described above, give first-class ride and exhibit few, if any visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavements may be beginning to show evidence of slight surface deterioration, such as minor cracks and spalling.
3–2	Fair	The riding qualities of pavements in this category are noticeably inferior to those of new pavements, and may be barely tolerable for high-speed traffic. Surface defects of flexible pavements may include rutting, map cracking, and more or less extensive patching. Rigid pavements in this group may have a few joint failures, faulting and cracking, and some pumping.
2–1	Poor	Pavements that have deteriorated to such an extent that they are in need of resurfacing.
1–0	Very Poor	Pavements which are in an extremely deteriorated condition and may even need complete reconstruction.

Figure 5. Present Serviceability Rating (PSR)

Source: U.S. DOT, Status of the Nation's Highways, July, 1983.

expression (P_i - P_t) represents the total decline in pavement serviceability which is possible from the time the pavement is built (or replaced) until it reaches failure (terminal serviceability). Intuitively, equation (19) is saying that the deterioration of a highway section at any time can be measured by a damage index which represents the proportion of the total capacity or pavement life of a section which has been consumed to-date.

Because the accurate modeling of pavement deterioration is essential to the success of subterminal impact analysis, an in-depth review of literature was undertaken in an effort to identify an appropriate submodel for the report. Altogether, five major pavement damage models were given detailed scrutiny:

1. The AASHO damage function,
2. The HPMS deterioration model,
3. The revised AASHTO pavement design equation,
4. The FHWA pavement damage model (the Rauhut model),
5. The revised FHWA model.

The results of the evaluation are presented at the end of this section. But first, each model is briefly introduced, starting with the original AASHO model. Because most rural arterials, collectors, and local roads consist of asphalt pavements (as opposed to PCC) the examples and equations presented in this section deal with flexible rather than with rigid pavements. However, each model described also entails a rigid pavement deterioration function which may be obtained from the references given.

The AASHO Damage Function

Perhaps the best known pavement deterioration function is the one developed by the American Association of State Highway Officials (AASHO). The AASHO damage model is based on the results of a road test conducted in Ottawa, Illinois between November, 1958 and November, 1960[33].

AASHO Variables and Relationships

So that pavement decay could be evaluated on the test sections at Ottawa, a serviceability measure known as the Present Serviceability Index (PSI) was constructed. The PSI is a composite index which reflects the extent to which certain physical distresses affect the serviceability of a pavement section.

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[33]Six test loops were constructed in Ottawa over which 110 vehicles operated between six and seven days per week (except in spring thaw). Altogether, the vehicles applied 1.14 million axle loads to the test sections over the duration of the project.
Tractor semi-trailer combinations operated over the four largest test loops. To control for axle configuration, both single- and tandem-axle combination trucks were used. The load levels on the four loops were: 14, 18, and 22 kips respectively for single-axle vehicles, and 18, 26, 34, and 38 kips for tandem-axle trucks.

Four types of distresses were considered in the calculation of the PSI for flexible pavements during the road test:

1. cracking,
2. patching,
3. slope variance or longitudinal roughness,
4. rut depth.

The extent to which each of these distresses altered the PSI for a given pavement section was measured by the following formula:

$$PSI = 5.03 - 1.91\ LOG10(1 + SV) - .01 \cdot (c + p)^{1/2} - 1.3\ RD^2 \qquad (20)$$

where:

SV = slope variance
RD = rut depth
c = extent of cracking
p = extent of patching

Using the PSI, AASHO officials were able to relate accumulated traffic and axle loads to changes in pavement serviceability. The process by which this was accomplished is described in the following paragraphs.

Each highway section at Ottawa was evaluated at two week intervals throughout the duration of the test. From the occurrence of distress (or lack thereof) the current PSI was calculated. Given the current PSI and the cumulative axle loads, the value of the damage index (g) was calculated (for each test section) based on the original and terminal

PSI[34]. The unknown parameters in the equation (ß and τ) were estimated through regression analysis. The form of the regression equation for each parameter is given by equations (21) and (22) respectively.

$$LOG_{10}(\tau) = 5.93 + 9.36 \cdot LOG_{10}(SN+1) - 4.79 \cdot LOG_{10}(L1+L2) + 4.33 \cdot LOG_{10}(L2) \quad (21)$$

$$\beta = .40 + \frac{.081 \ (L1 + L2)^{3.23}}{(SN + 1)^{5.19} L2^{3.23}} \quad (22)$$

where:

SSN = AASHO soil support index

R = Regional factor

L1 = Axle load (in kips or thousand pounds)

L2 = Axle type (where "1"= single axle and "2"= tandem axle)

In pavement damage analysis, the 18,000 pound single axle is typically used as a reference axle for developing

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[34]AASHO officials found, somewhat surprisingly, that the PSI of a new section which had never been exposed to traffic was 4.2. In other words, none of the sections were ever rated at their theoretical maximum of 5.0. The terminal PSI for pavements at the road test was determined to be 1.5. This figure represents actual pavement failure; that is the point at which the serviceability of the section is such that safe and reasonably economic transport is no longer possible. True pavement failure is different from effective terminal serviceability, in which a threshold or trigger PSI is established (e.g. 2.5) which when reached, results in the decision to rehabilitate.

traffic equivalence factors. Thus the values of τ and β for this axle type are of particular importance. Substituting a value of "18" for L1 and "1" for L2 in equation (21) yields a condensed function for τ which is specific to the reference axle (referred to as τ_{18}).

$$LOG_{10}(\tau_{18}) = 9.36 \cdot LOG_{10}(SN+1) - .2 \qquad (23)$$

A similar substitution into equation (22) yields β for the reference axle (β_{18}).

$$\beta_{18} = .40 + \frac{1094}{(SN + 1)^{5.19}} \qquad (24)$$

Recall from equation (18) that τ represents the number of axle passes of a given configuration and load at which the damage index equals 1.0. Consequently, τ may be thought of (at least in theory) as the life of a pavement in axle passes. It follows then that τ_{18} represents the theoretical life of a pavement in 18,000 pound single-axle passes or ESALs.

While equation (23) represents the life of a pavement in theory, the effective or actual life of a section may be much shorter. Equation (23) assumes that the pavement will be allowed to deteriorate until its reaches a terminal serviceability of 1.5 (at which time safe and economic transport over the section will be impractical).[35] In actuality, most highway sections are replaced or upgraded much earlier. Federal Aid Highways (which include the Interstate and much of the principal arterial system) are typically replaced when the PSR reaches 2.5. Other arterials, collectors, and local roads are usually rehabilitated when the PSR declines to 2.0. In these instances, equation (25) may be used in lieu of equation (23) to predict the **effective** ESAL life of a highway section. The terminal serviceability level in the equation (P_t) may be set at either 2.5 or 2.0 to reflect the expected replacement cycle for a given class of highway.

$$LOG_{10}(ESAL) = 9.36 \cdot LOG_{10}(SN+1) - .2 + G/\beta \quad (25)$$

where:

$LOG_{10}(ESAL)$ = Log of effective ESAL life

$$G = LOG_{10}((4.2-P_t)/2.7) \quad (26)$$

[35]At a terminal serviceability of 1.5, user costs will rise dramatically and the quality of ride will be at an unacceptable level.

Problems and Qualifications

The AASHO damage function has been widely criticized by practitioners and academics alike[36]. The major criticisms are:

1. Only one climatic zone was evaluated at the road test;

2. All test sections had essentially the same type of soil;

3. Only one level of load was applied to a test section for a given axle type (thus the effects of mixed traffic and axle loads were not analyzed);

4. The range of axle loads applied to the test sections was small;

5. Because of accelerated testing, the effects of the environment over a relatively long period of time were not accounted for.

But for all of its criticisms, the AAHSO model has been widely used (Van Til, 1972). And to its credit, a recent study by Wang (1982) found that the decay of test sections at the Pennsylvania Transportation Research Facility tended

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[36]An implicit assumption of the AASHO Road Test is that the decline in pavement serviceability (PSI) is due entirely to the effects of traffic (axle loads) upon pavements. A recent critique by Coree and White (1988) suggests that the initiation of significant deterioration in the test sections at Ottawa was linked to spring-thaw, a fact which critically affected the performance of test sections in subsequent evaluation periods. In addition, the flexible pavement layer coefficients used in the calculation of the structural number were criticized by Coree and White as "secondary regression coefficients with no physical significance as indicators of pavement strength."

to follow the AASHO power function shown in Figure 2. So while the AASHO damage function must be qualified whenever it is used outside of the climatic and soil regions for which it was intended, it has been shown to provide at least "ballpark" estimates of pavement life.

The HPMS Damage Function

The Highway Performance Monitoring System (HPMS) employs a modified AASHO damage function. The original AASHO function has been modified in two major ways.

First, HPMS uses the PSR instead of the PSI used at the road test. The difference is that the PSR entails a verbal rating scheme (as shown in Figure 5) whereas the PSI is derived from the mathematical relationship shown in equation (20). Also in HPMS, the original or design serviceability rating is set at its theoretical maximum (5.0) instead of at 4.2. This has the effect of increasing the range over which the pavement serviceability index is allowed to decline.

The second major modification to the AASHO equation (and perhaps the most important) concerns the rate of decay of flexible pavement with ESALs. In order to illustrate this change, the HPMS flexible pavement damage function is introduced in equation (27).[37]

$$LOG_{10}(ESAL) = 9.36 \bullet LOG_{10}(SN+(6/SN)^{0.5}) + G/\beta \qquad (27)$$

where:

$$G = LOG_{10}((5-PSR)/3.5) \qquad (28)$$

$$\beta = .4 + 1094/(SN+(6/SN)^{0.5})^{5.19} \qquad (29)$$

Note that the term "SN+1" in the AASHO equation has been replaced by the term "$(6/SN)^{0.5}$" in the HPMS function. In practice, this modification has the effect of predicting higher ESAL life-times on highways with lower structural numbers (e.g. 2.5 or lower).

One of the applied problems associated with the AASHO pavement damage function is that it has been shown to exhibit poor predictive capabilities at the lower end of the range of highway structural numbers.[38] For example, on a highway section with a structural number of 2.0, equation

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[37]The term "G" represents the damage index in the HPMS function. When the PSR is set to 1.5 (terminal serviceability), the term "G/ß" becomes zero. The log of G then becomes zero and the entire term (G/ß) resolves to zero.

[38]This observation is based on conversations with NDHWD engineers, and is felt to be a fairly common perception of the AASHO formula.

(25) predicts on ESAL life of 16,458. On the same highway section, equation (27) predicts a pavement life of 115,011 ESALs.

The Rauhut Model

While the AASHO model has been roundly criticized, until recently a strong effort had not been made to come up with a workable alternative. In the Federal-Aid Highway Act of 1978, Congress stipulated that DOT must conduct a new highway cost allocation study and report the findings to Congress by January of 1982. As part of a set of studies funded by the FHWA, a new set of pavement damage functions was developed by Rauhut, Lytton, and Darter (1982).

Background

The form of the equation relating damage to axle loads in the Rauhut model is the same as that which was shown earlier in equation (18). Damage is defined as an index ranging from 0.0 to 1.0, as a pavement moves from initial or design serviceability to terminal serviceability. Like the AASHO model, τ denotes a constant which represents the number of cumulative axle passes which accrue at terminal serviceability.[39]

In the Rauhut study, a regression model was formulated which will predict either τ or ß based on the thickness of the pavement layers for a given highway section and the resilient modulus of elasticity (an indicator of soil support). The function (shown in equation 30) has the same form for either parameter. However, the values of the constants and the coefficients in the equation are different for each.

$$\tau,\beta = C + A \bullet (L1 + L2)^{(B_1+B_2t+B_3t^2+E_2E_s+E_3E_s^2)} \bullet (L_2)^{(C_1+C_2t+C_3t^2+G_2E_s+G_3E_s^2)} \bullet E_s^D \, SN^E t^F \qquad (30)$$

where:

t = thickness of all asphaltic concrete layers (in inches);

E_s = subgrade modulus of elasticity (psi).

[39]But unlike the AASHO function, the Rauhut model assumes a higher terminal serviceability rating (2.5). This is based on the observation that Federal Aid highways are rarely allowed to deteriorate to a serviceability rating of 2.0 or lower.

Values for the constants and coefficients were estimated for each of four different climatic zones:

1. A wet freeze zone
2. A dry freeze zone
3. A wet no-freeze zone
4. A dry no-freeze zone.

Calibration

The flexible pavement damage functions developed in the Rauhut study reflect a combination of mechanistic and statistical techniques. Mechanistic models consist of a set of mathematical relationships that depict the way in which multi-layered pavements respond to applied loads over time. The models are based upon elastic theory in which a flexible pavement can be modeled as a system of elastic layers resting upon an elastic foundation. From the theory, analytical solutions can be derived for the stresses in the system, and the strain or deflection caused by applied loads can be computed at a given point (or points) beneath the surface. The concepts of multi-layered elastic systems and the occurrence of stress in flexible pavements are fully developed in Yoder and Witczak (1975, Chapter 2).

Mechanistic models do not directly predict pavement deterioration. Instead, they simulate structural responses. The structural responses are related to pavement deterioration through means of a performance model which predicts the level of distress or loss of serviceability that occurs from wheel loadings or environmental conditions. The mechanistic-statistical modeling process is essentially as follows.

1. A mechanistic model is applied to a range of hypothetical axle loads, pavement types, and subgrade conditions in order to generate a "data base" of structural responses.

2. The **output** of the mechanistic model is used to calculate the values of the parameters in the damage function (τ and ß) for various combinations of input variables.

3. The manner in which τ and ß vary with changes in the independent variables in the model (e.g. pavement thickness or subgrade modulus) is determined through regression analysis on the data base of observations.

4. The formulated regression model is then used to predict the values of τ and ß for any given load level, axle configuration, and soil support measure.

Generally (as a check against the reasonableness of the estimates), the distress or loss of serviceability which is predicted by the regression model is compared to observed values for sample pavement sections. In fact, the predicted results may be correlated with actual observations (if sufficient data are available) and the equations for τ and ß refined to reflect real-world effects and experiences.

The major inputs to the mechanistic model in the Rauhut study consisted of: (1) the environmental region, (2) the subgrade modulus, (3) the thickness of the surface course, (4) the structural number, and (5) the load level. Within each environmental zone, 3 subgrade values were simulated. In addition, 3 different levels of surface thickness, 3 subgrade thicknesses, 3 structural numbers, and 8 different load levels were analyzed. Altogether, a total of 216 computer runs resulting from the combinations of these variables were made in each of the 4 environmental zones. In the author's words, the computer runs represented:

> ...separate, miniature versions of the AASHO Road Test in each of the four climatic regions with the importance distinction that three different subgrades were used instead of one as at the AASHO Road Test.[40]

In addition to equation (30), a second regression model for τ and β was formulated which included the thickness of the aggregate base as an independent variable.

The Revised FHWA Model

The original FHWA pavement damage model (the Rauhut Model) was updated in 1987 by Villarreal, Garcia-Diaz, and Lytton. The updated deterioration model employs an "S-

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[40]Rauhut, 1984, p. 152.

shaped" decay function in lieu of the power function shown in equation (30). In addition to the revised functional form, the updated FHWA model utilizes an expanded and improved data base. With these exceptions, the theory and calibration of the model are essentially the same as those described previously with respect to the original version.

Perhaps the major enhancement contained in the revised edition (from a predictive standpoint) is the inclusion of explanatory variables in the model to account for the effects of different types of tires (bias versus radial) and variations in truck tire pressure. This modification has the potential for greatly enhancing the predictive capabilities of the model. However, it requires detailed information regarding the distribution of tire usage in the impact area and actual tire pressures (by type of truck).

Model Inputs

The revised FHWA model (like the original function) can be used to predict the loss of serviceability on a given highway section caused by accumulated axle passes. However, before the model can be applied, the analyst must specify values for three types of parameters:

1. tire characteristics and use,
2. pavement surface thickness,
3. subgrade support.

In describing tire use in the impact area, the analyst must estimate typical values for three important truck operating factors:

1. the type of tire which is used (radial versus bias),

2. the number of tires (dual or single),

3. the tire pressure (in psi).

The exact distribution of truck tire use in North Dakota is unknown. However, a recent study in Montana sheds some light on typical tire-use patterns in the Upper Great Plains. In the Fall of 1984, the Montana Department of Highways conducted a truck tire survey at various sites along the interstate and arterial network. Altogether, over 2,300 tires were sampled. The major conclusions of the study were:

1. over 82% of the truck tires employed in Montana consist of belted radials;

2. the average (statewide) air pressure for truck radial tires is 105 pounds;

3. the average tire pressure for bias-ply tires is 84 psi;

4. on the average, tire pressures in eastern Montana are higher than in the West, ranging between 100 and 110 psi.

In the Fall of 1984, the NDHWD conducted a truck-tire study of its own. The type of tire was not determined in the North Dakota study. However, sample data were compiled regarding truck tire pressures. The results of the North Dakota survey are summarized in Table 5.

As Table 5 depicts, the mean tire pressure in North Dakota (for CO-5AX trucks) is somewhat lower than the average in Montana. However, both estimates tend to support

TABLE 5. TRUCK TIRE PRESSURES IN NORTH DAKOTA

Truck-Type	N	Mean	Standard Deviation
CO-5AX	530	97	13.7
SU-3AX	35	92	12.7
SU-2AX	12	85	9.0

Source: Unpublished NDHWD survey data.

the same general conclusion: that truck tire pressures are considerably higher today than the 75 psi which is reflected in the AASHO damage function.

Differences in projected pavement life attributable to truck tire pressure and usage are illustrated later in the discussion. But first, to summarize the major implications of the North Dakota and Montana studies, it may be said that: (1) truck tires (particularly on heavy trucks) consist largely of steel belted radials, and (2) the average pressure per tire on combination trucks operating in North Dakota is 97 PSI.

Model Structure and Form

Predicting the ESAL life of a flexible pavement section using the revised FHWA model is a multi-step process. First, the values of τ and β must be predicted based on the characteristics of the highway and patterns of tire use. The form of the predictive equation for either parameter is given by:

$$LOG_{10}(\tau, \beta) = (L1 + L2 + L3)^{K1} \cdot L2^{K2} \cdot L3^{K3} \cdot (L4 + 1)^{K4} \cdot T1^{A17} \cdot ES^{A18} \cdot P^{A19} - C \quad (31)$$

where:

$$K1 = A1 + A2 * T1 + A3 * ES + A4 * P \quad (32)$$

$$K2 = A5 + A6 * T1 + A7 * ES + A8 * P \quad (33)$$

$$K3 = A9 + A10 * T1 + A11 * ES + A12 * P \quad (34)$$

$$K4 = A13 + A14 * T1 + A15 * ES + A16 * P \quad (35)$$

L3 = Tire code ("1" for one tire, "2" for dual tires)

L4 = Tire type ("1" for radial, "2" for bias)

T1 = Thickness of AC surface layer

ES = Subgrade modulus of elasticity

P = Tire inflation pressure (PSI)

The dry-freeze zone constants and coefficients for τ and β which were used in the Devils Lake study are shown in Table 6.

TABLE 6. DRY-FREEZE ZONE COEFFICIENTS AND CONSTANTS FOR REVISED FHWA MODEL

Coefficient	τ	β
A0	8.54580997	-0.86987349
A1	-1.92636492	0.00000000
A2	0.00000000	0.09442385
A3	0.00000900	-0.00001860
A4	-0.00087092	-0.00022683
A5	1.79275336	0.00000000
A6	0.00000000	-0.10482985
A7	-0.00001170	0.00001300
A8	0.00000000	0.00000000
A9	1.85872192	0.00000000
A10	0.00000000	-0.10122395
A11	-0.00000860	0.00002340
A12	0.00000000	0.00000000
A13	-4.37832061	-0.08745997
A14	0.67225250	0.01632584
A15	0.00000930	-0.00000080
A16	0.00000000	0.00000000
A17	0.00000000	-0.84335410
A18	-0.12346038	0.63703782
A19	0.00000000	0.00000000
C	0.00000000	11.00000000

As noted previously, the revised damage function is a sigmoidal or S-shaped curve (rather than a concave function). So the form of the damage function is given by:

$$g = c \cdot e^{(\tau_{18}/N_{18})^{\beta_{18}}} \qquad (36)$$

where:

$$c = (P_i - P_f) / (P_i - P_t) \tag{37}$$

N_{18} = ESAL life
P_i = initial or design PSR
P_f = final terminal PSR
P_t = effective terminal PSR

The true terminal serviceability rating (that which occurs at structural failure) is generally assumed to be 1.5, while the effective terminal serviceability rating is typically much higher (2.0-2.5). In the Devils Lake study, the terminal PSR (P_t) was assumed to be 2.5 for interstates and principal arterials, and 2.0 for all other highways.

In order to predict ESAL life, equation (36) must be solved for "N." Taking the natural log of the equation and manipulating the terms yields:

$$N_{18} = \tau_{18} \;/\; [-\ln(g/c)]^{1/\beta_{18}} \tag{38}$$

which can be used to predict the effective life of a flexible pavement for an assumed terminal serviceability rating.

Sensitivity to Inputs

Because of the number of factors involved and the newness of the model, the effects of changes in important inputs (such as tire pressure and subgrade modulus) were investigated in the study. A range of reasonable values was established for each variable. For example, the subgrade modulus was allowed to vary between 4,500 and 8,000 psi, while the tire pressure was permitted to range from 75 to 100 pounds.[41]

Figure 6 shows the difference in projected ESAL life for a range of surface thicknesses due to variations in tire type and pressure. In this example, the tire pressure was set at 75 pounds for bias-ply tires and 100 pounds for radials[42]. As Figure 6 depicts, the difference between the two types of tires on thinner pavements is minimal, with bias-ply tires actually yielding lower (projected) pavement lives. However, on thicker pavements, the effects of steel

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[41]Estimates of the typical subgrade modulus of elasticity for highway sections in the Devils Lake region were developed as follows. The low-range estimate (4,500) was adapted from AASHTO (1986), and is considered to be a conservative estimate for low-volume roads in the dry-freeze zone (Region VI). The upper-end estimate (8,000 psi) was calculated from guidelines contained in Rauhut (1984) using descriptions of the typical soil composition, density, and moisture content provided by Mr. Clay Sorenson, NDHWD district engineer. The FHWA model is apparently not very sensitive to reasonable or moderate variations in the subgrade modulus. For example, increasing the ES from 4,500 to 8,000 psi on a 5-inch pavement decreases the projected pavement life from 678,819 ESALs to 657,159, a change of 3.2 percent.

[42]As the Montana study illustrated, steel belted radials are usually inflated to a higher pressure than bias-ply tires.

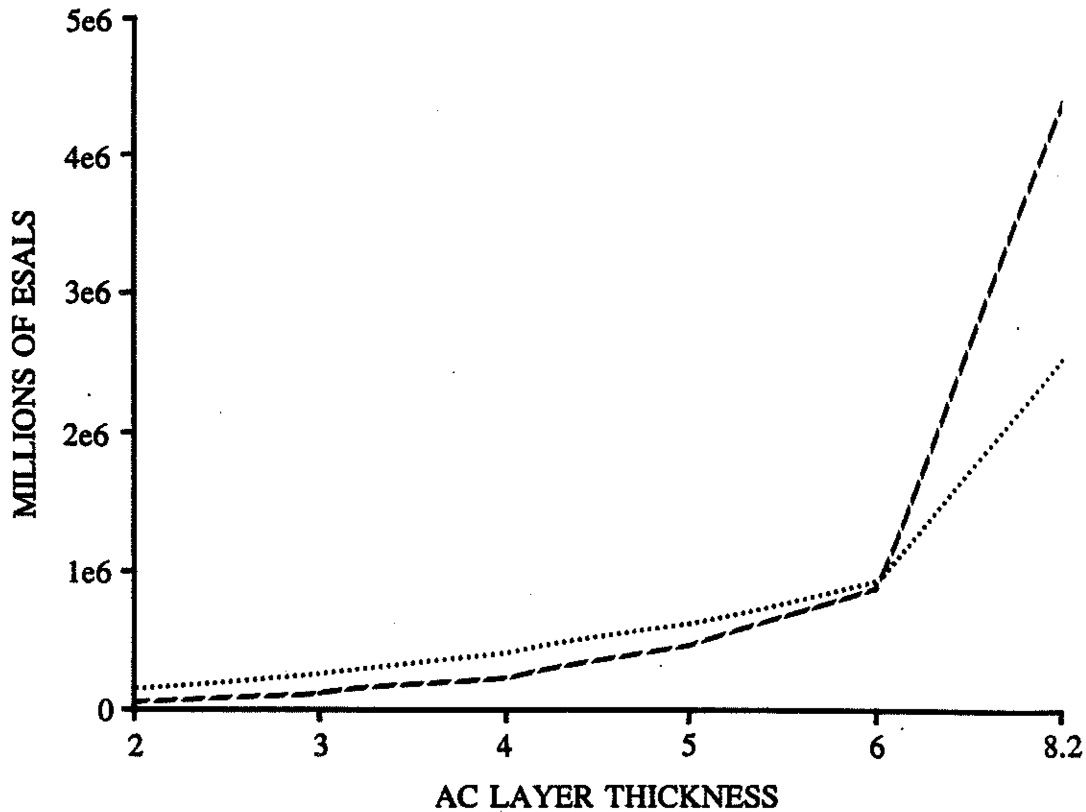

Figure 6. Estimated ESAL Life-Times Using Revised FHWA Model

Legend: — — — — Bias .... Radial belted radials are quite noticeable, markedly reducing the predicted pavement life of a section.

Figure 7 more clearly isolates the effects of tire pressure on pavement life, showing the projected life of a typical low-volume highway section when tire pressures are set at 75, 90, and 100 psi respectively.[43] As the graph depicts, increasing the average tire pressure on a 5-inch pavement from 75 to 100 psi reduces the projected ESAL life by 6.25 percent.

In summary, it may be said that the revised FHWA model is:

1. relatively insensitive to moderate changes in the subgrade modulus of elasticity,
2. moderately sensitive to changes in truck type pressure,
3. quite sensitive to the type of tire which is specified.

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[43]This example assumes: (1) radial tires, (2) a surface thickness of 5 inches (roughly equivalent to a SN of 2.6 in the Devils Lake region), and (3) a subgrade modulus (ES) of 4500.

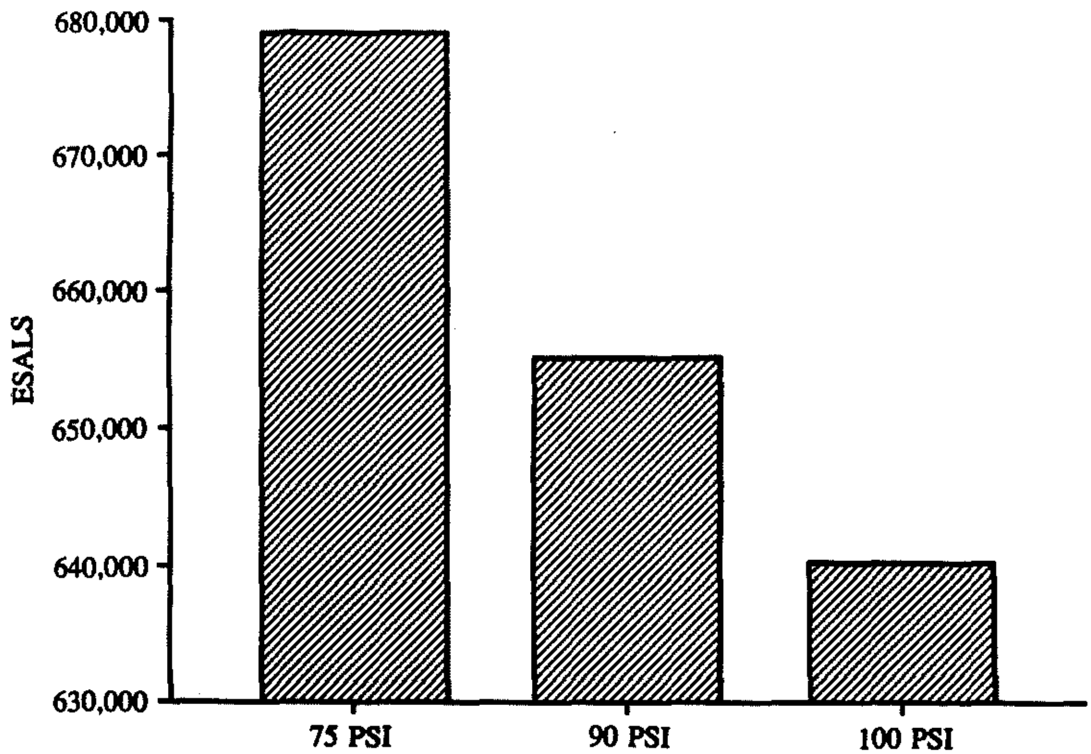

Figure 7. Effects of Truck Tire Pressure on Flexible Pavement Life

Evaluation of Flexible Pavement Deterioration Models

The sensitivity analysis presented above was just one element of an overall evaluation process which was used to determine the most appropriate pavement deterioration model for the Devils Lake study. Each of the deterioration models discussed in this chapter was evaluated with respect to:

1. Theory and estimation techniques,
2. The reasonableness of the estimates when contrasted with the estimates of other models,
3. The reasonableness of the estimates when compared with real-world experience and engineering expectations.

As part of the evaluation process, each model was used to predict the ESAL life of 30 sample sections in the Devils Lake region. For each highway section, data concerning the SN, the thickness of the AC surface layers, the thickness of the aggregate base, the likely elastic modulus of the subgrade, and the current PSR were collected.

Reasonableness of the Estimates

The reasonableness of the estimates was assessed in three major ways. First, the ESAL lives predicted by the various models were arrayed and compared. Second, the predicted ESAL life-times were compared to national averages (by functional class of highway) developed by the FHWA

(1982). And third, the results of the models were evaluated in light of the experiences and expectations of NDHWD engineers familiar with the nature and rate of pavement decay in the soil and climatic regimes of the Upper Great Plains.

With respect to the first test of reasonableness, two of the models predicted very similar results over the range of structural numbers represented by the 30 test sections. These were: (1) the HPMS deterioration function and (2) the revised FHWA model[44]. Both the original AASHO formula and the revised AASHTO model predicted little or no ESAL life at the lower end of the range. Furthermore, both models were quite sensitive to modest changes in the soil support variable (the SSN or the MR). The Rauhut model was particularly problematic on highway sections with moderate or high SN's, predicting extremely high ESAL lives.

Column (b) of Table 6 gives estimates of ESAL life-times developed by the FHWA for use in their 1982 highway cost allocation study. The estimates reflect the average pavement condition rating and strength of arterials,

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[44]When the revised FHWA model was set to a tire-type of "bias" and a PSI of 75, it closely paralleled HPMS predicted values for pavement life.

collectors, and local roads nationwide[45]. For purposes of comparison, mean values were predicted for the 30 test

TABLE 6. ESTIMATED ESAL LIFE OF PAVEMENTS: BY FUNCTIONAL CLASS

Functional Class (a)	FHWA Averages (b)	HPMS Predicted Values (c)	AASHO Predicted Values (d)
Arterial	1,500,000	1,762,734	422,858
Collector	400,000	88,051	5,053
Local	80,000	76,711	208

sections in the Devils Lake region using the AASHO equation (column d), HPMS (column c) and the updated FHWA model.

As Table 6 indicates, HPMS produces estimates which are roughly in line with the national averages (particularly on arterials and local roads). However, the AASHO model does not, predicting much lower pavement lives, especially on collectors and local roads. The new FHWA model generates estimates which are similar to HPMS when the tire type is set to "bias" and the tire pressure is set at 75 psi. The two remaining models (the Rauhut model and the AASHTO design

[45] While it cannot be contended that the attributes of North Dakota's rural highways are identical to national "averages", there should be similarities within functional classes.

equation) generally produce estimates which are out-of-range when compared with the other models.

As part of the evaluation process, comments were solicited from NDHWD engineers, particularly those familiar with the highway design and pavement deterioration processes. Based on some recent experiences with HPMS, the AASHO function, and the revised AASHTO design equation, Mr. Tim Horner (an engineer with the department) indicated that the low-range estimates produced by the AASHO and AASHTO models were not consistent with his experience or expectations.[46] Mr. Horner felt that HPMS simulated the deterioration process fairly closely, and he was generally comfortable with the predictive capabilities of the model.[47] On the other hand, he felt less at ease with the AASHO functions, echoing the concerns voiced by others regarding the sensitivity of the model to major variables (such the soil support index) and its tendency to predict unrealistic ESAL life-times at the extremes of the distribution of structural numbers.[48] These comments tend to support the

[46]Telephone conversation with Mr. Horner on June 10, 1988.

[47]Mr. Horner has recently completed a state-wide highway needs assessment using HPMS.

[48]Mr. Horner had no direct experience with either of the FHWA models, and thus could not directly comment on either.

conclusions of the evaluation process and the accompanying sensitivity analysis.

Model Selection

Both the HPMS and the revised FHWA deterioration models emerged from the evaluation process as acceptable candidates. Both functions predicted similar ESAL life-times, given the assumptions of bias-ply tires and tire pressures of 75 psi. However, the increasing tendency towards combination trucks with belted radials and tire pressures of 100 pounds or more may make these assumptions unrealistic in future years. The new FHWA model provides the analyst with a more versatile (and perhaps accurate) model under such conditions, allowing the prediction of pavement life under various assumptions regarding truck tire use and pressure. The theory behind the model appears to be sound and the estimating equations have been improved considerably over the original version (particularly in the dry-freeze zone). Given these considerations, the revised FHWA model was felt to be the most appropriate technique for the Devils Lake study.

The purpose of this chapter has been to set forth a theoretical framework for performing grain subterminal impact analysis. Because the problem is complex and multi-dimensional in nature, a variety of techniques is needed covering a range of disciplines. But underlying the entire process are the basic concepts of transportation demand, pavement deterioration analysis, and life-cycle costs introduced in this chapter.

CHAPTER 4
IMPACT ASSESSMENT PROCESS AND DATA REQUIREMENTS

The subject matter of Chapter 3 dealt with the theory of subterminal impact analysis and the measurement of incremental costs. The subject matter of this chapter is more mechanical in nature, dealing with the actual tasks and procedures involved, as well as with the data elements required.

The material is organized and presented so as to achieve two basic purposes. The major objective of the chapter is to describe the **process** of subterminal impact analysis, including the submodels, procedures, and data elements involved. A secondary (and complementary) objective is to highlight the data collection procedures and assumptions which were followed in the Devils Lake case study.

The first part of the chapter presents something of a "recipe" for subterminal impact analysis, covering in step-by-step fashion the various tasks involved and the data elements required. The second part of the chapter focuses on the collection of vehicle classification and axle weight data, and on adjustments to standard data collection practices necessary to effectively model subterminal traffic. The major reason for organizing and presenting the material in this fashion is so that the process can be replicated by different analysts in other regions or states in the future.

In subterminal impact analysis (as in most endeavors), there are generally several ways to approach a particular problem and more than one analytical technique which can be used to solve it. So instead of prescribing a rigid set of procedures, the chapter points-out some of the major alternatives which are available to analysts at various stages of the process.

In the first part of the chapter, some of the options and trade-offs which are inherent in the design of a subterminal impact case study are introduced. Then (later in the chapter and in Appendix D) some of the major advantages and disadvantages of alternative shipment distribution techniques are discussed. This information will hopefully provide future analysts with a base from which to work, and assist them in the evaluation of potential impact-assessment techniques.

It is recognized that when the process is repeated elsewhere that neither the amount of information which was compiled in the Devils Lake case study nor the level of resources which were employed are likely to be available. So in order to provide future analysts with some degree of flexibility in replicating the process, low-cost alternatives for data collection and analysis are introduced wherever possible.

For instance, it is unlikely that in future studies weigh-in-motion (WIM) data will always be available for the impacted highways in the region. Deploying and repositioning WIM equipment throughout the area can be an expensive (and perhaps impossible) strategy. So to ensure that future analysts will be able to implement the process in instances where weigh-in-motion data are not available, procedures involving the use of static truck weight data and other special study factors are presented.

PRELIMINARY ANALYSIS AND STUDY DESIGN

Subterminal impact analysis involves a series of steps, starting with an aggregate picture of the impact zone and culminating with a microscopic examination of individual highway sections and interzonal traffic patterns. The process begins with two routine but essential steps. First, the impact area is demarcated and partitioned into agricultural supply zones. And second, a time-period or "planning horizon" is specified for the analysis. Both steps are discussed in the following section of the chapter.

The initial task in subterminal impact analysis is to bound the impact region and subdivide the area into origin zones. This was accomplished in the Devils Lake case study through means of a top-down process which involved the following tasks (in descending and sequential order):

1. The impact area was delineated or "cordoned-off";

2. The impact zone was subdivided into broad zones of subterminal market power;

3. The zones of subterminal market power were partitioned into agricultural production or supply zones;

4. Within each agricultural production zone, one or more "centroids" or traffic-loading points were identified.

The impact zone for a given case study will generally coincide with the subterminal market region. So in order to demarcate the impact zone, the analyst must first determine the outer boundary of the subterminal's market area.

Delineating the Impact Zone

There are several ways to define the trade area of a subterminal. One may use the price relationships which exist between satellite elevators and competing elevators at the periphery of a subterminal's market area to define the trade area boundary at key points[49]. When these points are connected, an approximation of the circumference of a subterminal's market area results. But defining trade area boundaries in this manner requires detailed and precise information concerning price relationships between satellite elevators and their competitors at the fringe of a trade area. This information is not readily available and must be obtained by survey[50].

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[49]This technique uses farm truck costs in conjunction with elevator bid prices to define the point of equal drawing power between a given elevator and its closest competitor in a particular direction. Theoretically, farmers who are situated on an imaginary line connecting two points of equal drawing power will be indifferent with respect to where they truck their grain. However, farmers who are situated on one side of the line or the other will tend to favor one of the elevators. This is because the net farm price (the price paid at the elevator minus the farm truck costs) will be greater at one elevator than at the other. If this process of demarcation is repeated in each direction, a set of points will emerge representing locations of equal drawing power. When connected, these points will tend to approximate the outer boundary of an elevator's trade area. For an illustration of this approach see Cobia, Wilson, Gunn, and Coon (1986), particularly pages 14 through 18. The shortcomings of this approach are: (1) it has some detailed data requirements attached, (2) it ignores farmer patronage and other factors unrelated to price and distance, (3) the boundary line may be different for individual commodities, and (4) the line may change with fluctuations in prices and variations in farm truck costs.

[50]Even if the data were readily available, defining a trade area boundary in this fashion could still prove to be quite complex. The complexity arises from three underlying problems. First, the price relationships which exist between elevators will depend upon the extent to which each facility utilizes multiple-car and trainload rates during a given time period. Second, the price relationships between elevators may vary with the commodity or commodities

An alternative method of defining the trade area is to persuade the subterminal manager to delineate the outer boundary based on his or her knowledge of the price relationships and competitive pressures which exist. In the Devils Lake study, the subterminal manager was given a map of the region with a rough boundary line sketched-in, and asked to modify the line based on his knowledge of:

1. competition from nonmember elevators or competing subterminal systems,
2. the distribution of production in the region,
3. geographic constraints and barriers,
4. the capacity of his system, and
5. the perceived optimum volume at the subterminal.

Several iterations of the process were performed before the final boundary line emerged[51].

Once the outer boundary of the subterminal's market area has been demarcated, the impact region can be partitioned into origin or supply zones. This task was

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handled. Finally, temporal variance or instability in price relationships is likely due to changes in market forces.

[51] This information was obtained during an interview with Mr. Alfred Bareksten, Manager of the Lake Region Cooperative, Devils Lake, North Dakota, June 17, 1987, or in subsequent telephone conversations or written correspondence with Mr. Bareksten and employees of the organization.

accomplished in the Devils Lake study via a two-step process. First, the market area was subdivided into broad zones of subterminal market power. Second, within each zone of subterminal market power, specific production or supply zones were identified.

Defining Zones of Subterminal Market Power

Of all of the elevators in the impact region, the subterminal will exert the strongest attractive force over supply zones. This force will be at its greatest close to the facility (where the absolute attraction is strong) and in zones which are not adjacent to a local or satellite elevator. In the latter instance, the relative attraction of the subterminal will exceed that of the closest local elevator due to price advantage.

The market power of the subterminal elevator will directly affect two important variables in the highway impact assessment process. First, the drawing power of the subterminal elevator will strongly influence the allocation of grain between the subterminal-satellite system and competing (nonsystem) elevators in the region. Second, the attractive force exerted by the subterminal elevator (relative to its satellites) will determine the allocation of grain between flow-types 1 and 2. The allocation of grain among flow-types is important for two reasons: (1) farm-to-subterminal shipments (flow-type 2) will generally involve longer trip distances, and (2) the distribution of farm-to-elevator shipments among truck types is partly a function of the type of flow[52]. Thus the market power of the subterminal elevator will indirectly determine the distribution of grain shipments among truck types in the region.

Measuring the traffic effects of a subterminal elevator can be a complex task. As a first step in the process, it may prove useful for the analyst to develop a descriptive model of the subterminal's influence over the market region. This was accomplished in the Devils Lake study by dividing the impact area into zones of subterminal market power which were used to derive preliminary estimates of the subterminal's likely traffic effects in different parts of the region.

The zonal boundaries (shown in Figure 8) consist of concentric rings about the subterminal at various distance intervals. The innermost zone includes points which are

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[52]As noted in Chapter 1, farmers are more apt to use SU-3AX or CO-5AX trucks when transporting grain over longer distances to the subterminal elevator due to the economies of transporting larger payloads. This preference is important because differences in truck weights, axle weights, and axle configurations will determine (in large part) the extent of highway damage which is incurred.

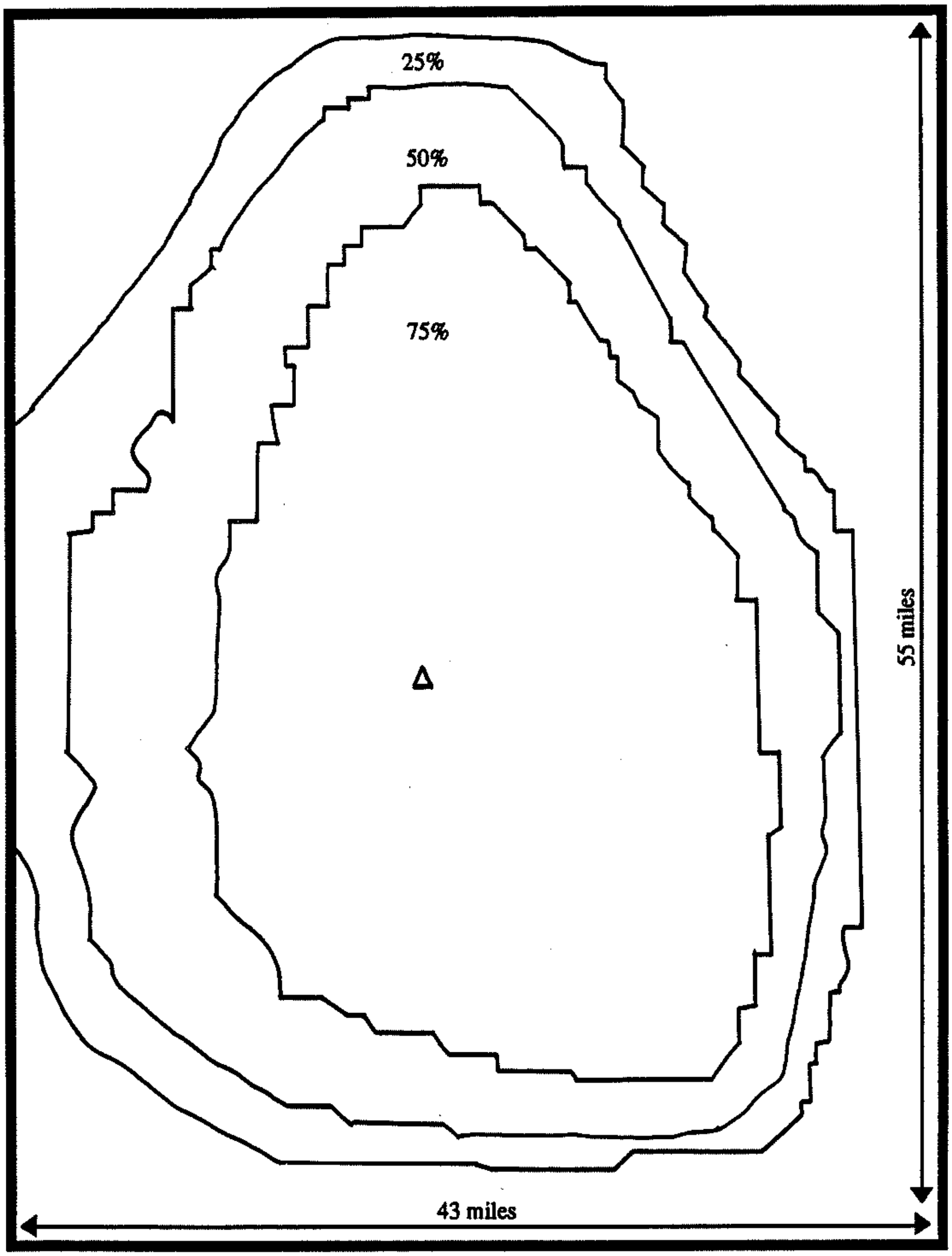

FIGURE 8. Subterminal Market Area: Zones of Equal Relative Attraction

within 25 miles of the subterminal (approximately). The second zone consists of locations which are less than 38 miles away. While the third zone includes locations up to 55 miles in distance. Within each zone, the subterminal exerts a different level of influence over grain flows.

Subterminal Market Share

The percentages shown in Figure 8 represent the projected market shares of the Devils Lake subterminal-satellite system in 1990 (the year in which the system will reach its long-run output level)[53]. For example, within 25 miles of the subterminal, the cooperative will capture roughly 75 percent of the grains and oilseeds produced. However, in Zone 2 the projected market share is only 50 percent, and it drops even further in Zone 3 (declining to 25 percent of total production). This is a typical pattern of subterminal market influence, wherein the market share of the system declines with distance from the subterminal.

In the Devils Lake study, the impact-year projections were compared to base-year estimates in an effort to

[53]This information was obtained during an interview with Mr. Alfred Bareksten, Manager of the Lake Region Cooperative, Devils Lake, North Dakota, June 17, 1987, or in subsequent telephone conversations and written correspondence with Mr. Bareksten and employees of the organization.

determine the likely magnitude and scope of the subterminal's traffic effects, and to assess whether it was worthwhile to perform a more detailed analysis. Before discussing the results of the Devils Lake market study, some background concepts regarding the nature of subterminal market power are introduced.

The share of grain captured by a subterminal-satellite system in the region will depend, in part, upon the scope and intensity of demand-point competition[54]. In general, the only demand-point competition which arises close to the subterminal is that which stems from nonmember elevators situated in the immediate geographic vicinity. Consequently, the percentage of grain captured by the system in the innermost zone will typically be quite high. However, as the distance from the subterminal increases, the percentage of grain captured by the system will generally decline. This is because at greater distances the attractive power of the subterminal tends to weaken and nonmember elevators begin to compete directly with nearby satellite elevators rather than with the subterminal itself.

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[54]A given subterminal-satellite system is typically subject to two sources of demand-point competition. The first is from noncooperative or "nonmember" elevators located within the subterminal's trade area. The second is from elevators or competing subterminals which lie outside of the subterminal's market boundary and which apply competitive pressure at the periphery of the trade area.

Also, as the distance from the subterminal increases, competition from independent elevators located at the fringe of the market area (as well as competition from neighboring satellite-subterminal systems) tends to intensify. The zones of subterminal market power (shown in Figure 8) tend to reflect these dynamics, depicting a decline in market share with distance.

In the Devils Lake study, the boundaries of the market zones (as well as the percentage of grain captured within each zone during the impact year) were defined by the subterminal manager. These are admittedly subjective estimates, subject to considerable uncertainty. However, they are a useful starting-point for developing "ballpark" estimates of potential impacts and pointing-out the general nature of expected changes in the region. In the Devils Lake study, the manager's forecasts were used to estimate the probable scope and magnitude of the subterminal's traffic effects in different parts of the region. This "rough-cut" analysis is discussed next.

Scope of the Impacts

The allocation of grain between system and nonsystem elevators in 1984 (the year prior-to the construction of the Devils Lake subterminal) was estimated from Upper Great

Plains Transportation Institute grain and oilseed movement statistics[55]. Of the estimated 9.3 million bushels handled by the facilities located in or near the innermost market zone, only 44 percent was captured by elevators in the system[56]. This compares to a projected market share of 75 percent (for the cooperative system) in 1990.

The additional 2.9 million bushels translates into roughly 6,400 annual farm truck trips in Zone 1 alone. Of the additional 2.9 million bushels, between 35 and 40 percent is projected to flow through the satellites and subsequently through the subterminal (in the form of transshipments). This pattern of flow will result in

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[55]All elevators in the state are required by law to report to the ND Public Service Commission on a monthly basis. The monthly report contains the number of bushels of each commodity shipped to each major destination, broken-down by truck versus rail. The UGPTI processes and maintains the data base. In the Devils Lake study, outbound elevator shipments were compiled (from this data base) for each elevator in the region for 1984, 1985, and 1986.

[56]Thirteen elevators are located in or near the periphery of the first (innermost) zone of subterminal market power in the Devils Lake region. Two are situated at Starkweather, two at Devils Lake, and one each at: Crary, Penn, Southam, Rohrville, Doyon, Hamar, Warwick, Garske, and Webster. Six of the elevators became members of the Lake Region Cooperative in 1985. Collectively, these six elevators garnered 44 percent of the 9.3 million bushels shipped by all elevators in the zone in 1984 prior-to the construction of the Devils Lake subterminal.

approximately 1,000 additional CO-5AX trips per year[57]. Similar impacts are projected for zones 2 and 3 (although to a lesser degree).

Because of the magnitude of the potential traffic shifts and the increase in CO-5AX truck usage in the Devils Lake region, it was concluded that significant impacts were likely to arise and that a more detailed analysis was warranted. So the process was continued.

Defining Agricultural Production Zones

The third step in the process of demarcating the impact area consists of subdividing the region into agricultural production or supply zones. Altogether, 54 supply zones were identified in the Devils Lake region (Figure 9). Six major criteria were followed in the definition of the zones.

1. A given zone should be large enough to generate a significant flow, and yet small enough to provide specific information concerning which farm-to-elevator highways are used.

2. Zones should recognize and follow natural boundaries (such as lakes and rivers) wherever possible.

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[57]This information was obtained during an interview with Mr. Alfred Bareksten, Manager of the Lake Region Cooperative, Devils Lake, North Dakota, June 17, 1987, or in subsequent telephone conversations and written correspondence with Mr. Bareksten and employees of the organization.

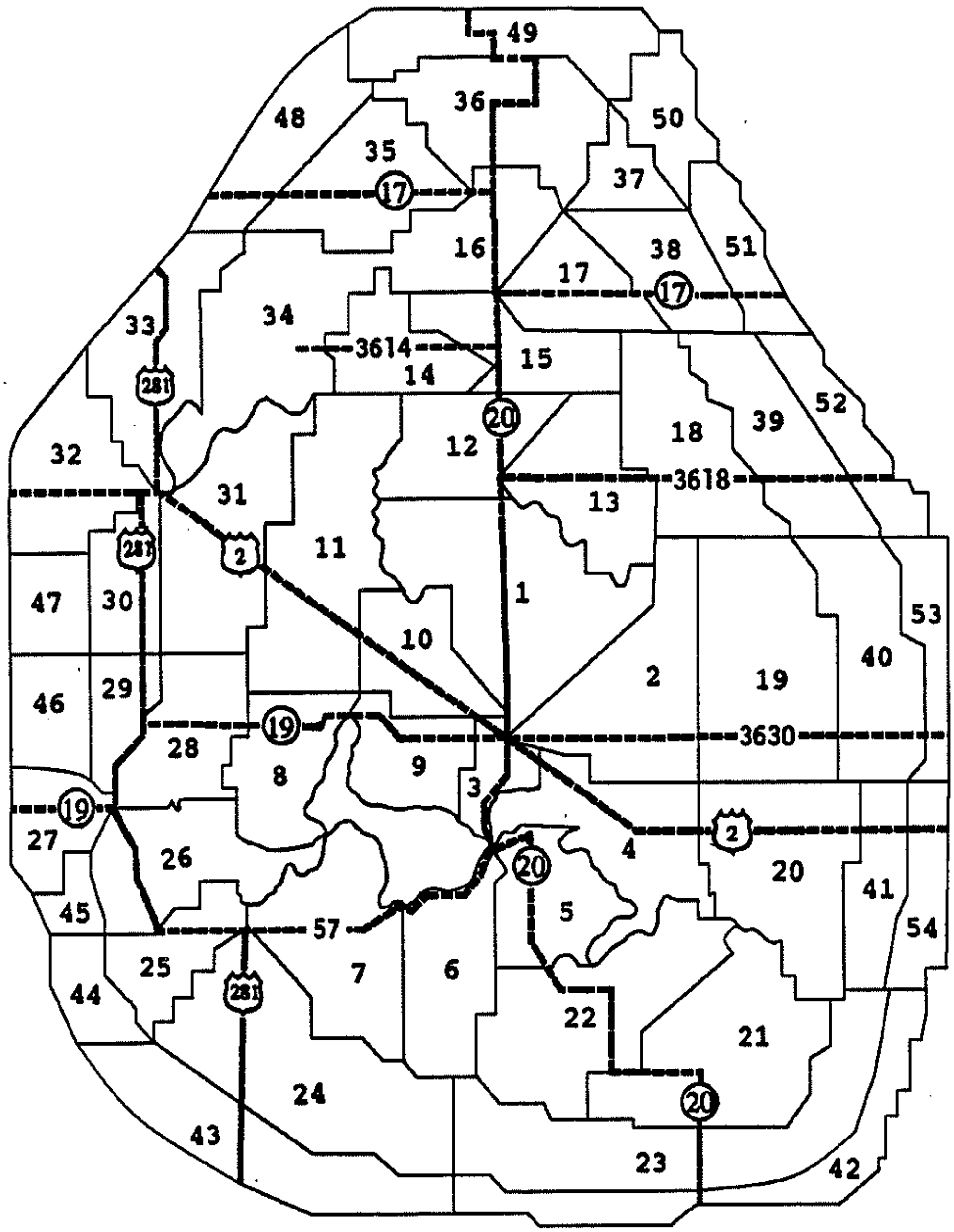

Figure 9. Devils Lake Land Use Zones and Highway Network

3. The boundaries of the zones should consider the coverage and characteristics of the highway network, and if possible include one or more access highways (such as a collector or minor arterial).

4. The zones should be defined so as to facilitate the identification of logical centroids (traffic loading points).

5. Each production zone should fall entirely within the boundaries of a single zone of subterminal market power.

6. The zones should be as homogenous as possible with respect to the types of non-agricultural land-uses present.

In the Devils Lake study, the ideal area of a zone was considered to be 25 square miles or less.[58] However, this figure was adjusted upward or downward depending on the land-uses in the area, the coverage of the highway network, and the amount of land under production.

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[58]One potential basis for identifying production zones is to make them consistent with township boundaries. This may prove desirable in instances where few natural boundaries or variations in land-use or highway attributes exist. However, using township boundaries may fail to consider important natural barriers and may ignore the characteristics of the highway network in the area, both of which can potentially affect grain flows.

In highway impact analysis, it is generally impractical to define every source of traffic generation and identify exactly where it originates or "loads-onto" the first highway link. So typically one or more traffic loading points (centroids) are identified in each agricultural production zone. Each centroid represents a weighted average of the projected traffic loadings in a given zone or area. The use of centroids minimizes the number of possible origin-destination combinations, thereby reducing the data collection and computer resources required.

The Planning Horizon

The horizon year is the farthest year into the future which the analyst can reasonably expect to forecast values for. In subterminal impact analysis, the planning period must be long enough so that it encompasses at least one "typical" replacement cycle but short enough so that forecasts can be made with some degree of assurance. In the Devils Lake study, 21 years was felt to be an appropriate time-frame for the study[59]. Twenty-one years represents the median projected life cycle for rural arterials and

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[59]The actual production forecasts in the Devils Lake case study were made during 1988. So in actuality, the forecast period was 19 rather than 21 years.

collectors in the impact region under baseline traffic conditions[60].

The base year in subterminal impact analysis is the year prior-to or during which the subterminal begins operations. The impact year (on the other hand) is the first year during which **substantial** impacts are generated. If there is a start-up phase in which the subterminal is moving toward long-run output levels, then the impact year may not directly follow the base year. Instead, the impact year may be 3 to 5 years in the future.

The Devils Lake subterminal began initial operations in June of 1985 (the base year). However, the facility had only a minimal effect on grain flows during the last half of 1985. Furthermore, little (if any) change was discernable in grain movements during 1986, and only moderate growth was evident in 1987. Because of the gradual pace of change in the region, 1990 was selected as the impact year.

The subterminal manager was asked to make some operational projections for the impact year based on his

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[60]Some arterials will have much longer service lives (30 years or so) while some collectors will have shorter ones. Of the sample sections in the Devils Lake region, the weighted-average pavement life under current traffic levels (as predicted by the HPMS damage function) was 21 years. This roughly corresponds to a typical design life of 20 years which is frequently used as an objective for flexible pavements.

knowledge of the market area, the cost structure of his elevator, and competition from nonmember elevators in the region. Specifically, he was asked to supply the following information:

1. The anticipated 1990 subterminal volume

   a) A pessimistic estimate
   b) A moderate estimate
   c) An optimistic estimate.

2. Subjective probabilities for each projection.

The subterminal manager's projections are summarized in Table 7 below. Since he gave equal weights or probabilities to each of the forecasts, the expected value of the subterminal's volume in the impact year is equal to the mid-range estimate.

TABLE 7. IMPACT-YEAR SUBTERMINAL VOLUME PROJECTIONS

	Scenario		
	Pessimistic	Mid-Range	Optimistic
Projected Bushels	8,000,000	11,000,000	14,000,000
Probability	.33	.33	.33

Source: An interview with Mr. Alfred Bareksten, Manager, Lake Region Cooperative, Devils Lake, North Dakota, June 17, 1987.

Figure 10 illustrates the gradual pace of growth in subterminal output in the Devils Lake region, starting from a base year volume of 3,614,494 bushels in 1985 and growing to a projected impact year volume of 11 million bushels in 1990. This clearly points-out the need for carefully selecting the impact year and projecting the long-run level of subterminal output (rather than using shipment data for the year following construction).

The purpose of this section of the chapter has been to overview the design of a subterminal impact study and describe the preliminary analyses and tasks involved. The discussion now turns to the topic of analytical modeling and impact assessment.

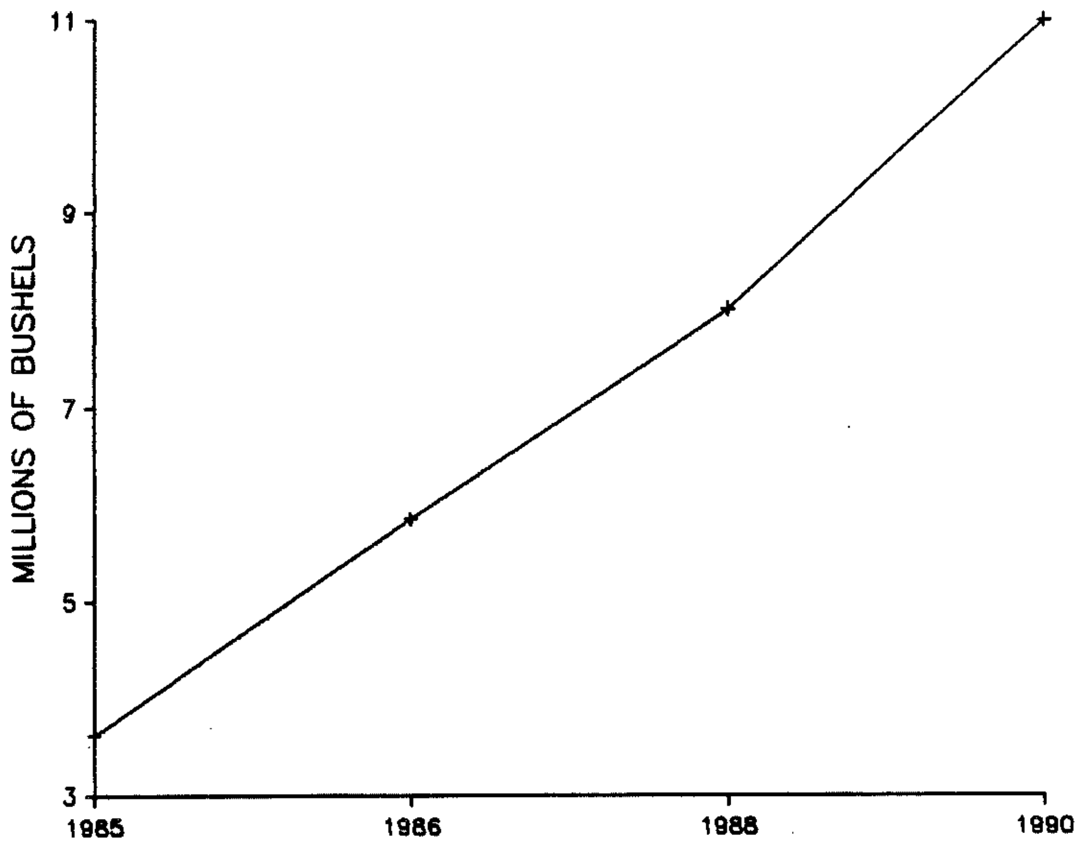


Figure 10. Devils Lake Subterminal Volume - 1985-1990

SUBTERMINAL IMPACT ASSESSMENT PROCESS

As depicted in Table 2 (of Chapter 2), the subterminal impact assessment process entails a battery of submodels or procedures, such that the output of one model essentially becomes the input to the next. The purpose of this section of the chapter is to overview the impact assessment process, and to highlight the major assumptions underlying the models.

General Process Flow

The initial step in the impact assessment process consists of the projection of agricultural production and shipment levels for the base year, the impact year, and the horizon year. Agricultural production estimates must be generated for each supply zone in the region. Outbound commodity shipments must be projected for each elevator, using inbound elevator volumes as a proxy (or some other source of data).

Once production and shipment levels have been estimated, the analyst is in a position to project the level of annual interzonal traffic flows in the region (for each year in the planning period). The projection of interzonal traffic flows is a key step in the impact assessment process because once the interzonal volumes have been forecast, grain flows can be converted to annual truck trips and assigned to the highway network. Then (based on the average axle weights of the vehicles) the annual ESALs applied to each highway section can be computed for each year in the planning period. Once the incremental ESALs have been projected, the analyst is in a position to predict any reductions in pavement service life which might occur and evaluate the need for upgrading impacted highways.

As the previous discussion has pointed-out, subterminal impact analysis involves a sequence of steps, certain ones of which must be completed prior-to the initiation of others. The overall flow of the process and the recommended order of events are depicted in Figure 11. As a complement to Figure 11, a more detailed synopsis of the major steps involved is presented in the following subsection of the chapter. It is hoped that this narrative (in conjunction with the flowchart) will help guide the reader through the detailed description of the analytical procedures which is to follow.

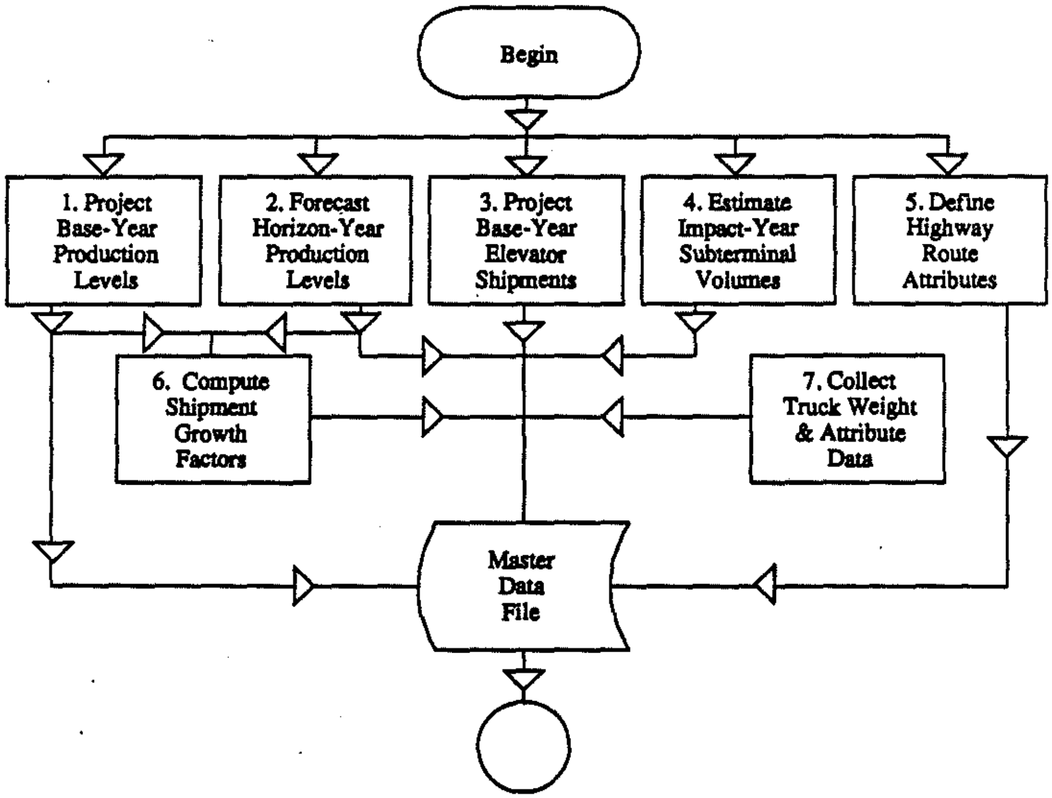


FIGURE 11. FLOW OF SUBTERMINAL IMPACT ASSESSMENT PROCESS

LEGEND:

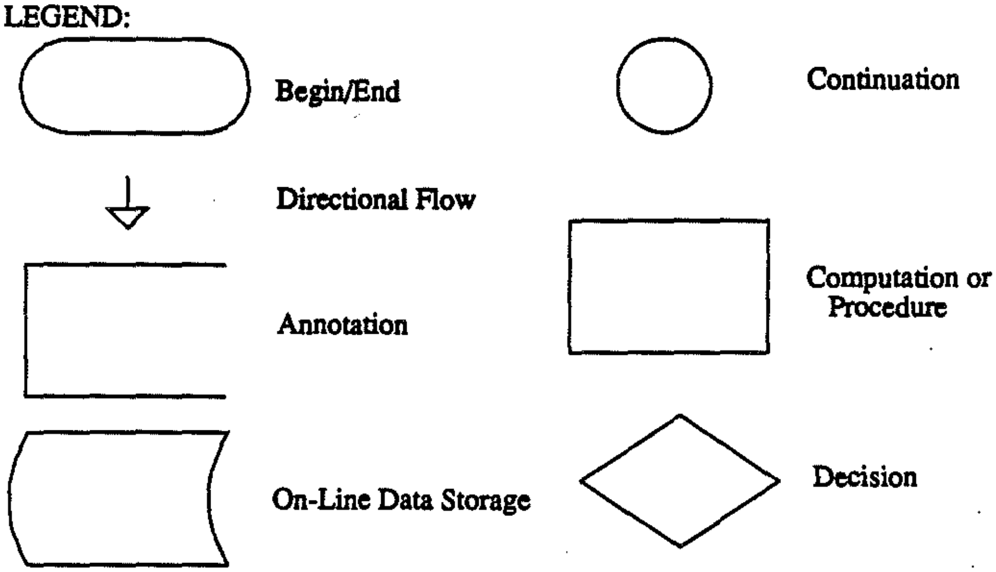


FIGURE 11 - cont.

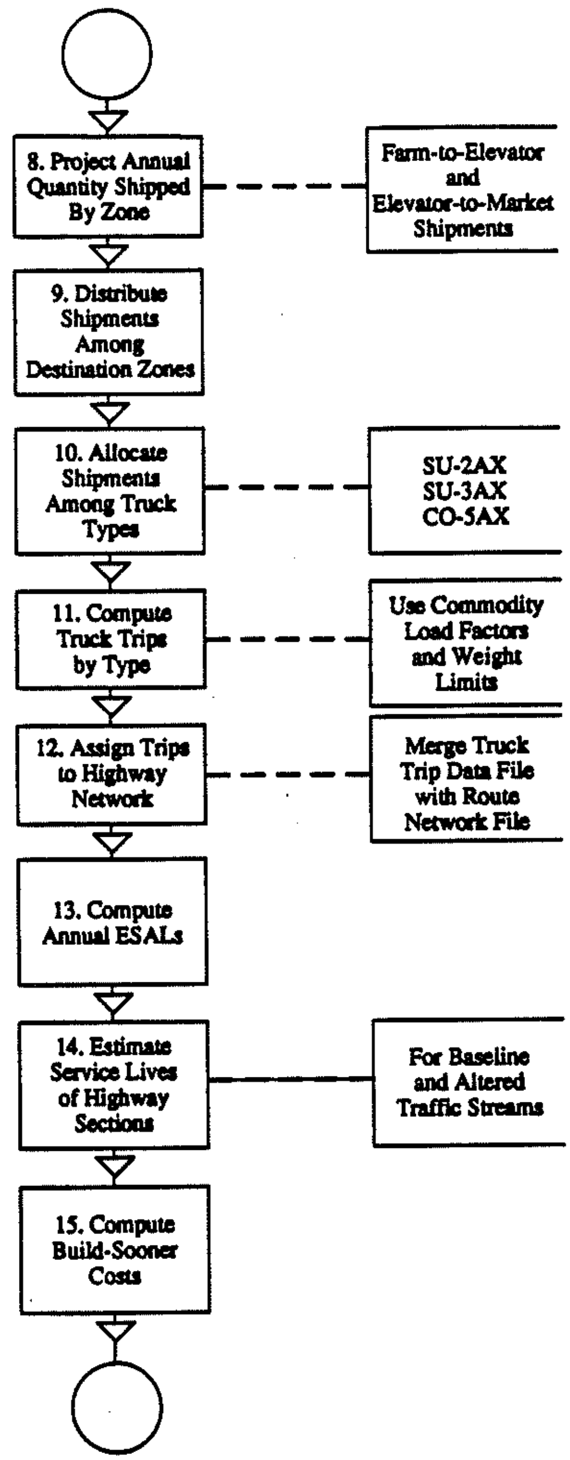
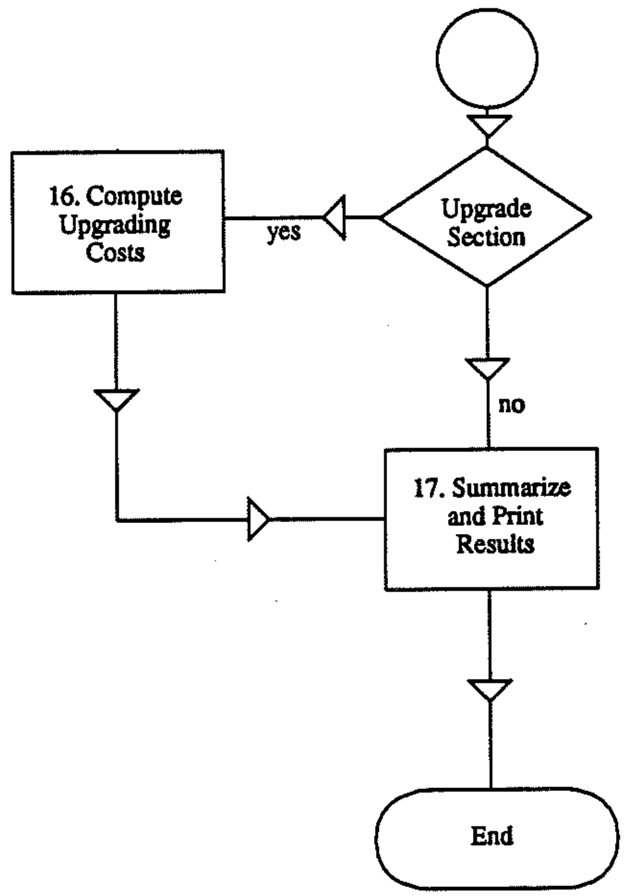


FIGURE 11 - cont.



Overview of the Impact Assessment and Computational Process

In summary form, the subterminal impact assessment process entails the following steps or computations.

1. Base year production levels are projected (by commodity) for each agricultural supply zone in the region.

2. Horizon year production forecasts are developed (by commodity) for each supply zone.

3. Annual growth factors are computed for each commodity in the impact region.

4. Zonal production levels are estimated for each year in the planning period (using the annual growth factors and base year production projections).

5. Base year and impact year shipments are estimated for each elevator in the impact region.

6. Farm-to-elevator traffic flows are modeled for both the base year and the impact year.

7. Outbound (elevator-to-market) flows are simulated for the base year and the impact year.

8. Annual (unadjusted) interzonal volumes are projected for each flow-type for the duration of the planning period.

9. The projected annual interzonal volumes are adjusted for changes in production levels over time.

10. The projected (annual) commodity flows are distributed among grain truck types.

11. The projected annual flows are converted to annual trips (by truck class).

12. Axle load factors are computed for each annual flow (by truck type).

13. The projected annual trips are assigned to the highway network.

14. The annual level of grain truck ESALs is calculated for each year in the planning period (for each highway in the impact study).

15. The ESAL life of each highway section is projected for the baseline traffic stream and the impact scenario.

16. Any reductions in pavement life which occur during the current replacement cycle are computed for each highway section.

17. Any build-sooner costs which might result are estimated in the manner described in Chapter 3.

18. Each section is evaluated with respect to the need for upgrading.

19. Upgrading costs (if applicable) are computed using a modification of Purnell's method.

Major Assumptions

Not all environmental forces or factors can be accounted for in subterminal impact analysis. So some simplifying assumptions are usually necessary. The assumptions made in the Devils Lake study relate primarily to the future state of technology and prices.

The grain handling and transportation system has only recently undergone a major restructuring in which subterminal-satellite systems have emerged and unit-train rail services have become dominate. This long-term process of rationalization is likely to continue and expand in the future, and the technology of the system is likely to remain at its current level for several years. No new railroad at its current level for several years. No new railroad technology is envisioned which will substantially alter the process of elevator rationalization.

The major change in the rail industry will consist of the development of short-line railroads in some areas of the Upper Great Plains. Due to low labor and operating costs, short-lines will be able to offer localized services, and perhaps implement elevator-to-elevator rates which will allow subterminal managers to bring grain into their facilities by rail. If this shipping pattern develops to any extent in North Dakota, it will change the transshipment equation dramatically, reducing the highway impacts of CO-5AX trucks.

No short-line carriers are currently operating in the Devils Lake region. However, a recent study by Tolliver, Dooley, and Zink (1988) determined that part of the rail network in the area could effectively be operated as a short-line system[61]. So while there is no evidence at

[61]The study estimated that by operating existing Burlington Northern branch lines as a short-line network, an independent operator in the Devils Lake region could realize a 35 percent reduction in the cost per car handled. The BN has indicated that they have been approached by several potential buyers looking to purchase parts of the branch line network in northern North Dakota. However, talk of sales is just speculation at present, as no pending transactions have been revealed. The importance of the short-line factor in subterminal impact analysis depends upon two basic items: (1) the disposition of pending legal decisions and possible legislation concerning the formation

present to suggest that a short-line network will be formed during the analysis period, it remains a possibility. Therefore, a short-line scenario has been analyzed in the study.

A new organizational structure is not likely to evolve in the North Dakota elevator industry during the foreseeable future. However, there are possible variations on the cooperative subterminal-satellite elevator model employed in this study which need to be addressed. For example, Cobia (1986) feels that many satellite elevators will become obsolete and fail to survive. If this trend is realized, it will mean that more direct farm-to-subterminal shipments will occur. This possibility is evaluated in the Devils Lake study through means of scenario analysis.

Commodity prices are extremely difficult to forecast because they are a function of a variety of market forces

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is currently waging over whether the labor protection provisions of certain legislative acts should apply to the sell of raillines to independent operators. The labor protection articles essentially require that the new operator pay settlements to displaced or dislocated railroad workers. In many instances, the settlements could amount to six years of pay plus railroad retirement. The general feeling is that the implementation of these standards would act as a capital barrier to short-line formation and would effectively end the short-line movement. Even if short-lines continue to form, there is no clear evidence as yet that they can capture the short-haul truck market (e.g. transshipments). Sufficient data regarding truck and short-line cost relationships are not available at present.

and government policies. In the Devils Lake study, elevator bid prices were assumed to remain constant over the analysis period. This assumption is not as critical as it would first appear. It is the price relationships between elevators (rather than the actual level of commodity prices over time) which are important. Within the subterminal-satellite system, the price at the satellite is a function of the subterminal price and the grain trucking cost. So the critical relationship over time is the relative price between the subterminal elevator and nonmember elevators in the region. Once the subterminal has achieved its long-run operating level and optimal flow pattern, price relationships should not change appreciably during the analysis period.

Two other important assumptions were made in the Devils Lake study. First, it was assumed that no other subterminals would be built in the Devils Lake region during the planning period. The historic pattern of subterminal development in North Dakota tends to support this contention. Typically, a given market can only support one major facility. As a result, subterminals are generally spaced so that they form separate (although sometimes overlapping) trade areas. Second, it was assumed that the state of motor carrier technology and the types of trucks used to transport grain would remain essentially the same over the analysis period. An important consideration here concerns the use of CO-5AX trucks to transport grain from farms-to-elevators in the future. As will be detailed later in this chapter, CO-5AX trucks may (under certain circumstances) assume a greater role in farm-to-elevator transport. This, in turn, may have serious implications for highway impacts. So a scenario which analyzes this possibility has also been developed.

The purpose of this section of the chapter has been to describe the flow of the impact assessment process and to highlight the major assumptions of the study. The chapter now turns to a detailed description of the submodels, starting with the land-use procedure.

LAND-USE SUBMODEL

The purpose of the land-use submodel is to define the potential volume or flow from each zone. To accomplish this objective, the analyst must make two fundamental projections. First, the base-year level of supply must be estimated using production and land-use data. And second, the level of supply in future years must be approximated.

The technique used in the Devils Lake case study to estimate the base-year level of supply consists of three steps or computations. In the first step, the number of acres under cultivation in each zone was estimated from land-use maps. Second, the cultivated acres in each zone were allocated among the various crops grown in the region based on historic production levels. For example, if barley comprised 40% of the historic production in the county where the zone was located, then 40% of the cultivated acres in the zone were allocated to barley production. In the final step, the crop production levels in each zone were computed by multiplying the number of acres of each crop under cultivation by the average county yield per acre[62].

Horizon-year forecasts were developed in the Devils Lake study through means of a Delphi survey. A committee of six persons was assembled, each familiar with agricultural policy and production expectations in the region. The committee was supplied with historic production statistics and trends, and asked to estimate production levels (by commodity) for the year 2006. But instead of a single estimate, the participants were asked to supply a range of

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[62]Historic production and crop yield data were obtained from a series of reports entitled: North Dakota Agricultural Statistics, 1984--1987, published by the North Dakota Agricultural Statistics Service, Fargo, ND. The extent of non-agricultural land-uses in the area and the approximate number of acres under cultivation in each zone were developed from land-use maps published by the U.S. Geological Survey, and/or from highway maps published by the NDHWD.

estimates (low, medium, and high) which might occur given different policy, market, and weather assumptions. Each participant was then asked to attach probabilities (or likelihoods) to each of the three scenarios. Using these probabilities, an "expected value" of future production levels was calculated.[63]

The output of the land-use submodel consists of an estimate of the number of bushels of each crop produced in each agricultural zone during the base year and the horizon year. These data constitute one of the major inputs to the shipment generation submodel, the next model in the chain.

SHIPMENT GENERATION SUBMODEL

The shipment generation model has a dual purpose. The first objective of the model is to predict the volume generated from each agricultural production zone in the region for each year of the analysis period. A second (and related) objective is to project the outbound volume from each elevator during each year of the planning period.

The shipment generation model is analogous to (although different from) the trip generation model in urban

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[63]The Delphi forecasts were complied on a county basis. The horizon year production levels for each zone were estimated by assuming that the rate of growth (or decline) in county agricultural production (over the planning horizon) would hold true for each zone in the county.

transportation planning. The essential difference between the two is that the shipment generation model is concerned with predicting the **volume** or quantity shipped from each zone rather than the trips. The rationale for this variation is as follows.

The number of annual trips required to haul a fixed volume of a particular commodity (from a given agricultural zone) will depend upon the type of truck which is used. Thus the number of trips cannot be determined until the annual quantity shipped is projected and allocated among flow-types 1 and 2. So a logical sequence of events in the of modeling farm-to-elevator shipments is:

1. the volume available for shipment in each supply zone is projected (from production data);
2. the potential volume in a given agricultural zone is distributed among flow-types and destination zones based on the prices at competing elevators, the farm trucking costs, and other trip-making factors;
3. the interzonal commodity flows are distributed among truck-types, based on projected usage patterns;
4. interzonal truck volumes are converted to truck trips using average commodity payload factors.

The initial step in the process consists of projecting the level of shipments generated from each production zone (and each elevator) for two intervals in time: the base-year and the horizon-year. Once the base-year and horizon-year shipments are known, the analyst can project the volumes generated during each year of the analysis period.

Computation of Base-Year and Horizon-Year Volumes

An initial (and perfunctory) step in the estimation of base-year and horizon-year volumes is the conversion of crop production estimates (which are in bushels) to hundreds of pounds (cwts). This conversion is necessary so that the projected volumes can later be translated into truck trips, and so that axle weights (which are expressed in thousands of pounds) can be calculated. Although this is a relatively unimportant (and assumed) step, it is presented here so that the basic notation which is used throughout the remainder of this section can be introduced.

Algebraically, the computation of the base-year shipment volume for a given agricultural production zone in the impact region is given by:[64]

$$VB_{co} = BB_{co} \bullet CF_c \qquad (39)$$

[64]This formulation implicitly assumes that all grains and oilseeds produced in a given zone will be shipped-out during the same year. This is not completely true, because some on-farm storage will occur, plus there will be a natural time-lag involved. But so long as the hold-over and the time-lag are consistent from year-to-year, the computation shown in equation (39) will be approximately correct.

where:

VB_{co} = Base-year volume of commodity "c" generated from zone "o"

BB_{co} = Bushels of crop "c" produced in zone "o" during the base year

CF_c = Factor for converting bushels of commodity "c" to hundred-pounds (cwts)

Similarly, the horizon-year volume generated from a given production zone is computed as:

$$VH_{co} = BH_{co} \cdot CF_c \qquad (40)$$

where:

VH_{co} = Horizon-year volume of commodity "c" generated from zone "o"

BH_{co} = Bushels of crop "c" produced in zone "o" during the horizon year

The conversion factor in the formula (CF_c) reflects the density of the commodity being shipped. The conversion factor is computed for a given commodity as follows:

$$CF_c = LB_c / 100 \qquad (41)$$

where:

LB_c = The pounds per bushel of commodity "c"

In order for the base-year and horizon-year estimates to be turned into annual traffic projections, the analyst must compute a shipment growth factor which translates the total increase (or decrease) in production between the base year and the horizon year into an annual increase (or decrease) in quantity shipped.

Computation of Shipment Growth Factor

Two types of traffic effects will be felt in the impact area during the analysis period. The first effect is due to the redistribution of existing volumes among flow-types. For example, some portion of the base-year farm-to-elevator volume may shift to flow-type 2 at some time during the analysis period. This change is strictly a function of the establishment of a subterminal elevator in the area. But the traffic flows generated in the region may also change during the analysis period due to variations in production levels or crop patterns over time. These effects have nothing to do with the location of a subterminal elevator[65]. Nevertheless, they are important to the analysis because

[65]The level of production or supply in the impact region is primarily a function of exogenous factors. The final market demand for the commodity, the nature of government programs and policies, and the weather and local production conditions will determine the amount which is produced in the impact region. The subterminal elevator itself will not affect the level of supply or the types of commodities grown. The major effect of the subterminal will be to redirect the allocation of supply among competing elevators.

they will compound any traffic impacts which are generated from subterminal development.

The purpose of a shipment growth factor is to calculate the increase (or decrease) in traffic which occurs during each year of the analysis period due to changes in regional production levels. A shipment growth factor may conceivably take many different forms (linear or nonlinear). In the Devils Lake study, the following functional form was used to represent the annual growth in shipments over time[66]:

$$GF_c = (VH_c/VB_c)^K \qquad (42)$$

where:

GF_c = Annual volume growth factor, commodity "c"

$K = [\ln(VH_c/VB_c)]/N \qquad (43)$

N = Number of years in planning period

Computation of Yearly Shipment Volumes

Given the base-year volume and a shipment growth factor, it is possible for the analyst to predict the volume which is generated from each production zone during each year of the analysis period. The volume shipped from a

[66]Adapted from FHWA (1986).

given production zone during any year other than the base year is computed as:

$$V_{coy} = V_{co(y-1)} \bullet e^{K} \qquad (44)$$

where:

V_{coy} = The predicted volume of commodity "c" shipped from production zone "o" during year "y"

$V_{co(y-1)}$ = The predicted volume of commodity "c" shipped from production zone "o" during year "y-1"

Equation (44) represents the basic formula used to project annual farm-to-elevator commodity flows in the Devils Lake region. But equation (44) represents only one part of the traffic generation procedure. Outbound elevator volumes must also be projected for each year in the analysis period.

In subterminal impact assessment, a given elevator can constitute both an originating and a terminating zone. So in order to avoid confusion, some new notation must be introduced. In the case of inbound commodity flows (where the elevator functions as a destination zone) a given facility is denoted by the subscript "d." Thus, the inbound commodity volume for any given year in the analysis period is given by:

$$V_{cdy} = \sum_{o} V_{cody} \qquad (45)$$

where:

V_{cdy} = Annual inbound volume of commodity "c" to elevator "d" during year "y"

V_{cody} = Annual volume of commodity "c" shipped from origin zone "o" to elevator "d" during year "y"

As equation (45) suggests, the inbound flow to a given elevator is equal to the sum of the flows from each origin zone in the market region. This balance condition will become very important later in the chapter when the traffic distribution submodels are introduced.

In the case of outbound commodity shipments (where the elevator functions as an originating traffic centroid) a given facility is denoted by the subscript "e." Outbound elevator volumes are primarily a function of two items: the inbound elevator flows and the amount of grain which is stored or held-over during the year. Thus, the outbound flow from a given elevator for a given year in the analysis period may be computed as follows:

$$V_{cey} = V_{cdy} - ST_{cey} + ST_{ce(y-1)} \qquad (46)$$

where:

V_{cey} = Outbound volume of commodity "c" during year "y"

V_{cdy} = Inbound volume of commodity "c" during year "y"

ST_{cey} = Inbound quantity of commodity "c" which is not reshipped from elevator "e" during year "y"

$ST_{ce(y-1)}$ = Quantity of commodity "c" held-over from previous year at elevator "e" which is reshipped during year "y"

The primary function of grain elevators in North Dakota is the merchandising of grain (as opposed to storage). So it is reasonable to assume that most of the volume which flows into an elevator during a particular time-period will flow out shortly thereafter (Zink and Casavant, 1984). So while there may be a time-lag involved, the outbound flows should closely approximate the inbound flows for a given year. Even if there is a sizable volume lag or holdover, so long as it is consistent from year-to-year the predicted result will be approximately correct. So with little loss of explanatory power, equation (46) may be condensed to:

$$V_{cey} = V_{cdy} = \sum_{O} V_{cody} \qquad (47)$$

The output of the shipment generation submodel is a year-by-year estimate of the volumes of each commodity shipped from each production zone as well as from each elevator in the region. The next submodel in the chain (the shipment distribution model) allocates these predicted flows among the competing destination zones.

SHIPMENT DISTRIBUTION SUBMODEL

The shipment distribution procedure lies at the heart of the impact assessment process. Because of its importance, the mechanics of the process and the choices which are open to the analyst will be covered in some detail. The intent of the discussion is to: (1) present a synopsis of the models which were evaluated during the study; (2) summarize the chief benefits and drawbacks associated with each technique (so that future analysts will have a base of information from which to work when selecting an appropriate grain modeling procedure); and (3) document the basic modeling techniques which were used in the Devils Lake case study.

So that the flow of the chapter will not be broken, most of the background material concerning the advantages and disadvantages of alternative analytical techniques is presented in Appendix D. The text in this section of the chapter contains a summary of the evaluation process and a brief overview of the theory behind the models.

Modeling Dimensions

The basic purpose of the shipment distribution procedure is to project **interzonal** traffic volumes for each year in the planning period. The modeling process has four major dimensions which will be discussed in this section:

1. the type of flow,

2. the motivations of the traveler or shipper,

3. the time at which the trip occurs,

4. the scope of the analysis.

The shipment distribution procedure must allocate both inbound (farm-to-elevator) shipments and outbound (elevator-to-market) flows among competing destinations. In the case of inbound flows, the competing destinations are the elevators and the transporter is generally the producer. The primary motivations of the farmer are:

1. to maximize the net price received for the commodity (the elevator price minus the farm truck cost),

2. to minimize the time and inconvenience associated with travel (particularly during periods of peak work demand, such as harvest).

In addition (as is discussed in Appendix D), the farmer may patronize certain elevators because he or she is a member of a local cooperative.

In the case of outbound flows, the destination is another elevator, a processing center, or a terminal market, and the shipper is an elevator manager. The primary motivation of an elevator manager is to maximize the net price received for a given commodity (the market price minus the distribution cost). Since market demand and commodity prices are beyond the control of elevator managers, their major concern is with minimizing distribution costs between the elevator and each market where grain is sold. The motivations of a general (subterminal) manager of a trainloading cooperative are fundamentally the same as those of the elevator manager except that he or she is concerned with minimizing distribution costs for the system of elevators as a whole. This objective is consistent with (although not necessarily the same as) minimizing the cost from any given elevator in the system.

The shipment distribution analysis must allocate inbound and outbound elevator volumes in the base year, the impact year, and all other future years. The distinction between time-periods is important for several reasons. First, the base-year represents a pre-subterminal environment. As such, the traffic patterns are likely to be different than in the impact year (or any other future year), when there may be substantial levels of transshipments. Second, more information is typically known in the base-year than in the impact year. The actual volume handled at each elevator in the impact region, the amount shipped to each market, and the actual production levels in the region are known. All of these values must be forecast for future years. The existence of more data in the base-year generally means that more modeling options are available and that a more accurate projection technique can be devised.

The question of scope is concerned with whether all elevators within (or near) the subterminal impact zone are included in the model, or whether only the members of the cooperative are modeled. The data requirements and computing resources are likely to be much greater under a region-wide analysis than for a system-only study. For example, there are only nine elevators in the Lake Region Cooperative. However, there are 24 elevators altogether located within or near the periphery of the subterminal's trade area. The choice which the analyst faces here is essentially a tradeoff between resource costs and accuracy, as detailed in Appendix D.

Modeling Techniques

As noted in Chapter 3, there are two broad classes of models which might be applied to the problem of traffic flow distribution: (1) spatial interaction models, and (2) optimization models. There are advantages and disadvantages to each. Furthermore, the utility of each type of model depends (to a certain degree) on the type of flow, the time-period, and the scope of the analysis. The possible uses of each model are presented in Appendix D, along with a discussion of the underlying theory and behavioral assumptions. The objective of the discussion here is simply to summarize the different procedures and describe the functions which were used in the Devils Lake study. The discussion begins with an overview of optimization models and their potential role in subterminal impact analysis.

Two types of optimization models are of particular importance in analyzing grain shipments. The first is a farmer (or producer) optimization model. The second is an elevator or cooperative (system) optimization model. The former relates to inbound elevators shipments, the latter to outbound elevator traffic.

Two producer optimization models are fully developed in Appendix D: (1) a net farm price (NFP) maximization model, and (2) a farm truck cost (FT) minimization model. Both models are formulated as "transportation problems", meaning that they can be stated in a mathematical programming format and solved by a computer algorithm. The logic of either model fits (at least to some degree) the primary motivations of the producer. However, both models tend to ignore the effects of travel time and patronage on producer delivery decisions. For example, in the NFP maximization model, a producer will theoretically be indifferent between an elevator which is two miles away and one which is 100 miles in distance, provided that the two have the same net farm price. But this is an illogical conclusion when the value of a farmer's time, the inconvenience associated with long-distance delivery, and the impacts of patronage are considered. The producer optimization models (in addition) are premised on the assumptions of linearity and determinism, neither of which may be very appropriate in the context of farm-to-elevator transport.

In lieu of optimization models, farm-to-elevator flows can be modeled with a spatial interaction model similar to that presented in equation (11) of Chapter 3. The spatial interaction model has several advantages (which are detailed in Appendix D), the most important of which are:

1. it can be easily formulated as a nonlinear problem,

2. it is especially designed for a zonal level of analysis or aggregation,

3. it accounts for the effects of demand-point competition on various producers within a given agricultural zone.

Outbound elevator flows can also be modeled with a spatial interaction model. However, as detailed in Appendix D, the shipment problem of a subterminal-satellite elevator system is more aptly formulated an as optimization problem.

A special type of transportation model (the transshipment model) is particularly well-suited to handle the combinations of routings and outbound flows which exist within a cooperative system of elevators.

Base-Year Farm-to-Elevator Shipment Distribution Model

The purpose of the base-year shipment distribution procedure is to simulate interzonal traffic patterns prior to the development of a grain subterminal in the region.

The primary objective of the analysis is to build a frame of reference for evaluating changes (or potential changes) in traffic patterns caused by the subterminal. But the base-year analysis meets another important objective: to estimate the grain truck trips at various locations in the impact area.[67] This latter objective cannot be achieved entirely within the bounds of the shipment distribution submodel, for it requires that shipments be allocated among truck types and routed over the highway network.

[67]Recall from Chapter 2 that grain truck traffic is normally not identified during the vehicle classification and weigh-in-motion process. As a result, the analyst will probably need a method of approximating grain truck AADT at monitoring sites throughout the region. This can be achieved through the modeling process described in this chapter, starting with the shipment distribution submodel and culminating with the network assignment procedure.

Nevertheless, the estimation process begins with the base-year shipment distribution model.

The isolation of grain truck traffic within the baseline traffic stream is quite important in subterminal impact analysis because the formation of a subterminal-satellite system will change the **existing** pattern of flows (as well as create new ones). As a result, the analyst will have to reallocate some of the baseline grain truck traffic to other highways and routes during the impact year. This can only be accomplished if the approximate number of average annual daily trips (AADT) accumulated by grain trucks is known for each monitoring site in the region during the base year.

The base-year shipment distribution procedure in the Devils Lake study employs a modified version of the spatial interaction model introduced in Chapter 3. The model was modified for three basic reasons:

1. to formulate the allocation process as a nonlinear problem,
2. to account for detailed information concerning elevator shipments which were available in the base year,
3. to apply regional supply and demand constraints to the model.

Farm-to-Elevator Impedance Function

The impedance function in equation (11) of Chapter 3 was represented by farm truck cost (FT_{od}). In this theoretical model, the transport impedance was implicitly assumed to be a linear function of distance (with an origin intercept). Thus the farm truck cost between a given supply zone and elevator was given by:

$$FT_{od} = FM \cdot D_{od} \qquad (48)$$

where:

FM = the unit cost per mile ($1.038)

D_{od} = distance between zones "o" and "d"

However, the assumption of linearity may not be appropriate within the context of farm-to-elevator shipments. Farm truck costs per se may a linear function of distance[68]. However, the impedance function must also reflect:

1. the value of the farmer's time,
2. the inconvenience, boredom, and fatigue associated with long-distance travel,
3. the effects of patronage on delivery decisions.

[68]Fuel costs, maintenance, depreciation, and most other elements of farm truck costs can logically be stated on a per-mile basis. An imputed wage per hour (based on comparable trucking wages for local movements) can also be computed and placed on a per-mile basis. However, the imputed wage will not necessarily capture the value of the producer's time or the inconvenience associated with travel.

Because of these effects, the farm-to-elevator impedance function is likely to be nonlinear in nature. So equation (48) may be more appropriately stated as:

$$FT_{od} = FM \bullet D_{od}^{x} \qquad (49)$$

Farm-to-elevator traffic flows have not been subjected to the same detailed empirical analysis or scrutiny as urban flows. So there is no empirical basis for the selection one form of the impedance function over another. However, there is an intuitive rational which tends to support the use of a power function with an exponent of 1.5.

The calibration of urban transportation models has been a common practice in the past, wherein the exponent of the power function has been empirically-derived. The work or business trip in urban transportation is perhaps the closest corollary to the farm-to-elevator trip in rural transportation. In both instances, the traveler wishes to minimize the distance, travel time, and cost of the journey. Blunden and Black (1984, page 60) note that the exponent for the work-related urban trip is usually found in the 0.5 to

2.5 range. Thus 1.5 would represent a mid-range estimate[69].

Graphic inspection of the impedance curves formed by exponents in this range tends to support the analogy presented above. Figure 12 presents a plot of three impedance functions at various distances, using Griffin's (1984) industry unit cost of $1.04. As Figure 12 portrays, the transport impedance (which is perceived by producers when delivering their crops to elevators) varies considerably with the value of the exponent over a range of distances. An exponent of 2.0 places a relatively high impedance on any movement over 30 miles. This probably reflects the situation which exists at harvest time, where the opportunity cost of a farmer's time is quite high. However, at other times during the year, when the demands on a producer's time are much less, an exponent of 2.0 might overstate the trip impedance. A modest price differential in off-peak periods might induce the producer to travel much farther than during harvest (perhaps up to 50 miles). So an exponent of 1.5 appears be a happy compromise, reflecting the average tendency during the year.

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[69]This analogy is not intended to justify the selection of the farm-to-elevator exponent (in absolute terms). It is only meant to show that an exponent of 1.5 falls clearly within the range of what has been found to be reasonable in previous studies.

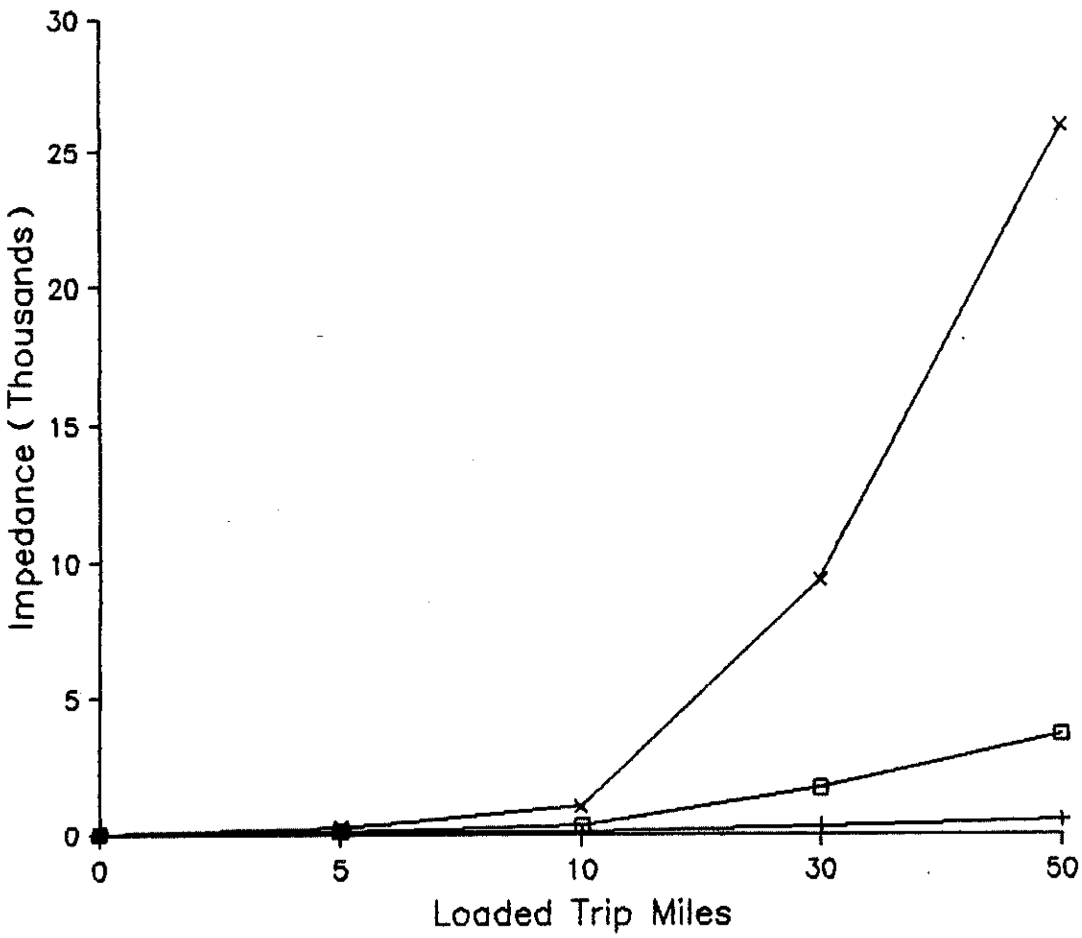

Figure 12. Plot of Farm-to-Elevator Impedance Functions

Legend: X=1.0 X=1.5 X=2.0

On the basis of the argument presented above, a power function of 1.5 was used to represent the impedance function in the Devils Lake study.

Revised Spatial Interaction Model

The following information was known (or estimated) for the base year (1985) in the Devils Lake region:

1. the amount of each commodity available for shipment in each production zone (S_{coy}),
2. the amount of each commodity shipped from each elevator in the region ($V_{cey} \approx V_{cdy}$),
3. the total amount shipped from all production zones in the region, by commodity (S_{cy}),
4. the total amount shipped from all elevators in the region (V_{cy}).

Given this information, it was possible to revise the basic interaction model presented in equation (11) so that a more precise estimate of flows could be developed.

The function in equation (11) represents a supply-constrained spatial interaction model. The formulation of the model ensures that the total quantity demanded at all elevators in the region will equal the total amount shipped from all origin zones. However, there is no destination or demand-constraint in the equation. Since the actual volume handled by each elevator in the base year is known, it makes sense to further constrain the interaction model so that the amount demanded at each elevator equals the sum of the inbound flows (as stated in equation 47). In other words, the spatial interaction model in equation (11) should be reformulated so that:

$$\sum_{d} V_{cody} = S_{coy} \tag{50}$$

$$\sum_{o} V_{cody} = V_{dcy} \tag{51}$$

where:

V_{cody} = Volume of commodity "c" shipped from zone "o" to elevator "d" in year "y"

S_{coy} = Supply of commodity "c" in zone "o" during year "y"

V_{cdy} = Volume of commodity "c" shipped out of elevator "d" in year "y"

Applying both the origin and destination constraints to the model leads to the following formulation:

$$V_{cody} = S_{coy}\ V_{cdy}\ RA_{od} \tag{52}$$

where:

RA_{od} = Relative attractiveness of elevator "d" for supply zone "o", which is given by:

$$A_{od} \ / \ \sum_{d} A_{od} \tag{53}$$

$$A_{od} = P_{cd} \ / \ FT_{od}^{1.5} \quad (54)$$

FT_{od} = Farm truck cost between zones "o" and "d"

Although correct, equation (52) contains a redundant term. The attractive force at zone "d" is represented by the bid price for the commodity (which is part of term A_{od}). However, the attractive force is also reflected in the actual quantity demanded (which is in turn a function of price). So the level of attraction at elevator "d" may be stated as "V_{cdy}", which reflects the bid price for the commodity, the size of the firm, and other measures of economic attraction exerted by the elevator. Consequently, equation (52) may be reformulated as follows:

$$V_{cody} = A_o \ B_d \ S_{coy} \ V_{cdy} \ F_{od} \quad (55)$$

where:

$$Fod = 1 \ / \ FT_{od}^{1.5} \quad (56)$$

A_o = a constant representing the supply constraint

B_d = a constant representing the demand constraint

The term "F_{od}" in equation (55) is generally referred to as a "friction factor." In this form, the spatial interaction model assumes the form a doubly-constrained gravity model which is common in urban transportation analysis. A_o and B_d represent balancing factors which are computed so as to satisfy the origin and destination constraints. The supply constraint (A_o) is derived by substituting equation (55) into equation (50), which yields:

$$\sum_{d} A_o \ B_d \ S_{coy} \ V_{cdy} \ F_{od} = S_{coy} \tag{57}$$

and solving for A_o the result is equation (58).

$$A_o = \frac{1}{\sum_{d} B_d V_{cdy} F_{od}} \tag{58}$$

Substituting equation (55) into equation (51) and performing a similar computation yields the balancing equation for B_d (the destination constraint):

$$B_d = \frac{1}{\sum_{o} A_o S_{coy} F_{od}} \tag{59}$$

The solution to equation (55) is derived through an iterative process. The process is initiated by assuming that the value of B_d equals 1.0 for all zones, and solving for A_o. The values of V_{cody} are then computed, representing the output of the first iteration. In the second iteration, the values of B_d are computed using the calculated values of

A_o from the first iteration. New values are then computed for A_o, and the estimates of V_{cody} are recomputed, concluding the second iteration. This process continues until the value of V_{cody} from the previous iteration is approximately equal to the value of V_{cody} for the current iteration.

Impact-Year Farm-to-Elevator Model

The purpose of the impact-year shipment distribution analysis is to provide a "snapshot" of grain traffic patterns in the impact region under the "altered" traffic stream (the traffic stream which exists after the subterminal has reached its long-run operating volume). As in the case of the base-year analysis, the analyst is concerned with forecasting grain truck AADT at various highway locations throughout the region. If the subterminal has a significant effect on traffic in the area, then several of the sites can be expected to show either an increase or decrease in grain truck AADT.

In the impact year (and other future years) the volume of each elevator is unknown. It cannot be assumed that the elevator volumes will remain the same as in the base year. In fact, they will almost surely change because of the formation of the subterminal. So the model presented in equation (55) cannot be used. Instead, the (original) supply constrained version of the model (presented in equation 11) must be applied.

Elevator-to-Market Model

In the Devils Lake study, the base year shipments from each elevator to each market were compiled from UGPTI grain and oilseed movement statistics (or were collected in a survey administered to the subterminal manager). This approach is feasible for the base-year (where outbound volumes can typically be obtained through survey or from historic shipment records). However, shipments in future years are unknown and must be projected using some modeling technique or forecast. In the Devils Lake study, impact-year (and other future-year) shipments were estimated using the transshipment model detailed in Appendix D.

The transshipment model is a mathematical programming technique which minimizes the distribution cost between a set of origins and destinations. In this study, the objective of the transshipment model is to minimize the distribution cost for the system of elevators as a whole. In doing so, the procedure determines when it is cheaper to transship the grain through the subterminal (as opposed to shipping it directly from the satellite elevators to terminal market). Thus it identifies the optimal allocation of grain between flow-types 3 and 4.

One of the key inputs to the transshipment model is the distribution cost. The distribution costs in the model (TC_{od}) include not only the transportation rate but the cost of double-handling grain at the subterminal (in cases where the commodities are transshipped). The transportation rates may be obtained from rail tariffs (or through interviews with elevator managers). However, double-handling costs usually require a special study.

Zink and Casavant (1982) compiled cost data for various sizes of elevators operating at various levels of output. This data was used to compute unit costs for double-handling grain at elevators in the Devils Lake region. These costs (shown in Table 8) may provide reasonable approximations of elevation costs for other areas in the Upper Great Plains in instances where more specific estimates are not available.

The mechanics of the transshipment model are outlined in Appendix D (and are detailed in Lee, Moore, and Taylor: 1985). The model is simply a special case of the transportation problem (depicted in equation D1 of Appendix D), which utilizes an expanded tableau to derive an optimal solution. The problem is typically solved by a heuristic process. An initial basic feasible solution is obtained using the Northwest Corner Rule, Vogel's Approximation Method (VAM), or the Minimum Cell Cost Method. The initial solution is improved upon through an iterative technique such as the stepping stone or modified distribution method.[70]

The final outputs of the flow distribution submodel are:

1. the allocation of inbound elevator shipments between farm-to-satellite elevator and farm-to-subterminal flows,

2. the distribution of farm-to-elevator shipments among competing elevators,

3. the allocation of outbound elevator flows between transshipments and satellite elevator-to-market shipments, and,

4. the distribution of elevator-to-market shipments among potential markets and processing centers.

While inbound elevator shipments occur exclusively by truck, outbound elevator shipments may originate by rail or by truck. The next step in the process consists of allocating outbound elevator shipments among alternative modes.

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[70]The SAS TRANS procedure (found in the SAS-OR package) was used to derive the optimal solution in the Devils Lake study. For a detailed description of this procedure, see: SAS (1985). Other packages are available which the analyst may wish to evaluate.

Table 8. Cost of Double-Handling Grain and Oilseeds at North Dakota Elevators.

Storage Capacity (Bushels)	Volume Handled (Bushels)	Average Variable Cost per bushel ($)
300,000	5,000,000	.0500
	8,000,000	.0451
	11,000,000	.0430
500,000	5,000,000	.0548
	8,000,000	.0477
	11,000,000	.0445
	16,000,000	.0418
850,000	5,000,000	.0585
	8,000,000	.0493
	11,000,000	.0451
	16,000,000	.0416
1,110,000	5,000,000	.0653
	8,000,000	.0533
	11,000,000	.0477
	16,000,000	.0432

MODAL SPLIT

The distribution of traffic among modes typically depends on a range of variables, including:

1. The service attributes of each mode;
2. The cost of service to the carrier;
3. The relative rates charged; and
4. The cross-price elasticity of demand.

There are a variety of techniques available which may be used to allocate traffic among modes, and a substantial body of literature on the subject. A detailed review of the literature and the models which are available is beyond the scope of this document. For a more detailed development of the theory and a more extensive set of references, the reader is referred to: Kananafi (1983), Dickey (1984), Mannhiem (1980), or Wilson (1981).

Since actual elevator shipments (by mode) were known for the Devils Lake region, a predictive model was not developed. Instead, the distribution of base-year shipments between modes was calculated directly from UGPTI grain and oilseed movement statistics. The modal split in future years was approximated from historic data and market trends. The results of this process (as well as some of the issues involved in modal split analysis) are outlined in the following paragraphs.

In subterminal traffic analysis, the analyst must be concerned with three types of outbound flows:

1. satellite elevator-to-market shipments (#3)
2. transshipments (#4)
3. subterminal-to-market shipments (#5)

Transshipments (flow-type 4) have traditionally occurred by truck. However, short line railroads, with their low labor and train-mile operating costs, may be able to compete with trucks for satellite elevator-to-subterminal traffic in certain markets. For example, the Red River Valley & Western Railroad (a short-line carrier which operates in the south-central part of North Dakota) has instituted elevator-to-elevator rates which are comparable to (and in some instances below) the short-haul truck rate per bushel. In situations where short lines exist, the analyst will have to perform some type of modal distribution for flow-type 4.

However, no short-line carriers are currently operating in the Devils Lake region. So flow-type 4 can be assumed to move exclusively by truck.

Flow-type 5 (subterminal-to-market shipments) occur almost exclusively by rail. Because of lower trainload and/or contract rates, trucks typically cannot compete with railroads in the long-haul market. Less than one percent of the outbound shipments from the Devils Lake subterminal occurred by truck during crop-year 1986-1987[71]. This type of dominance by railroads is typical of the shipping patterns of large subterminals where the rail share is 90 percent or higher[72]. So the analyst is generally safe in assuming a modal distribution of 90-100 percent (or even higher) for outbound subterminal shipments in the Upper

[71]Source: unpublished UGPTI grain and oilseed movement statistics.

[72]This information was developed from unpublished UGPTI grain and oilseed movement statistics. The five largest subterminals in the state all shipped 90 percent or more of their grains and oilseeds by rail. The rail share for the largest facility in the state was 98%.

Great Plains.

While flow-type 3 occurs primarily by rail (in North Dakota), there are still some truck movements. As Figure 13 depicts, railroads have steadily increased their market share in North Dakota, from 73% in crop year 1983-1984 to 79% in crop year 1986-1987[73]. However, there is a practical maximum (in terms of market share) which railroads can hope to achieve. Trucks will always be competitive in short-distance markets (such as movements to domestic processing plants). Thus, the current market split is likely to be reflective of the future allocation of traffic.

Once the highway portion of the outbound elevator traffic has been determined, the forecasted commodity flows can be translated into truck trips. However, a prerequisite to the calculation of truck trips is the distribution of inbound and outbound elevator shipments among truck types.

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[73]Source: unpublished UGPTI grain movement data.

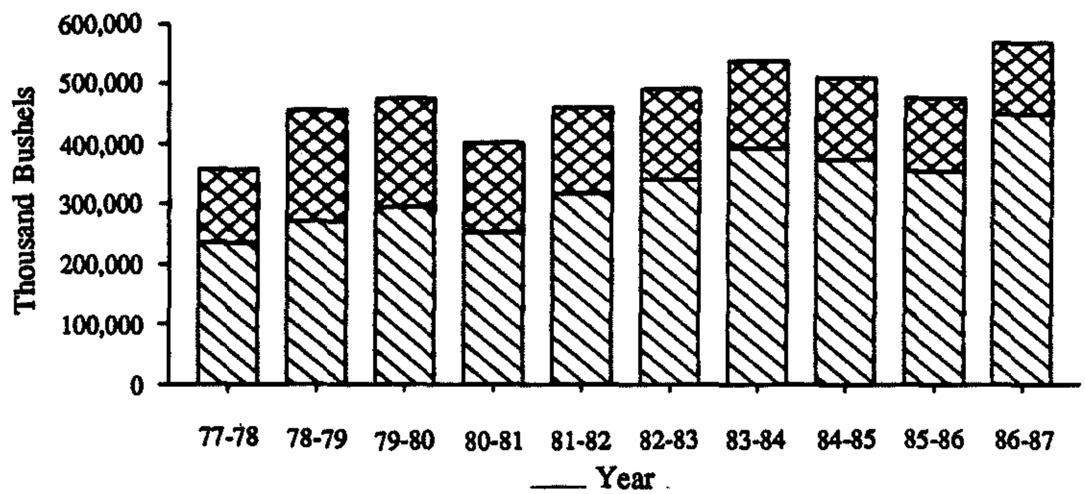

Figure 13. Historic Modal Distribution of Grain and Oilseed Shipments in North Dakota

Source: Upper Great Plains Transportation Institute Grain & Oilseed Movement Statistics.

Legend: TRUCK RAIL

TRUCK DISTRIBUTION SUBMODEL

Recall from Chapter 1 that the frequency of SU-3AX and CO-5AX trucks in the impact area will increase with distance and with the relative proportion of grain moving directly from farms to the subterminal elevator (flow-type 2)[74]. One way for the analyst to estimate the volume of grain shipped in each type of truck is to project the frequency of use in each subterminal market zone.

Table 9 shows the estimated distribution of farm-to-subterminal shipments (by truck-type) in the Devils Lake region[75]. As the data depict, farm-to-subterminal shipments in the area are dominated by SU-3AX trucks. However, there are two other trends which deserve mention. First, as the distance from the subterminal elevator increases, the share of grain shipments in SU-2AX trucks declines. Second, as

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[74]In general, the economies of larger payloads make the SU-3AX and CO-5AX trucks more attractive to farmers over long distances. In addition, the greater payload capacity of the trucks makes them attractive to the subterminal manager. Larger trucks reduce the number of trips required to accumulate a fixed amount of grain, thus minimizing the queuing and unloading time at the subterminal.

[75]This information was obtained during an interview with Mr. Alfred Bareksten, Manager of the Lake Region Cooperative, Devils Lake, North Dakota, June 17, 1987, or in subsequent telephone conversations and written correspondence with Mr. Bareksten and employees of the organization. The estimates were based partly on historic shipment data and partly on the manager's knowledge of the market area.

the distance from the subterminal increases (to around 40 miles) there is an increased tendency towards the use of CO-5AX trucks in the region.

TABLE 9. DISTRIBUTION OF FARM-TO-SUBTERMINAL SHIPMENTS AMONG TRUCK-TYPES IN THE DEVILS LAKE REGION BY MARKET ZONE

		Truck Type		
Zone	Distance Interval	SU-3AX	SU-2AX	CO-5AX
1	25 miles	75%	25%	0%
2	26 to 38 miles	82%	13%	5%
3	over 38 miles	85%	5%	10%

The use of CO-5AX trucks to transport grain from farms to the subterminal elevator is a trend which the subterminal manager expects to see heighten in future years. One possible scenario is that the cooperative will lease or operate a fleet of CO-5AX trucks which will provide pickup service at farms in the area.

The information presented in Table 10 (and graphically in Figure 14) helps to explain why these trends are evident in the data. As Table 10 depicts, the transportation cost incurred by the farmer in a SU-3AX truck is less than the for-hire rate (for a CO-5AX truck) at trip-distances of less than 21 miles. However, at 35 miles the reverse is true, and this trend continues over distance.

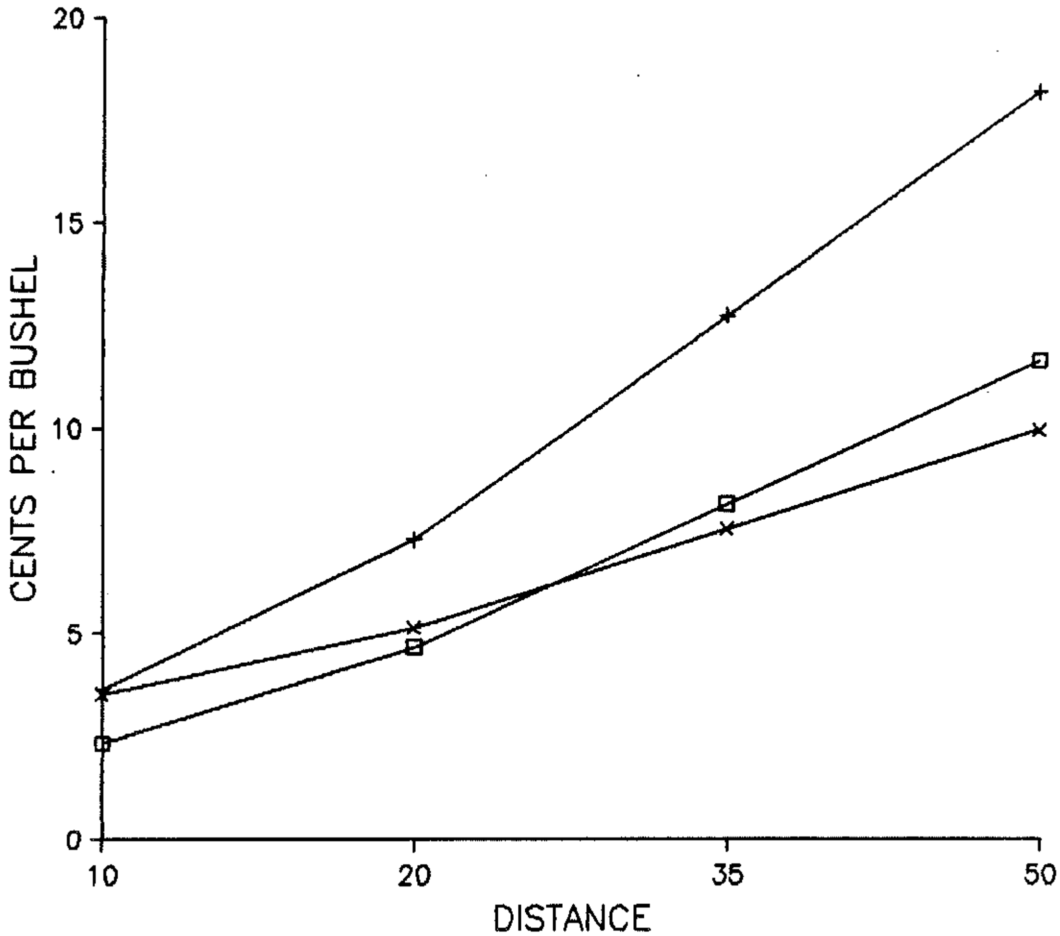

Figure 14. Transport Cost by Truck-Type and Distance

Legend: —+— SU-2AX —□— SU-3AX —×— CO-5AX

TABLE 10. GRAIN TRUCKING COSTS PER BUSHEL BY TRUCK TYPE AT VARIOUS DISTANCE INTERVALS (IN CENTS)

		Truck Type		
Zone	Distance	SU-2AX*	SU-3AX*	CO-5AX**
1	10 miles	3.64	2.33	3.51
1	20 miles	7.28	4.66	5.13
2	35 miles	12.74	8.16	7.56
3	50 miles	18.20	11.65	9.99

* Source: Griffin, Wilson, and Casavant (1984)
** Source: Unpublished UGPTI survey data

The subterminal manager estimated that roughly 60 percent of the grains and oilseeds moving to the satellite elevators in the system were being transported in SU-2AX trucks, with the remainder moving in SU-3AX trucks. While this is a subjective estimate, it tends to fit the results of previous studies and paints a realistic picture of the composition of the farm truck fleet and historic patterns of use[76]. At relatively short distances (such as from farms to satellite elevators) there is a higher probability that farmers will use SU-2AX trucks: (1) because there are simply more of them, and (2) because the cost discrepancy

[76]Griffin (1984) found that the majority of the farm truck fleet (over 80 percent) consisted of SU-2AX trucks. Zink (1988) found that the average distance from farms to the nearest satellite elevator ranged from 6.3 to 13.9 miles. Both are important factors in determining the distribution of farm-to-satellite elevator traffic among truck types.

between SU-2AX and SU-3AX trucks is less at shorter distances. For example, the transportation cost differential between two-axle and three-axle farm trucks is only a penny per bushel at 8 miles, but increases to 7 cents at 50 miles.

Outbound grain shipments from North Dakota elevators occur almost exclusively in CO-5AX trucks, so truck distribution is of little or no concern for flow-types 4 and 5[77]. For purposes of this study, all outbound elevator shipments were assumed to occur in CO-5AX trucks.

Once the interzonal trips have been allocated among vehicle types, it is possible to calculate the annual trips required. The annual trips between a given origin zone and elevator are a function of two items: (1) the volume of each commodity shipped, and (2) the distribution of the volume among truck types. If the type of grain truck used is denoted by the subscript "g", then the annual trips (AT) for a given year can be projected as:

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[77]In an interview conducted June 17, 1987, Mr. Alfred Bareksten, Manager of the Lake Region Cooperative estimated that most of the outbound grain shipments from elevators in the system occurred in CO-5AX trucks. This fits the traditional picture of grain transport in North Dakota where the predominant vehicle has been the combination five-axle semi. In the Devils Lake study, all elevator-to-market shipments were assumed to occur in CO-5AX trucks.

$$AT_{coydg} = V_{coyd} \bullet TS_g / PL_{cg} \tag{60}$$

where:

TS_g = Truck share or percent of type "g"

PL_{cg} = Average payload for commodity "c" in truck-type "g"

The average payload by truck-type was determined from a survey of North Dakota subterminal managers in the spring of 1988. The information (presented in Table 11) illustrates the differences which can occur for different combinations of commodities and truck-types.

TABLE 11. AVERAGE COMMODITY PAYLOAD IN LBS, BY TRUCK-TYPE

	Truck Type	
Commodity	SU-2AX	SU-3AX
Wheat	18,000	31,800
Barley	15,380	27,800
Sunflower	10,992	20,372
Other	15,593	28,329

The average payload for a CO-5AX truck typically will not vary substantially across commodities. Due to vertical extensions and hopper bottoms on trailers, most truckers are able to reach the legal load limit of 80,000 lbs on even light-loading commodities before the capacity of the payload area is reached. The subterminal manager verified this assumption, stating that combination trucks in the region were generally operating at 80,000 lbs. Given this fact, the average payload for grain and oilseeds can be obtained by subtracting the tare or empty weight of the vehicle from the gross weight. As noted in Table 2 (of Chapter 1), the average tare weight for a CO-5AX truck in North Dakota is roughly 26,650 pounds, leaving an average net weight of 53,350 pounds (or 534 cwt). Using this value, the annual outbound trips from a given elevator during a particular year (AT_{ey}) can be computed by:

$$AT_{ey} = V_{ey} / 534 \qquad (61)$$

The output of the truck distribution submodel consists of the projected interzonal trips by type of grain truck. The projected annual trips, in conjunction with the vehicle axle weights, are used to estimate annual ESALs. But before ESALs can be calculated, the annual trips must be assigned to the highway network, the next step in the process.

NETWORK ASSIGNMENT SUBMODEL

The truck trips were assigned to the highway network through means of a highway network (link-node) model. A computer file was created which defined the routes and highway characteristics between each origin-destination combination. The centroids of the supply zones and the elevators in the system were each treated as a possible origin, with the elevators in the system comprising the destinations.

For each feasible origin-destination combination, a record was created consisting of the highway "links" which comprised the route. The definition of highway links considered the number of different highways in the route and any appreciable changes in roadway condition which occurred from section-to-section. Some origin-destination pairs were assigned as many as eight links (for a distance of 50 miles or less). For each link, the beginning and ending mileposts, the distance, and the structural number were derived from the NDHWD's EXPRO file.

A given highway link may be part of more than one route. In fact, some links turned-out to be common to many different origin-destination routes. So an algorithm was written which accumulated the annual trips (by truck type) for each highway link in the network. Once the trips were accumulated, the grain ESALs on each link were computed. And since the beginning and ending mileposts of each link were known, the annual grain truck ESALs at each NDHWD monitoring site in the region (which were also referenced by milepost number) could be determined.

The highway routes between agricultural production zones and elevators (and between satellite elevators and the subterminal) were estimated from highway maps using two criteria: (1) distance, and (2) the approximate level of transportation services which exist. At first glance, the ideal highway route might appear to be the shortest possible path between origin and destination. However, truck operators are sensitive to the average speed of a highway and to the condition or quality of the road. Both factors affect operator costs. Consequently, in determining highway routes, differences in travel time and highway condition were factored into the equation[78].

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[78]The travel time was computed for each route in the network using the estimated average speed on each link. The average speed on rural arterials in North Dakota is 57.4 MPH, while the average speed on rural collectors is 57.2 MPH (FHWA, 1985). The average speed on rural local roads is unknown. So the state average for rural collectors has been used as a proxy. The process of determining the most likely route is as follows. First, the feasible routes between an origin-destination pair are estimated. Second, the travel times are estimated for each route in the set. Third, the quality of each route is approximated by calculating a weighted-average structural number. This represents the SNs of the various links, weighted by the mileage. Fourth, the weights given to travel time versus highway quality are set. In the Devils Lake study, a weight of .75 was attached to travel time and .25 to highway quality. This means that a truck operator (in deciding which route to select) will attach a greater significance to travel time than to highway quality. This process is analogous to calculating a generalized cost for each route. A standardized score was computed for each attribute for each route. The standardized scores for highway quality and travel time were then multiplied by the weights to compute a composite score or rank. The route with the highest composite rank was selected.

TRUCK WEIGHT SUBMODEL

The purpose of the truck weight submodel is to compute average axle weights and ESALs (by truck-type and axle group). The fully-loaded axle weight of a given truck is a function of:

1. the number and configuration of axles,
2. legal gross weights and axle weights,
3. the average commodity payload,
4. the distribution of the gross weight among axle groups.

On SU-2AX and SU-3AX trucks, the density of the commodity will help determine the axle weights. Not all commodities will load to the legal limits, particularly on the SU-2AX truck. Table 12 shows the tare and gross axle weights for wheat (the major commodity transported).

TABLE 12. LOADED AND EMPTY AXLE WEIGHTS FOR WHEAT BY TRUCK-TYPE, IN THOUSANDS OF POUNDS

	Tare Weight			Loaded Weight		
Axle Group	SU-2AX	SU-3AX	CO-5AX	SU-2AX	SU-3AX	CO-5AX
1	5.2	7.0	8.9	9.9	11.0	12.0
2	7.2	9.8	11.2	20.0	34.0	34.0
3	-	-	7.6	-	-	34.0

The tare weights in Table 12 were obtained from a special study of grain trucks at North Dakota weigh stations in the spring of 1988[1]. The loaded axle weights represent

[1]The weights and tare axle loads in Table 12 were obtained from a survey conducted at Grand Forks and Fargo weigh stations by the Truck Regulatory Division. The

the maximum legal axle weights in North Dakota for the type of axle and tire. In the case of SU-2AX and SU-3AX trucks, the sum of the possible payload capacity (shown in Table 11) and the tare weight (shown in Table 12) exceeds the maximum axle weights. So a constraint was built-into the model which capped the axle weights at the legal limit for each

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reasonableness of the survey estimates were verified by the professional judgment of Mr. Dennis Erickson, director of the division.

axle group[80]. In the case of lighter-loading commodities, the loaded axle weights for SU-2AX and SU-3AX trucks were less than the maximums.

Estimating truck axle weights is a central part of subterminal impact analysis. There are generally three ways to arrive at usable estimates:

1. through the use of truck weight (scale) data;
2. through the use of weigh-in-motion statistics;
3. through a hybrid (modified) truck weight approach.

[80]This procedure assumes that grain trucks in the Devils Lake area will not be loaded beyond the legal maximum gross weights or exceed the maximum legal axle weights. Generally, it is known (or assumed) that farm trucks exceed the maximum axle weights for some commodities (primarily wheat) on off-interstate highways. However, there has never been a study which explicitly defines the frequency or amount of the overload in North Dakota. The survey of elevator managers undertaken in the Devils Lake study indicates that farm trucks hauling wheat in North Dakota are overloaded. However, the survey was not random, and included only five elevator managers (who themselves sampled truck weight records at their facilities). So any interpretation concerning the level of overloads must be made with caution. The survey was not designed to determine the extent of overloads, but rather to estimate a representative payload for each commodity. Since the true level of farm truck overloads is unknown, I feel that it is inappropriate to model excessive axle weights in the study. So the computed axle weights for farm trucks are constrained by the legal axle load limits. A study is clearly needed which identifies the frequency and level of farm truck overloads so that more accurate estimates of highways needs may be computed. But until such a study is completed, I feel that the most appropriate assumption is that of legal compliance. Furthermore, there is some reason to believe that enforcement activities will increase in the future and that closer compliance will be realized during the planning period. So the assumption may be more realistic than it first appears.

The Devils Lake case study employed a modified truck weight approach in which both weigh-in-motion data and grain truck payload and axle weight factors were utilized.

The Truck Weight Method

The analyst may not always have access to weigh-in-motion data in the impact region. However, annual ESALs can still be computed for a sample of highway sections using static truck weight data. Typically, data which describe the gross and tare weights of trucks (as well as the distribution of the tare and gross weights among the axle groups) are collected at weigh stations in a given state or region. These data can be combined with vehicle classification (non-WIM) data to estimate average daily ESALs (ADE) for each monitoring site in the impact region. The process is essentially as follows.[81]

1. The average empty and loaded weights on each axle group are obtained from state-wide or regional truck weight data;

[81]Typically, vehicle classification data do not tell the number of empty versus loaded trips. Consequently, an average ratio of empty-to-loaded truck trips must be used to factor the ADT at a given monitoring site into loaded and empty trips. If the ratio of empty-to-loaded truck trips at each site is assumed to be 1.0, then the above computations may be simplified by first averaging the empty and loaded ESALs per VMT and applying this average to the ADT derived through vehicle classification.

2. The AASHTO traffic equivalency formulas are used to convert the raw axle loads to ESALs (given the strength and condition rating of the highway section);

3. The empty ESALs for each axle group are summed to obtain ESALs per empty VMT;

4. The loaded ESALs for each axle group are calculated in a similar manner;

5. The loaded ESALs for each axle group are summed to obtain ESALs per loaded VMT;

6. The hypothetical empty ESALs per day (for a given vehicle class) are calculated by multiplying the number of empty truck trips per day by the empty ESALs per VMT;

7. The hypothetical loaded ESALs per day are calculated by multiplying the number of loaded truck trips per day by the loaded ESALs per VMT;

8. The loaded and empty ESALs are summed to obtained an estimate of total daily ESALs for a given vehicle class.

Weighing-in-Motion

The shortcoming of the truck weight approach is that it uses average axle weight factors obtained from "static" or stationary weighings at a limited number of locations throughout the state or region. If the equipment and resources are available, in-motion weighing can represent an attractive alternative to the truck weight approach. When a vehicle is weighed in motion, the number of axles and the spacing between the axles are determined.[82] From the spacing between the axles, the type or configuration of each axle group is ascertained (e.g. single axle, tandem axle, or tridem). Using this information, the vehicle is placed into a general category or class (for example, one of the 13 classes shown in Table 13). At the same time that the number of axles is being recorded, the dynamic weight of each axle group is being determined.

Once the weight and configuration of each axle group is known, the AASHTO traffic equivalency formulas described in Appendix C are used to convert the raw axle weights into 18-kip ESALs. The ESALs for each axle group are then summed to obtained the total for each vehicle. This is all done automatically through means of electronic data transmission from the WIM scale or electronic pads to a computer, which carries-out predetermined data calculations and classification procedures. The advantages of weighing-in-motion are:

1. Dynamic rather than static weights are calculated;
2. Actual weights and axle loads are obtained (as opposed to average factors);
3. Local traffic conditions and factors are accounted for.

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[82]The spacing between the axles determines the axle type (single axle, tandem axle, or tridem).

The shortcoming of weighing-in-motion is that the process cannot determine the commodity being transported in the vehicle. Thus grain truck traffic is typically not identified as such at the time the data are collected. Instead, grain truck traffic remains buried within broader vehicle categories.

Modified Truck Weight Approach

The application of class averages derived from truck weight data or WIM sessions to grain traffic will typically not provide very accurate or specific estimates of grain truck ESALs per VMT in the impact region. Not only are there general differences between grain trucks and other vehicle types within the same broad class, but there are typically regional variations in farm truck ESALs due to differences in the pattern of commodity shipments within a given area.

TABLE 13. Vehicle Classification Records

1. Motorcycles (Optional)--All two- or three-wheeled motorized vehicles. Typical vehicles in this category have saddle-type seats and are steered by handle bars rather than a wheel. This category includes motorcycles, motor scooters, mopeds, motor-powered bicycles, and three-wheel motorcycles. This vehicle type may be reported at the option of the State.

2. Passenger Cars--All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.

3. <u>Other Two-Axle, Four-Tire Single Unit Vehicles</u>--All two-axle, four-tire vehicles, other than passenger cars. Included in this classification are pickups, panels, vans and other vehicles such as campers, motor homes, ambulances, hearses, and carryalls. Other two-axle, four-tire single unit vehicles pulling recreational or other light trailers are included in this classification.

4. <u>Buses</u>--All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles. This category includes only traditional buses (including school buses) functioning as passenger-carrying vehicles. All two-axle, four-tire minibuses should be classified as other two-axle, four-tire single unit vehicles. Modified buses should be considered to be a truck and be appropriately classified.

5. <u>Two-Axle, Six-Tire, Single Unit Trucks</u>--All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., having two axles and dual rear wheels.

6. <u>Three-Axle Single Unit Trucks</u>--All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, ect., having three axles.

7. <u>Four or More Axle Single Unit Trucks</u>--All trucks on a single frame with four or more axles.

8. <u>Four or Less Axle Single Trailer Trucks</u>--All vehicles with four or less axles consisting of two units, one of which is a tractor or straight truck power unit.

9. <u>Five-Axle Single Trailer Trucks</u>--All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.

10. <u>Six or More Axle Single Trailer Trucks</u>--All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.

11. <u>Five or Less Axle Multi-Trailer Trucks</u>--All Vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.

12. <u>Six-Axle Multi-Trailer Trucks</u>--All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.

13. <u>Seven or More Axle Multi-Trailer Trucks</u>--All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

The modified truck weight approach adopted in the Devils Lake study uses a combination of WIM or truck weight data (by vehicle class) and specific grain truck factors developed from special studies. For non-grain traffic, vehicle class averages were used to estimate the ADE on impact highways. For grain traffic, the specific tare weights, load factors, and axle weights shown in Tables 11 and 12 were used.

The non-grain ESALs and AADT in the Devils Lake region were computed from WIM and vehicle classification data collected by the NDHWD. The following section of the chapter discusses the data collection practices which were employed in the Devils Lake study and the adjustments which were necessary to derive usable data. The chapter then concludes with a discussion of the financial impact submodel and a synthesis of the process.

VEHICLE CLASSIFICATION AND AXLE WEIGHT DATA

In the Devils Lake study, vehicle classification data were compiled at 30 monitoring sites by the NDHWD using two types of portable equipment: (1) Streeter-Richardson weigh-in-motion (WIM) equipment, and (2) Streeter-Richardson tube-style (Non-WIM) classifiers[83]. The data collection schedule for both WIM and non-WIM sessions is shown in Appendix F. As the schedule depicts, WIM data were collected for the majority of the 30 sites at various intervals during 1985 and 1986. Thus, the actual ESALs per VMT (by vehicle class) were known for most impacted highway sections on the arterial network. However, Streeter-Richardson "tube-style" classifiers were deployed in lieu of (or addition to) WIM classifiers at several monitoring sites. Tube-style classifiers determine the classification of a vehicle but do not weigh it in motion. So at sites where WIM equipment was never deployed, an alternative method of estimating ESALs had to be devised. In these instances, the ESAL factor at

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[83]In the Devils Lake case study, WIM data were collected for the majority of the 30 monitoring sites at some time during 1985 or 1986, thus providing the actual ESALs per VMT at most sites. However, for the Non-WIM sites, the ESALs per VMT were not available. In order to attribute an approximate ESAL value per VMT to the Non-WIM sites, they were generally correlated with the closest WIM site (which had WIM data). Directions and years were matched-up as closely as possible during the process.

the closest WIM site on the same highway was used to approximate the ADE.

The vehicle classification process in the Devils Lake case study utilized the 13 primary FHWA categories shown in Table 13 (with one minor modification). A separate (fourteenth) category was introduced to account for vehicles which did not fall into one of the 13 FHWA classifications[84].

While the NDHWD data collection effort covered the arterial highway network in the impact region, it did not address minor collectors and local roads. In order to assess the impacts on collectors and local roads, a data collection program was launched to obtain analogous information for these types of highways. The data collection effort is described later in this chapter. But first the process by which raw traffic counts were adjusted for seasonal variance and other effects is described in the following paragraphs.

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[84]The vehicle classes which are of primary importance to this study are: 5, 6, and 9. SU-2AX farm trucks fall into category 5. SU-3AX farm trucks belong to vehicle class 6. And CO-5AX trucks are included in vehicle class 9.

Adjustment of Raw Traffic Data

In order to provide usable information, the raw traffic counts in the Devils Lake region had to be turned into estimates of average annual daily trips (AADT). The adjustment process which was used is essentially as follows:

1. Multiple traffic counts within a given month were averaged to arrive at monthly average daily trips (ADT),

2. The monthly ADT was adjusted for seasonal variance using Minnesota DOT seasonal control data (by vehicle class) and Upper Great Plains Transportation Institute grain and oilseed movement statistics (which were specifically applied to grain truck ADT),

3. Where multiple months of observations existed, the adjusted monthly ADTs were averaged to produce an estimate of AADT.

The adjustment of raw traffic counts to reflect seasonal variations in shipments is particularly important in subterminal traffic analysis. As Figure 15 depicts, monthly variations in grain shipments can be substantial. Consequently, the ADT (and ADE) derived from vehicle classification activities during any given month may bear little relationship to the annual mean. Therefore, the raw ADT must be factored by a seasonal adjustment index.

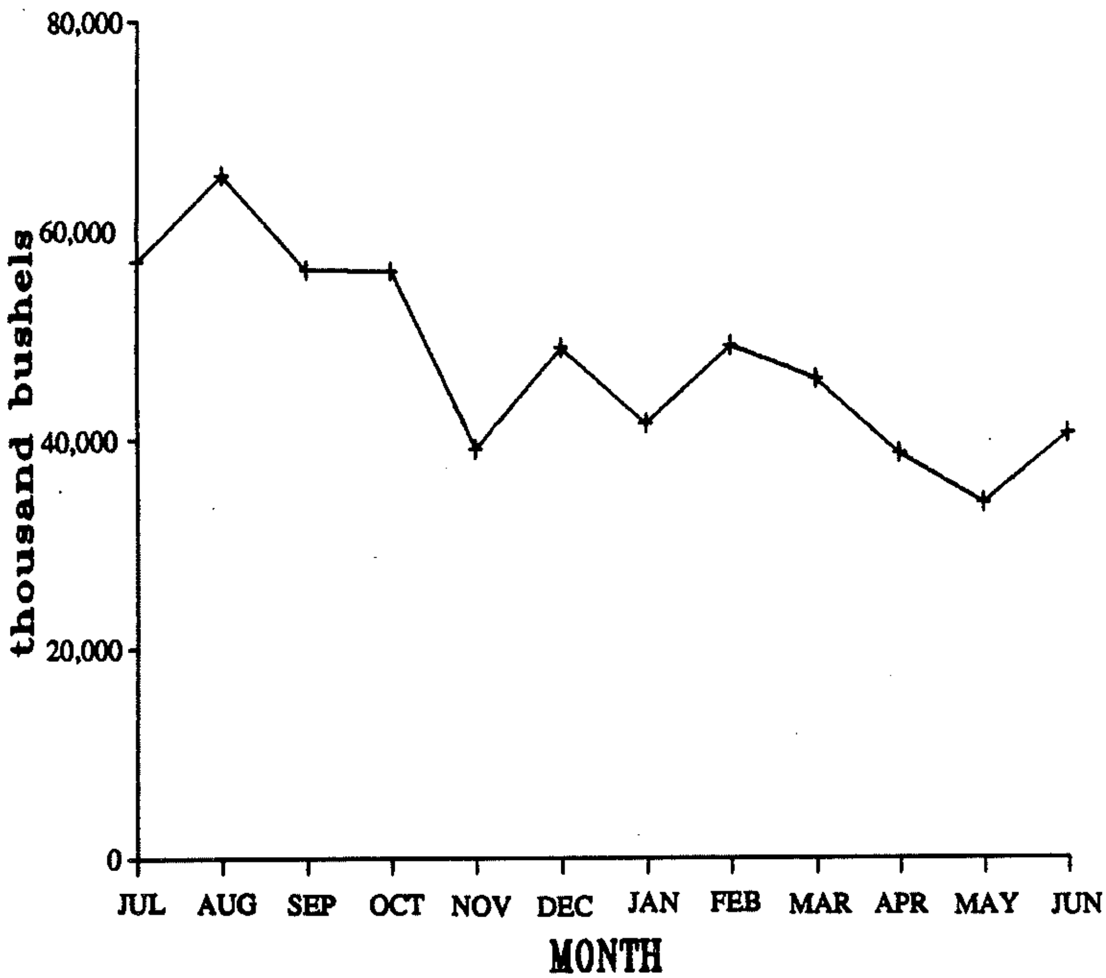

Figure 15. North Dakota Monthly Grain and Shipment - 1986-87

At present, the best source of data regarding seasonal variations in rural truck traffic in the Upper Great Plains is a continuous weigh-in-motion station near Bemidji, Minnesota. Information regarding monthly ADT and ADE were obtained from the Minnesota DOT for 1985 and 1986 (by vehicle class). From the raw statistics, a seasonal adjustment factor was calculated for each vehicle class as follows:

$$SAF_{jk} = ADT_{jk} / \overline{ADT_j} \tag{62}$$

where:

SAF_{jk} = seasonal adjustment factor for vehicle class "j", month "k"

ADT_{jk} = ADT for vehicle class "j", month "k"

$\overline{ADT_j}$ = Mean monthly ADT for vehicle class "j"

Considerable confidence was placed in the Minnesota seasonal adjustment factors with respect to non-grain traffic. However, the application of class averages to grain flows was felt to be inappropriate. Therefore, specific indexes were computed from other sources to reflect the monthly variations in grain traffic in the Devils Lake region.

As part of the modeling process described in this chapter, a highway network model was developed which routed shipments between origin and termination zones in the Devils Lake region. This model was applied to 1985 and 1986 grain and oilseed truck shipments in order to approximate the grain truck ADT at various locations on the arterial highways.

Once the grain truck ADT was approximated at each site, a weighted-average set of monthly indexes was computed for vehicle classes 5, 6 and 9 (which include SU-2AX, SU-3AX, and CO-5AX trucks respectively). The indexes were weighted by the estimated percentage of grain traffic (as opposed to nongrain traffic) in the Devils Lake region. The CO-5AX grain truck seasonal index was computed from the values shown in Figure 15. In addition, monthly indexes for farm-to-elevator shipments were developed from information concerning the average percentage of various crops sold on the open market in each month.[85] These indexes were used in conjunction with Minnesota DOT seasonal control data to compute weighted-average seasonal adjustment factors for vehicle classes five and six.

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[85]The underlying source of the information is: North Dakota Agricultural Statistics, 1987, page 69.

TABLE 14. SEASONAL ADJUSTMENT FACTORS FOR CO-5AX, SU-2AX AND SU-3AX GRAIN TRUCKS

MONTH	CO-5AX INDEX	SU-2AX AND SU-3AX INDEX
January	1.12763	0.82558
February	0.7388357	1.24348
March	0.8222269	0.67125
April	0.8486768	1.03600
May	0.7198375	0.91921
June	1.04513	1.27225
July	0.6685787	0.92259
August	2.194321	1.21461
September	1.362976	0.83123
October	1.248131	1.16563
November	1.02862	0.78574
December	0.7916829	0.61038

Expanding upon the notation introduced earlier, equation (63) depicts the computation of adjusted ADTs for each monitoring session.

$$ADTJ_{ijkl} = ADT_{ijkl}/SAF_{ijk} \tag{63}$$

where:

$ADTJ_{ijkl}$ = Adjusted ADT at monitoring site "i" for vehicle class "j" during month "k", session (day) "l"

ADT_{ijkl} = Raw (unadjusted) ADT

In many instances, multiple observations of ADT existed for a particular monitoring site during a given month. So in order to obtain the average adjusted ADT for a given month, vehicle class, and site, the arithmetic mean was computed as shown in equation (64).

$$ADTJ_{ijk} = \sum_{l} ADTJ_{ijkl}/n \qquad (64)$$

where:

n = number of measurements within a given month

As depicted in Appendix F, data were typically collected for more than one month at a given monitoring site. Thus in computing the average annual daily trips, the arithmetic mean of the adjusted monthly ADT was calculated (as follows).

$$AADT_{ij} = \sum_{k} ADTJ_{ijk}/n \qquad (65)$$

where:

$AADT_{ij}$ = Average annual daily trips at monitoring site "i" for vehicle class "j"

Equation (65) represents the culmination of an adjustment process which turned the number of average daily trips generated from a given traffic monitoring session into a usable estimate of AADT. An analogous process was followed with respect to the adjustment of ESALs. But because the seasonal variation in ESALs was unknown, an indirect (rather than a direct) approach was taken. First, the ESAL factor (ESALs per VMT) was computed for each vehicle class at each monitoring site, as shown in equation (66).

$$EAL_{ijk} = (\sum_{l} ADE_{ijkl} / \sum_{l} ADT_{ijkl})/n \qquad (66)$$

where:

EAL_{ijk} = ESAL factor for site "i", vehicle class "j", and month "k"

ADE_{ijkl} = Average daily ESALs at monitoring site "i", for vehicle class "j", month "k", and session "l"

Once the average ESALs per VMT was calculated for a given month, this factor was applied to the adjusted monthly ADT to produce an estimate of monthly ADE adjusted for seasonal variance. This computation is depicted in equation (67).

$$EALJ_{ijk} = ADTJ_{ijk} \bullet EAL_{ijk} \qquad (67)$$

where:

$EALJ_{ijk}$ = Adjusted monthly ADE for monitoring site "i", vehicle class "j", and month "k"

In the final step, the average annual daily ESALs (AADE) were calculated as the arithmetic mean of the adjusted monthly values.

The principal assumption underlying this adjustment is that the primary source of variance in ADEs is the variance in ADT. That is to say, the average ESALs per VMT for a given truck type hauling a given commodity will not vary significantly throughout the year. Rather, it is the number of average daily trips (by truck type and commodity) which vary. This is felt to be a realistic assumption in the Devils Lake region. With the possible exception of spring load restrictions on some highways, there is no reason to believe that the average payload of a CO-5AX truck transporting wheat will be different in July than it is in September. While it cannot be contended that this adjustment process produces faultless estimates of AADE, the values computed should represent reasonable approximations.

Extension of the Analysis to Collector Roads

Initially, the data base consisted of information collected by the NDHWD (supplemented with data obtained from the EXPRO file). This information provided a sound basis for analyzing the impacts of subterminal development on principal arterials and minor rural arterials in the area. However, it provided little (if any) insight into the impacts on collectors and local roads. Yet, rural collectors may be the most heavily impacted highways because they are typically low-design roads which are not built for heavy traffic. Part of the problem is that they are frequently part of the most direct route to an elevator, or constitute a "short-cut" to the subterminal.

In order to account for minor collector and local road impacts, additional data were collected (beyond that supplied by the NDHWD). Information was developed for 23 collectors (which comprise some of the most essential links in the farm-to-elevator flow chain in the region). The condition and attributes of the highways were determined from interviews with district engineers at the Devils Lake regional office (of the NDHWD), as well as through interviews with county engineers. For each highway section, the type of surface, the thickness of surface layers, the thickness of the aggregate base, and the general age and condition of the pavement were determined. From this information, the SN and PSR were approximated.

Baseline traffic characteristics were approximated for minor collectors in the region by using statewide averages (where available) and mean functional class values (where statewide averages were not available).[86] The average AADT on collectors and local roads was calculated from statewide statistics as depicted in Table 15. While it cannot be

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[86]All values or averages which were attributed to local roads and minor collectors were calculated from Highway Statistics, FHWA, 1985. Data for three major collectors were available from the NDHWD's collection efforts. When other major collectors were added to the data file, their attributes were obtained by survey if possible. If not, the average of the attributes for the three major collectors in the data base were used.

TABLE 15. COMPUTATION OF AADT FOR NORTH DAKOTA MINOR COLLECTORS AND MINOR ROADS

Item	Source	Minor Collectors	Local Roads
1. Miles of Highway	Table HM-220*	7,504	59,838
2. Annual VMT	Table VM-202*	185,000,000	720,000,000
3. Avg. Annual VMT	Line 2 ÷ 365	506,849	1,972,603
4. AADT	Line 3 ÷ Line 2	68	33

*FHWA (1985)

contended that the use of statewide averages for rural minor collectors and local roads provides for an exact representation of the true baseline traffic characteristics on each highway section, these values should provide reasonable approximations. The reason for this lies with the homogeneity of the functional classes.

There are clearly considerable variations among principal arterials (and even minor arterials) in North Dakota with respect to traffic characteristics. However, rural minor collectors and rural local roads should form two fairly homogenous functional classes. Although the true population variance is unknown, it is felt to be quite small for these subgroups.

Heavy truck traffic on rural minor collectors and local roads is typically quite small. Although the exact percentages are unknown, functional class data are available (at the national level) which can provide a workable approximation. Using information contained in Table 16 VM-201A of (FHWA, 1985), the proportion of truck traffic on rural collectors and local roads has been computed at: 3.6% for single-unit trucks and 3.0% for combination trucks. Given these proportions, the average baseline truck AADT and AADE can be computed for single-unit (SU) and combination (CO) trucks as shown in Table 16. Again, given the relative homogeneity of rural minor collectors and local roads, these values should constitute usable approximations for the Devils Lake study.

TABLE 16. COMPUTATION OF AADE FOR RURAL MINOR COLLECTORS AND LOCAL ROADS

Item	Source	Minor Collector	Local Roads
1. AADT	Table 15, Line 4	68.000	33.000
2. Proportion:SU Trucks	FHWA (1985)	.036	.036
3. SU-AADT	Line 1 x Line 2	2.500	1.200
4. Proportion:CO Trucks	FHWA (1985)	.030	.030
5. CO-AADT	Line 1 x Line 4	2.000	1.000
6. ESALs/VMT:SU Trucks	Calculated	.8181	.8181
7. ESALs/VMT:CO Trucks	Calculated	1.275	1.275
8. AADE:SU Trucks	Line 3 x Line 6	2.045	.9817
9. AADE:CO Trucks	Line 5 x Line 7	2.550	1.275
10. Estimated AADE	Line 8 x Line 9	4.595	2.256

FINANCIAL IMPACT ANALYSIS

The previous discussion has outlined all of the submodels in the chain (up to the final procedure) and has documented the data collection and adjustment process which took place in the Devils Lake study. The chapter now concludes with a synopsis of the financial impact procedure.

As noted earlier, subterminal impact costs were defined to include two components: (1) build-sooner costs, and (2) potential upgrading costs. The flow of computations within the submodel goes something like this.

1. The ESAL life of each sample section is computed,
2. The (baseline) ESALs are computed in the base year,
3. The incremental ESALs are computed for the impact year,
4. ESALs under the altered traffic stream are computed for each year of the analysis period,
5. The years of remaining service life are computed under the base case,
6. The years of remaining service life are computed under the altered traffic case,
7. The replacement cost is computed under each scenario and discounted to present value, with the difference comprising the build-sooner cost,
8. The incremental pavement thickness required (if any) is computed,
9. Upgrading costs are computed for any incremental thickness of .5 inches or more.

The process must be repeated for any new or different scenario which is analyzed.

The purpose of this chapter has been to describe the process of subterminal impact assessment and to highlight the various models which were used. It is recognized that (in several instances) the description was somewhat cursory in nature. This is unavoidable, as it is impossible to do justice to all of the models and procedures without unduly expanding the text of the document. For a more detailed description of some of the analytical techniques, the reader is referred to Appendix D and to the references cited.

CHAPTER 5
CASE STUDY AND CONCLUSIONS

Chapter 4 of the dissertation (in conjunction with Appendices C and D) presented a synopsis of the analytic model and the computer program which underlies it. A more detailed discussion of the computer program is presented in Appendix G. The purpose of this Chapter is to describe the scenarios which were analyzed in the Devils Lake case study, and to discuss and contrast the findings.

The chapter is organized as follows. First, the set of impact scenarios (and the forces of uncertainty which they are meant to address) are outlined. Second, the dimensions of the analysis are highlighted, including a description of the major effects and cross-effects which are evaluated in the study. Third, an assessment of the subterminal's effects on the problem dimensions is presented. Fourth, the projected short-run incremental and long-run incremental costs under the primary impact scenario are summarized. Fifth, the results of the alternative scenarios are highlighted and the sensitivity of the findings of the primary impact scenario are evaluated. Sixth, the major hypotheses stated in Chapter 2 are either accepted or rejected on the basis of the scenarios' projections. Seventh, the findings of the study are summarized.

SCENARIOS

Six major scenarios were analyzed in the Devils Lake case study (in addition to the main "impact" scenario). Several of the scenarios were specifically designed to address hypotheses stated in Chapter 2. Others are variations on major assumptions or themes.

Before outlining the individual scenarios, we will highlight the major environmental forces or factors which impact the study.

Major Variables or Forces

The environment of grain transportation is subject to considerable uncertainty. 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. Variations 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. Cobia (1986) feels that many substations will be shut-down in the future. On page 86, he writes: "Satellite stations will, with few exceptions, decline in use and will in many cases be eliminated as receiving stations." If this occurs, two events which have implications for grain flows will also happen. First, more direct farm-to-subterminal shipments will occur since the substations will no longer be available as receiving points. Second, with the closing of substations, fewer transshipments and satellite elevator-to-market shipments will be made.

In addition to affecting the allocation of traffic among flow-types, elevator rationalization can also impact the distribution of traffic among truck-types. Under a rationalization scenario, the subterminal manager may engage in differential pricing, providing producers with incentives to deliver grain to the subterminal. Thus the price at the substations may no longer be the price at the subterminal minus the grain trucking rate from the satellite elevator to the subterminal. Instead, the subterminal price may be higher, designed to attract grain from producers located at greater distances from the main facility. As the relative price at the subterminal increases and substations begin to close, producers will truck from even greater distances to the main facility. As the trip distance increases, the cost per bushel-mile in CO-5AX trucks becomes substantially lower than in SU-2AX or SU-3AX trucks. Consequently, elevator rationalization is likely to go hand-in-hand with increased CO-5AX farm-to-elevator shipments. Since the receivers (elevator managers) prefer larger payloads, there may be a dual incentive for a shift to CO-5AX truck utilization in the impact region.

Another major set of assumptions which underlies the projected pattern of flows in the impact year relates to the organizational structure of (and future management practices in) the grain elevator industry. The impact-year analysis is based on a cooperative organizational model, which assumes that the general manager is trying to optimize the net price for the system of elevators. This is only one possible organizational/management scenario. In North

Dakota, there are many private elevators with trainloading capabilities. These elevators tend to function in a similar manner to subterminals in the cooperative model, purchasing grain from smaller, single-car elevators in the surrounding area. However, there are important differences between a private and a cooperative subterminal which may impact the pattern of grain flows in a region. These differences relate primarily to the optimizing behavior of the elevator managers under the two organizational structures.

The general manager of a cooperative subterminal-satellite system attempts to optimize net prices for the group of elevators as a whole. In contrast, the manager of a private trainloading subterminal is concerned only with optimizing his or her own net price. Furthermore, the local elevators in the region do not necessarily function as "satellites" of the private subterminal. Instead, each manager markets his or her own grain, deciding whether to deliver to the subterminal or ship directly to the terminal market. Consequently, the optimal transshipment solution derived under the primary impact scenario may have little or no relevance under this pattern of elevator organization and management.

The private subterminal is only one possible variation on elevator organizational structure. Even within a cooperative framework, variations may exist which result in more local autonomy for satellite elevators. In cooperatives like these, satellites tend to function somewhat like private elevators with the managers marketing much of their own grain. Thus the cooperative model would not apply very well to this organizational structure.

The fourth major force which may impact the conclusions of the study is railroad rationalization. There are essentially three possible arrangements regarding the future of light-density branch lines in the Devils Lake region. The first arrangement is one in which the network remains essentially in place under Class I ownership. The second alternative is one in which the lines are abandoned by the Class I carrier in the future. The third possible arrangement is one where the lines are sold to an independent short-line operator. The primary impact scenario assumes that the status quo will be maintained. So if one of the other possible outcomes (of railroad rationalization) occurs, the projected grain flows and highway impacts under Scenario One may be in error.

The case study is designed to account for the effects of the four major forces on future highway impacts. The method by which this is accomplished is "scenario analysis."

Altogether, seven impact scenarios are analyzed in the Devils Lake case study:

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 trainloading 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 branchline abandonment).

These scenarios are all contrasted to the base-case scenario, referred to as "Scenario Zero."

Base-Case Scenario

Scenario Zero reflects the baseline grain flow pattern in the Devils Lake region. Base-year farm-to-elevator flows are projected using the doubly-constrained spatial interaction model described in Chapter 4. Outbound elevator flows are modeled using actual elevator-to-market shipment data.[87]

The basic objective of Scenario Zero is to establish a frame-of-reference for assessing changes in grain traffic flows in the impact region.

Scenario One

Under Scenario One, farm-to-elevator shipments are projected using the spatial interaction model defined in Chapter 3. The model (as detailed previously) is based on the "law of relative attraction" and utilizes elevator bid prices, satellite-subterminal price relationships, and farm truck costs.

Outbound elevator flows within the cooperative system of elevators are projected using the transshipment procedure discussed in Chapter 4 and Appendix C. Outbound shipments from noncooperative elevators are simulated on the basis of historic market and modal allocation factors.

Inbound flows are modeled under Scenario One on the strength of two major assumptions: (1) the distribution of grain among truck-types will remain relatively static over time, and (2) the cooperative system of elevators will

[87]An important side benefit of the base-year traffic analysis is that it provides an estimate of the proportion of grain trucks in the major rural traffic stream.

remain intact (having basically the same relationships throughout the impact period). These assumptions are allowed to vary in Scenarios 2 and 3 which address the implications of changes in future farm-to-elevator truck use patterns and possible elevator rationalization.

Scenario Two: The CO-5AX Farm Truck Scenario

The exact allocation of future traffic among truck-types is unknown. The subterminal manager indicated during an interview that a fleet of leased or for-hire CO-5AX trucks might be operating between the subterminal and area farms in the future. The objective of Scenario 2 is to isolate the effects of increased combination 5-axle shipments (within the farm-to-elevator traffic stream) on annual ESALs and highway costs.

Table 17 shows what a likely allocation of traffic among truck-types might be if this scenario were to come to pass. These factors are based on the relative economies of truck classes as well as the distances from the subterminal.

TABLE 17. CO-5AX TRUCK USE AS A PERCENTAGE OF TOTAL SHIPMENTS UNDER THE BASE CASE AND SCENARIO 2

	Flow-Type 2			
	<25 Miles	25-38 Miles	>38 Miles	Flow-Type 1
Scenario 1	0%	5%	10%	0%
Scenario 2	50%	75%	90%	15%

It is unlikely that CO-5AX trucks will become prevalent in the farm-to-satellite elevator traffic stream. As Figure 14 (of Chapter 4) depicted, the cost per bushel-mile in single-unit farm trucks is typically lower than the for-hire CO-5AX truck rate at short distances. Thus flow-type 1 will probably continue to be dominated by SU-2AX and SU-3AX trucks. However, the economies of combination trucks increase with distance. Consequently, for long-distance shipments to the subterminal (flow-type 2), the CO-5AX's share of grain is likely to increase dramatically.

In summary, Scenario Two entails the following assumptions:

1. Farm-to-elevator shipments reflect the CO-5AX percentages shown in Table 17,

2. Outbound elevator shipments are modeled in the same manner as under Scenario One.

Scenario Three: Elevator Rationalization Scenario

Scenarios 2 and 3 are closely related. The objective of Scenario 3 is to assess the effects on grain flows of closing "nonessential" substations.

On the basis of the market area study discussed in Chapter 4, and historic shipment data, four satellite elevators have been identified which might be subject to elimination if the system is rationalized. The remaining three satellites either perform specialized functions or provide cost-effective farm-to-elevator transfer points for grain in competitive parts of the region. So it is unlikely that any of the three would be eliminated as receiving points under a rationalization strategy. In contrast to the three "essential" substations, the four "nonessential" satellites have historically shipped small volumes of grain, are relatively close to the subterminal, and do not perform any specialized functions.

In summary, Scenario 3 entails all of the assumptions of Scenario 2, plus the additional assumption that some substations will be closed during the impact period.

Scenario Four: The Private Subterminal Scenario

The objective of this scenario is to identify the flow patterns which might arise under a noncooperative organizational structure, or in cooperative systems where a high degree of local automony exists

In Scenario One, cooperative elevator shipments are simulated with a transshipment model. In contrast, outbound elevator traffic for satellite elevators under Scenario Four is allocated between transshipments and direct elevator-to-market shipments using the decision rule depicted in equation D4 of Appendix D. This rule results in an "all-or-nothing" assignment of the grain from each elevator.

The decision rule essentially assumes that if an individual elevator can receive a higher net price at the subterminal than at terminal market, then the grain will be sold to the subterminal. But if the net price at terminal market is higher than the subterminal price, then the elevator manager will market the grain directly. While such an all-or-nothing assignment might not always be realized in practice because of non-price considerations, the profit-maximization principle which underlies it nevertheless provides a good approximation of reality.

Scenario Five: The Abandonment Scenario

Both the Impact Scenario and Scenario Four assume that the rail branch line network will remain in place for the duration of the analysis period. Thus, satellite elevators will have the option of shipping directly to market by rail as opposed to transshipping the grain or using long-haul trucking services.

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 lines may be dropped. If the branch line network in the Devils Lake region 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 would occur under the "all-or-nothing" assignment procedure employed in Scenario Four if the branch lines serving the satellite elevators were abandoned. This is accomplished by substituting the long-haul truck rate for the rail rate in the assignment rule in equation (D4). Since the long-haul truck rate is higher than the single-car rail rate in many instances, abandonment may affect the allocation of traffic between transshipments and direct elevator-to-market shipments.

In summary, Scenario Five entails the following assumptions:

1. The branch lines on which the satellite elevators are located are abandoned in the impact-year,

2. The distribution of farm-to-elevator shipments is the same as in Scenario Two,

3. Outbound elevator shipments from "satellite" elevators are allocated between flow-types 3 and 4 using the decision rule in equation D4.

Scenario Six: The Short-Line Scenario

In the context of railroad rationalization, the sale of branch lines to a short-line operator frequently represents an alternative to abandonment. Because of lower labor and train-mile operating costs short lines are sometimes able to make a profit on unprofitable or marginally-profitable Class I lines. Just as there is a possibility that the branch lines in the Devils Lake area will be abandoned in the future, there is an alternative possibility that the lines will sold to an independent operator instead.

The operation of branch lines by a short line operator can impact the findings of the study in the following way. Short-line operators in certain parts of the nation (including North Dakota) have instituted elevator-to-elevator rail rates. Such rates would allow a subterminal manager to gather grain from substations by rail instead of by motor carrier. Under such an arrangement, the transshipments between satellite elevators and the subterminal could conceivably occur by rail instead of truck. So rail rates have been projected for local wheat and barley shipments within the impact region. These projections are based on actual freight rates published by the Red River Valley and Western Railroad (a regional North

Dakota carrier) in the Spring of 1988. The published rates were based on a mileage scale, starting at 50 miles and increasing with distance. The rates were also volume-based, decreasing with the amount of grain consigned per car. The lowest rate which a grain shipper could obtain under this rate structure was 9.7 cents per cwt for a single-car shipment, and 5.1 cents per cwt for a multiple-car consignment. Both rates were applicable for distances of 50 miles or less.

The projected rates were used to allocate traffic between truck and rail under Scenario Six. Once the traffic was allocated among the modes, the decision rule in equation (D4) was used to determine the levels of transshipments.

In summary, Scenario Six assumes:

1. The same farm-to-elevator truck allocation as Scenario 2,

2. The same all-or-nothing elevator shipment assignment procedure employed in Scenario Four,

3. The option of using rail instead of truck to transship grain from elevator-to-elevator.

ANALYTIC DIMENSIONS OF SUBTERMINAL IMPACTS

The potential effects of grain subterminals on the problem dimensions were outlined in Chapter 1 of the dissertation, and the likely impacts of subterminals upon market share were outlined in Chapter 4. The purpose of this section of the dissertation is to define more clearly the effects (and cross-effects) of subterminal-generated traffic.

Grain subterminals generate a fairly intricate set of impacts and cross-impacts. The major effects (when 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 utilized.

In the analysis which follows, grain flow effects are evaluated by contrasting the allocation of grain among the five types of flows between the "base case" and the "impact scenario." Truck-type effects are modeled in a similar fashion using the three truck classes introduced in Chapter 1. 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 functional class is an important dimension of the analysis, a brief overview of rural functional types and their relationship to typical grain truck journeys is presented next.

Highway 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. 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 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.

Rural arterials are categorized as either principal or minor arterials. Principal arterials are further differentiated between "freeways" and "other principal arterials."[88]

Principal arterials are typically (but not always) multilane 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.

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

A typical farm-to-satellite (local) elevator trip will involve the use of the local, minor collector, major collector and/or minor arterial 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 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 generally located on arterial highways.[89] 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).

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 Chapter 3, the average ESAL life for a typical rural arterial is 1.5 million, while an average ESAL lifetime is roughly 400,000 for rural collectors and 80,000 for local roads respectively.

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

Although rural functional classes are not completely homogenous in nature, the highways which comprise the classes are generally quite similar in design. Thus 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 principal 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.

Each of the singular effects and cross-effects discussed in this section have been analyzed in the case study. The results of the dimensional analysis are presented next, prior to a discussion of the projected incremental cost under each scenario.

DIMENSIONAL ANALYSIS

This section of the chapter focuses on the analytic dimensions discussed previously. The objective of the discussion is to explain the forces underlying the projected replacement and upgrading costs presented in the following section.

Table 18 (which depicts mean annual shipments for the analysis period) illustrates the potential effects of the subterminal on grain flows in the region. As Table 18 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).[90] As depicted in Table 19, this is only 28 percent of total production. In contrast, the subterminal-satellite system is projected to draw over 16 million bushels from the surrounding area under the impact scenario.[91] This amounts to over 40 percent of the grain produced annually during the impact period (Table 19). 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 assumed to be the price at the subterminal minus the grain trucking cost, a great deal of the subterminal's economies will be passed-on to the satellites. Thus, all of the elevators in the cooperative will enjoy some price advantage over noncooperative elevators.

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

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

TABLE 18. PROJECTED DISTRIBUTION OF GRAIN BETWEEN COOP AND NONCOOP ELEVATORS

	SCENARIO	
	BASE CASE	IMPACT CASE
	CWTS	CWTS
	(000)	(000)
ELEVATOR STATUS		
NONCOOP ELEVATORS	15,280	13,484
COOP ELEVATORS	6,070	9,184
TOTAL	21,350	22,668

TABLE 19. PERCENTAGE DISTRIBUTION OF GRAIN BETWEEN COOP AND NONCOOP ELEVATORS

	SCENARIO	
	BASE CASE	IMPACT CASE
	CWTS	CWTS
	(000)	(000)
ELEVATOR STATUS		
NONCOOP ELEVATORS	72	59
COOP ELEVATORS	28	41
TOTAL	100	100

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 that results in highway impacts. Tables 20 and 21 show the "before" and after" patterns of flow in the impact area.[92] The tables graphically illustrate the projected change in flow patterns predicted by the model. As the subterminal moves toward its long-run market and operating position, transshipments are projected to reach 34 percent of total shipments within the impact region. Farm-to-subterminal and satellite elevator-to-market shipments meanwhile are projected to decline. These trends point-out the potential fallacy of focusing on early volume and shipment patterns only.

Changes in flow-types are the catalyst of the impact process. However, the highway impacts themselves are actually generated by changes in truck traffic within the impact region. Tables 22 and 23 depict the distribution of traffic among truck-types during the base case and the impact scenario. As Table 23 shows, CO-5AX truck trips are projected to increase 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 trips are expected to decline, dropping seven and ten percentage points respectively. Much of this reallocation of shipments among truck-types is due directly to the change in flow-types discussed above.

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[92]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 20. DISTRIBUTION OF SHIPMENTS AMONG FLOW TYPES

	SCENARIO	
	BASE CASE	IMPACT CASE
	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
TOTAL	21,350	34,581

TABLE 21. PERCENTAGE DISTRIBUTION OF SHIPMENTS AMONG FLOW TYPES

	SCENARIO	
	BASE CASE	IMPACT CASE
	CWTS	CWTS
	(000)	(000)
FLOW TYPE		
FARM-TO-SATELLITE	68	52
FARM-TO-SUBTERMINAL	23	7
SATELLITE-TO-MARKET	9	4
TRANSSHIPMENT	.	34
SUBTERMINAL-TO-MARKET	.	2
TOTAL	100	100

TABLE 22. ANNUAL TRIPS BY TRUCK CLASS

TRUCK TYPE	SCENARIO: BASE CASE ANNUAL TRIPS	SCENARIO: IMPACT CASE ANNUAL TRIPS
CO_5AX	7,774	53,174
SU_2AX	115,590	135,252
SU_3AX	67,792	64,256
TOTAL	191,156	252,682

TABLE 23. PERCENT OF ANNUAL TRIPS BY TRUCK CLASS

TRUCK TYPE	SCENARIO: BASE CASE ANNUAL TRIPS	SCENARIO: IMPACT CASE ANNUAL TRIPS
CO_5AX	4	21
SU_2AX	61	54
SU_3AX	35	25
TOTAL	100	100

Tables 24 and 25 present a similar display concerning highway use. As Table 24 shows, the number of annual trips are projected to increase within all functional classes during the impact scenario, but particularly on the principal and minor arterials in the region. This is primarily the result of transshipments between the satellite elevators (which are situated mostly on minor rural arterials) and the subterminal which is located on a principal arterial.

TABLE 24. TRUCK TRIPS BY FUNCTIONAL CLASS

	SCENARIO	
	0	1
	ANNUAL TRIPS	ANNUAL TRIPS
FUNCTIONAL CLASS		
MAJOR ARTERIAL	120,262	184,030
MINOR ARTERIAL	186,690	235,508
MAJOR COLLECTOR	59,422	79,064
MINOR COLLECTOR	24,764	34,274
TOTAL	391,138	532,876

TABLE 25. PERCENT OF TRUCK TRIPS BY FUNCTIONAL CLASS

	SCENARIO 0	SCENARIO 1
	ANNUAL TRIPS	ANNUAL TRIPS
FUNCTIONAL CLASS		
MAJOR ARTERIAL	30	35
MINOR ARTERIAL	48	44
MAJOR COLLECTOR	15	15
MINOR COLLECTOR	6	6

Interestingly, Table 25 indicates that the distribution of truck trips among functional classes is projected to remain relatively unchanged throughout the impact period. However, this finding can be somewhat misleading since the table does not show the change in CO-5AX truck traffic on various functional classes of highways. And it is the cross-effects of highway classes and truck-types that is most directly related to highway damage.

Perhaps a better indicator of the change in highway utilization in the region is the increase in annual vehicle miles of travel (VMT) attributable to each truck class on each highway system. Tables 26 and 27 present a breakdown of annual VMT by truck-type and functional class for the

TABLE 26. GRAIN TRUCK VMT BY TRUCK TYPE AND FUNCTIONAL CLASS

SCENARIO	FUNCTIONAL CLASS	TRUCK TYPE CO_5AX ANNUAL VMT (000)	SU_2AX ANNUAL VMT (000)	SU_3AX ANNUAL VMT (000)	TOTAL ANNUAL VMT (000)
BASE CASE	MAJ. ART.	162	208	233	604
	MIN. ART.	74	756	556	1,386
	MAJ. COL.	37	239	136	412
	MIN. COL.	2	98	47	147
	TOTAL	277	1,302	971	2,549
IMPACT CASE	MAJ. ART.	598	184	149	931
	MIN. ART.	663	704	385	1,752
	MAJ. COL.	86	267	125	477
	MIN. COL.	13	93	41	148
	TOTAL	1,359	1,249	701	3,308

TABLE 27. PERCENT OF ANNUAL TRUCK VMT BY SCENARIO AND FUNCTIONAL CLASS

SCENARIO	FUNCTIONAL CLASS	TRUCK TYPE: CO_5AX ANNUAL VMT (000)	TRUCK TYPE: SU_2AX ANNUAL VMT (000)	TRUCK TYPE: SU_3AX ANNUAL VMT (000)	ALL ANNUAL VMT (000)
BASE CASE	MAJ. ART.	6	8	9	24
	MIN. ART.	3	30	22	54
	MAJ. COL.	1	9	5	16
	MIN. COL.	0	4	2	6
IMPACT CASE	MAJ. ART.	18	6	5	28
	MIN. ART.	20	21	12	53
	MAJ. COL.	3	8	4	14
	MIN. COL.	0	3	1	4

base case and the impact scenario. As the tables depict, CO-5AX annual VMT are projected to increase substantially on rural minor arterials, as well as on principal arterials. At the same time, SU-2AX and SU-3AX truck trips are projected to decline on both classes of highways.

As the tables show, collector highways are also likely to experience an absolute increase in CO-5AX VMT under the impact case. While the increases do not represent large amounts in percentage terms, they still may present problems for low-design highways.

It is interesting to note that the distribution of annual VMT is somewhat different than that of annual truck trips. A larger percentage of VMT than annual truck trips is logged on rural minor arterials. Relatively lengthy trips from the satellite elevators located on Highway 20 to the subterminal or directly to terminal market are the primary reason for the difference.

Changes in truck distribution and highway usage are translated into incremental highway costs through changes in ESALs. Table 28 shows the incremental average annual daily ESALs (AADE) by road and functional class for the impact scenario. As Table 28 portrays, the principal arterial in the region (Highway 2) shows substantial projected increases in AADE, as does Highway 20 north and south of Devils Lake. Three major collectors (3618, 3627, and 3630) may also be impacted, as well as three minor collectors.

Several items are particularly noteworthy regarding Table 28. First, the highway on which the subterminal is located (2W) is projected to experience a substantial increase in grain AADE. This is to be expected since both direct farm-to-subterminal shipments and transshipments will traverse parts of the highway. Second, Highway 20 (on which three of

TABLE 28. 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

the satellite elevators are located) may also be heavily impacted. Again, this is primarily due to transshipments under the impact case. Third, Highway 3627 (a major collector) is likely to incur substantial incremental cost. This is because one of the major satellite elevators in the system is located on a section of that highway. As a result, the road is likely to experience both heavy inbound and outbound truck shipments.

It should be noted that negative or decremental values are possible in Table 28. This is because, as the subterminal exerts its influence over the market region, traffic will be diverted from some highways, actually reducing impacts. However, in the final analysis Table 28 shows that a net gain of 204 incremental grain truck AADE is likely to occur. This is the "bottom line" of the dimensional analysis since it is the incremental AADE which will determine (in large part) the level of short-run and long-run incremental costs which will accrue.

The previous discussion has attempted to construct an analytical chain of cause-and-effect in subterminal impact analysis. Table 29 brings the potential financial impacts into sharper focus by displaying the projected replacement costs for the analysis period, by functional class and road. It should be pointed out that the projected replacement

TABLE 29. REPLACEMENT COST BY FUNCTIONAL CLASS

	FUNCTIONAL CLASS				
	MAJ. ART.	MIN. ART.	MAJ. COL.	MIN. COL.	TOTAL
	REPLACE-MENT COST	REPLACE-MENT COST	REPLACE-MENT COST	REPLACE-MENT COST	REPLACE-MENT 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

costs are not incremental costs. They represent the projected replacement costs for each section of highway included in the impact study. For evaluation of short-run incremental costs, the "build-sooner" cost for each section must be computed. This is the topic of the following section of the chapter.

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 29 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 dollars. Much of it is concentrated on the major collector system and two minor rural arterials subject to the heaviest transshipments.

Table 30 shows the projected short-run incremental cost for the analysis period. Two major conclusions may be drawn from the table. 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 costs is substantial, the accelerated

TABLE 30. 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

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 heavily-impacted highways such as 3627 and 20S.[93]

The build-sooner costs represent only the short-run impacts of subterminal traffic incurred during the current replacement cycle. They say little or nothing about the true long-run costs. So in addition to the SRIC, upgrading or LRIC were computed for each highway section (where applicable). The projected LRIC for the impact area are displayed in Table 31.

As Table 31 depicts, not all highways in the impact region will have to be strengthened. 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

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[93]Highway 3627 provides access to one of the satellites which has trainloading 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 31. LONG RUN COST

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

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.

EVALUATION OF HYPOTHESES

Four major hypotheses concerning subterminal traffic were set forth in Chapter 2. The purpose of this section of the chapter is to evaluate and reassess the original, guiding hypotheses in light of the findings of the case study.

The first general hypothesis stated in Chapter 2 is that subterminal traffic reduces the life of highway sections in the impact region. The results of the case study suggest that this is not universally true, and this hypothesis should be restated in terms of specific functional classes. While the study did find that collectors (as a class) tended to incur some SRIC, the magnitude for the group as a whole was not great. However, individual highways within the class were heavily-impacted. The results were also mixed for arterials. Only one minor arterial (Highway 20) incurred any SRIC at all under the impact scenario. Similarly, only Highway 2W in the vicinity of the subterminal incurred any significant short-run costs within the principal arterial grouping. Consequently, the general hypothesis stated in Chapter 2 cannot be categorically accepted. Perhaps the best statement which could be made is that some SRIC will occur and will be significant on a localized scale, particularly on collector highways and on arterials in the vicinity of the subterminal or on major transshipment routes.

Hypothesis 2 posits that long-run incremental costs will occur in the impact region. Again, this hypothesis needs to be rephrased in terms of functional highway classes. As Table 31 showed, 85 percent of the long-run incremental costs is projected to occur on the collector network. But perhaps more significant than that, 53 percent is projected to occur on the minor collector system alone. Meanwhile, only 2 percent of the projected long-run costs will fall to the principal arterial network. So perhaps the best statement which can be made regarding Hypothesis 2 is that rural collector and minor arterial highways can be expected to incur significant LRIC as a result of subterminal development (particularly on a localized scale) but that principal arterials may not be impacted at all.

Hypothesis 3 (subterminals will alter the distribution of highway funding needs among functional classes of highways) appears to be clearly supported by the findings of the case study. As Table 31 shows, the majority of the LRIC will fall to the collector network. Highways which have historically been designed for low traffic levels (with correspondingly low structural numbers) will require more resources in the future and more attention from state and local highway planners. These are the highways which need to be closely monitored in a subterminal impact region.

Hypothesis 4 (that subterminal impacts will vary with organizational or management strategies) also appears to have been born-out by the analysis. As will be detailed in the following section the LRIC drop appreciably under an elevator rationalization scenario. Essentially, any management plan which results in high levels of transshipments in CO-5AX trucks will generate correspondingly high levels of highway impacts. Those that do not will generate opposite conclusions.

SENSITIVITY ANALYSIS

Tables 32 and 33 summarize the SRIC and LRIC under each of the six alternative scenarios. As the tables indicate, the greatest LRIC would occur under Scenarios 2 and 7. Both scenarios entail heavy combination five-axle truck-use:

TABLE 32. 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 33. 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

Scenario 2 on the farm-to-elevator leg of the truck journey and Scenario 7 on the outbound leg. As the tables display, the SRIC show little fluctuation from the values forecast under the impact scenario.

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 2 (which entails high CO-5AX farm truck use) could result in even higher incremental cost. But the greatest SRIC would be generated under an abandonment scenario. And 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 32 and 33 point-out, this would not cause a major change in the forecasted impacts.

CONCLUSIONS AND FUTURE RESEARCH

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, transshipments appear to be the industry norm or model.

The case-study highways represent less than 2 percent of the rural arterial and collector highway mileage in North

Dakota.[94] So on a statewide basis, the aggregate subterminal impacts will be much greater than the case-study projections.

There are many differences among subterminal-satellite systems around the state due to variations in the size and location of elevators, the condition and coverage of the highway network, and other key variables. So a straight expansion of the case-study results is not likely to produce a scientific estimate of statewide impacts. Some parts of the state will experience greater impacts per mile of road while other areas will experience lower per-mile costs than the Devils Lake region.[95] However, expanding the case-study projections can provide a rough indication of the scale and magnitude of the potential problem. If the Devils Lake network is truly a microcosm of the state, then the

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[94] In 1985, North Dakota rural arterial and collector mileage (excluding interstates and local roads) totaled 23,884 miles (FHWA, 1986). Approximately 452 miles of arterials and collectors are contained within the Devils Lake impact region, or roughly 2 percent of the 23,884 miles.

[95] The impacts which occur in a given region will depend upon: (1) the layout of the existing highway network, (2) the size of the system, and (3) the location of the satellites and the subterminal. In the Devils Lake region, three of the satellite elevators (as well as the subterminal) are located on Highway 2 (a principal arterial). Had this not been the case, the impacts may have been much greater.

projected statewide SRIC will be in the vicinity of $57 million, while the LRIC will be $420 million or thereabouts.[96]

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.

The principal implications of the study for highway planners are: (1) the collector network in subterminal impact regions will require close scrutiny and more detailed planning, (2) the allocation of funding among functional classes will probably have to be changed, (3) the relationship between the elevators and the highway network in the region will determine the scale of the impacts, and (4) improved subterminal site-selection can partially mitigate future highway impacts.

The methodology presented in this study represents an essential first step in evaluating the impacts and options

[96]These figures should be interpreted with caution. They represent "ballpark" estimates and are useful only in ascertaining the probable scale of statewide impacts.

associated with grain subterminal development. Given these baseline methods, analysts may explore higher levels of economic and policy analysis. Several of the extensions and possible policy applications which were contemplated in the study are discussed in the concluding paragraphs of the dissertation.

Although the incremental costs of subterminal development were calculated in this study, they were not allocated to vehicle classes (as is typically done). The next step beyond impact assessment is to determine the changes in cost responsibility for each vehicle class, and adjust user fee schedules accordingly. This is a complex task which requires an existing highway cost allocation model and a rational set of user fees.

A highway cost allocation/pricing study addresses the question of which vehicle classes should pay (and how much). But it does not address the question of improved site selection and the minimization of highway impacts which could be achieved through such a process. An optimization model could be designed that minimizes the highway infrastructure costs associated with alternative subterminal sites. Such a model could help highway officials identify feasible subterminal locations which generate relatively low highway costs.

Although useful, such a model would omit two important criteria: elevator profitability and producer costs.

Mainline rail locations allow elevator cooperatives to access low trainload rates and direct services, which lower logistical costs. Thus prime rail locations will generate substantial elevator benefits, even if they engender large-scale highway costs. Subterminal locations can also affect producer (farmer) benefits and costs. So in lieu of a highway cost minimization model, a broader optimization model could be developed, one which minimizes or maximizes some socially-optimal objective function. Here, the private benefits and costs of producers and elevator managers, as well as public infrastructure costs, could be considered together.

Even if a socially-optimal location can be identified, there is a limited likelihood that elevator managers can be persuaded to locate their facilities accordingly.[97] So a related extension of the dissertation may prove more practical. In this latter application, the location of the subterminal is given and the objective is to route each class of truck traffic over the network so as to minimize highway damage. As the case study illustrates, if CO-5AX trucks are routed away from collector highways, lower levels of pavement damage will occur. However, higher operator costs may result from circuity. An optimization model could

[97]Elevator managers tend to locate their facilities where their individual profits are maximized. This will only agree with a socially-optimal location through coincidence.

"trade-off" increased operator travel time against reduced infrastructure costs to find an optimal route for each truck-type from each elevator to the subterminal (or to terminal market).

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APPENDIX A
RTAP PROJECT HISTORY AND EVOLUTION

The purpose of this appendix is to describe the evolution of the RTAP project from the initial stages of data collection and analysis to the finalization of models and procedures. This information will hopefully shed light on the research design presented in Chapter 2, and provide some background or contextual material for readers of the dissertation.

The Evolutionary Nature of the RTAP Project

The RTAP project has followed a pattern which is typical of evolutionary research, unfolding in phases or sequential stages. The collection and early analysis of traffic data lead to a clearer understanding of the problem, and to the realization that additional data would be required. In an analogous fashion, the evaluation of existing highway models and early model formulation lead to the conclusion that new or revised procedures would be needed in order to adequately address the subterminal traffic problem.

In essence, the RTAP project evolved through three phases or stages. At each stage of the process, a more precise definition of the problem and a clearer understanding of the necessary analytical techniques emerged.

Phase I Data Collection

The initial phase of the project entailed the purchase and deployment of weigh-in-motion (WIM) equipment in the Devils Lake region, a subterminal impact zone. In Phase I of the study, WIM or other vehicle classification data were collected by the North Dakota Highway Department at 30 different monitoring sites in the Devils Lake area for two intervals in time: a base year (1985) and an impact year (1986). Although the data collection strategy was sound, some unforseen problems later arose.

Theoretically, the base year data were supposed to capture the traffic patterns which existed prior to the development of the subterminal elevator in Devils Lake. Conversely, impact year data were intended to reflect the conditions which existed after the opening of the facility. However, construction proceeded at a rapid pace and little information was actually collected before the opening of the subterminal in June of 1985. So the delineation of a "before" and "after" traffic sample was not clear-cut.

A second problem arose specifically with respect to the base year data. A relatively high frequency of construction traffic was noted in and around the subterminal during 1985. Although attempts were made to adjust or "clean" the data, the relationship between the "before" and "after" data periods remained somewhat clouded by the effects of construction traffic.

Later in Phase I of the project, a third potential problem was uncovered. From an inspection of elevator shipments which occurred in 1986, it became apparent that the subterminal did not actually commence "normal" or long-term operations during the impact year. Rather, 1986 was something of a start-up period. The volume handled by the subterminal was relatively low with respect to the long-run expectations of such a facility. A subsequent interview with the subterminal manager supported this contention. During the course of the interview, the manager revealed that his expected 1990 volume would more than double the amount of grain moved through his facility in 1986.

Primarily for the reasons cited above, an initial analysis undertaken by the NDHWD did not reveal any clear-cut trends or patterns in the data. But from the preliminary analysis it became apparent that:

1. some type of secondary data would probably be needed;

2. raw WIM and vehicle classification data would have to be adjusted to account for the seasonal variance of grain shipments before meaningful estimates of average annual daily trips and average annual daily axle loads could be developed;

3. an analytical approach was needed which could turn estimates of changes in truck trips and axle loads into financial effects or dollars;

4. additional models would be needed to account for the long-run effects of subterminals.

It was at this juncture in the evolution of the project that the NDHWD contracted with the Upper Great Plains Transportation Institute (UGPTI) to develop an analytical approach to the subterminal traffic problem. With the signing of the contract, the RTAP project entered a second phase in which the primary concerns were: (1) adjusting the raw WIM and classification data for seasonal variance and related factors, and (2) formulating an overall analytical approach to the problem.

The Formulation of Highway Impact Models

Initially during the second phase of the project, the Highway Performance Monitoring System of the FHWA was employed in an effort to determine the incremental highway costs of subterminal traffic. HPMS input records were developed for each of the 30 highway sections in the area where monitoring sites had been established. Collectively, these sections constituted nearly a 100 percent sample of the principal and minor arterial highway network in the impact area.

The basic strategy in Phase II was to employ HPMS as a highway impact submodel within an overall "chain" of land-use, traffic, and highway network models. The intent was to use HPMS to forecast future financial needs under both a "base case" and an "impact scenario", and then by examining differences in the level of projected highway needs over time, identify the effects of subterminal traffic on future financial outlays.

Several different impact scenarios were developed based on the subterminal manager's 1990 business plan, future production estimates, and transshipment levels. However, as Phase II unfolded, it became apparent that HPMS was not sensitive enough to relatively small changes in traffic levels on low-volume roads to be able to provide the types of answers which were needed. As a result, the project entered a third phase in which a set of highway impact models was developed independent of HPMS, and incorporated into an integrated chain of submodels for analyzing subterminal traffic effects.

The third phase of the project focused primarily on the development of a separate set of highway impact models and on the refinement of other (existing) submodels. In Phase III, an extensive review of existing flexible pavement damage models was undertaken in an effort to identify a procedure which would predict the reduction in pavement life attributable to incremental grain truck traffic. During the search for a model, the state's pavement management data base was obtained from the NDHWD and used as a check against the reasonableness of the predicted results of each model. At the same time, a parallel effort was made to identify a procedure which would predict the need for upgrading (or adding strength to) an under-designed pavement. Thus, both deterioration and upgrading models were addressed and evaluated in Phase III.

Extension of the Analysis to Collector Roads

In Phase II of the project, a highway network submodel was developed which routed shipments from farms or production zones to satellite elevators as well as to the Devils Lake subterminal. From a preliminary application of the model, it became apparent that much of the impact would likely occur off the state system, on major or minor collectors for which traffic and highway attribute data had not been collected. Consequently, in Phase III of the project, data were collected concerning the attributes of collector highways in the impact area (such as the surface type, the thickness of the aggregate base, the thickness of surface layers, and the current condition of the highway). In addition, estimates of the average annual daily trips and the percentage of trucks on local highways were developed in an effort to approximate baseline traffic conditions. Together, these data elements were used to extend the analysis to the collector system in the region, something which was beyond the original intent of the project.

Altogether, data were collected for 23 collector highways in the Devils Lake region. Much of the information was obtained through interviews with the NDHWD District Engineer (Mr. Clay Sorenson) or county engineers. The structural number of each collector was computed as follows. For each inch of AC surface layer, .44 was added to the SN. And for every inch of aggregate base, a value of .11 was added to the total.

In summary, the RTAP project evolved through three principal stages consisting of:

1. data collection and preliminary analysis,
2. initial model development (utilizing HPMS as a highway impact submodel),

3. model revision and refinement, including an extension of the modeling process to collector roads.

At each stage during this process, a clearer picture of the problem, and the analytical models and data elements required, emerged.

APPENDIX B
CHANGES IN THE NORTH DAKOTA GRAIN ELEVATOR INDUSTRY AND TRUCK TRAFFIC PATTERNS SINCE 1980

The purpose of this appendix is to present background information regarding the transformation which has occurred in the North Dakota grain elevator industry since 1980, and to overview the changes in railroad regulation and pricing which have lead to this restructuring. Also, recent trends in modal share and truck traffic patterns are highlighted.

Impetus for Change in the Grain Transportation Industry

The restructuring of the grain transportation network had its roots in the Railroad Revitalization and Regulatory Reform Act (4-R Act) of 1976. The 4-R Act created a zone of pricing freedom for railroads; directed the Interstate Commerce Commission (ICC) to consider the adequacy of railroad revenues in regulatory decisions; mandated consideration of current capital costs in commission proceedings; and streamlined the abandonment process. Collectively, these provisions established a political climate which was conducive to the development of incentive rates, and which fostered the rationalization of railroad plant.

The Staggers Rail Act of 1980 built on the foundation of the 4-R Act. The Staggers Act encouraged greater pricing flexibility and freedom, requiring that traffic must be subject to "market dominance" or be "captive" to the railroad industry before the Interstate Commerce Commission could exercise jurisdiction in rate matters. The Staggers Act provided additional pricing incentives by explicitly authorizing the establishment of rail contracts. The Act also enhanced the opportunity for disinvesting in unprofitable or marginally-profitable branch lines by expediting the time frame for abandonment.

In a lesser known provision, the Staggers Act also allowed for the assessment of surcharges on light-density lines with traffic densities less than 1 million gross ton miles per mile. When combined with the expedited abandonment proceedings, the light-density surcharge provisions provided carriers such as Conrail with a powerful tool for rationalizing the light-density network.

In December of 1980, just prior to the passage of the Staggers Act, the Burlington Northern Railroad introduced multiple-car and trainload rates on export wheat shipments from North Dakota origins to the Pacific Northwest. The Pacific Northwest rates were followed shortly by similar rate structures to eastern markets on wheat, barley, sunflowers, and other commodities.

The differentials between the trainload and single-car rates, when coupled with the prospect of light-density surcharges and/or branch line abandonment, provided powerful incentives for elevators to band together into cooperatives and build large, centrally located facilities. These facilities, known as "subterminals", provided the cooperatives with mainline rail access and with the capability to load trainload shipments, thereby accessing the lower trainload rates and avoiding abandonments or surcharges.

Changes in the North Dakota Grain Elevator Industry

Prior to 1981, the grain handling and merchandising system in North Dakota consisted primarily of local, "country" elevators which collectively processed and marketed the majority of the state's grains and oilseeds. In 1980, the average elevator had a storage capacity of 263,000 bushels, and handled 678,000 bushels of grains and oilseeds during the year. Since then, the elevator industry has undergone significant structural change, partly in response to railroad rationalization.

Four trends in the North Dakota elevator industry clearly stand-out over the last six years:

1. Increasing size (storage capacity),
2. Increasing volume,

3. Greater concentration of volume in the hands of fewer firms,

4. Increasing numbers of multiple-car and trainload shippers.

By 1986, the average storage capacity had grown from 263,000 to 411,000 bushels (Figure B.1). Over the same period, the average volume increased 47 percent to 997,000 bushels (Figure B.1).

The trend towards larger facilities with high volume has been paralleled by a trend towards concentration within the industry. In crop year 1979-80, the top ten elevators in the state handled 10.7 percent of the state's grains and oilseeds. By 1986, the ten largest firms handled 16.2 of the total volume. Within this group, the average volume handled was 8.5 million bushels, with the largest facility handling approximately 26 million bushels.

With the introduction of multiple-car and trainload rates in December of 1980, many elevators moved to increase their storage capacity and lengthen their rail sidings. New trainload facilities were built and existing ones were upgraded to handle 26-car or 52-car shipments.

Figure B.2 depicts the growth in multiple-car and trainload shippers as a component of the overall elevator industry. In 1981, only 25 shippers in the state could consign multiple-car or trainload shipments. By 1986, this number had grown to 123. Meanwhile, the number of elevators in the state declined from 592 to 573.

The growth of subterminals is responsible for much of the increase in size, volume, concentration, and trainload capability which have occurred in the North Dakota elevator industry over the last six years. But beyond that, subterminals have had a more direct effect on highway transportation through their influence over modal share and the patterns of truck transportation which have emerged in the state since 1981.

Changes in Traffic Patterns and Modal Share

Changes in the North Dakota elevator industry brought about by rail rationalization and the development of subterminal-satellite elevator systems have sparked changes in the pattern of truck traffic and in the modal allocation of shipments. A completely new class of truck traffic has been introduced: the transshipment of grain from elevator-to-elevator.

Figure B.3 shows the increase in transshipments as a percentage of total bushels shipped over the last 3½ years. In the first half of 1984, 7.6 percent of all grains and oilseeds shipped in North Dakota were transshipped. By the first half of 1987, this figure had grown to 10.4 percent

(Figure B.3). As a percentage of total truck volume, the growth in transshipments has been even more impressive, increasing from 21.3 percent in the first half of 1984 to 35 percent in the first half of 1987 (Figure B.4).

The growth in transshipments has been paralleled by a shift in aggregate modal share toward rail. As Figure B.5 depicts, aggregate truck share has dropped from 24.7 percent in crop year 1983-84 to 19 percent in crop year 1986-87.

In summary, the growth of subterminals and parallel changes in the grain transportation system have resulted in an increasing proportion of transshipments while lowering the overall truck share. Outbound movements from the subterminal are almost entirely by rail. However, truck shipments are increasingly localized and short-haul in nature, intensively utilizing the minor arterial and collector system.

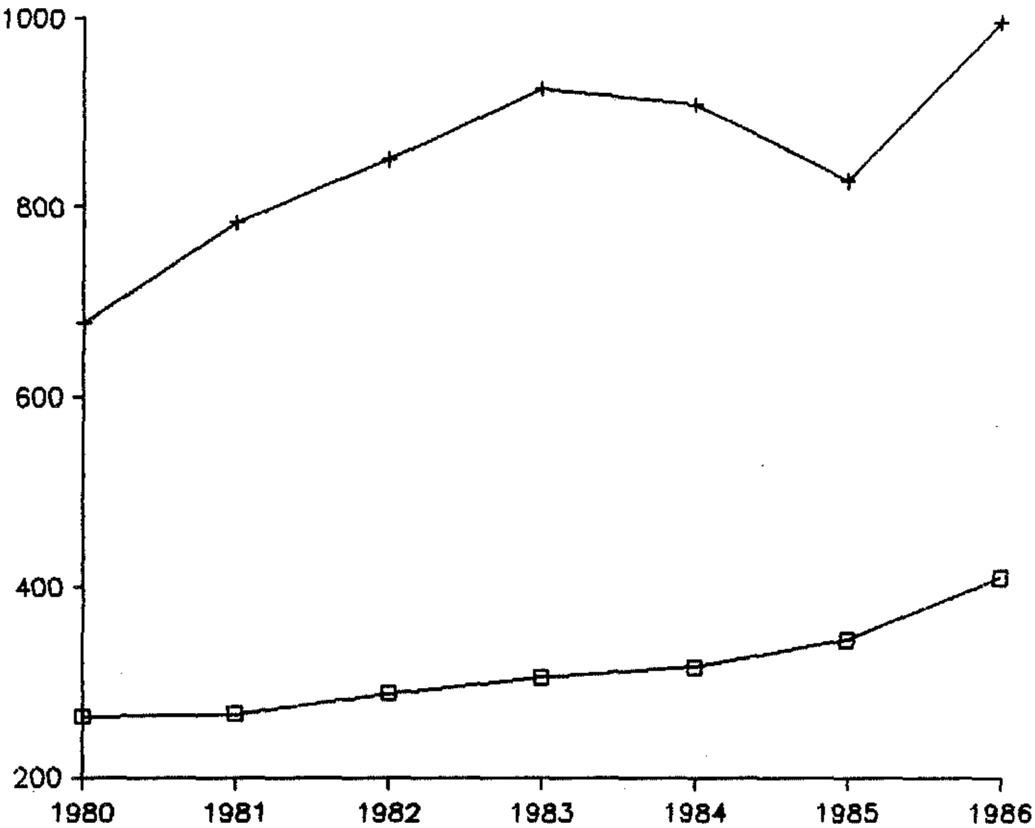

Figure B.1. Trends in Elevator Storage Capacity and Average Volume Handled

Source: Zink (1988).

Legend: —+— VOLUME —□— CAPACITY

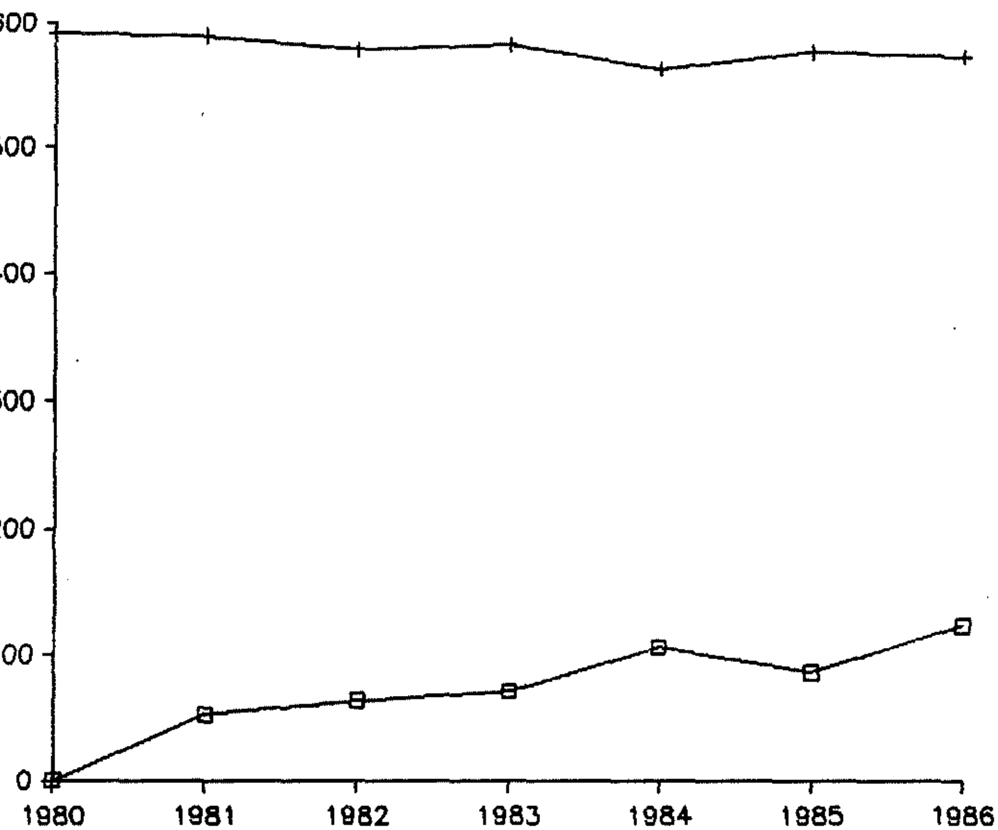

Figure B.2. Number of North Dakota Elevators and Multiple Car Shippers

Source: Zink (1988).

Legend: —+— ELEVATORS —⊟— MULTI-CAR

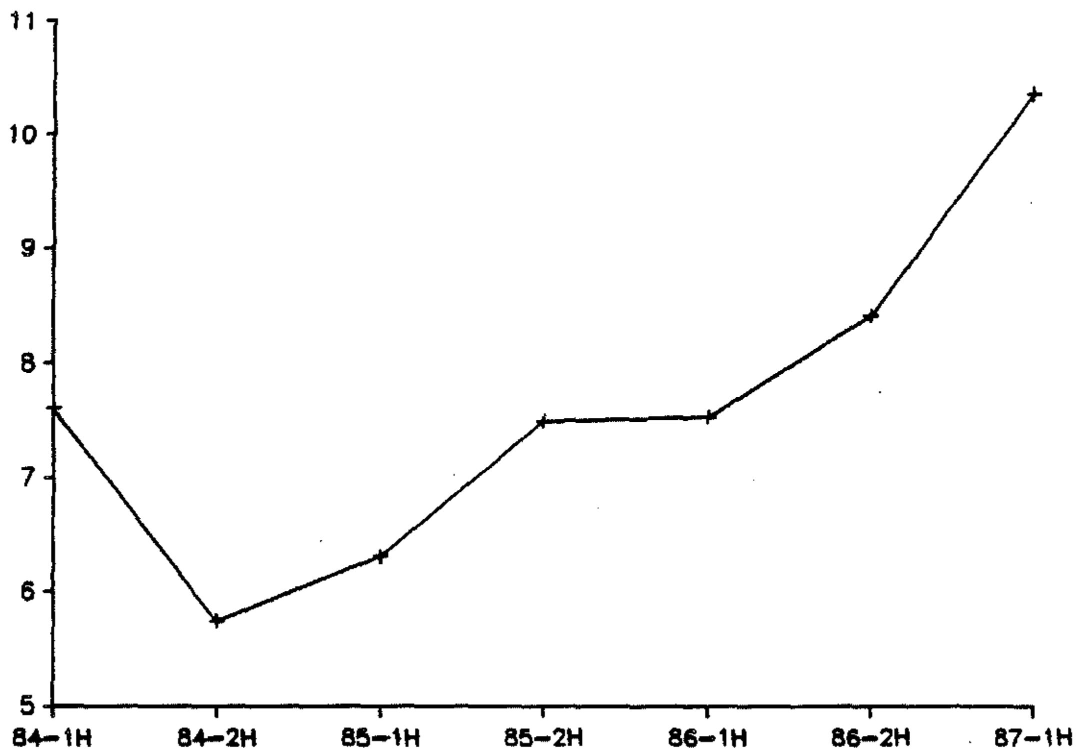

Figure B.3. Transshipments as a Percentage of Total Bushels Shipped: 1984-1987
Source: Unpublished UGPTI Grain & Oilseed Movement Statistics.

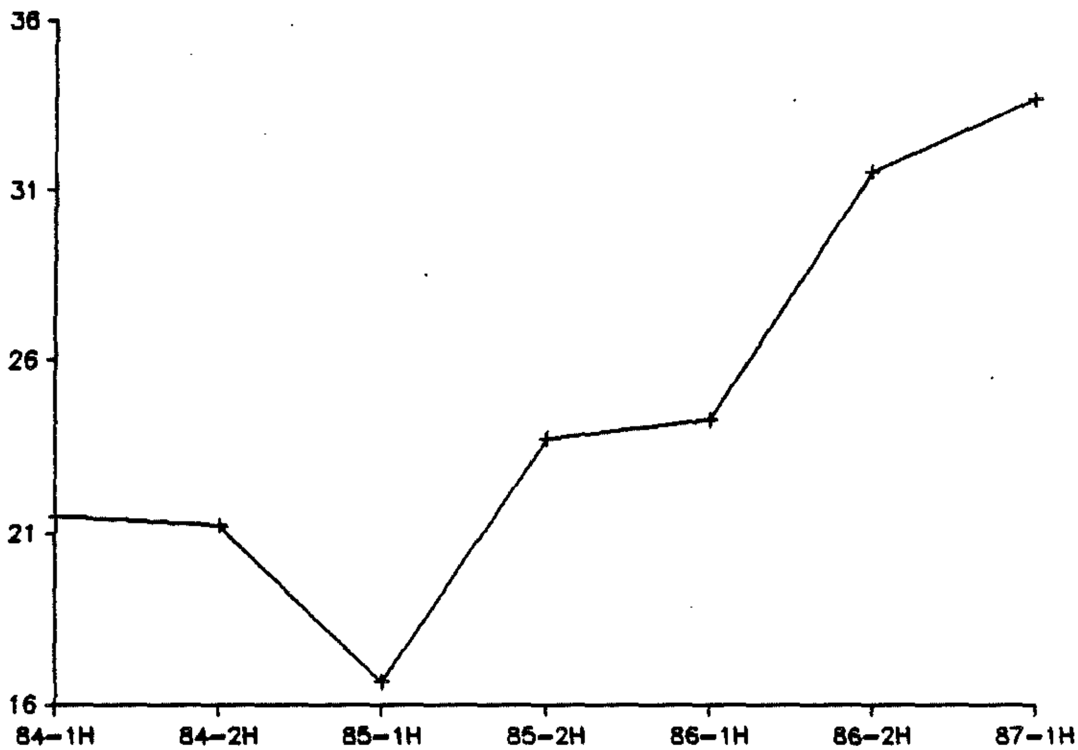

Figure B.4. Transshipments as a Percentage of Total Truck Bushels: 1984-1987

Source: Unpublished UGPTI Grain & Oilseed Movement Statistics.

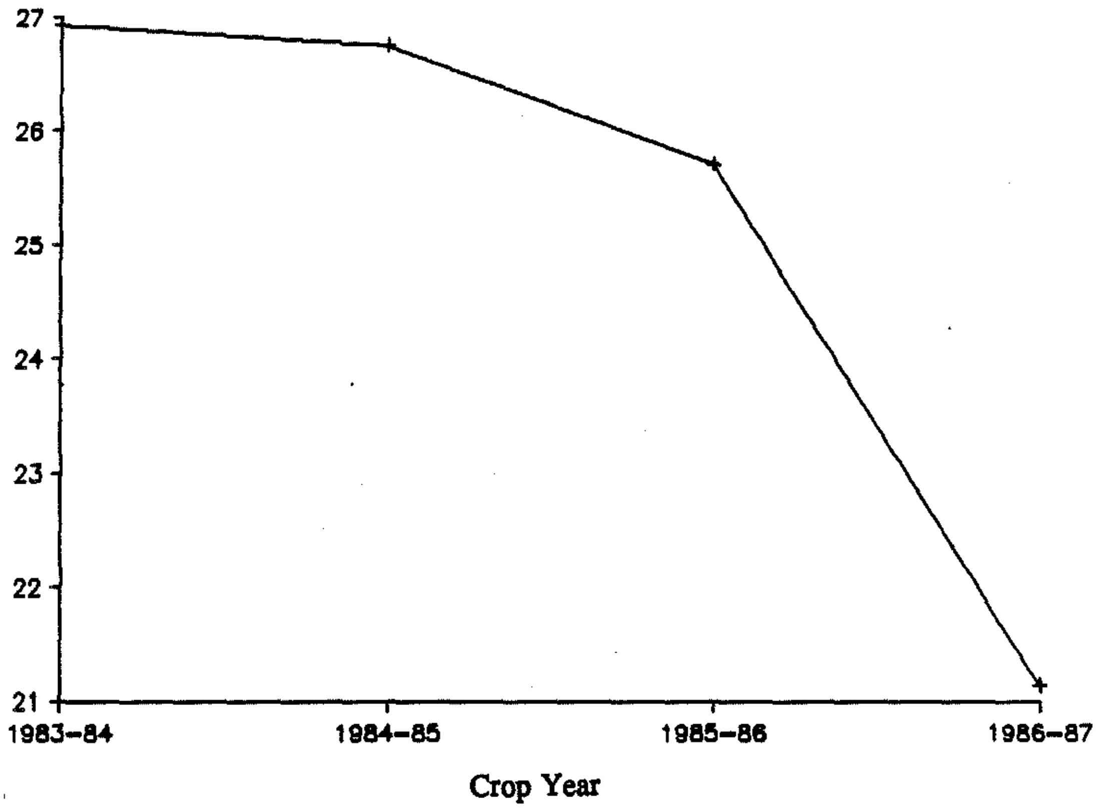

Figure B.5. Truck Bushels as a Percentage of Total Bushels Shipped: 1983-1987
Source: Unpublished UGPTI Grain & Oilseed Movement Statistics.

APPENDIX C
TRAFFIC EQUIVALENCY FACTORS

This appendix presents the AASHO axle equivalency formulas for single and tandem axles, and the axle equivalency formula which was used in the updated FHWA model. The AASHO formula (for flexible pavements) for single axles is given by:

$$LOG_{10}(N_r/N_x) = 4.79 \bullet LOG_{10}(L_x + 1) - 4.79 \bullet LOG_{10}(L_r + 1) + G/\beta_r - G/\beta_x \quad (C.1)$$

where:

$LOG_{10}(N_r/N_x)$ = log of the traffic equivalency factor

$G = LOG_{10}[(P_i - P)/(P_i - P_t)]$

L_r = reference axle weight (kips)

L_x = axle weight (kips)

β_r and β_x are computed in accordance with equation (22) in Chapter 3.

The AASHO formula for tandem axle (on flexible pavements) is given by:

$$LOG_{10}(N_r/N_x) = 4.79 \bullet LOG_{10}(L_x + 2) - 4.79 \bullet LOG_{10}(L_r + 1) - 4.33 \bullet LOG_{10}(2) + G/\beta_r - G/\beta_x \quad (C.2)$$

The AASHO formulas for rigid pavements are given in Langsner (1962).

The load equivalence formula used in the updated FHWA model is given by:

$$LE_x = (\tau_{18}/\tau_x)[-\ln(g/c)]^{EXP} \qquad (C.4)$$

where:

τ_x = computed value of τ for axle of interest

$$c = (P_i - P_f)/(P_i - P_t) \qquad (C.5)$$

$$g = (P_i - P)/(P_i - P_t) \qquad (C.6)$$

$$EXP = 1/\beta_x - 1/\beta_r \qquad (C.7)$$

APPENDIX D
SHIPMENT DISTRIBUTION TECHNIQUES

The shipment distribution procedure lies at the heart of the impact assessment process. Because of the pivotal role of this submodel, several different analytical techniques were considered and evaluated during the course of the study. The purpose of this appendix is to describe the analytical techniques which considered, and highlight the tradeoffs which exist between resource costs and precision in subterminal impact analysis.

Modeling Techniques

As noted in Chapter 3, there are two broad classes of models which might be applied to the problem of traffic flow distribution: (1) spatial interaction models, and (2) optimization models. Both techniques attempt to model the behavior of trip-makers. However, they are somewhat different in form and structure.

Two types of optimization models are of particular importance in analyzing grain shipments. The first is a farmer (or producer) optimization model. The second is an elevator or cooperative (system) optimization model. The former relates to inbound elevators shipments, the latter to outbound elevator traffic.

Both types of optimization models are discussed in the following subsections of this appendix. But first, some insights into the producer's and elevator manager's decision-making frameworks are presented. Hopefully, this material will provide the reader with a brief sketch of the behavioral motivations of grain producers and shippers (particularly as they relate to the generation of farm truck trips or outbound elevator shipments), and provide future analysts with a frame of reference for judging the appropriateness of alternative shipment distribution techniques.

Behavioral Motivations and Determinants of Grain Shipment Flows

The farmer's decision framework can be summarized in three words: (1) price, (2) proximity, and (3) patronage. Price and proximity are both economic variables which can be measured quantitatively. Patronage is a human factor which cannot. Nevertheless, patronage can be an important factor in the selection of a local elevator.

Farmers may patronize a local elevator for two basic reasons. First of all, they may be members of a local cooperative and thus have interests and equity in the elevator. Second, they may want to ensure the survival of the local elevator and support economic development within the community. Patronage, in and of itself, is not likely to be a decisive factor in the farmer's decision-making equation. However, when combined with proximity, patronage tends to enhance the relative attractiveness of a local facility.

Proximity is a composite measure of two underlying factors: (1) distance, and (2) time. The interrelationship between the two is quite important is the formulation of an impedance function. Certain farm truck costs such as fuel, use-related maintenance, and use-related depreciation tend to increase in proportion to distance. However, others do not. In particular, it is unlikely that the cost of a farmer's time will increase in a linear fashion. Previous studies have shown that as the length of a journey increases, the inconvenience, discomfort, boredom and fatigue of the traveler increases more-than-proportionately to distance. Thus the real value which a farmer places on time spent behind the wheel of a truck may not be consistent with a comparable hourly wage for labor[94].

The intuitive logic set forth above is supported by the results of previous farm truck studies in North Dakota.

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[94]This is particularly true during harvest or other periods of peak work demand. During these intervals, the opportunity cost of a farmer's time (particularly the time spent behind the wheel of a truck) may be quite high due to the competing demands for his or her time.

Griffin (1984) found that North Dakota farmers transported their grain to the closest elevator approximately 67 percent of the time. Eighty-one percent of those surveyed indicated that they traveled 15 miles or less in order to reach their most frequent destination. Furthermore, 86 percent said that they spent 30 minutes or less driving to the elevator of their choice. These findings have two very important implications for this study:

1. they support the contention that the combined influence of proximity and patronage tends to favor the selection of nearby elevators,

2. they indicate that because of the value which farmers place on time, the impedance function (with respect to farm-to-elevator shipments) is probably nonlinear in nature.

Although patronage and proximity are strong influences in the distribution of farm-to-elevator shipments, they are not necessarily the decisive factors. Griffin (1984) found that one-third of the farmers surveyed did not deliver their grain to the closest facility. When asked why they bypassed the local elevator, the majority of those responding (74 percent) gave low prices as the reason. This is not a surprising conclusion, but it does provide empirical support for the theoretical model of grain flows presented in equation (11) of Chapter 3, in which price was defined as the measure of attraction and farm truck costs as the impedance factor.

The role of price in the farmer's decision-making equation can best be represented through the concept of "net farm price." The net farm price is the price which the farmer receives at the elevator minus the farm truck cost associated with positioning the grain at the facility. If the effects of patronage and time are ignored, then net farm price (NFP) becomes the primary decision variable. In this case, the farmer would logically deliver the grain to the facility which offers the highest NFP. However, this abstraction represents a simplified model of farm-to-elevator flows and (as will be pointed-out later) can lead to an illogical allocation of traffic in specific instances.

In many respects, the behavior of an elevator manager is easier to model than that of a farmer. The primary motivation of an elevator manager is to maximize the net price received for a given commodity (the market price minus the distribution cost). Since managers cannot influence the market price or the quantity demanded, their major concern is with minimizing the distribution cost between the elevator and each market where grain is sold. In pursuing this objective, the manager usually has a choice among modes of transport (and sometimes routes). If the nontransportation components of the distribution cost are roughly equal, then the manager will generally choose the mode which offers the lowest freight rate[95].

The motivations of a general (subterminal) manager are somewhat different than those of the traditional elevator manager. He or she must be concerned with revenues and costs for the cooperative system of elevators as a whole, rather than for any individual facility. Since market demand and prices are beyond the control of subterminal managers, their primary motivation is to minimize the aggregate distribution cost for shipping grain from all elevators in the system to all potential markets. Although this is a complex task, as will be discussed later, it is a relatively straightforward one to model.

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[95]Nontransportation (or more correctly nonrate) distribution costs consist of expenses other than the freight rate which are associated with the positioning of grain in a particular market. These costs can include: (1) warehousing or storage costs, (2) inventory costs, (3) packaging, and (4) loss and damage. The nonrate components of distribution costs may vary among modes. For example, one mode may require special packaging or dunnage of freight while another does not. Similarly, loss and damage or accessorial charges (fees in addition to the freight rate) may vary between truck and rail. Typically, these nonrate distribution costs are not a major concern in the transportation of grain. This does not mean that one mode may not have service advantages over another. What it does mean is that in the case of grain, the transportation rate is the primary element of the distribution cost which affects mode choice.

The purpose of the preceding discussion has been to describe the motivations of agricultural producers and shippers so that their transportation behavior can be more effectively modeled. The appendix now turns to a discussion of farm-to-elevator optimization models which are largely premised on assumptions concerning the farmer's motivations and transportation behavior.

Farm-to-Elevator Optimization Models

The producer optimization model mentioned earlier may have one of two objectives as its optimizing function. First, the analyst may seek to maximize net farm prices. This is somewhat analogous to a profit maximization objective function in operations research.

Maximizing net farm price may be a logical extension of economic theory. But (as pointed-out earlier) proximity and patronage are also considerations in the producer's decision-making equation, and these factors are not accounted for in the NFP maximization model. In the net farm price model, a farmer will theoretically be indifferent between an elevator which is 75 miles away and one which is two miles in distance, provided that the two have the same net farm price. However, this is an illogical conclusion when the effects of time, convenience, and patronage are considered.

Instead of maximizing net farm prices, the analyst may seek to minimize producer transportation costs. Since farm truck costs represent only one component of the net farm price equation, a cost minimization approach paints only a partial picture of the producer's decision-making formula. However, the cost minimization model does give an explicit advantage to nearby elevators. Thus, it reflects (in a limited and indirect sort of way) the influence of proximity and patronage on the farmer's decision process.

The farm-to-elevator optimization problem can be handled through a special type of linear (mathematical) programming technique: the transportation algorithm.[96] The general formulation of the transportation problem is:

$$\text{Minimize } Z = \sum_{i}\sum_{j} C_{ij}X_{ij} \qquad \text{(D1)}$$

subject to:

$$\sum_{j} X_{ij} = S_i \text{ (supply at zone "i")}$$

$$\sum_{i} X_{ij} = D_j \text{ (demand at zone "j")}$$

$$X_{ij} \geq 0$$

[96]The transportation algorithm is explained in a variety of operations research and management science texts, including: Hillier and Lieberman (1980) and Lee, Moore, and Taylor (1984).

where:

X_{ij} = Volume shipped between zones "i" and "j"

C_{ij} = Unit cost of transportation between zones "i" and "j"

In this general formulation, supply and demand are balanced. The balance condition is given by:

$$\sum_i S_i = \sum_j D_j$$

However, an exact balance between supply and demand rarely exists in a subterminal market area during a given interval of time. Instead, the supply typically exceeds the collective demand expressed by the system of cooperative elevators. The remainder flows to other elevators (in or outside of the region), or is stored temporarily on-farm.

A special variant of the transportation algorithm can be employed to handle an imbalance between supply and demand. If the notation in equation (D1) is changed to be consistent with that which is used elsewhere in the report, the unbalanced formulation of the transportation algorithm is given by:

$$\text{Minimize } Z = \sum_o \sum_d FT_{od} V_{od} \qquad \text{(D2)}$$

subject to:

$$\sum_d V_{od} \leq S_o$$

$$\sum_o V_{od} \geq V_d$$

$$V_{od} \geq 0$$

where:

V_{od} = Volume between zones "o" and "d"

FT_{od} = Farm truck cost between "o" and "d"

S_o = Supply at "o"

V_d = Demand at elevator "d"

In order to maximize net farm price, equation (D2) can be restated as follows:

$$\text{Maximize } Z = \sum_o \sum_d NFP_{od} V_{od} \qquad \text{(D3)}$$

where:

NFP_{od} = Net farm price for grains and oilseeds originating in zone "o" at elevator "d"

Elevator-to-Market Flow Optimization Models

The general objective in modeling outbound elevator flows is to minimize the total cost of distribution (including transportation). The primary components of the distribution cost equation (for a cooperative system of elevators) are:

1. The grain trucking rate from the satellite elevator to the subterminal;

2. The cost of double-handling the grain at the subterminal[97];

3. The transportation rates from the subterminal and satellite elevators to terminal markets.

The cost of distribution between a given satellite elevator and market can be minimized through the application of a simple decision rule. In general, the grain which is stored at a satellite elevator will be transshipped through the subterminal (as opposed to being shipped directly to terminal market) if the following condition holds true:

$$GT_{ce} + DH + SR_{ct} \leq ER_{ct} \qquad \text{(D4)}$$

where:

GT_{ce} = Grain trucking rate for commodity "c" from satellite elevator "e"

DH = Cost of double-handling grain at the subterminal

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[97]The cost of double-handling grain at a subterminal consists of: (1) the variable cost of elevation, (2) interest on the grain while it is stored at the facility, and (3) other variable interest costs. Fixed interest payments on capital (construction) outlays, fixed depreciation, insurance costs and other constant expenses related to the existence of the facility are not considered in the cost of doubling-handling (grain).

SR_{ct} = Rate for commodity "c" from the subterminal to terminal market "t"

ER_{ct} = Rate on commodity "c" from the satellite elevator to terminal market "t"

In other words, if the sum of the grain trucking rate to the subterminal, the additional cost of handling the grain at the facility, and the outbound elevator rate is less than the transportation rate from the satellite elevator to terminal market, then the commodity will be transshipped[98]. Otherwise, it will be shipped directly to terminal market.

While equation (D4) may produce an optimal flow pattern between a given satellite elevator and market, it will not (necessarily) produce an optimal flow for the network of elevators as a whole. All possible commodity flows from all elevators in the system to all potential markets must be considered simultaneously in order for this to happen. A special form of the transportation model (the transshipment model) is especially designed to handle the combination of flows and routings which are possible within a cooperative system of elevators.

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[98]Because of volume loading capabilities and rail mainline location, the subterminal manager typically has access to low trainload or contract rail rates which the substation manager does not. Consequently, the outbound rail rate from the subterminal is typically low relative to the rates at the satellites.

In the transshipment problem, a company is trying to minimize the total transportation cost of shipping products from several origins to several destinations. Instead of shipping everything directly from origin to destination, the company has the option of routing shipments through intermediate locations or "transshipment points." That is, a shipment which is consigned at a given location may be shipped through another supply point (or destination) enroute to market in order to attain the lowest possible shipping or distribution cost.

The shipping patterns of a subterminal-satellite system closely conform to the structure and definition of the classic transshipment problem. There are several possible origins for a given commodity (the elevators) and several possible destinations (terminal markets and processing centers). The objective of the general manager is to ship the volume of commodities available at each elevator to the terminal markets in a manner which minimizes the total cost of distribution. In doing so, he or she may transship the grain; that is, route it through the subterminal (or conceivably through another elevator in the system).

The transshipment model is a special case of the balanced transportation problem. As such, it can be solved (with a few minor adjustments) using the transportation algorithm. Recall that in the balanced transportation problem, total supply must equal total demand. This balance condition must hold true for the transshipment problem as well. But in the transshipment formulation, all of the available supply can conceivably be originated at (or transshipped through) a single supply point. As a result, the supply at each source must be increased by an amount which is at least equal to the total supply. This allows the algorithm to route all shipments via another supply point, if this represents the minimum-cost solution.

In the transshipment problem formulation, shipments may also be routed through an intermediate destination. This means that the total number of units which either pass-through or are terminated at a given destination can conceivably equal the total supply (which in turn equals the total demand). Consequently, the amount which is demanded at any given destination must be increased by an amount which is at least equal to the total demand.

A thorough discussion of the theory and solution procedures which underlie the transshipment problem is beyond the scope of this study. For a more detailed description of the problem formulation and some sample tableaus the reader is referred to: Hillier and Lieberman (1980) or Lee, Moore, and Taylor (1984)[99].

The preceding discussion has focused on optimization models and associated solution techniques. However, optimization models represent only one possible method of projecting grain flows within a subterminal-satellite system. The spatial interaction model (discussed in Chapter 4) represents an attractive alternative to the optimization models, particularly with respect to farm-to-elevator flows.

Evaluation of Alternative Modeling Techniques

As the preceding discussion has pointed-out, the analyst has several options available with respect to the modeling of farm-to-elevator grain flows. The producer optimization models introduced earlier offer the analyst the advantage of a relatively simple, standardized solution process. There are several software packages available which can be used to derive the optimal solution. But there are several potential problems associated with the use of the producer optimization models which the analyst should be aware of.

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[99]In the Devils Lake study, the TRANS procedure contained in the SAS operations research computer package was used to formulate and solve the subterminal transshipment problem. See SAS (1985) for details.

1. The assumption of linearity which goes with the procedures may not be appropriate within the context of producer cost minimization (or NFP maximization).

2. The optimization procedures are not designed to account for the effects of time, convenience, and patronage on producer transportation decisions.

3. The models are deterministic in nature, although the flow problem itself has a great deal of uncertainty involved.

There is an additional problem which arises in the application of the producer optimization models which prospective analysts should note. Both the NFP and the farm truck cost models are based on assumptions and motivations which are relevant at the level of the individual producer or traveler. However, it is not possible to model the travel of each farmer within a 1,000 square mile area[100]. So the aggregation of data to the level of supply zones is necessary. Within a given supply zone, the analyst may be dealing with ten or more producers, all represented by a single centroid. At this level of aggregation, the optimization models become somewhat divorced from their

[100]The trade area of the Devils Lake subterminal-satellite system is over 1000 square miles. This is probably not the largest trade area in North Dakota and much larger volumes exist in other parts of the state.

underlying assumptions. So they are not likely to yield traffic projections which are very precise in nature[101].

The optimization models permit the analyst to draw upon a set of "canned" software packages to derive an optimal solution. However, there is no existing computer program which will generate a solution to the farm-to-elevator shipment problem via the spatial interaction model[102]. Instead, analysts must write the computer code themselves. Nevertheless, the spatial interaction model has some attractive features which may make the effort worthwhile. First, the spatial interaction model explicitly incorporates the transportation demand and impedance functions into the predictive equation via a logical relationship. The

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[101]Of the two optimization procedures, the farm truck cost minimization model has the lowest resource cost. In certain instances, it may offer a viable alternative for the analyst. Perhaps the best context for applying the farm truck cost minimization model would be in the analysis of pre-subterminal grain flows. In a pre-subterminal environment, the preference of farmers for local elevators should be strong, and decisive price advantages among elevators (such as that which is due to a subterminal in the region) are generally not present.

[102]There is a software package used in urban transportation planning which calibrates the "gravity model", a particular type of spatial interaction model. This program (developed by the FHWA) is called the Gravity Model Calibration Program or GMCP. Although the shipment distribution procedure is analogous to the trip generation model in urban transportation planning, the processes, the variables, and the relationships involved are different. So the GMCP is not really a viable option for this study. For a description of the GMCP see: FHWA (1977).

attractiveness of a given elevator is assumed to be directly proportional to the bid price for the commodity and inversely proportional to the impedance to flow. Second, the spatial interaction model is expressly designed to function at the zonal level of aggregation. The model directly addresses the effects of demand-point competition on individual producers in the zone through the law of "relative attraction." Even though a single centroid is used to represent many producers, the flow patterns which emerge reflect the fact that producers which are situated in different subregions of the zone (potentially 30 miles apart) will prefer different elevators[103]. Third, the impedance function in the spatial interaction model can be modified to assume any functional form, linear or nonlinear. As a result, the spatial interaction model can be tailored to farm-to-elevator shipments.

As the previous discussion has pointed-out, there are tradeoffs involved in the selection of a farm-to-elevator modeling technique, particularly between precision and

[103]Recall that in the spatial interaction model (according to the law of relative attraction), the amount available for shipment in a given zone is distributed among competing elevators based on the relative attractiveness of each. So the model predicts that some grain will flow to most or all of the feasible elevators in the given area. Thus, the flow pattern which is predicted reflects the fact that some farmers within a 25 or 30 square mile area will ship to different elevators.

resource costs. When making this selection, the analyst may wish to weigh the benefits of greater precision against the incremental costs of data collection and programming.

Tradeoffs in Modeling Farm-to-Elevator Flows

Table D.1 presents a subjective appraisal of the resource costs and precision associated with each of the alternatives which were considered in the Devils Lake study. Both the resource costs and precision will differ depending upon the scope of the study. If all elevators in the region are included in the model, the resources will be greater than if only the elevators in the cooperative system are considered.

As the table depicts, the greatest degree of precision is likely to be achieved with a spatial interaction model. However, this approach also entails the highest resource cost (for both data collection and computing)[104]. At the other end of the spectrum, the farm truck cost model can

[104]The NFP and spatial interaction models require commodity prices for all elevators in the region, plus distances. The farm truck cost model requires only distances. In the impact year, estimates of prices at the elevators in the cooperative system are much easier to generate since the price at the satellite elevators is typically equal to the price at the subterminal plus the grain trucking cost between the satellite and the subterminal. So if the analyst has an equation for short-haul truck rates and knows the price at the subterminal, then he or she can predict the price at the satellites.

generate moderate levels of precision at low-to-moderate resource costs[105]. The other options fall somewhere in between.

In the final analysis, the selection of an appropriate analytical approach and a farm-to-elevator model really depends upon the objectives of the investigator. In the Devils Lake study, the region-wide spatial interaction model was selected due to the desired precision.

TABLE D.1. PRECISION AND RESOURCE COSTS OF ALTERNATIVE FARM-TO ELEVATOR MODELING TECHNIQUES

	Region-Wide		System-Only	
Model	Precision	Resources	Precision	Resources
Net Farm Price	Medium	High	Medium	Medium
Farm Truck Cost	Medium	Low	Medium	Low
Spatial Interaction	Highest	High	High	Medium

Assessment of Elevator-to-Market Shipment Models

A spatial interaction model could conceivably be used to project elevator-to-market flows in much the same manner as farm-to-elevator traffic. However, the outbound flow

[105]As noted previously, the best context for applying the farm truck cost model is in a pre-subterminal environment such as in the base year.

problem for a system of elevators is more aptly formulated as an optimization problem. Here, it is quite realistic to assume that the general manager will attempt to minimize the logistical cost of moving grain from elevator storage to final market. But it is less realistic to assume that elevator-to-market shipments will conform to the laws of spatial interaction[106].

While the transshipment model is sound in both logic and procedure, it nevertheless has some potential drawbacks

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[106]The law of interaction applies (at least in theory) to the distribution of outbound elevator shipments, just as it does to inbound elevator traffic. The attractiveness of each terminal market or processing center for each elevator is directly proportional to the market price and inversely proportional to the transportation cost (as required by the model). So if the analyst knows the average price at each market and the average transportation rate for a particular time-period (such as a calendar year), then a spatial interaction model can conceivably be applied to outbound elevator flows. However, the use of a spatial interaction model to predict elevator-to-market flows for a particular satellite elevator may produce unrealistic results. The primary reason for this predictive failure is that central management may be pursuing objectives which optimize some conditions for the cooperative as a whole (such as profit levels), but which result in shipment patterns which have little behavioral significance at the individual elevator or substation level. So it would be difficult (if not impossible) for the spatial interaction model to project the outbound flows from any given elevator in a cooperative system. In addition to this potential problem, there are many variables other the relative attractiveness of competing destinations which are involved in the merchandising of grain. Furthermore, there are considerable distances between elevators and terminal markets. Both factors tend to mitigate against the success of the spatial interaction model.

which the analyst should be aware of. The first concerns the assumption of determinism-- that the distribution costs (including the freight rate) are known with certainty for the analysis period. There may be some validity to this assumption during the base-year. However, the analyst must also forecast values for the impact year and the horizon year, where uncertainty in the parameters becomes a concern[107].

Uncertainty in the parameters of the transportation model can be handled (somewhat) through sensitivity analysis, or by re-solving the problem with different values assumed for the distribution costs. However, a second source of uncertainty exists in forecasting elevator shipments. This concerns the applicability of the cooperative elevator model to all systems.

Most subterminal-satellite systems conform to the cooperative prototype discussed above, wherein the system is managed collectively by a general manager and a board of directors. However, individual systems may vary in the degree of centralization and in the amount of local autonomy available to the satellite or local elevators. In a system

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[107]One option is to assume that the rail rates, the grain trucking rates, and the cost of handling grain at the subterminal will remain the same over the analysis period (or that at least the relationships will not change).

with strong centralized management, most of the operating authority and business discretion is vested in the general manager. The satellite elevators or substations have little or no autonomy.

In many instances, a defacto subterminal-satellite network may exist outside of the cooperative organizational structure. That is, a private subterminal elevator (with trainload capabilities) may be constructed in a market area. The trainloading elevator will purchase grain from surrounding elevators (which may be privately-owned or members of a local cooperative), thus simulating the effect and flow patterns of a subterminal-satellite system. This arrangement may, in fact, be more common in North Dakota (and in other parts of the country) than the cooperative model. Under a private model, the decision-making system is not centralized. The subterminal manager is not trying to optimize profits for a network of elevators from which he or she buys grain. Instead, his or her primary concern is with the subterminal. The local (satellite) elevator manager (under this model) exercises complete autonomy, reacting to the bid price of the subterminal as well as to market prices and freight rates. So the cooperative model is not really appropriate. In fact, the flows would be governed primarily by the decision rule presented in equation (D4).

The bottom line of this discussion is that considerable uncertainty exists in forecasting the outbound flows within a system of elevators. As noted in Chapter 2, one way of handling uncertainty in forecasting (or in the assumptions which underlie the model) is to formulate and analyze several alternative scenarios. This is the approach which was taken in the Devils Lake study. The transshipment model was used to generate an "optimization scenario" for outbound elevator shipments[108]. In addition, several other scenarios were identified which might hold true in certain situations (or in certain cooperative systems). A scenario involving local autonomy (or the presence of a private subterminal in the area) was analyzed. Here, the satellite elevators in the system were assumed to be acting in a somewhat independent manner. So the elevator-to-market flows (in this scenario) were allocated using the decision rule presented in equation (D4). Also, an abandonment scenario was analyzed in which the branch line system in the Devils Lake region (on which most of the satellite elevators are situated) was assumed to be abandoned in the impact year. Without the benefit of rail rates and services, a high

[108]The transshipment scenario was projected using the optimization procedure "TRANS" in the SAS Operations Research package. See for details concerning the procedure see: SAS/OR USERS GUIDE, SAS Institute, Cary, NC 1985.

percentage of the satellites' grain would (out of necessity) have to be transshipped via the subterminal. This scenario is quite important in the overall analysis because it generally represents the highest frequency of transshipments (and CO-5AX truck use) in the impact region.

APPENDIX E
DEVILS LAKE ELEVATOR SYSTEM AND TRANSPORTATION NETWORK

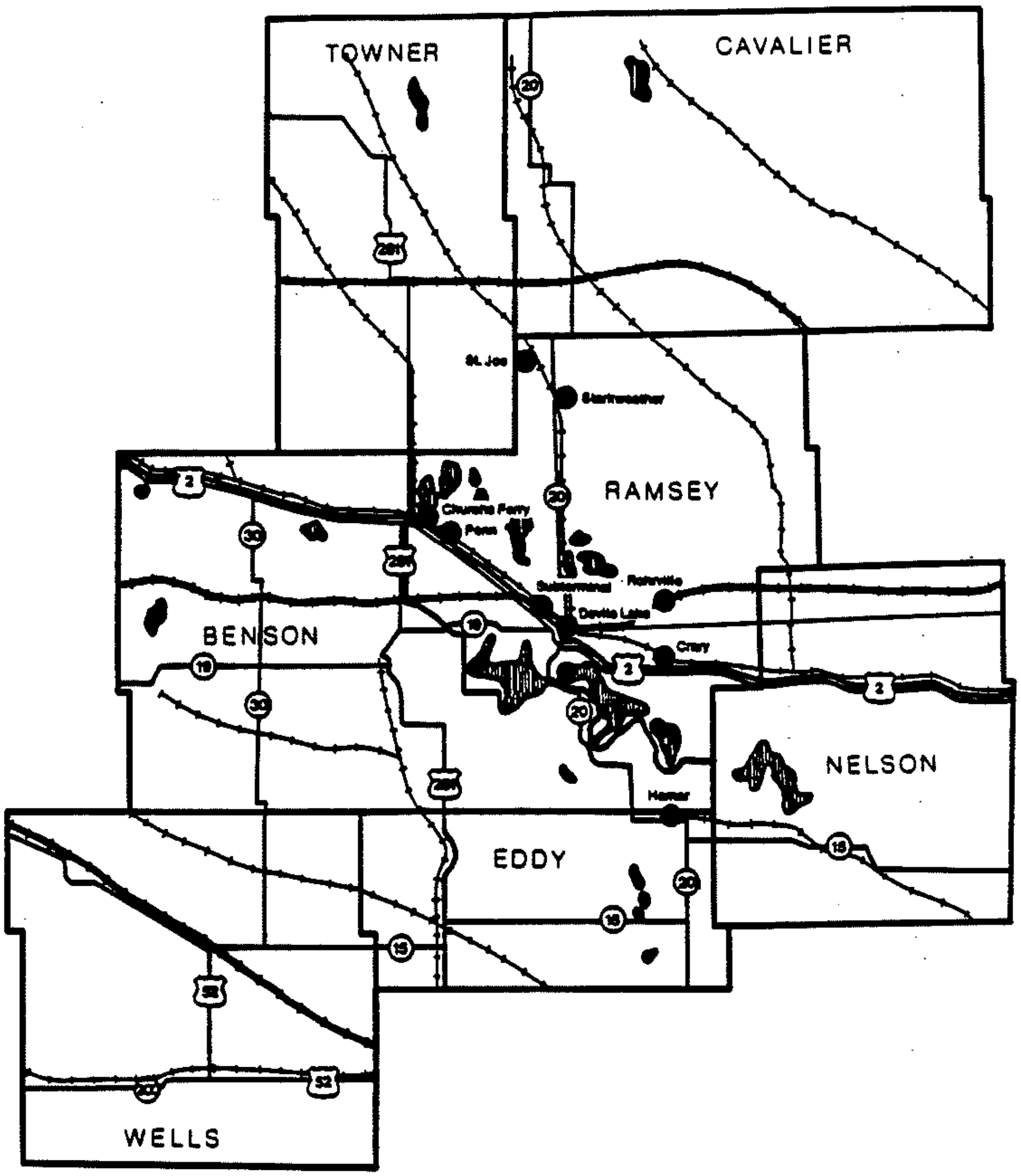

Figure E.1. Devils Lake Elevator System and Transportation Network

Legend: Burlington Northern R.R. Soo Line Railroad Co.

Appendix F

Data Collection Schedule in the Devils Lake Region

1986
DEVILS LAKE W.I.M.

STATION	HWY	MILE POINT	DATE OF COUNT	HOURS OF COUNT	DIRECTION
C1	ND#20	106	6/2/86 THRU 6/4/86	48	N & S
C2	FAS	3630	5/12/86 THRU 5/15/86	72	E & W
C3 W.B.	US#2	272	7/7/86 THRU 7/8/86	24	WEST
C3 E.B.	US#2	272	6/25/86 THRU 6/26/86	24	EAST
C4	ND#20	101	6/23/86 THRU 6/25/86	48	N & S
C5	ND#19	152	5/28/85 THRU 5/29/86	24	E & W
C6 W.B.	US#2	268	5/19/86 THRU 5/20/86	24	WEST
C7 W.B.	US#2	265	6/4/86 THRU 6/5/86	24	WEST
C7 E.B.	US#2	265	6/11/86 THRU 6/12/86	24	EAST
C8	ND#20	119	6/9/86 THRU 6/11/86	48	N & S
C10	ND#20	113	7/28/86 THRU 7/30/86	48	N & S
S18	ND#57	11	7/23/86 THRU 7/25/86	48	E & W
S19	ND#57	5	7/21/86 THRU 7/23/86	48	E & W
S20	ND#19	141	7/9/86 THRU 7/11/86	48	E & W
S23	ND#20	131	7/14/86 THRU 7/16/86	48	N & S
S24	ND#17	52	6/16/86 THRU 6/18/86	48	E & W
S25	ND#17	55	6/19/86 7/17/86 THRU 7/18/86	24 24	N & S N & S
S26	ND#17	57	7/30/86 THRU 8/1/86	48	N & S

1985
DEVILS LAKE W.I.M.

STATION	HWY	MILE POINT	DATE OF COUNT	HOURS OF COUNT	DIRECTION
C1	ND#20	106	7/11/86	24	N & S
C2	FAS	3630	10/1/86 THRU 10/3/86	48	E & W
C3 E.B.	US#2	272	8/20/86 THRU 8/21/86	24	EAST
C3 W.B.	US#2	272	8/21/86 THRU 8/22/86	24	WEST
C4	ND#20	101	8/26/86 THRU 8/27/86	24	N & S
C5	ND#19	152	7/16/86 THRU 7/18/86	48	E & W
C6 W.B.	US#2	268	8/27/86 THRU 8/28/86	24	WEST
C7 W.B.	US#2	265	7/9/86 THRU 7/10/86	24	WEST
C10	ND#20	113	8/29/86 THRU 8/30/86	24	N & S
S12 W.B.	US#2	279	9/5/86 THRU 9/6/86	24	WEST
S12 E.B.	US#2	279	9/4/86 THRU 9/5/86	24	EAST
S13 E.B.	US#2	283	9/23/86 THRU 9/24/86	24	EAST
S13 W.B.	US#2	283	9/24/86 THRU 9/25/86	24	WEST
S16	ND#20	80	9/17/86 THRU 9/18/86	48	N & S
S21	US#2	256	9/26/86 THRU 9/27/86	24	WEST
S27	ND#17	1	9/12/86	24	E & W
S28	ND#20	122	9/10/86	24	N & S

1985
DEVILS LAKE TRAFICOMP

STA	DIR	HWY	MILE	O	A	B
1	N	ND#20	106		8/13-8/18 120 HRS.	7/8-7/11 48 HRS.
1	S	ND#20	106		8/13-8/18 120 HRS.	7/8-7/11 48 HRS.
2	E	FAS 3630	2.5 MI. E. OF ND#20		8/14-8/19 120 HRS.	7/8-7/11 48 HRS.
2	W	FAS 3630	2.5 MI. E. OF ND#20		8/14-8/19 120 HRS.	7/8-7/11 48 HRS.
3	E	US#2	272		8/14-8/19 120 HRS.	7/9-7/10 24 HRS.
3	W	US#2	272		8/14-8/19 120 HRS.	7/9-7/10 48 HRS.
4	N	ND#20	101		7/10-7/16 144 HRS.	8/15-8/20 120 HRS.
4	S	ND#20	101		7/9-7/16 72 HRS.	8/15-8/20 120 HRS.
5	E	ND#19	152		7/9-7/16 72 HRS.	8/21-8/26 120 HRS.
5	W	ND#19	152		7/9-7/16 168 HRS.	
6	E	US#2	268		7/9-7/16 168 HRS.	
6	W	US#2	268		7/9-7/16 144 HRS.	
7	E	US#2	265		7/9-7/16 168 HRS.	
7	W	US#2	265		7/9-7/16 168 HRS.	
8	N	ND#20	119		7/25-7/30 120 HRS.	
8	S	ND#20	119		7/25-7/30 120 HRS.	
9	E	FAS 3618	1.5 MI. E. OF ND#20		7/25-7/30 120 HRS.	
9	W	FAS 3618	1.5 MI. E. OF ND#20		7/25-7/30 120 HRS.	

10	N	ND#20	113	7/25-7/30 120 HRS.
10	S	ND#20	113	7/25-7/30 120 HRS.
11	E	FAS 3630	9.5 MI. E. OF ND#20	7/25-7/30 120 HRS.
11	W	FAS 3630	9.5 MI. E. OF ND#20	7/25-7/30 120 HRS.
12	E	US#2	279	7/25-7/30 96 HRS.
12	W	US#2	279	7/25-7/30 120 HRS.
13	E	US#2	283	7/25-7/30 120 HRS.
13	W	US#2	283	7/25-7/30 120 HRS.
14	E	US#2	289	7/25-7/30 120 HRS.
14	W	US#2	289	7/25-7/30 120 HRS.
15	N	ND#20	73	8/6-8/11 120 HRS.
15	S	ND#20	73	8/6-8/11 120 HRS.
16	N	ND#20	81	8/6-8/11 120 HRS.
16	S	ND#20	81	8/6-8/11 120 HRS.
17	N	ND#20	91	8/6-8/11 120 HRS.
17	S	ND#20	91	8/6-8/11 120 HRS.
18	E	ND#57	11	8/6-8/11 120 HRS.
18	W	ND#57	11	8/6-8/11 120 HRS.
19	E	ND#57	5	8/7-8/12 120 HRS.
19	W	ND#57	5	8/7-8/12 120 HRS.

20	E	ND#19	141	8/22-8/27 120 HRS.
20	W	ND#19	141	8/22-8/27 120 HRS.
21	E	US#2	258	8/13-8/18 120 HRS.
21	W	US#2	258	8/13-8/18 120 HRS.
22	E	US#2	253	8/13-8/18 120 HRS.
22	W	US#2	253	8/13-8/18 120 HRS.
23	N	ND#20	131	7/17-7/22 120 HRS.
23	S	ND#20	131	7/17-7/22 120 HRS.
24	E	ND#17	52	7/17-7/22 120 HRS.
24	W	ND#17	52	7/17-7/22 120 HRS.
25	E	ND#17	55	7/17-7/22 120 HRS.
25	W	ND#17	55	7/17-7/22 120 HRS.
26	E	ND#17	57	7/17-7/22 120 HRS.
26	W	ND#17	57	7/17-7/22 120 HRS.
27	E	ND#17	60	7/17-7/22 120 HRS.
27	W	ND#17	60	7/17-7/22 120 HRS.
28	N	ND#20	122	7/17-7/22 120 HRS.
28	S	ND#20	122	7/17-7/22 120 HRS.
29	E	FAS 3614	1.2 MI. W. OF ND#20	7/17-7/22 120 HRS.
29	W	FAS 3614	1.2 MI. W. OF ND#20	7/17-7/22 120 HRS.

1986
DEVILS LAKE TRAFICOMP

STA	DIR	HWY	MILE	A	B	C	D	E	F	G	H
1	N	ND#20	106	5/12-5/14 48 HRS.	5/22-5/27 120 HRS.	6/20-6/24 96 HRS.	7/8-7/10 48 HRS.	6/3-6/5 48 HRS.	7/11-7/15 96 HRS.	5/30-6/3 96 HRS.	6/17-6/19 48 HRS.
1	S	ND#20	106	5/12-5/14 48 HRS	5/22-5/23 24 HRS.	6/20-6/24 96 HRS.	7/8-7/10 48 HRS.	6/3-6/5 48 HRS.	7/11-7/16 120 HRS.	5/30-6/3 96 HRS.	6/17-6/19 48 HRS.
2	E	FAS 3630	2.5 MI. E. OF ND#20	5/21-5/26 120 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.	6/27-7/2 120 HRS.	6/24-6/27 72 HRS.			
2	W	FAS 3630	2.5 MI. E. OF ND#20	5/21-5/26 120 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.		6/24-6/26 48 HRS.			
3	E	US#2	272	5/12-5/14 48 HRS.	5/15-5/19 96 HRS.	6/17-6/22 120 HRS.	7/8-7/10 48 HRS.	6/3-6/5 48 HRS.		5/30-6/3 96 HRS.	
3	W	US#2	272	5/12-5/14 48 HRS.	5/15-5/19 96 HRS.	6/17-6/22 120 HRS.	7/8-7/10 48 HRS.	6/3-6/5 48 HRS.	7/11-7/16 120 HRS.	5/30-6/3 96 HRS.	
4	N	ND#20	101	5/12-5/14 48 HRS.	5/15-5/19 96 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.	6/3-6/6 72 HRS.	6/27-6/30 72 HRS.	5/30-6/3 96 HRS.	6/24-6/26 48 HRS.
4	S	ND#20	101	5/12-5/14 48 HRS.	5/15-5/19 96 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.	6/3-6/6 72 HRS.	6/27-6/30 72 HRS.	6/24-6/26 48 HRS.	
5	E	ND#19	152	5/13-5/15 48 HRS.	5/15-5/20 96 HRS.	6/26-6/26 144 HRS.	6/3-6/6 48 HRS.	7/11-7/13 48 HRS.	5/30-6/3 96 HRS.	6/17-6/19 648 HRS. 648	
5	W	ND#19	152	5/13-5/15 48 HRS.		6/20-6/26 120 HRS.	6/3-6/5 120 HRS.	7/11-7/16 96 HRS.	5/30-6/3 96 HRS.	6/17-6/19 48 HRS.	
6	E	US#2	268	5/22-5/26 96 HRS.	6/11-6/13 48 HRS.	6/13-6/17 96 HRS.	6/27-6/28 24 HRS.	6/24-6/27 72 HRS.			
6	W	US#2	268	5/22-5/27 120 HRS.	6/10-6/11 24 HRS.	6/13-6/17 96 HRS.	6/27-6/31 96 HRS.	6/24-6/26 48 HRS.			
7	E	US#2	265	5/22-5/23 24 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.					
7	W	US#2	265	5/22-5/27 120 HRS.	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.					
8	N	ND#20	119	7/18-7/23 120 HRS.	7/16-7/17 24 HRS.						
8	S	ND#20	119	7/18-7/23 120 HRS.	7/16-7/17 24 HRS.						
9	E	FAS 3618	1.5 MI. E. OF ND#20	7/17-7/22 120 HRS.							
9	W	FAS 3618	1.5 MI. E. OF ND#20	7/17-7/22 120 HRS.							

10	N	ND#20	113	7/29-7/31 48 HRS.	7/23-7/28 120 HRS.		
10	S	ND#20	113	7/29-7/31 48 HRS.	7/23-7/28 120 HRS.		
11	E	FAS 3630	9.5 MI. E. OF ND#20	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.		
11	W	FAS 3630	9.5 MI. E. OF ND#20	6/10-6/12 48 HRS.	6/13-6/17 96 HRS.		
12	E	US#2	279	5/21-5/26 120 HRS.			
12	W	US#2	279	5/21-5/26 120 HRS.			
13	E	US#2	283	6/17-6/22 120 HRS.			
13	W	US#2	283	6/17-6/22 120 HRS.			
14	E	US#2	289	7/22-7/27 120 HRS.	7/28-7/29 24 HRS.		
14	W	US#2	289	7/22-7/27 120 HRS.	7/28-7/29 24 HRS.		
15	N	ND#20	73	7/18-7/21 72 HRS.	7/15-7/17 48 HRS.		
15	S	ND#20	73	7/18-7/21 72 HRS.	7/15-7/17 48 HRS.		
16	N	ND#20	81	6/3--6/5 48 HRS.	7/29-7/31 48 HRS.	7/24-7/29 120 HRS.	5/30-6/2 72 HRS.
16	S	ND#20	81	6/3-6/5 48 HRS.	7/29-7/31 48 HRS.	7/24-7/29 120 HRS.	5/30-6/2 72 HRS.
17	N	ND#20	91	7/18-7/21 72 HRS.	7/15-7/17 48 HRS.		
17	S	ND#20	91	7/18-7/21 72 HRS.	7/15-7/17 48 HRS.		
18	E	ND#57	11	5/13-5/15 48 HRS.	5/15-5/20 120 HRS.		
18	W	ND#57	11	5/13-5/15 48 HRS.	5/15-5/20 120 HRS.		
19	E	ND#57	5	7/18-7/22 96 HRS.	7/16-7/17 24 HRS.		
19	W	ND#57	5	7/18-7/22 96 HRS.	7/16-7/17 24 HRS.		

20	E	ND#19	141	6/12-6/17 120 HRS.	7/29-7/31 48 HRS.	7/25-7/29 96 HRS.	6/17-6/18 24 HRS.
20	W	ND#19	141	6/12-6/17 120 HRS.	7/29-7/31 48 HRS.	7/25-7/29 96 HRS.	6/17-6/18 24 HRS.
21	E	US#2	258	5/13-5/15 48 HRS.	5/15-5/20 120 HRS.		
21	W	US#2	258	5/13-5/15 48 HRS.	5/15-5/20 120 HRS.		
22	E	US#2	253	6/20-6/24 96 HRS.	7/29-7/31 48 HRS.	7/25-7/29 96 HRS.	6/17-6/19 48 HRS.
22	W	US#2	253	6/20-6/24 96 HRS.	7/29-7/31 48 HRS.	7/25-7/29 96 HRS.	6/17-6/20 48 HRS.
23	N	ND#20	131	6/27-7/2 120 HRS.	6/24-6/26 48 HRS.		
23	S	ND#20	131	6/27-7/2 120 HRS.	6/24-6/26 48 HRS.		
24	E	ND#17	52	6/24-6/26 48 HRS.	6/27-7/2 120 HRS.		
24	W	ND#17	52	6/24-6/26 48 HRS.	6/27-7/2 120 HRS.		
25	E	ND#17	55	6/27-6/31 96 HRS.	6/24-6/26 48 HRS.		
25	W	ND#17	55	6/27-6/31 96 HRS.	6/24-6/26 48 HRS.		
26	E	ND#17	57	5/30-6/3 96 HRS.	6/3-6/4 24 HRS.		
26	W	ND#17	57	5/30-6/3 96 HRS.	6/3-6/5 24 HRS.		
27	E	ND#17	60	7/8-7/10 48 HRS.	7/10-7/14 96 HRS.		
27	W	ND#17	60	7/8-7/10 48 HRS.	7/10-7/14 96 HRS.		
28	N	ND#20	122	7/8-7/10 48 HRS.	7/10-7/14 96 HRS.		
28	S	ND#20	122	7/8-7/10 48 HRS.	7/10-7/14 96 HRS.		
29	E	FAS 3614	1.2 MI. E. OF ND#20	7/8-7/9 24 HRS.	7/18-7/22 96 HRS.	7/15-7/17 48 HRS.	
29	W	FAS 3614	1.2 MI. W. OF ND#20			7/10-7/14 96 HRS.	

APPENDIX G
Computer Program and Data Files

The purpose of this appendix is to document the computer model which was used. The program is written in the SAS Macro language and uses procedures from the SAS/OR (Operations Research) package. It is primarily designed for CMS. A description of the SAS language and OR Procedures can be found in the following user guides:

1. SAS Guide to Macro Processing,
2. SAS/OR User's Guide,
3. SAS User's Guide: Basics.

All three documents are published by the SAS Institute, Cary, North Carolina.[109]

The program contains two types of macros: (1) general utility macros, and (2) subprograms or procedures. The utility macros are used for performing repetitive tasks or substituting common text in different areas of the program. Subroutine macros are procedures that correspond to major submodels (such as the flow generation submodel). These macros allow a modular program design and simplify the control of various functions and tasks.

---

[109]The SAS PROC TRANS procedure (which was used to derive a solution to the transshipment problem) was verified by solving a textbook problem found in Lee, Moore, and Tayler (1985). The TRANS procedure produced the identical solution and minimum cost routing expense stated for the textbook problem.

The program consists of two main modules. Module 1 performs all the functions of flow generation, traffic distribution, and network assignment up to the point of computing ESALs. Module 2 picks up at this point, computing the incremental ESALs for each scenario and calculating short-run and long-run costs. The two modules are nested within an outer macro which provides for a uniform referencing environment for all macro variables.

The logic of the program is shown in Figure G.1. Macro "Shell" controls the overall program and referencing environment. Macro "Module 1" calls eight procedures to perform tasks related to various submodels, while Macro "Module 2" calls four major procedures for each scenario.

Macro Shell

Macro Module 1
%RFACT
%FLOW
%SPATIAL
%TRAFFIC
%TRUCK
%AXKIP1
%AXKIP2
%AXKIP3

Macro Module 2
%ESALCAL
%ESALIFE
%BSOONER
%UPGRADE

Figure G.1 Program Macros and Calling Sequence

```
OPTIONS NONUMBER NODATE MPRINT NOMACROGEN NOSYMBOLGEN
   NOMLOGIC NODATE NONUMBER;
CMS FILEDEF RTAP DISK DUMMY DUMMY B;
CMS FILEDEF UGPT DISK DUMMY DUMMY C;

%MACRO SHELL;
*-------------------------------------------------------*
|  THIS MACRO CONTROLS THE SEQUENCE OF OPERATIONS AND   |
|  THE OVERALL FLOW OF THE SUBPROGRAMS. IT PROVIDES A   |
|  "SHELL" FOR VARIOUS LEVELS OF PROGRAM ENVIRONMENT.   |
|  ALL VARIABLES WITHIN THE SHELL ARE GLOBAL VARIABLES  |
|  AVAILABLE TO ALL PROCEDURES OR MACROS CALLED.        |
*-------------------------------------------------------|
|///////////////////////////////////////////////////////|
*-------------------------------------------------------|
|  THE FOLLOWING MACROS ARE GENERAL UTILITY PROCEDURES  |
|  WHICH PERFORM ROUTINE REPETITIVE TASKS/COMPUTATIONS  |
|  OR WHICH ALLOW TEXT SUBSTITUTION IN DIFFERENT AREAS  |
|  OF THE PROGRAM (IN DIFFERENT ENVIRONMENTS).          |
*-------------------------------------------------------*;

%MACRO MROAD;
*------------------------------------------------------*
| THIS MACRO CONVERTS HIGHWAY AND MILEPOST NUMBERS TO  |
| "ROADS"--   A MORE LOCALIZED LEVEL OF AGGREGATION.   |
*------------------------------------------------------*;
LENGTH ROAD $ 4;
IF HWY = 2 THEN
   IF MP <= 269 THEN
      ROAD = '2W';
   ELSE ROAD = '2E';
ELSE IF HWY = 20 THEN
   IF MP > 102 THEN
      ROAD = '20N';
   ELSE ROAD= '20S';
ELSE IF HWY = 17 THEN
   IF MP < 58 THEN
      ROAD = '17W';
   ELSE ROAD = '17E';
ELSE DO;
   RD   = PUT(HWY,$4.);
   ROAD = LEFT(RD);
END;
%MEND MROAD;
```

```
%MACRO M17;
*----------------------------------------------------*
| THIS MACRO REASSIGNS HIGHWAY AND MILEPOST FOR TWO  |
| HIGHWAYS WHICH OVERLAP AND HAVE CONGRUENT SITES    |
*----------------------------------------------------*;
IF HWY = 17 AND MP = 55 OR MP = 57 THEN DO;
   IF MP = 55 THEN MP = 128;
   IF MP = 57 THEN MP = 126;
END;
%MEND M17;

%MACRO CO5AX;
*---------------------------------------------------*
|  THIS MACRO SETS THE AXLE WEIGHTS & LOAD FACTORS  |
|       FOR COMBINATION 5-AXLE GRAIN TRUCKS         |
*---------------------------------------------------*;
TRUCTYPE= 'CO_5AX';
GROSS_WT= 80000;
GWT_AX1 = 12000;
GWT_AX2 = 34000;
GWT_AX3 = 34000;
TWT_AX1 =  8890;
TWT_AX2 = 11170;
TWT_AX3 =  7590;
TARE_WT = 26650;
NET_WT  = GROSS_WT - TARE_WT;
NET_CWT = NET_WT / 100;
AN_TRIPS= ROUND(TKCWTS / NET_CWT) * 2;
LKIP_AX1= ROUND(GWT_AX1 / 1000);
LKIP_AX2= ROUND(GWT_AX2 / 1000);
LKIP_AX3= ROUND(GWT_AX3 / 1000);
EKIP_AX1= ROUND(TWT_AX1 / 1000);
EKIP_AX2= ROUND(TWT_AX2 / 1000);
EKIP_AX3= ROUND(TWT_AX3 / 1000);
%MEND CO5AX;

%MACRO COMNAME;
*-------------------------------------------------------------*
|     THIS MACRO CONVERTS UGPTI COMMODITY CODES TO NAMES      |
*-------------------------------------------------------------*;
LENGTH COMM $ 7;
IF C = 'A' OR C = 'C' THEN COMM = 'WHEAT';
ELSE IF C = 'E' THEN COMM = 'BARLEY';
ELSE IF C = 'H' THEN COMM = 'SUNFLWR';
ELSE COMM = 'OTHER';
%MEND COMNAME;
```

```
%MACRO EXP(DSN,VARN,SHIP);
*-------------------------------------------------------*
|  THIS MACRO CHECKS INPUT DATA AND CREATES "ZERO"      |
|  SHIPMENT RECORDS IF A COMMODITY OR MODE IS MISSING |
*-------------------------------------------------------*;
RETAIN BCHECK WCHECK 0;
SET &DSN;
BY &VARN;
IF FIRST.&VARN THEN DO;
   BCHECK = 0;
   WCHECK = 0;
END;
IF COMM = 'WHEAT'  THEN WCHECK = 1;
IF COMM = 'BARLEY' THEN BCHECK = 1;
OUTPUT;
IF LAST.&VARN THEN DO;
   IF BCHECK = 0 THEN DO;
      COMM = 'BARLEY';
      &SHIP = 0;
      OUTPUT;
   END;
   IF WCHECK = 0 THEN DO;
      COMM = 'WHEAT';
      &SHIP = 0;
      OUTPUT;
   END;
END;
%MEND EXP;

%MACRO RFACT;
*-----------------------------------------------------------*
|  THE PURPOSE OF THIS MACRO IS TO DEFINE A SET OF MODAL    |
|  AND TRAFFIC ALLOCATION FACTORS COMPUTED FROM HISTORIC    |
|  UGPTI GRAIN SHIPMENT DATA.  THE ALLOCATION FACTORS ARE |
|  USED IN THE ELEVATOR-TO-MARKET TRAFFIC PROCEDURES.       |
*-----------------------------------------------------------*
|///////////////////////////////////////////////////////////|
*-----------------------------------------------------------*
|  A)  SUMMARIZE HISTORIC GRAIN SHIPMENTS BY ELEVATOR,      |
|          COMMODITY, AND MODE OF TRANSPORTATION            |
*-----------------------------------------------------------*;
DATA CWT85;
   SET RTAP.DLCWT85;
   %COMNAME
   IF M = '2' OR M = '3' THEN M = '1';
   DROP C;
PROC SORT DATA = CWT85;
   BY ELEVATOR COMM M;
PROC SUMMARY DATA = CWT85;
   BY ELEVATOR COMM M;
```

```
   VAR CWT MSPCWT DULCWT PNWCWT;
   OUTPUT OUT = CWT85B SUM = ;
DATA FACTOR1;
   KEEP ELEVATOR COMM PCTWEST PCTEAST PCTWTK PCTETK;
   SET CWT85B;
   BY ELEVATOR COMM M;
   RETAIN WESTR WESTT EASTR EASTT TOTAL PCTWEST PCTEAST
      PCTETK PCWTK 0;
   OTHCWT = CWT - MSPCWT -DULCWT - PNWCWT;
   IF FIRST.COMM THEN DO;
      WESTR = 0;
      WESTT = 0;
      EASTR = 0;
      EASTT = 0;
   END;
   IF M = '1' THEN DO;
      WESTR = PNWCWT + OTHCWT * .4;
      EASTR = CWT - WESTR;
   END;
   ELSE DO;
      WESTT = PNWCWT + OTHCWT * .4;
      EASTT = CWT - WESTT;
   END;
   IF LAST.COMM THEN DO;
      TOTAL   = SUM(OF WESTR--EASTT);
      IF TOTAL = 0 THEN DO;
         PCTWEST = .15;
         PCTEAST = .85;
         PCTWTK  = .22;
         PCTETK  = .30;
      END;
      ELSE DO;
         PCTWEST = (WESTR + WESTT) / TOTAL;
         PCTEAST = 1 - PCTWEST;
         IF PCTWEST  = 0 THEN PCTWTK = 0;
         ELSE PCTWTK = WESTT / (WESTR + WESTT);
         IF PCTEAST  = 0 THEN PCTETK = 0;
         ELSE PCTETK = EASTT / (EASTR + EASTT);
      END;
      OUTPUT;
   END;
RUN;
%MEND RFACT;
```

```
%MACRO MODULE1(SCENARIO,BASEYRS,HORZYRS);
*-----------------------------------------------------*
|  THIS MACRO REPRESENTS THE FIRST OF TWO MAJOR PROGRAM|
|  MODULES.  MODULE 1 COMPUTES THE ANNUAL INTERZONAL   |
|  TRIPS IN THE IMPACT AREA AS WELL AS THE WEIGHTED    |
|  AVERAGE AXLE LOADS (IN KIPS) FOR EACH TRUCK CLASS.  |
|  MODULE 1 PERFORMS ALL OF THE ANALYTICAL MODELING    |
|  FUNCTIONS OF THE FLOW GENERATION, SHIPMENT DISTRI-  |
|  BUTION, TRUCK DISTRIBUTION, AND NETWORK ASSIGNMENT  |
|  SUBMODELS (UP TO THE POINT OF COMPUTING THE ESALS   |
|  ON EACH HIGHWAY SECTION IN THE IMPACT REGION.  THE  |
|  MACRO CALLS OTHER MACROS OR PROCEDURES TO PERFORM   |
|  THE TASKS OF THE SUBMODELS.  THE MAIN COMMAND AREA  |
|  OR CALLING SEQUENCE IS LOCATED AT THE END OF THE    |
|  MACRO.  THE FIRST PROCEDURE WHICH IS CALLED IS THE  |
|  FLOW GENERATION SUBMODEL CONTAINED IN MACRO "FLOW". |
*-----------------------------------------------------*;

%MACRO FLOW;
*---------------------------------------------------------*
|           RTAP FLOW-GENERATION PROCEDURE                |
*---------------------------------------------------------*
|/////////////////////////////////////////////////////////|
*---------------------------------------------------------*
|  THIS PROCEDURE PERFORMS ALL NECESSARY FUNCTIONS FOR    |
|  THE LAND-USE AND FLOW-GERNATIONS SUBMODELS.  THE       |
|  THE LAND-USE ZONAL PRODUCTION FILE IS THE MAJOR INPUT  |
|  FILE.  THE PROCEDURE INVOLVES FIVE MAJOR STEPS--       |
|    1.  COMPUTE CWTS PRODUCED IN EACH ZONE (BASE YR.)    |
|    2.  COMPUTE CWTS PRODUCED IN EACH ZONE (HORIZ. YR.)  |
|    3.  COMPUTE CWTS PRODUCED IN EACH ZONE (IMPACT YR.)  |
|    4.  COMPUTE CWTS SHIPPED FROM EACH ELEV. (BASE YR.)  |
|    5.  COMPUTE BASE-YEAR ZONAL SUPPLY LEVELS (IN CWTS)  |
*---------------------------------------------------------*
|/////////////////////////////////////////////////////////|
*---------------------------------------------------------*
| A.)  READ IN PRODUCTION DATA & CONVERT BUSHELS TO CWTS  |
*---------------------------------------------------------*;
DATA LAND;
   KEEP ORGZONE C GF BCWTS HCWTS ICWTS;
   SET RTAP.LANDUSE;
   *-----------------------------------------------*
   | B.)  CREATE COMMODITY RECORDS AND LINK COMMON  |
   |        COMPUTATIONAL SUB-PROC FOR EACH GROUP   |
   *-----------------------------------------------*;
   C = 'A';
   BCWTS = DURUM  * .60;
   LINK LAND2;
   OUTPUT;
```

```
   C = 'C';
   BCWTS = WHEAT  * .60;
   LINK LAND2;
   OUTPUT;
   C = 'E';
   BCWTS = BARLEY * .48 + SUNFLWR * .32 + OTHER * .50;
   LINK LAND2;
   OUTPUT;
   RETURN;
LAND2:
   *-------------------------------------------------*
   | C.) SET PRODUCTION MULTIPLIERS FOR HORIZON YEAR |
   *-------------------------------------------------*;
   MULT= 1.030;
   IF C = 'A' OR C = 'C' THEN MULT = 1.249;
   IF C = 'E' THEN MULT = 1.109;
   IF C = 'H' THEN MULT = 1.557;
   IF C = 'Z' THEN MULT = 1.109;
   *----------------------------------------*
   | D.)   COMPUTE HORIZON-YEAR CWTS        |
   *----------------------------------------*;
   HCWTS = BCWTS * MULT;
   *----------------------------------------*
   | E.)   COMPUTE IMPACT-YEAR CWTS         |
   *----------------------------------------*;
   BASEY = INPUT(SYMGET('BASEYRS'),2.0);
   IF BCWTS = 0 THEN K = 0;
   ELSE K  = LOG(HCWTS/BCWTS)/BASEY;
   IF K = 0 THEN GF = 1.0;
   ELSE GF = (HCWTS/BCWTS)**K;
   IMP = BCWTS * GF;
   DO I = 1 TO BASEY;
      IF I = 1 THEN IMP = IMP;
      IMX = LAG(IMP);
      IF I > 1 THEN IMP = IMX * GF;
   END;
   ICWTS = IMP;
RETURN;
*-------------------------------------------------*
| F.)   COMPUTE BASE-YEAR ELEVATOR SHIPMENTS      |
*-------------------------------------------------*;
PROC SORT DATA = RTAP.DLCWT85 OUT = DLCWT85;
   BY ELEVATOR C;
PROC SUMMARY DATA = DLCWT85;
   CLASSES ELEVATOR C;
   VAR CWT;
   OUTPUT OUT = ELVSHIP SUM = SHIPCWT;
```

```
*-----------------------------------------------*
| G.)  COMPUTE BASE-YEAR ZONAL SUPPLY LEVELS    |
|      CONSTRAINED BY BASE-YEAR SHIPMENTS       |
*-----------------------------------------------*;
PROC SORT DATA = LAND OUT = LAND2;
   BY C;
PROC SUMMARY DATA = LAND2;
   BY C;
   VAR BCWTS;
   OUTPUT OUT = LAND3 SUM = PRODCWT;
DATA ELVSHIP2;
   KEEP C SHIPCWT;
   SET ELVSHIP;
   IF _TYPE_ = 1;
DATA LAND3;
   KEEP C PCTSHIP;
   MERGE LAND3 (IN=X) ELVSHIP2;
   BY C;
   IF X;
   IF PRODCWT = 0 THEN PCTSHIP = 1;
   ELSE PCTSHIP = SHIPCWT / PRODCWT;
DATA LAND;
   KEEP ORGZONE C GF BCWTS HCWTS ICWTS BYCWTS;
   MERGE LAND3 (IN=Y) LAND2 (IN=Z);
   BY C;
   IF Z;
   BYCWTS = BCWTS * PCTSHIP;
PROC SORT DATA = LAND;
   BY ORGZONE C;
RUN;
%MEND FLOW;
```

```
%MACRO SPATIAL;
*-----------------------------------------------------------*
|          RTAP SPATIAL INTERACTION PROCEDURE               |
*-----------------------------------------------------------*
|///////////////////////////////////////////////////////////|
*-----------------------------------------------------------*
|  THIS PROCEDURE COMPUTES THE RELATIVE ATTRACTIVE FORCE    |
|  BETWEEN EACH PRODUCTION ZONE AND ELEVATOR IN THE         |
|  IMPACT REGION.  THE PROCEDURE IS BASED ON THE LAW OF     |
|  RELATIVE ATTRACTION AND USES ELEVATOR PRICES, FARM       |
|  TRUCK UNIT COSTS, AND DISTANCES AS ITS MAJOR INPUTS.     |
|  THE MAJOR STEPS INVOLVED IN THE PROCEDURE ARE--          |
|    1.  DEFINE GRAIN TRUCK COST FACTORS AND FORMUALS       |
|    2.  SET TRUCK-TYPE TRAFFIC DISTRIBUTION FACTORS        |
|    3.  COMPUTE WEIGHTED AVERAGE FARM TRUCK COSTS          |
|    4.  COMPUTE TRIP IMPEDANCES FOR EACH ORIGIN-DEST.      |
|    5.  COMPUTE RELATIVE ATTRACTIVENESS FOR EACH O-D       |
|    6.  COMPUTE SUM OF REL. ATTRACT. FOR EACH ELVEVATOR    |
*-----------------------------------------------------------*;
DATA RA1;
   KEEP ORGZONE DESTNODE CITY ELEVATOR COOP C DIST PE PT GF
      BCWTS HCWTS ICWTS BYCWTS FT RA PCT5AX PCT2AX PCT3AX;
   MERGE RTAP.PRICEX (IN=A) LAND;
   BY ORGZONE C;
   IF A;
   SCEN = SYMGET('SCENARIO');
   *--------------------------------------------*
   | A) SET GRAIN TRUCK COST FACTORS AND FORMUALS |
   *--------------------------------------------*;
   SU2 = .364;
   SU3 = .233;
   SU2X = SU2 * DIST * 2;
   SU3X = SU3 * DIST * 2;
   CO5X = 1.89598812 + 0.16183477 * DIST;
   *------------------------------------------------------*
   | B) DEFINE TRUCK ALLOCATION FACTORS AT VARIOUS DISTANCES |
   *------------------------------------------------------*;
   IF DESTNODE = 'S1' THEN
      DO;
         IF DIST <= 25 THEN
            DO;
               IF SCEN = '2' OR SCEN = '3' OR SCEN = '7' THEN
                  DO;
                     PCT2AX = .15;
                     PCT3AX = .35;
                     PCT5AX = .50;
                  END;
               ELSE
                  DO;
```

```
                PCT2AX = .25;
                PCT3AX = .75;
                PCT5AX = .00;
            END;
        END;
    ELSE IF 25 < DIST <= 38 THEN
        DO;
            IF SCEN = '2' OR SCEN = '3' OR SCEN = '7' THEN
                DO;
                    PCT2AX = .10;
                    PCT3AX = .15;
                    PCT5AX = .75;
                END;
            ELSE
                DO;
                    PCT2AX = .13;
                    PCT3AX = .82;
                    PCT5AX = .05;
                END;
        END;
    ELSE
        DO;
            IF SCEN = '2' OR SCEN = '3' OR SCEN = '7' THEN
                DO;
                    PCT2AX = .00;
                    PCT3AX = .10;
                    PCT5AX = .90;
                END;
            ELSE
                DO;
                    PCT2AX = .05;
                    PCT3AX = .85;
                    PCT5AX = .10;
                END;
        END;
END;
ELSE
    DO;
        IF SCEN = '2' OR SCEN = '3' OR SCEN = '7' THEN
            DO;
                PCT2AX = .50;
                PCT3AX = .35;
                PCT5AX = .15;
            END;
        ELSE
            DO;
                PCT2AX = .60;
                PCT5AX = .00;
            END;
    END;
```

```
*-------------------------------------------------------*
| C) COMPUTE WEIGHTED TRUCK COST BETWEEN ORIGINS & DEST. |
*-------------------------------------------------------*;
FTC = SU2X * PCT2AX + SU3X * PCT3AX + CO5X * PCT5AX;
*----------------------------*
| D) COMPUTE TRIP IMPEDANCE  |
*----------------------------*;
FT  = FTC ** 1.5;
*-------------------------------------------*
| E) COMPUTE RELATIVE ATTRACTION OF EACH ZONE |
*-------------------------------------------*;
RA  = PE / FT;
*---------------------------------------------*
| SIMULATE SUBSTATION CLOSINGS UNDER SCENARIO 3 |
*---------------------------------------------*;
IF SCEN = '3' AND (ELEVATOR = 473 OR ELEVATOR = 104
   OR ELEVATOR = 109 OR ELEVATOR = 521) THEN
      RA = 0;
*--------------------------------------------------------*
| F) COMPUTE SUM OF RELATIVE ATTRACTIONS OVER ALL ZONES |
|    EXERTED BY EACH ELEVATOR    SEE LAW OF ATTRACTION   |
*--------------------------------------------------------*;
PROC SUMMARY DATA = RA1;
   BY ORGZONE C;
   VAR RA;
   OUTPUT OUT= RA2 (DROP = _TYPE_ _FREQ_) SUM = SRA;
*--------------------------------------------------------*
| G) ATTACH THE SUMMATION TO EACH ORIGIN-DESTINATION    |
|    NOTE- THIS IS NECESSARY FOR COMPUTATIONAL REASONS  |
*--------------------------------------------------------*;
DATA GRAIN;
   KEEP ORGZONE DESTNODE CITY ELEVATOR COOP C DIST PE BCWTS
   GF HCWTS ICWTS BYCWTS FT RA SRA PCT2AX PCT3AX PCT5AX;
   MERGE RA1 RA2;
   BY ORGZONE C;
PROC SORT;
   BY ELEVATOR C;
RUN;
%MEND SPATIAL;
```

```
%MACRO TRAFFIC;
*--------------------------------------------------------*
|     RTAP INTERZONAL TRAFFIC DISTRIBUTION PROCEDURE     |
*--------------------------------------------------------*
|////////////////////////////////////////////////////////|
*--------------------------------------------------------*
|  THE PURPOSE OF THIS PROCEDURE IS TO DISTRIBUTE THE    |
|  POTENTIAL SHIPMENTS IN EACH ZONE AMONG COMPETING      |
|  ELEVATORS BASED ON THE LAWS OF REL. ATTRACT. & FLOW.  |
|  THE PROCEDURE USES THE RELATIVE ATTRACTIONS COMPUTED  |
|  IN MACRO "SPATIAL"  AS WELL AS THE SUPPLY AND ELEV.   |
|  VOLUMES COMPUTED IN OTHER ROUTINES.                   |
*--------------------------------------------------------*;

*------------------------------------------------*
| A) MERGE BASE-YEAR ELEVATOR SHIPMENT FILE WITH |
|   SPATIAL INTERACTION FILE, BY ELEV. & COMMOD. |
*------------------------------------------------*;
DATA ELVSHIP3;
   KEEP ELEVATOR C SHIPCWT;
   SET ELVSHIP;
   IF _TYPE_ = 3;
   RENAME SHIPCWT = TOTCWT;
DATA GRAIN;
   KEEP ORGZONE DESTNODE CITY ELEVATOR COOP C DIST
      PE GF BCWTS HCWTS ICWTS BYCWTS FT RA SRA
      PCT2AX PCT3AX PCT5AX TOTCWT;
   MERGE GRAIN (IN=A) ELVSHIP3 (IN=B);
   BY ELEVATOR C;
   IF A;
   IF TOTCWT = . THEN TOTCWT = .0001;
*-----------------------------------------------*
| B) COMPUTE INTERZONAL VOLUMES FOR IMPACT YEAR |
*-----------------------------------------------*;
PROC SORT DATA = GRAIN;
   BY ORGZONE C ELEVATOR;
DATA RA1;
   KEEP ORGZONE ELEVATOR C RELATR IVOD;
   SET GRAIN;
   RELATR = RA / SRA;
   IVOD = ICWTS * RELATR;
*-----------------------------------------------*
| C) SORT INPUT DATA SET FOR BASE-YEAR ANALYSIS |
*-----------------------------------------------*;
PROC SORT DATA = GRAIN OUT = GRAINX;
   BY ELEVATOR C ORGZONE;
```

```
*-----------------------------------------------------------*
| D) INITIALIZE DATA SETS NEEDED FOR BASE-YEAR ANALYSIS    |
*-----------------------------------------------------------*;
DATA B2;
   A = 1;
DATA A1;
   B = 1;
DATA IZM3;
   ORGZONE  = '99';
   ELEVATOR = 100;
   BYCWTS = 0;
   BVOD   = 0;
   FT = 1;
   A  = 1;
   BD = 1;
   FC = 0;
   LC = 0;
   C = 'Y';
DATA IZM2;
   ORGZONE  = '99';
   ELEVATOR = 000;
   PVOD = 0;
   C  =  'Y';
DATA IZM1;
   ORGZONE  = '99';
   ELEVATOR = 000;
   BYCWTS = 0;
   BVOD = 0;
   FT = 1;
   BD = 1;
   A  = 1;
   C  ='Y';
RUN;
*-----------------------------------------------------------*
| E) ITERATIVELY COMPUTE INTERZONAL TRAFFIC DISTRIBUTION |
|   MATRIX FOR BASE-YEAR UNTIL CLOSURE CRITERION IS MET  |
*-----------------------------------------------------------*;
%LET CNT  = 1;
%LET ERRZ = 100;
%*********************************************;
%**   DEFINE LOOP FOR ITERATIVE COMPUTATIONS   **;
%*********************************************;
%DO %WHILE(&ERRZ > 5);
%IF &CNT =10 %THEN %LET ERRZ = 4;
%PUT %STR(CNT ) &CNT;
DATA BB;
   KEEP ELEVATOR C B;
   RETAIN A ACNT LA BD FC LC 0;
   LCNT = INPUT(SYMGET('CNT'),2.0);
```

```
   *---------------------------------------*
   |  IF FIRST ITERATION, SET "B" TO 1.0    |
   |  AND COMPUTE DENOMINATOR OF CONSTRAINT |
   *---------------------------------------*;
   IF LCNT = 1 THEN DO;
      SET GRAINX END = EOF1;
      BY ELEVATOR C;
      ACNT = 1;
      IF LAST.C THEN DO;
         IF ACNT = 0 THEN ACNT = .000001;
         B = 1 / ACNT;
         OUTPUT;
      END;
      IF EOF1 THEN STOP;
   END;
   *-------------------------------------------*
   |  ELSE COMPUTE B FROM PREVIOUS VALUE OF A  |
   *-------------------------------------------*;
   ELSE DO;
      SET IZM3 END = EOF2;
      LA = A;
      BD = LA * BYCWTS * (1/FT);
      IF FC = 1 THEN ACNT = 0;
      ACNT = ACNT + BD;
      IF LC = 1 THEN DO;
         IF ACNT = 0 THEN ACNT = .000001;
         B = 1 / ACNT;
         OUTPUT;
      END;
      IF EOF2 THEN STOP;
   END;
   RUN;
*-----------------------------------------------*
|  MERGE FILE CONTAINING "B" WITH ORIGINAL FILE |
*-----------------------------------------------*;
DATA BX;
   MERGE GRAINX (IN=X) BB;
   BY ELEVATOR C;
   IF X;
RUN;
PROC SORT DATA = BX OUT = BZ;
   BY ORGZONE C ELEVATOR;
*-----------------------------*
|    COMPUTE VALUE OF "A"     |
*-----------------------------*;
DATA A1;
   KEEP ORGZONE C A;
   RETAIN BCNT 0;
   SET BZ;
   BY ORGZONE C;
```

```
   IF FIRST.C THEN BCNT = 0;
   AD = B * TOTCWT * (1/FT);
   BCNT = BCNT + AD;
   IF LAST.C THEN
      DO;
         A = 1 / BCNT;
         OUTPUT;
      END;
RUN;
DATA A2;
   MERGE GRAIN (IN=X) A1;
   BY ORGZONE C;
   IF X;
PROC SORT;
   BY ORGZONE C ELEVATOR;
RUN;
*-------------------------------------------*
|  MERGE FILES CONTAINING A AND B, AND THEN |
|  COMPUTE THE INTERZONAL VOLUME FOR THE    |
|  CURRENT ITERATION OF THE LOOP.           |
*-------------------------------------------*;
DATA IZM1;
   MERGE BZ A2;
   BY ORGZONE C ELEVATOR;
   BVOD = A * B * BYCWTS * TOTCWT * (1/FT);
RUN;
PROC SORT DATA = IZM1 OUT = IZM3;
   BY ELEVATOR C;
DATA IZM3;
   SET IZM3;
   BY ELEVATOR C;
   FC = FIRST.C;
   LC = LAST.C;
RUN;
*----------------------------------------------*
| PASS CURRENT ITERATION VALUES TO LAG VARIABLES|
*----------------------------------------------*;
%IF &CNT > 1 %THEN %DO;
   DATA IZM2;
      KEEP ORGZONE C ELEVATOR PVOD;
      SET IZM1;
      PVOD = BVOD;
   RUN;
```

```
   *-----------------------------------------*
   | COMPUTE CLOSURE CRITERION FROM CURRENT  |
   |   AND PREVIOUS INTERZONAL VOLUMES.      |
   *-----------------------------------------*;
   DATA CLOSE;
      RETAIN DCNT ERRX 0;
      KEEP PCTC DCNT;
      DCNT = DCNT + 1;
      MERGE IZM1 IZM2 END = EOF;
      BY ORGZONE C ELEVATOR;
      DIF  = ABS(BVOD - PVOD);
      IF DIF = 0 THEN PCT = 0;
      ELSE PCT  = DIF / PVOD * 100;
      PCTC + PCT;
   IF EOF THEN DO;
      ERRX = ROUND(PCTC / DCNT);
      CALL SYMPUT('ERR',ERRX);
      OUTPUT;
   END;
   RUN;
%END;
%*****************************************;
%* INDEX COUNT VARIABLE FOR NEXT ITERATION *;
%*****************************************;
%LET CNT = %EVAL(&CNT+1);
%END;
%MEND TRAFFIC;
```

```
%MACRO TRUCK;
*--------------------------------------------------------*
|           RTAP TRUCK DISTRIBUTION PROCEDURE            |
*--------------------------------------------------------*
|////////////////////////////////////////////////////////|
*--------------------------------------------------------*
|  THE PURPOSE OF THIS PROCECURE IS TO DISTRIBUTE THE    |
|  INTERZONAL TRAFFIC VOLUMES AMONG TYPES OF TRUCKS      |
*--------------------------------------------------------*
|  A)  MERGE BASE- AND IMPACT-YEAR TRAFFIC DATA SETS     |
*--------------------------------------------------------*;
PROC SORT DATA = RA1;
   BY ORGZONE C ELEVATOR;
PROC SORT DATA = IZM1;
   BY ORGZONE C ELEVATOR;
DATA RA9;
   LENGTH TRUCTYPE $ 6;
   KEEP ORGZONE DESTNODE ELEVATOR COMM TRUCTYPE TKCWTS;
   RETAIN BASEVOD HORZVOD IMPVOD 0 SCEN;
   MERGE RA1 IZM1;
   BY ORGZONE C ELEVATOR;
   *----------------------------------------------*
   | B) CONVERT UGPTI COMMODITY CODES TO NAMES   |
   *----------------------------------------------*;
   %COMNAME
   *----------------------------------------------*
   | C) COMPUTE ANNUAL INTERZONAL VOLUMES FOR    |
   |    EACH YEAR IN THE IMPACT PERIOD           |
   *----------------------------------------------*;
   ARRAY V {21} V1 - V21;
   SCEN = SYMGET('SCENARIO');
   BASEYRS = INPUT(SYMGET('BASEYRS'),2.0);
   HORZYRS = INPUT(SYMGET('HORZYRS'),2.0);
   V1 = BVOD;
   BASEVOD = BVOD;
   IF SCEN = '0' THEN LAST = HORZYRS;
   ELSE LAST = BASEYRS - 1;
   DO I = 2 TO LAST;
      BASEVOD = BASEVOD * GF;
      V {I} = BASEVOD;
   END;
   IF SCEN > '0' THEN
      DO;
         IMPVOD = IVOD;
         I = BASEYRS;
         V {I} = IVOD;
         DO I = BASEYRS TO HORZYRS;
            IMPVOD = IMPVOD * GF;
            V {I} = IMPVOD;
         END;
```

```
      END;
   *------------------------------------------------------*
   | D) COMPUTE MEAN INTERZONAL VOLUMES FOR THE PERIOD    |
   *------------------------------------------------------*;
   TOTVOD = SUM(OF V1-V21);
   AVGVOD = TOTVOD / HORZYRS;
   *------------------------------------------------------*
   | E) DISTRIBUTE INTERZONAL VOLUMES AMONG TRUCK TYPES   |
   |  CREATING AN OUTPUT RECORD FOR EACH TYPE & COMMOD.   |
   *------------------------------------------------------*;
   TRUCTYPE = 'SU_2AX';
   TKCWTS = AVGVOD * PCT2AX;
   OUTPUT;
   TRUCTYPE = 'SU_3AX';
   TKCWTS = AVGVOD * PCT3AX;
   OUTPUT;
   TRUCTYPE = 'CO_5AX';
   TKCWTS = AVGVOD * PCT5AX;
   OUTPUT;
   PROC PRINT;  TITLE 'DATA SET RA9';
DATA COMM3;
   KEEP ORGZONE DESTNODE ELEVATOR COMM TRUCTYPE TKCWTS
      GROSS_WT NET_WT TARE_WT TWT_AX1 TWT_AX2 TWT_AX3
      GWT_AX1 GWT_AX2 GWT_AX3 AN_TRIPS;
   SET RA9;
   RETAIN SCEN;
   SCEN = SYMGET('SCENARIO');
   *-----------------------------*
   | F)  SET TARE AXLE WEIGHTS   |
   *-----------------------------*;
   IF TRUCTYPE = 'SU_2AX' THEN
      DO;
         TARE_WT = 12407;
         TWT_AX1 = 5208;
         TWT_AX2 = 7178;
      END;
   ELSE IF TRUCTYPE = 'SU_3AX' THEN
      DO;
         TARE_WT = 16671;
         TWT_AX1 = 6993;
         TWT_AX2 = 9793;
      END;
   *----------------------------------------------*
   | G) SET TRUCK LOAD FACTORS FOR EACH COMMODITY |
   *----------------------------------------------*;
   IF TRUCTYPE = 'SU_2AX' THEN
      DO;
         IF      COMM = 'WHEAT'    THEN AVG_NET = 18000;
         ELSE IF COMM = 'BARLEY'   THEN AVG_NET = 15380;
         ELSE IF COMM = 'SUNFLWR'  THEN AVG_NET = 10992;
```

```
      ELSE IF COMM = 'OTHER'     THEN AVG_NET = 15593;
   END;
IF TRUCTYPE = 'SU_3AX' THEN
   DO;
      IF       COMM = 'WHEAT'     THEN AVG_NET = 31800;
      ELSE IF COMM = 'BARLEY'    THEN AVG_NET = 27800;
      ELSE IF COMM = 'SUNFLWR'   THEN AVG_NET = 20372;
      ELSE IF COMM = 'OTHER'     THEN AVG_NET = 28329;
   END;
IF TRUCTYPE = 'CO_5AX' THEN AVG_NET = 54300;
*-------------------------------------------------------------*
| H) DEFINE THE MAXIMUM LEGAL PAYLOAD FOR EACH AXLE GROUP |
*-------------------------------------------------------------*;
IF TRUCTYPE = 'SU_2AX' THEN
   DO;
      MAX_AX1 = 9900;
      MAX_AX2 = 20000;
      MAX_AX3 =    .;
   END;
IF TRUCTYPE = 'SU_3AX' THEN
   DO;
      MAX_AX1 = 11000;
      MAX_AX2 = 34000;
      MAX_AX3 =    .;
   END;
IF TRUCTYPE = 'CO_5AX' THEN
   DO;
      MAX_AX1 = 12000;
      MAX_AX2 = 34000;
      MAX_AX3 = 34000;
   END;
*-----------------------------------------------------------*
| I)  DEFINE LEGAL GROSS AXLE WEIGHTS AND NET PAYLOADS   |
|     AND CONSTRAIN AXLE WEIGHTS TO LEGAL LIMITS          |
*-----------------------------------------------------------*;
COM_AX2 = 0;
RES_AX2 = 0;
IF TRUCTYPE= 'CO_5AX' THEN
   DO;
      GROSS_WT= 80000;
      GWT_AX1 = 12000;
      GWT_AX2 = 34000;
      GWT_AX3 = 34000;
      TWT_AX1 =  8890;
      TWT_AX2 = 11170;
      TWT_AX3 =  7590;
      TARE_WT = 26650;
      NET_WT  = GROSS_WT - TARE_WT;
   END;
ELSE
```

```
        DO;
           COM_AX2= AVG_NET + TWT_AX2;
           RES_AX2= AVG_NET + TWT_AX2 - MAX_AX2;
           GWT_AX2= MIN(MAX_AX2,COM_AX2);
           IF RES_AX2 <= 0 THEN
              GWT_AX1= TWT_AX1;
           ELSE
              GWT_AX1= MIN(MAX_AX1,RES_AX2 + TWT_AX1);
           GROSS_WT= GWT_AX1 + GWT_AX2;
           NET_WT= GROSS_WT - TARE_WT;
        END;
     *----------------------------------*
     | J)  COMPUTE ANNUAL TRUCK TRIPS   |
     *----------------------------------*;
     AN_TRIPS= ROUND(TKCWTS/(NET_WT/100)) * 2;
     RUN;
  %MEND TRUCK;

  %MACRO AXKIP1;
  *-------------------------------------------------------------*
  |            RTAP FARM TRUCK AXLE WEIGHT PROCEDURE            |
  *-------------------------------------------------------------*
  |/////////////////////////////////////////////////////////////|
  *-------------------------------------------------------------*
  |  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE EMPTY      |
  |  AND LOADED KIPS ON EACH AXLE GROUP FOR EACH FARM TRUCK     |
  |  TYPE FOR EACH INTERZONAL (FARM-TO-ELEV.) TRAFFIC FLOW.     |
  |  WEIGHTED MEAN VALUES ARE COMPUTED FOR TRUCK TYPE           |
  *-------------------------------------------------------------*;
  DATA AXLE1;
     SET COMM3;
     *------------------------------------------------------*
     | A) CONVERT AXLE WEIGHTS TO LOADED AND EMPTY KIPS |
     *------------------------------------------------------*;
     LKIP_AX1= ROUND(GWT_AX1 / 1000);
     LKIP_AX2= ROUND(GWT_AX2 / 1000);
     EKIP_AX1= ROUND(TWT_AX1 / 1000);
     EKIP_AX2= ROUND(TWT_AX2 / 1000);
     IF TRUCTYPE= 'CO_5AX' THEN
        DO;
           LKIP_AX3= ROUND(GWT_AX3 / 1000);
           EKIP_AX3= ROUND(TWT_AX3 / 1000);
        END;
     ELSE
        DO;
           LKIP_AX3= 0;
           EKIP_AX3= 0;
        END;
```

```
   *-------------------------------------------*
   | B) WEIGHT THE TRUCK FACTORS BY ANNUAL TRIPS |
   *-------------------------------------------*;
   ARRAY KP {8} EKIP_AX1-EKIP_AX3 LKIP_AX1-LKIP_AX3
      NET_WT GROSS_WT;
   DO I = 1 TO 8;
      KP {I} = KP {I} * AN_TRIPS;
   END;

*-------------------------------------------------*
| C) COMPUTE THE SUM OF TRUCK FACTORS AND TRIPS |
*-------------------------------------------------*;
PROC SORT DATA = AXLE1;
   BY ORGZONE DESTNODE ELEVATOR TRUCTYPE;
PROC SUMMARY DATA = AXLE1;
   BY ORGZONE DESTNODE ELEVATOR TRUCTYPE;
   VAR AN_TRIPS TKCWTS NET_WT GROSS_WT EKIP_AX1
      EKIP_AX2 EKIP_AX3 LKIP_AX1 LKIP_AX2 LKIP_AX3;
   OUTPUT OUT= AXLE2 SUM =;
DATA AXLEK;
   LENGTH ORGNODE $ 3;
   KEEP ORGZONE ORGNODE FL_TYPE DESTNODE ELEVATOR
      TRUCTYPE EKIP_AX1 EKIP_AX2 EKIP_AX3 TKCWTS
      LKIP_AX1 LKIP_AX2 LKIP_AX3 AN_TRIPS;
   SET AXLE2;
   BY ORGZONE DESTNODE ELEVATOR TRUCTYPE;
   *-------------------------------------------------*
   | D) DIVIDE WEIGHTED TRUCK FACTORS BY AN. TRIPS |
   *-------------------------------------------------*;
   ARRAY KP {8} EKIP_AX1-EKIP_AX3 LKIP_AX1-LKIP_AX3
      NET_WT GROSS_WT;
   DO I = 1 TO 8;
      IF AN_TRIPS = 0 THEN KP {I} = 0;
      ELSE KP {I} = KP {I} / AN_TRIPS;
   END;
   TKCWTS  = ROUND(TKCWTS);
   ORGNODE = 'P'||ORGZONE;
   *-------------------------------------*
   | E)     ASSIGN FLOW TYPE             |
   *-------------------------------------*;
   IF DESTNODE = 'S1' THEN FL_TYPE = '2';
   ELSE FL_TYPE = '1';
RUN;
%MEND AXKIP1;
```

```
%MACRO AXKIP2;
*-----------------------------------------------------------*
|     BASE-CASE ELEVATOR TRUCK AXLE WEIGHT PROCEDURE        |
*-----------------------------------------------------------*
|///////////////////////////////////////////////////////////|
*-----------------------------------------------------------*
|  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE EMPTY    |
|  AND LOADED KIPS ON EACH AXLE GROUP FOR OUTBOUND CO_5AX   |
|  SHIPMENTS FROM ELEVATORS TO FINAL MARKETS DURING THE     |
|  "BASE CASE" SCENARIO (ASSUMING NO SUBTERMINAL).          |
*-----------------------------------------------------------*;
DATA OUT1;
   LENGTH DESTNODE $ 3;
   KEEP ELEVATOR COMM DESTNODE TKCWTS;
   *------------------------------------------------*
   | A)   INPUT BASE-YEAR ELEVATOR TRUCK SHIPMENTS   |
   *------------------------------------------------*;
   SET RTAP.DLCWT85;
   IF M = '4';
   %COMNAME
   *--------------------------------------------------------*
   | B) COMPUTE MEAN ELEV. SHIPMENTS DURING IMPACT PERIOD |
   |  USING PRODUCTION MULTIPLIERS FROM DELPHI SURVEY      |
   *--------------------------------------------------------*;
   BCWTS = CWT;
   LINK GFACT;
   CWT = AVGSHIP;
   BCWTS = MSPCWT;
   LINK GFACT;
   MSPCWT = AVGSHIP;
   BCWTS = DULCWT;
   LINK GFACT;
   DULCWT = AVGSHIP;
   BCWTS = PNWCWT;
   LINK GFACT;
   PNWCWT = AVGSHIP;
   OTHCWT = CWT - DULCWT - MSPCWT - PNWCWT;
   *--------------------------------------------------------*
   | C) ALLOCATE ELEV. VOLUME BETWEEN EAST & WEST MARKETS |
   *--------------------------------------------------------*;
   DESTNODE = 'M55';
   TKCWTS = OTHCWT * .6 + DULCWT + MSPCWT;
   OUTPUT;
   DESTNODE = 'M56';
   TKCWTS = OTHCWT * .4 + PNWCWT;
   OUTPUT;
   RETURN;
   GFACT:
      ARRAY V {*} V1 - V&HORZYRS;
      MULT= 1.0;
```

```
        IF C = 'A' OR C = 'C' THEN MULT = 1.249;
        IF C = 'E' THEN MULT = 1.109;
        HCWTS = BCWTS * MULT;
        HORZY = INPUT(SYMGET('HORZYRS'),2.0);
        IF BCWTS = 0 THEN K = 0;
        ELSE K  = LOG(HCWTS/BCWTS)/HORZY;
        IF K = 0 THEN GF = 1.0;
        ELSE GF = (HCWTS/BCWTS)**K;
        IMP = BCWTS * GF;
        DO I = 1 TO HORZY;
           IF I = 1 THEN IMP = IMP;
           IMX = LAG(IMP);
           IF I > 1 THEN IMP = IMX * GF;
           V {I} = IMP;
        END;
        TOTSHIP = SUM(OF V1-V&HORZYRS);
        AVGSHIP = TOTSHIP / HORZY;
     RETURN;
  PROC SORT;
     BY ELEVATOR;
  *-----------------------------------------*
  | D) MERGE WITH ELEVATOR DESCRIPTOR FILE  |
  *-----------------------------------------*;
  DATA OUT2;
     KEEP DESTNODE ELEVATOR ZONE;
     SET RTAP.ELEVLIST;
     RENAME DESTNODE=ORGNODE  ZONE=ORGZONE;
  PROC SORT;
     BY ELEVATOR;
  DATA OUT3;
     KEEP ORGZONE ORGNODE FL_TYPE DESTNODE ELEVATOR TRUCTYPE
        EKIP_AX1 EKIP_AX2 EKIP_AX3 LKIP_AX1
        LKIP_AX2 LKIP_AX3 AN_TRIPS TKCWTS;
     MERGE OUT1 (IN=A) OUT2;
     BY ELEVATOR;
     IF A;
     *----------------------------------------------------------*
     | E) COMPUTE KIPS & AN. TRIPS FOR EACH INTERZONAL FLOW     |
     *----------------------------------------------------------*;
     FL_TYPE = '3';
     %C05AX
  *----------------------------------------------------------*
  | F) CONCATENATE FARM-TO-ELEV. & ELEV.-MARKET DATA SETS    |
  *----------------------------------------------------------*;
  DATA AXLEK;
     SET AXLEK OUT3;
     RUN;
  %MEND AXKIP2;
```

```
%MACRO AXKIP3;
*----------------------------------------------------------*
|    RTAP IMPACT-CASE ELEVATOR TRUCK WEIGHT PROCEDURE      |
*----------------------------------------------------------*
|//////////////////////////////////////////////////////////|
*----------------------------------------------------------*
|  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE EMPTY   |
|  AND LOADED KIPS ON EACH AXLE GROUP FOR OUTBOUND CO_5AX  |
|  SHIPMENTS FROM ELEVATORS TO FINAL MARKETS DURING THE    |
|  IMPACT CASE OR SCENARIO.  THIS SCENARIO ASSUMES THAT    |
|  ELEVATOR SHIPMENTS WITHIN THE COOP CAN BE MODELED WITH  |
|  AN OPTIMIZATION PROCEDURE-- THE TRANSSHIPMENT MODEL.    |
|  NONCOOP SHIPMENTS ARE MODELED USING HISTORIC SHIPPING   |
|  PATTERNS AND MODAL ALLOCATIONS.  THE TRANSSHIPMENT      |
|  MODEL IS IMPLEMENTED USING THE SAS  "PROC-TRANS"        |
|  PROCEDURE.  THE DATA MUST BE TRANSFORMED INTO THE       |
|  FORMAT BEFORE "PROC-TRANS" CAN BE APPLIED.              |
*----------------------------------------------------------*
|//////////////////////////////////////////////////////////|
*----------------------------------------------------------*
| A) COMPUTE MEAN ANNUAL ELEVATOR VOLUMES FOR THE IMPACT   |
|   PERIOD USING AVERGE INBOUND ELEVATOR SHIPMENTS         |
*----------------------------------------------------------*;
PROC SORT DATA = COMM3;
   BY ELEVATOR COMM;
PROC SUMMARY DATA = COMM3;
   BY ELEVATOR COMM;
   VAR TKCWTS;
   OUTPUT OUT= ELEV1 SUM= ;
DATA ELEV1;
   %EXP(ELEV1,ELEVATOR,TKCWTS)
*------------------------------------------------------------*
| B) SET THE AXLE WEIGHTS AND GROSS WEIGHTS FOR GRAIN SEMIS |
*------------------------------------------------------------*;
DATA ELEV2;
   KEEP ELEVATOR COMM NET_WT GROSS_WT EKIP_AX1 EKIP_AX2
      EKIP_AX3 LKIP_AX1 LKIP_AX2 LKIP_AX3
      AN_TRIPS TKCWTS TRUCTYPE;
   SET ELEV1;
   %CO5AX
*------------------------------------------------------------*
| C) COMPUTE HISTORIC MARKET DISTRIBUT. & MODE SPLIT FACTORS |
*------------------------------------------------------------*;
PROC SORT DATA = CWT85B;
   BY ELEVATOR M COMM;
DATA CWT85B;
   RETAIN BCHECK WCHECK 0;
   SET CWT85B;
   BY ELEVATOR M;
   IF FIRST.M THEN DO;
```

```
      BCHECK = 0;
      WCHECK = 0;
   END;
   IF COMM = 'WHEAT'  THEN WCHECK = 1;
   IF COMM = 'BARLEY' THEN BCHECK = 1;
   OUTPUT;
   IF LAST.M THEN DO;
      IF BCHECK = 0 THEN DO;
         COMM = 'BARLEY';
         PNWCWT = 0;
         MSPCWT = 0;
         DULCWT = 0;
         CWT = 0;
         OUTPUT;
      END;
      IF WCHECK = 0 THEN DO;
         COMM = 'WHEAT';
         PNWCWT = 0;
         MSPCWT = 0;
         DULCWT = 0;
         CWT = 0;
         OUTPUT;
      END;
   END;
PROC SORT;
   BY ELEVATOR COMM M;
*-----------------------------------------------------------*
| D) MERGE IMPACT-YEAR INTERZONAL VOLUME DATA SET WITH      |
|    ELEVATOR DESCRIPTOR AND DISTRIBUTION FACTOR FILES      |
*-----------------------------------------------------------*;
PROC SORT DATA = RTAP.ELEVLIST OUT = ELIST;
   BY ELEVATOR;
PROC SORT DATA = ELEV2;
   BY ELEVATOR COMM;
PROC SORT DATA = FACTOR1;
   BY ELEVATOR COMM;
DATA ELEV1;
   MERGE FACTOR1 ELEV2(IN=A);
   BY ELEVATOR COMM;
   IF A;
DATA ELEV3;
   MERGE ELEV1 (IN=X) ELIST;
   BY ELEVATOR;
   RENAME ZONE=ORGZONE DESTNODE=ORGNODE;
PROC PRINT DATA = ELEV3;
   TITLE 'ELEVATOR 3 DATA SET';
DATA ELEV3;
   KEEP ORGZONE ORGNODE ELEVATOR DESTNODE COOP COMM CWTS
      PCTETK PCTWTK;
   SET ELEV3;
```

```
   IF PCTWEST = . THEN PCTWEST = .15;
   IF PCTEAST = . THEN PCTEAST = .85;
   IF PCTETK  = . THEN PCTETK  = .30;
   IF PCTWTK  = . THEN PCTWTK  = .30;
   *--------------------------------------------------*
   | E) ALLOCATE OUTBOUND SHIPMENTS BETWEEN EASTERN    |
   |            AND WESTERN MARKETS                    |
   *--------------------------------------------------*;
   LENGTH DESTNODE $ 3;
   DESTNODE = 'M55';
   CWTS = TKCWTS * PCTEAST;
   OUTPUT;
   DESTNODE = 'M56';
   CWTS = TKCWTS * PCTWEST;
   OUTPUT;
PROC SORT;
   BY ELEVATOR DESTNODE COMM;
*-------------------------------------------------------*
| F) SUMMARIZE PROJECTED SHIPMENTS FOR COOP ELEVATORS   |
*-------------------------------------------------------*;
DATA COOP1;
   SET ELEV3;
   IF COOP = '1';
PROC SUMMARY DATA = COOP1;
   CLASSES ORGNODE DESTNODE COMM;
   VAR CWTS;
   OUTPUT OUT = COOP2 SUM = ;
DATA _NULL_;
   FILE PRINT HEADER = H;
   SET COOP1;
   IF _TYPE_ = 1;
   TITLE 'COOP BUSHELS SHIPPED- SCENARIO ' &SCENARIO;
   PUT @10 COMM $ @30 CWTS;
   RETURN;
   H: PUT @10 'COMMODITY' @30 'CWTS';
   RETURN;
RUN;
*-----------------------------------------------------------*
| G)  COMPUTE AVERAGE RATES FROM EACH ELEVATOR TO MARKETS   |
*-----------------------------------------------------------*;
DATA CLIST;
   SET RTAP.ELEVLIST;
   IF COOP = '1';
DATA RATE1;
   KEEP DESTNODE DEST COMM RATE;
   LENGTH COMM $ 7;
   MERGE RTAP.DLRATE(IN=A) CLIST (IN=B);
   BY CITY;
   IF B;
   IF DEST = 'MSP' OR DEST = 'PNW';
```

```
   IF DESTNODE = 'S1' THEN DO;
      COMM = 'WHEAT';
      RATE = WHT52 * .90 + WHT26 * .10;
      OUTPUT;
      COMM = 'BARLEY';
      RATE = BAR52 * .75 + BAR26 * .25;
      OUTPUT;
   END;
   ELSE DO;
      COMM = 'WHEAT';
      RATE = WHT1;
      OUTPUT;
      COMM = 'BARLEY';
      RATE = BAR1;
      OUTPUT;
   END;
   RENAME DESTNODE = ORGNODE;
*-------------------------------------------------------------*
| H) COMPUTE DISTANCES FROM SATELLITES TO THE SUBTERMINAL    |
*-------------------------------------------------------------*;
DATA DIST1;
   KEEP ORGNODE DISTRANS;
   ARRAY LDIST {8} LDIST1-LDIST8;
   RETAIN CNT5 0;
   *----------------------------*
   |  READ HIGHWAY ROUTE FILE  |
   *----------------------------*;
   SET RTAP.ROUTES;
   IF FL_TYPE = '4' OR FL_TYPE = '5';
   *----------------------------*
   |     SUM LINK DISTANCES     |
   *----------------------------*;
   DISTRANS = 0;
   IF FL_TYPE = '4' THEN
      DO I = 1 TO NOLINKS;
         DISTRANS = DISTRANS + LDIST {I};
      END;
   ELSE  /* IF FL_TYPE = '5' */
      DO;
         CNT5 = CNT5 + 1;
         IF CNT5 > 1 THEN DELETE;
      END;
*----------------------------------------------------*
| I)  MERGE RATE FILE WITH ELEVATOR DISTANCE FILE   |
*----------------------------------------------------*;
PROC SORT DATA = RATE1;
   BY ORGNODE COMM DEST;
PROC SORT DATA = DIST1;
   BY ORGNODE;
DATA RATE2;
```

```
   MERGE RATE1 (IN=A) DIST1;
   BY ORGNODE;
   IF A;
RUN;
%IF &SCENARIO=1 OR &SCENARIO=2 OR &SCENARIO=3 %THEN %DO;
*-----------------------------------------------------*
| J)  CREATE COMMODITY DATA SETS IN THE FORM OF       |
|            TRANSSHIPMENT TABLEAUS                   |
*-----------------------------------------------------*;
DATA WHEAT1(KEEP = E1-E7 S1 T1 T2 ELVSUP ORGNODE)
   WHEAT2(KEEP = ELVSUP ORGNODE);
   RETAIN COMCWT E1-E7 S1 T1 T2 0 ELVSUP ORGNODE;
   SET COOP2 END = EOF;
   IF _TYPE_ > 5 THEN DELETE;
   IF COMM = 'WHEAT';
   *-----------------------------------------------------*
   |  CHECK FOR MISSING SHIPMENT DATA & ROUND VALUES |
   *-----------------------------------------------------*;
   IF CWTS = . THEN CWTS = 0;
   CWTS = ROUND(CWTS);
   *-------------------------------------------*
   |  REASSIGN DESTNODE NAMES IN SORT ORDER    |
   *-------------------------------------------*;
   IF DESTNODE = 'M55' THEN DESTNODE = 'T1';
   IF DESTNODE = 'M56' THEN DESTNODE = 'T2';
   *----------------------------------------*
   |  DEFINE TOTAL SYSTEM SUPPLY VARIABLE   |
   *----------------------------------------*;
   IF _TYPE_ = 1 THEN COMCWT = CWTS;
   IF _TYPE_ = 3 THEN DO;
      *-------------------------------------*
      |  CREATE DEMAND RECORD IN TABLEAU    |
      *-------------------------------------*;
      IF DESTNODE = 'T1'  THEN T1 = CWTS + COMCWT;
      IF DESTNODE = 'T2'  THEN T2 = CWTS + COMCWT;
   END;
   IF _TYPE_ = 5 THEN DO;
      *-----------------------------------*
      | CREATE SUPPLY AND SOURCE COLUMNS  |
      *-----------------------------------*;
      ELVSUP = CWTS + COMCWT;
      OUTPUT WHEAT2;
   END;
   IF EOF THEN DO;
      ARRAY EV {8} E1-E7 S1;
      DO I = 1 TO 8;
         EV {I} = COMCWT;
      END;
      ORGNODE = .;
      ELVSUP  = .;
```

```
      OUTPUT WHEAT1;
      ORGNODE = 'T1';
      ELVSUP = COMCWT;
      OUTPUT WHEAT2;
      ORGNODE = 'T2';
      ELVSUP = COMCWT;
      OUTPUT WHEAT2;
      STOP;
   END;
DATA COOPB;
   SET COOP2;
   IF COMM = 'BARLEY';
   IF _TYPE_ <= 5;
DATA BARLEY1(KEEP = E1-E7 S1 T1 T2 ELVSUP ORGNODE)
   BARLEY2(KEEP = ELVSUP ORGNODE);
   RETAIN COMCWT E1-E7 S1 T1 T2 0 ELVSUP ORGNODE;
   SET COOPB END = EOF;
   *-------------------------------------------------*
   |  CHECK FOR MISSING SHIPMENT DATA & ROUND VALUES |
   *-------------------------------------------------*;
   IF CWTS = . THEN CWTS = 0;
   CWTS = ROUND(CWTS);
   *-------------------------------------------*
   |  REASSIGN DESTNODE NAMES IN SORT ORDER    |
   *-------------------------------------------*;
   IF DESTNODE = 'M55' THEN DESTNODE = 'T1';
   IF DESTNODE = 'M56' THEN DESTNODE = 'T2';
   *---------------------------------------*
   |  DEFINE TOTAL SYSTEM SUPPLY VARIABLE  |
   *---------------------------------------*;
   IF _TYPE_ = 1 THEN COMCWT = CWTS;
   IF _TYPE_ = 3 THEN DO;
      *------------------------------------*
      |  CREATE DEMAND RECORD IN TABLEAU   |
      *------------------------------------*;
      IF DESTNODE = 'T1'  THEN T1  = CWTS + COMCWT;
      IF DESTNODE = 'T2'  THEN T2  = CWTS + COMCWT;
   END;
   IF _TYPE_ = 5 THEN DO;
      *-----------------------------------*
      | CREATE SUPPLY AND SOURCE COLUMNS  |
      *-----------------------------------*;
      ELVSUP = CWTS + COMCWT;
      OUTPUT BARLEY2;
   END;
      IF EOF THEN DO;
      ARRAY EV {8} E1-E7 S1;
      DO I = 1 TO 8;
         EV {I} = COMCWT;
      END;
```

```
      ORGNODE = ' ';
      ELVSUP  = .;
      OUTPUT BARLEY1;
      ORGNODE = 'T1';
      ELVSUP = COMCWT;
      OUTPUT BARLEY2;
      ORGNODE = 'T2';
      ELVSUP = COMCWT;
      OUTPUT BARLEY2;
      STOP;
   END;
*--------------------------------------------------------*
| K) TRANSFORM RATE FILE INTO TRANSSH. TABLEAU FORMAT    |
|    WHERE THE RATES REPRESENT THE CELL SHIPPING COSTS   |
*--------------------------------------------------------*;
DATA RATE3;
   KEEP E1-E7 S1 T1 T2 ORGNODE COMM;
   SET RATE2;
   BY ORGNODE COMM;
   RETAIN E1-E7 S1 T1 T2 9999;
   IF DEST = 'MSP' THEN T1 = RATE;
   IF DEST = 'PNW' THEN T2 = RATE;
   *-----------------------------------------------*
   |  DEFINE CONVERSION FACTOR- BUSHELS TO CWTS    |
   *-----------------------------------------------*;
   FACT = .50;
   IF COMM = 'WHEAT'  THEN FACT = .60;
   IF COMM = 'BARLEY' THEN FACT = .48;
   *-----------------------------------------------------*
   | COMPUTE INBOUND SUBTERMINAL RATE PLUS HANDLING COST |
   *-----------------------------------------------------*;
   IF LAST.COMM THEN DO;
      S1 = (1.89598812 + 0.16183477 * DISTRANS + 4.18)
           * FACT;
      OUTPUT;
   END;
*--------------------------------------------------------*
| L) COMBINE TRANSPORTATION COST AND SUPPLY & DEMAND     |
|    DATA SETS TO CREATE TRANSSHIP. TABLEAU FOR WHEAT    |
*--------------------------------------------------------*;
DATA WRATE1;
   SET RATE3;
   IF COMM = 'WHEAT';
   DROP COMM;
PROC SORT DATA = WHEAT2;
   BY ORGNODE;
DATA WRATE2;
   KEEP E1-E7 S1 T1 T2 ORGNODE ELVSUP;
   MERGE WHEAT2 (IN=A) WRATE1;
   BY ORGNODE;
```

```
   IF A;
DATA WRATE3;
   KEEP E1-E7 S1 T1 T2 ORGNODE ELVSUP;
   SET WHEAT1 WRATE2;
   IF ORGNODE = 'S1' THEN ELVSUP = ELVSUP + 1;
   ARRAY EV {10} E1-E7 S1 T1 T2;
   IF ORGNODE = 'T1' OR ORGNODE = 'T2' THEN
      DO I = 1 TO 10;
         EV {I} = 9999;
      END;
   IF ORGNODE = 'E1' THEN E1 = 0;
   IF ORGNODE = 'E2' THEN E2 = 0;
   IF ORGNODE = 'E3' THEN E3 = 0;
   IF ORGNODE = 'E4' THEN E4 = 0;
   IF ORGNODE = 'E5' THEN E5 = 0;
   IF ORGNODE = 'E6' THEN E6 = 0;
   IF ORGNODE = 'E7' THEN E7 = 0;
   IF ORGNODE = 'S1' THEN S1 = 0;
   IF ORGNODE = 'T1' THEN T1 = 0;
   IF ORGNODE = 'T2' THEN T2 = 0;
*-----------------------------------------------------*
| M)  EXECUTE THE TRANSSHIPMENT PROCEDURE FOR WHEAT   |
*-----------------------------------------------------*;
PROC TRANS                /*  WHEAT TRANSSHIPMENT     */
   COST = WRATE3          /*  DEFINE INPUT DATA SET   */
   ADDSUPPLY              /*  SET UNBALANCE OPTION    */
   DEMAND = 1             /*  IDENTIFY DEMAND OBS.    */
   DEFCAPACITY = 9E10     /*  SET ARC CAPACITIES      */
   OUT = WHT10;           /*  DEFINE OUTPUT DATA SET */
   ID ORGNODE;            /*  IDENTIFY ORG./DEST. ID */
   VAR E1-E7 S1 T1 T2;    /*  TRANSP. COST VARIABLES */
   SUPPLY ELVSUP;         /*  IDENTIFY SUPPLY VARB.   */
PROC PRINT;
   TITLE 'TRANSPORTATION SOLUTION FOR WHEAT';
*---------------------------------------------------------*
| N) TRANSFORM BARLEY RATE FILE INTO TABLEAU FORMAT       |
|   WHERE THE RATES REPRESENT THE CELL SHIPPING COSTS     |
*---------------------------------------------------------*;
DATA BRATE1;
   SET RATE3;
   IF COMM = 'BARLEY';
   DROP COMM;
PROC SORT DATA = BARLEY2;
   BY ORGNODE;
DATA BRATE2;
   KEEP E1-E7 S1 T1 T2 ELVSUP ORGNODE;
   MERGE BARLEY2 (IN=A) BRATE1;
   BY ORGNODE;
   IF A;
DATA BRATE3;
```

```
   KEEP E1-E7 S1 T1 T2 ELVSUP ORGNODE;
   SET BARLEY1 BRATE2;
   ARRAY EV {10} E1-E7 S1 T1 T2;
   IF ORGNODE = 'T1' OR ORGNODE = 'T2' THEN
      DO I = 1 TO 10;
         EV {I} = 9999;
      END;
   IF ORGNODE = 'E1' THEN E1 = 0;
   IF ORGNODE = 'E2' THEN E2 = 0;
   IF ORGNODE = 'E3' THEN E3 = 0;
   IF ORGNODE = 'E4' THEN E4 = 0;
   IF ORGNODE = 'E5' THEN E5 = 0;
   IF ORGNODE = 'E6' THEN E6 = 0;
   IF ORGNODE = 'E7' THEN E7 = 0;
   IF ORGNODE = 'S1' THEN S1 = 0;
   IF ORGNODE = 'T1' THEN T1 = 0;
   IF ORGNODE = 'T2' THEN T2 = 0;
*----------------------------------------------------*
| O) EXECUTE THE TRANSSHIPMENT PROCEDURE FOR BARLEY  |
*----------------------------------------------------*;
PROC TRANS                  /*  BARLEY TRANSSHIPMENT    */
   COST = BRATE3            /*  DEFINE INPUT DATA SET   */
   ADDSUPPLY                /*  SET UNBALANCE OPTION    */
   DEMAND = 1               /*  IDENTIFY DEMAND OBS.    */
   DEFCAPACITY = 9E10       /*  SET ARC CAPACITIES      */
   OUT = BAR10;             /*  DEFINE OUTPUT DATA SET  */
   ID ORGNODE;              /*  IDENTIFY ORG./DEST. ID  */
   VAR E1-E7 S1 T1 T2;      /*  TRANSP. COST VARIABLES  */
   SUPPLY ELVSUP;           /*  IDENTIFY SUPPLY VARB.   */
PROC PRINT;
   TITLE 'BARLEY TRANSPORTATION SOLUTION';
*------------------------------------------------------*
| P) SUM ELEVATOR-TO-MARKET FLOWS FOR ALL COMMODITIES  |
*------------------------------------------------------*;
DATA FLOW10;
   KEEP ORGNODE COMM S1 T1 T2;
   LENGTH COMM $ 7;
   *-----------------------------------------------*
   |  CONCATENATE OPTIMAL COMMODITY TRANSS. TABLEAUS |
   *-----------------------------------------------;
   SET WHT10 (IN=W) BAR10 (IN=B);
   *-------------------------------*
   |  DROP UNNECESSARY OBSERVATIONS |
   *-------------------------------*;
   IF ORGNODE = 'S1' OR ORGNODE = 'E1' OR ORGNODE = 'E2' OR
      ORGNODE = 'E3' OR ORGNODE = 'E4' OR ORGNODE = 'E5' OR
      ORGNODE = 'E6' OR ORGNODE = 'E7';
```

```
   *-------------------------*
   |  ASSIGN COMMODITY NAMES  |
   *-------------------------*;
   IF W THEN COMM = 'WHEAT';
   IF B THEN COMM = 'BARLEY';
   *--------------------------------------------*
   |  SET EXCESS ALLOCATIONS ON DIAGONAL TO ZEROS |
   *--------------------------------------------*;
   IF ORGNODE = 'E1' THEN E1 = 0;
   IF ORGNODE = 'E2' THEN E2 = 0;
   IF ORGNODE = 'E3' THEN E3 = 0;
   IF ORGNODE = 'E4' THEN E4 = 0;
   IF ORGNODE = 'E5' THEN E5 = 0;
   IF ORGNODE = 'E6' THEN E6 = 0;
   IF ORGNODE = 'E7' THEN E7 = 0;
   IF ORGNODE = 'S1' THEN S1 = 0;
   IF ORGNODE = 'T1' THEN T1 = 0;
   IF ORGNODE = 'T2' THEN T2 = 0;
*----------------------------------------------------*
| Q) MERGE PROJECTED FLOWS WITH ELV. DESCRIPTOR FILE  |
*----------------------------------------------------*;
DATA ELEV4;
   KEEP ORGZONE ORGNODE ELEVATOR DESTNODE COMM PCTETK PCTWTK;
   SET ELEV3;
   IF COOP = '1';
PROC SORT DATA = ELEV4;
   BY ORGNODE COMM;
PROC SORT DATA = FLOW10;
   BY ORGNODE COMM;
DATA FLOW20;
   KEEP ORGZONE ORGNODE ELEVATOR COMM DESTNODE TKCWTS;
   LENGTH DESTNODE $ 3;
   MERGE FLOW10 (IN=A) ELEV4;
   BY ORGNODE COMM;
   IF A;
   *-------------------------------------------*
   | R) ALLOCATE VOLUMES BETWEEN TRUCK AND RAIL  |
   |  ASSIGN DEST. NODES, AND OUTPUT TO DATA SET |
   *-------------------------------------------*;
   IF ORGNODE = 'S1' THEN
      DO;
         PCTETK = .05;
         PCTWTK = .05;
      END;
   DESTNODE = 'S1';
   TKCWTS = S1;
   OUTPUT;
   DESTNODE = 'M55';
   TKCWTS = T1 * PCTETK;
   OUTPUT;
```

```
   DESTNODE = 'M56';
   TKCWTS = T2 * PCTWTK;
   OUTPUT;
RUN;
%END;
%IF &SCENARIO > 3 %THEN %DO;
*------------------------------------------------------------*
| T) COMPUTE COOP ELV. SHIPMENTS UNDER ALTERTIVE SCENARIOS |
*------------------------------------------------------------*
|  VARIATIONS ON THE BASIC IMPACT SCENARIO ARE ANALYZED IN |
|  THIS STEP.  UNDER THE ALTERNATE SCENARIOS, TRANSSHIP-   |
|  MENTS ARE MODELED ON THE BASIS OF THE DECISION RULE     |
|  DISCUSSED IN THE REPORT.  OTHER CHANGES ARE MADE TO     |
|  REFLECT THE ABANDONMENT & SHORT-LINE SCENARIOS AS WELL. |
*------------------------------------------------------------*
|////////////////////////////////////////////////////////////|
*------------------------------------------------------------*
|     COMPUTE RATES TO BOTH EASTERN AND WESTERN MARKETS     |
*------------------------------------------------------------*;
DATA FOUR1;
   KEEP ORGNODE COMM DESTNODE DISTRANS RATE;
   SET RATE2;
   IF DEST = 'MSP' THEN DESTNODE = 'M55';
   ELSE DESTNODE = 'M56';
*----------------------------*
|  COMPUTE SUBTERMINAL RATE  |
*----------------------------*;
DATA FOUR2;
   KEEP COMM DESTNODE SUBRATE;
   SET FOUR1;
   IF ORGNODE = 'S1';
   SUBRATE = RATE;
PROC SORT DATA = FOUR1;
   BY COMM DESTNODE;
*------------------------------------------*
|  ATTACH SUBTERMINAL RATE TO EACH RECORD  |
*------------------------------------------*;
DATA FOUR3;
   MERGE FOUR1 (IN=A) FOUR2;
   BY COMM DESTNODE;
   IF A;
*-------------------------------------*
|  SUBSET COOP ELEVATORS FROM DATA SET  |
*-------------------------------------*;
DATA ELEV4;
   KEEP ORGZONE ORGNODE ELEVATOR DESTNODE COMM
      CWTS PCTETK PCTWTK;
   SET COOP1;
```

```
*----------------------------------------------------*
|   SORT AND MERGE RATE AND SHIPMENT DATA SETS       |
*----------------------------------------------------*;
PROC SORT DATA = FOUR3;
   BY ORGNODE COMM DESTNODE;
PROC SORT DATA = ELEV4;
   BY ORGNODE COMM DESTNODE;
DATA FLOW10;
   KEEP ORGZONE ORGNODE ELEVATOR COMM PCTETK PCTWTK
      EASTCWT WESTCWT TRANSCWT EASTRATE WESTRATE
      ESUBRATE WSUBRATE DISTRANS;
   RETAIN EASTCWT WESTCWT TRANSCWT EASTRATE
      WESTRATE ESUBRATE WSUBRATE 0;
   MERGE FOUR3(IN=A) ELEV4;
   BY ORGNODE COMM DESTNODE;
   *---------------------------------------*
   |  INITIALIZE TRANSSHIPMENT AND RATE    |
   |  VARIABLES TO 0 FOR FIRST DESTINATION |
   *---------------------------------------*;
   IF FIRST.DESTNODE THEN
      DO;
         EASTCWT = 0;
         WESTCWT = 0;
         TRANSCWT= 0;
         EASTRATE= 0;
         WESTRATE= 0;
         ESUBRATE= 0;
         WSUBRATE= 0;
      END;
   *---------------------------------------*
   |  REFORMAT VAR. AND OUTPUT TO NEW FILE |
   *---------------------------------------*;
   IF DESTNODE = 'M55' THEN
      DO;
         EASTCWT = CWTS;
         EASTRATE= RATE;
         ESUBRATE= SUBRATE;
      END;
   IF DESTNODE = 'M56' THEN
      DO;
         WESTCWT = CWTS;
         WESTRATE= RATE;
         WSUBRATE= SUBRATE;
      END;
   IF LAST.DESTNODE THEN OUTPUT;
DATA FLOW20;
   KEEP ORGZONE ORGNODE ELEVATOR COMM DESTNODE TKCWTS;
   LENGTH DESTNODE $ 3;
   SCEN = SYMGET('SCENARIO');
   SET FLOW10;
```

```
*-----------------------------------*
|  SET COMMODITY CONVERSION FACTOR  |
*-----------------------------------*;
FACT = .50;
IF COMM = 'WHEAT'  THEN FACT = .60;
IF COMM = 'BARLEY' THEN FACT = .48;
*-----------------------------------*
|     SET DOUBLE-HANDLING COST      |
*-----------------------------------*;
DHX = 4.18;
*-----------------------------------*
|   COMPUTE GRAIN TRUCKING COST     |
*-----------------------------------*;
GTC = (1.89598812 + 0.16183477 * DISTRANS)
      * FACT;
*-----------------------------------*
|  REDUCE FOR SHORT LINE SCENARIO   |
*-----------------------------------*;
GTC = GTC * .88;
*-----------------------------------*
|     SET SUBTERMINAL MARGIN        |
*-----------------------------------*;
IF SCEN = '4' THEN EM = 8;
ELSE EM = 0;
*-----------------------------------*
|   COMPUTE SUBTERMINAL PRICE       |
*-----------------------------------*;
ESBPRICE = ESUBRATE + GTC + DHX + EM;
WSBPRICE = WSUBRATE + GTC + DHX + EM;
*-----------------------------------*
|  SET LONG-HAUL TRUCKING PRICE     |
*-----------------------------------*;
IF SCEN = '5' OR SCEN = '7' THEN
   DO;
      EASTRATE = EASTRATE * 1.10;
      WESTRATE = WESTRATE * 1.10;
   END;
*-------------------------------------------------*
| DETERMINE TRANSSIPMENTS BASED ON DECISION RULES|
| FOR SCENARIOS FOUR, FIVE, SIX AND SEVEN.        |
*-------------------------------------------------*;
IF ORGNODE NE 'S1' THEN
   DO;
      IF ESBPRICE <= EASTRATE THEN
         DO;
            TRANSCWT= TRANSCWT + EASTCWT;
            EASTCWT = 0;
         END;
      IF WSBPRICE <= WESTRATE THEN
         DO;
```

```
                TRANSCWT= TRANSCWT + WESTCWT;
                WESTCWT = 0;
             END;
       END;
    *----------------------------------------*
    |  SET OUTBOUND SUBTERMINAL TRUCK SHARE  |
    *----------------------------------------*;
    IF ORGNODE = 'S1' THEN
       DO;
          PCTETK = .05;
          PCTWTK = .05;
       END;
    *----------------------------------------*
    |  SET INBOUND SUBTERMINAL TRUCK SHARE   |
    *----------------------------------------*;
    IF SCEN = '6' THEN PCTTRAN = .50;
    ELSE PCTTRAN = 1.0;
    *---------------------------------------------------*
    | SET TRUCK SHARE TO 1.0 FOR ABANDONMENT SCENARIO |
    *---------------------------------------------------*;
    IF SCEN = '5' OR SCEN = '7' THEN DO;
       PCTETK = 1.0;
       PCTWTK = 1.0;
    END;
    *----------------------------------------------------*
    | ALLOCATE OUTBOUND ELEVATOR TRAFFIC TO TRUCK MODE |
    *----------------------------------------------------*;
    TKCWTS = ROUND(EASTCWT * PCTETK);
    DESTNODE = 'M55';
    OUTPUT;
    TKCWTS = ROUND(WESTCWT * PCTWTK);
    DESTNODE = 'M56';
    OUTPUT;
    TKCWTS = ROUND(TRANSCWT * PCTTRAN);
    DESTNODE = 'S1';
    OUTPUT;
RUN;
%END;
*-------------------------------------------------------*
| U) SUM TRUCK CWTS ACROSS COMMODITIES AND COMPUTE KIPS |
*-------------------------------------------------------*;
PROC SORT DATA = FLOW20;
   BY ORGZONE ORGNODE ELEVATOR DESTNODE;
PROC SUMMARY DATA = FLOW20;
   BY ORGZONE ORGNODE ELEVATOR DESTNODE;
   VAR TKCWTS;
   OUTPUT OUT = FLOW20 SUM = ;
DATA FLOW30;
   KEEP ORGZONE ORGNODE FL_TYPE DESTNODE ELEVATOR TRUCTYPE
      EKIP_AX1 EKIP_AX2 EKIP_AX3 LKIP_AX1
```

```
      LKIP_AX2 LKIP_AX3 AN_TRIPS TKCWTS;
   SET FLOW20;
   *-----------------------*
   |   ASSIGN FLOW TYPES    |
   *-----------------------*;
   IF ORGNODE = 'S1' THEN DO;
      IF DESTNODE = 'S1' THEN DELETE;
      ELSE FL_TYPE = '5';
   END;
   ELSE DO;
      IF DESTNODE = 'S1' THEN FL_TYPE = '4';
      ELSE FL_TYPE = '3';
   END;
   *-----------------------------------------------------*
   |  ASSIGN TRUCK TYPE, COMPUTE KIPS & ANNUAL TRIPS     |
   *-----------------------------------------------------*;
   %CO5AX
*------------------------------------------------------------*
| V) COMPUTE OUTBOUND FLOWS FOR NONCOOPERATIVE ELEVATORS |
*------------------------------------------------------------*;
DATA NC1;
   *-------------------------------------------*
   |  ALLOCATE VOLUMES BETWEEN TRUCK AND RAIL   |
   *-------------------------------------------*;
   SET ELEV3;
   IF COOP = '0';
   IF DESTNODE = 'M55' THEN TKCWTS = CWTS * PCTETK;
   IF DESTNODE = 'M56' THEN TKCWTS = CWTS * PCTWTK;
*-----------------------------------------------*
|     SUMMARIZE PROJECTED ELEVATOR SHIPMENTS       |
*-----------------------------------------------*;
PROC SORT DATA = NC1;
   BY ORGZONE ORGNODE ELEVATOR DESTNODE;
PROC SUMMARY DATA = NC1;
   BY ORGZONE ORGNODE ELEVATOR DESTNODE;
   VAR TKCWTS;
   OUTPUT OUT = NC2 (DROP = _TYPE_ _FREQ_) SUM = ;
*-----------------------------------------------*
|  COMPUTE EMPTY & LOADED KIPS AND ANNUAL TRIPS  |
*-----------------------------------------------*;
DATA NC3;
   KEEP ORGZONE ORGNODE FL_TYPE DESTNODE ELEVATOR
      TRUCTYPE EKIP_AX1 EKIP_AX2 EKIP_AX3 LKIP_AX1
      LKIP_AX2 LKIP_AX3 AN_TRIPS TKCWTS;
   SET NC2;
   FL_TYPE = '3';
   %CO5AX
```

```
*-----------------------------------------------*
| W) CONCATENATE FARM-TO-ELEVATOR, COOP, AND    |
|   NON-COOP ELEVATOR-TO-MARKET DATA SETS       |
*-----------------------------------------------*;
DATA AXLEK;
   SET AXLEK FLOW30 NC3;
   *-----------------------------------------*
   |    WEIGHT AXLE KIPS BY ANNUAL TRIPS      |
   *-----------------------------------------*;
   ARRAY KP {6} EKIP_AX1-EKIP_AX3 LKIP_AX1-LKIP_AX3;
   DO I = 1 TO 6;
      KP {I} = KP {I} * AN_TRIPS;
   END;
*----------------------------------------------------*
| X) SUMMARIZE THE RESULTS AND CREATE FLOW REPORTS |
*----------------------------------------------------*
| 1) COMPUTE SUM OF ANNUAL TRIPS AND WEIGHTED KIPS |
*----------------------------------------------------*;
PROC SORT DATA = AXLEK;
   BY ORGZONE ORGNODE DESTNODE FL_TYPE TRUCTYPE;
PROC SUMMARY DATA = AXLEK;
   BY ORGZONE ORGNODE DESTNODE FL_TYPE TRUCTYPE;
   VAR EKIP_AX1 EKIP_AX2 EKIP_AX3 LKIP_AX1 LKIP_AX2
      LKIP_AX3 AN_TRIPS TKCWTS;
   OUTPUT OUT = AXLEK (DROP = _TYPE_ _FREQ_) SUM=;
*-----------------------------------------------------*
|  2) DIVIDE WEIGHTED KIPS BY THE SUM OF AN. TRIPS  |
*-----------------------------------------------------*;
DATA AXLEK (KEEP = ORGZONE ORGNODE DESTNODE FL_TYPE
   TRUCTYPE AN_TRIPS TKCWTS EKIP_AX1 EKIP_AX2
   EKIP_AX3 LKIP_AX1 LKIP_AX2 LKIP_AX3)
   /*    CREATE OUTPUT FLOW REPORT DATA SET       */
   AXLE5 (KEEP = FL_TYPE TRUCTYPE COOP TKCWTS
   AN_TRIPS  RENAME = (TKCWTS = CWTS));
   /*   INPUT THE RESULTS OF STATS SUMMARY        */
   SET AXLEK;
   /*   DIVIDE WEIGHTED FACTORS BY ANNUAL TRIPS   */
   ARRAY KP {6} EKIP_AX1-EKIP_AX3 LKIP_AX1-LKIP_AX3;
   DO I = 1 TO 6;
      IF AN_TRIPS = 0 THEN KP {I} = 0;
      ELSE KP {I} = KP {I} / AN_TRIPS;
   END;
   *-----------------------------------*
   |  3)    ASSIGN COOP FLAG           |
   *-----------------------------------*;
   IF DESTNODE = 'S1' OR
      ('E1' <= DESTNODE <= 'E7') THEN
         COOP = '1';
```

```
*----------------------------------------*
| D) CREATE SUMMARY FLOW REPORT FOR SCENARIO |
*----------------------------------------*;
PROC SUMMARY DATA = AXLE5;
   CLASSES FL_TYPE TRUCTYPE COOP;
   VAR AN_TRIPS CWTS;
   OUTPUT OUT = UGPT.FLOW&SCENARIO SUM = ;
RUN;
%MEND AXKIP3;
```

```
%MACRO ROUTE;
*-------------------------------------------------------*
|         RTAP HIGHWAY ASSIGNMENT PROCEDURE             |
*-------------------------------------------------------*
|///////////////////////////////////////////////////////|
*-------------------------------------------------------*
|  THE PURPOSE OF THIS PROCEDURE IS TO ASSIGN THE       |
|  PROJECTED INTERZONAL TRUCK SHIPMENTS TO THE HIGHWAY  |
|  NETWORK.  THE PROCEDURE USES AS INPUTS THE FINAL     |
|  DATA SET FROM THE TRUCK WEIGHT PROCEDURES AND A      |
|  HIGHWAY ROUTE OR NETWORK FILE.                       |
*-------------------------------------------------------*
|///////////////////////////////////////////////////////|
*-------------------------------------------------------*
| A)  MERGE TRUCK WEIGHT AND HIGHWAY ROUTE DATA SETS    |
*-------------------------------------------------------*;
PROC SORT DATA = AXLEK;
   BY ORGZONE ORGNODE DESTNODE FL_TYPE;
DATA HW1;
   MERGE AXLEK (IN=A) RTAP.ROUTES (IN=B);
   BY ORGZONE ORGNODE DESTNODE FL_TYPE;
   IF A;
*-------------------------------------------------------*
| B)  READ IN HIGHWAY AND MILEPOST VALUES FOR NDHWD     |
|  MONITORING SITES AND CONVERT HIGHWAYS TO ROADS       |
*-------------------------------------------------------*;
DATA INHWY;
   SET RTAP.AADT85;
   BY HWY MP;
   KEEP ROAD HWY MP;
   %M17
   %MROAD
*---------------------------------------------------------*
| C) REFORMAT SITE RECORDS FOR MORE EFFICIENT PROCESSING- |
|    DEFINE A VECTOR OF MILEPOSTS FOR EACH ROAD AND       |
|    DEFINE THE NUMBER OF MILEPOSTS IN EACH ROAD VECTOR   |
*---------------------------------------------------------*;
PROC SORT DATA= INHWY;
   BY ROAD;
DATA INHWY2;
   SET INHWY;
   BY ROAD;
   KEEP ROAD NO_MP MP1-MP7;
   ARRAY RMP {7} MP1-MP7;
   RETAIN MP1-MP7 C;
   IF _N_= 1 THEN C= 0;
   C = C + 1;
   RMP {C} = MP;
   IF LAST.ROAD THEN
      DO;
```

```
         NO_MP = C;
         OUTPUT;
         C = 0;
         DO I = 1 TO 7;
            RMP {I}= .;
         END;
      END;
DATA INHWY3;
   SET RTAP.LOCMP (IN=X) INHWY2;
   IF X THEN DO;
      NO_MP = 6;
      MP7 = . ;
   END;
PROC SORT DATA = INHWY3;
   BY ROAD;
*---------------------------------------------------*
| D) CONVERT THE FORMAT OF INTERZONAL VOLUME FILE    |
|   CREATING A RECORD FOR EACH HWY. LINK IN NETWORK |
*---------------------------------------------------*;
DATA TRANS;
   KEEP ROAD TRUCTYPE BEG_MP END_MP EKIP_AX1 EKIP_AX2
      EKIP_AX3 LKIP_AX1 LKIP_AX2 LKIP_AX3
      AN_TRIPS VMT;
   SET HW1;
   ARRAY LN {8} $ LNAME1 - LNAME8;
   ARRAY BM {8}   BEG_MP1- BEG_MP8;
   ARRAY EM {8}   END_MP1- END_MP8;
   ARRAY LD {8}   LDIST1 - LDIST8;
   IF TRUCTYPE NE 'CO_5AX' THEN
      DO;
         EKIP_AX3= 0;
         LKIP_AX3= 0;
      END;
   DO I= 1 TO NOLINKS;
      ROAD = LN {I};
      BEG_MP = BM {I};
      END_MP = EM {I};
      VMT = LD {I} * AN_TRIPS;
   END;
*-----------------------------------------------*
| E)  MERGE INTERZONAL VOLUME FILE WITH NDHWD    |
|  FILE AND COUNT THE TRUCK TRIPS, EMPTY KIPS,   |
|  AND LOADED KIPS FOR EACH ROAD AND MILEPOST    |
*-----------------------------------------------*;
PROC SORT DATA= TRANS;
   BY ROAD;
DATA ROAD6;
   MERGE TRANS(IN=A) INHWY3(IN=B);
   BY ROAD;
   IF A;
```

```
*---------------------------------------------------*
| F)  ASSIGN PROJECTED TRUCK TRIPS TO MILEPOSTS     |
*---------------------------------------------------*;
IF AN_TRIPS = 0 THEN DELETE;
ARRAY RMP     {7} MP1     - MP7;
ARRAY TKCNT   {7} TKCNT1  - TKCNT7;
ARRAY EK1     {7} EK1_AX1 - EK1_AX7;
ARRAY EK2     {7} EK2_AX1 - EK2_AX7;
ARRAY EK3     {7} EK3_AX1 - EK3_AX7;
ARRAY LK1     {7} LK1_AX1 - LK1_AX7;
ARRAY LK2     {7} LK2_AX1 - LK2_AX7;
ARRAY LK3     {7} LK3_AX1 - LK3_AX7;
ARRAY VM      {7} VMT1    - VMT7;
DO I= 1 TO 7;
   TKCNT  {I}= 0;
   EK1    {I}= 0;
   EK2    {I}= 0;
   EK3    {I}= 0;
   LK1    {I}= 0;
   LK2    {I}= 0;
   LK3    {I}= 0;
   VM     {I}= 0;
   IF I <= NO_MP THEN
      DO;
         IF (BEG_MP LE RMP {I} LE END_MP) OR
            (BEG_MP LE RMP {I} LE END_MP) THEN
            DO;
               TKCNT  {I}= AN_TRIPS;
               EK1    {I}= EKIP_AX1;
               EK2    {I}= EKIP_AX2;
               EK3    {I}= EKIP_AX3;
               LK1    {I}= LKIP_AX1;
               LK2    {I}= LKIP_AX2;
               LK3    {I}= LKIP_AX3;
               VM     {I}= VMT;
            END;
      END;
END;
DROP I;
*----------------------------------------------------*
|  G) ACCUMULATE THE TRUCK COUNTS AND COMPUTE MEAN   |
|  KIPS (BY AXLE GROUP) FOR EACH ROAD AND MILEPOST   |
*----------------------------------------------------*
|////////////////////////////////////////////////////|
*----------------------------------------------------*
|     1.   WEIGHT AXLE LOADS BY TRUCK COUNTS         |
*----------------------------------------------------*;
DO I= 1 TO 7;
   EK1 {I}= EK1 {I} * TKCNT {I};
   EK2 {I}= EK2 {I} * TKCNT {I};
```

```
   EK3 {I}= EK3 {I} * TKCNT {I};
   LK1 {I}= LK1 {I} * TKCNT {I};
   LK2 {I}= LK2 {I} * TKCNT {I};
   LK3 {I}= LK3 {I} * TKCNT {I};
END;
*---------------------------------------------------*
|    2.  SUM TRUCK COUNTS AND WEIGHTED KIPS         |
*---------------------------------------------------*;
PROC SORT DATA= ROAD6;
   BY ROAD TRUCTYPE;
PROC SUMMARY DATA= ROAD6;
   BY ROAD TRUCTYPE;
   VAR TKCNT1-TKCNT7 EK1_AX1-EK1_AX7
      EK2_AX1-EK2_AX7 EK3_AX1-EK3_AX7
      LK1_AX1-LK1_AX7 LK2_AX1-LK2_AX7
      LK3_AX1-LK3_AX7 VMT1-VMT7;
   OUTPUT OUT= ONE (DROP = _TYPE_ _FREQ_) SUM=;
*----------------------------------------------------*
|    3.  COMPUTE WEIGHTED MEAN KIPS BY AXLE GROUP    |
*----------------------------------------------------*;
DATA ROADCNT;
   SET ONE;
   ARRAY TKCNT  {7} TKCNT1 - TKCNT7;
   ARRAY EK1    {7} EK1_AX1 - EK1_AX7;
   ARRAY EK2    {7} EK2_AX1 - EK2_AX7;
   ARRAY EK3    {7} EK3_AX1 - EK3_AX7;
   ARRAY LK1    {7} LK1_AX1 - LK1_AX7;
   ARRAY LK2    {7} LK2_AX1 - LK2_AX7;
   ARRAY LK3    {7} LK3_AX1 - LK3_AX7;
   DO I= 1 TO 7;
      IF TKCNT {I}= 0 OR TKCNT {I}= . THEN
         DO;
            EK1    {I}= 0;
            EK2    {I}= 0;
            EK3    {I}= 0;
            LK1    {I}= 0;
            LK2    {I}= 0;
            LK3    {I}= 0;
         END;
      ELSE
         DO;
            EK1 {I}= EK1 {I} / TKCNT {I};
            EK2 {I}= EK2 {I} / TKCNT {I};
            EK3 {I}= EK3 {I} / TKCNT {I};
            LK1 {I}= LK1 {I} / TKCNT {I};
            LK2 {I}= LK2 {I} / TKCNT {I};
            LK3 {I}= LK3 {I} / TKCNT {I};
         END;
   END;
```

```
*-----------------------------------------------------*
|  G) CONVERT THE FILE BACK TO ORIGINAL FORMAT FOR    |
|            PURPOSES OF PRINTING                      |
*-----------------------------------------------------*;
DATA TRANS;
   MERGE ROADCNT(IN=A) INHWY3;
   BY ROAD;
   IF A;
   ARRAY RMP    {7} MP1 - MP7;
   ARRAY TKCNT  {7} TKCNT1 - TKCNT7;
   ARRAY EK1    {7} EK1_AX1 - EK1_AX7;
   ARRAY EK2    {7} EK2_AX1 - EK2_AX7;
   ARRAY EK3    {7} EK3_AX1 - EK3_AX7;
   ARRAY LK1    {7} LK1_AX1 - LK1_AX7;
   ARRAY LK2    {7} LK2_AX1 - LK2_AX7;
   ARRAY LK3    {7} LK3_AX1 - LK3_AX7;
   ARRAY VM     {7} VMT1    - VMT7;
   DO I= 1 TO NO_MP;
      MP= RMP {I};
      AN_TRIPS= TKCNT {I};
      EKIP_AX1= EK1 {I};
      EKIP_AX2= EK2 {I};
      EKIP_AX3= EK3 {I};
      LKIP_AX1= LK1 {I};
      LKIP_AX2= LK2 {I};
      LKIP_AX3= LK3 {I};
      VMT     = VM  {I};
      OUTPUT;
   END;
   DROP I;
*-----------------------------------------------------*
| H)  ADD HWY AND MP TO RECORD AND OUTPUT TO FILE     |
*-----------------------------------------------------*;
DATA UGPT.KIP&SCENARIO;
   LENGTH HWY 4;
   KEEP HWY MP ROAD TRUCTYPE NDHWD AN_TRIPS VMT EKIP_AX1
      EKIP_AX2 EKIP_AX3 LKIP_AX1 LKIP_AX2 LKIP_AX3;
   SET TRANS;
   *------------------------------------*
   |  CONVERT "ROAD" BACK TO "HIGHWAY"  |
   *------------------------------------*;
   IF ROAD= '2E' OR ROAD= '2W' THEN HWY= 2;
   ELSE IF ROAD= '20N' OR ROAD= '20S' THEN HWY= 20;
   ELSE IF ROAD= '17E' OR ROAD= '17W' THEN HWY= 17;
   ELSE IF ROAD= '281S' OR ROAD= '281N' THEN HWY= 281;
   ELSE HWY=INPUT(ROAD,4.0);
   *-----------------------------------------------------*
   | IDENTIFY ROADS WITH NDHWD DATA COLLECTION SITES     |
   *-----------------------------------------------------*;
   IF ROAD = '2E' OR ROAD = '2W' OR ROAD = '20N' OR
```

```
      ROAD = '20S' OR ROAD = '17E' OR ROAD = '17W' OR
      ROAD = '57' OR ROAD = '19' OR ROAD = '3630' OR
      ROAD = '3614' OR ROAD = '3618' THEN NDHWD = '1';
   ELSE NDHWD = '0';
   PROC SORT;
      BY HWY MP TRUCTYPE;
   PROC PRINT;
      TITLE 'OUTPUT DATA SET- SCENARIO&SCENARIO';
   RUN;
%MEND ROUTE;
**********************************************************;
*  MAIN MODULE--  SETS CALLING SEQUENCE OF PROCEDURES   *;
**********************************************************;
%RFACT
%FLOW
%SPATIAL
%TRAFFIC
%TRUCK
%AXKIP1
%IF &SCENARIO  = 0 %THEN %AXKIP2;
%IF &SCENARIO >= 1 %THEN %AXKIP3;
%ROUTE
**********************************************************;
**********           END OF MODULE I        *************;
**********************************************************;
%MEND MODULE1;

%MODULE1(0,5,21)
```

```
%MACRO MODULE2(SCENARIO);
%**********************************************;
%*  THE PURPOSE OF THIS MACRO IS TO COMPUTE SHORT *;
%*  AND LONG-RUN INCREMENTAL COSTS FOR EACH CASE  *;
%**********************************************;


%MACRO EALX;
%**********************************************;
%*      AASHTO FLEXIBLE ESAL FORMULA            *;
%**********************************************;
   G = LOG10((4.2 - PSR2)/(4.2 - 1.5));
   B18 = 0.40 +  1094 / (SN + 1)**5.19;
   BX = 0.40 + ( 0.081 * (L1 + L2)**3.23) /
      ((SN + 1)**5.19 * L2**3.23);
   IF L2 = 1 THEN LGW = 4.79 * LOG10(L1 + 1) - 4.79
      * LOG10(18 + 1) + G/B18 - G/BX;
   IF L2 = 2 THEN LGW = 4.79 * LOG10(L1 + 2) - 4.79
      * LOG10(18 + 1) - 4.33 *
        LOG10(2) + G/B18 - G/BX;
   ESAL = 10**LGW;
%MEND EALX;

%MACRO EAL;
%**********************************************;
%*         ESAL COMPUTATIONAL PROCEDURE         *;
%**********************************************;
%*  THIS MACRO SETS THE PARMATER VALUES FOR THE   *;
%*  FLEXIBLE ESAL EQUATION FOR EACH AXLE GROUP    *;
%*  (BOTH EMPTY AND LOADED) FOR EACH TRUCK-TYPE   *;
%**********************************************;
L1 = ROUND(LKIP_AX1);
L2 = 1;
IF L1 = 0 THEN L_ESAL1 = 0;
ELSE DO;
   %EALX;
   L_ESAL1 = ESAL;
END;
L1 = ROUND(LKIP_AX2);
IF TRUCTYPE = 'SU_2AX' THEN L2 = 1;
ELSE L2 = 2;
IF L1 = 0 THEN L_ESAL2 = 0;
ELSE DO;
   %EALX;
   L_ESAL2 = ESAL;
END;
L1 = ROUND(LKIP_AX3);
L2 = 2;
IF L1 = 0 THEN L_ESAL3 = 0;
ELSE DO;
```

```
   %EALX;
   L_ESAL3 = ESAL;
END;
L1 = EKIP_AX1;
L2 = 1;
IF L1 = 0 THEN E_ESAL1 = 0;
ELSE DO;
   %EALX;
   E_ESAL1 = ESAL;
END;
L1 = EKIP_AX2;
IF TRUCTYPE = 'SU_2AX' THEN L2 = 1;
ELSE L2 = 2;
IF L1 = 0 THEN E_ESAL2 = 0;
ELSE DO;
   %EALX;
   E_ESAL2 = ESAL;
END;
L1 = EKIP_AX3;
L2 = 2;
IF L1 = 0 THEN E_ESAL3 = 0;
ELSE DO;
   %EALX;
   E_ESAL3 = ESAL;
END;
EAL_EVMT = E_ESAL1 + E_ESAL2 + E_ESAL3;
EAL_LVMT = L_ESAL1 + L_ESAL2 + L_ESAL3;
EAL_VMT = (EAL_EVMT + EAL_LVMT) / 2;
%MEND EAL;


%MACRO ESALCAL(SCENARIO,TIMES);
%**************************************************;
%*              RTAP ESAL-CALC PROCEDURE          *;
%**************************************************;
%*  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE  *;
%*  BASE YEAR ESALS AND ESALS FOR EACH SCENARIO.     *;
%**************************************************;

%IF &TIMES = 1 %THEN %DO;
%**************************************************;
%*   A)  COMPUTE BASE-LINE TRIPS AND ESALS        *;
%**************************************************;
DATA UGPT.ESAL&SCENARIO (KEEP= SECTION ROAD FUNCLASS
   SECLENG TRUCTYPE PSR PSR2 SN T AN_TRIPS EAL_LVMT
   EAL_VMT GESAL_0 ESVMT_0)
   ZERO (KEEP= SECTION TRUCTYPE TRIPS_0 EALVMT_0
   GESAL_0 ESVMT_0);
   MERGE RTAP.DLHWY UGPT.KIP0 (IN=B);
```

```
   BY SECTION;
   IF B;
   %EAL
   TRIPS_0   = AN_TRIPS;
   GESAL_0   = AN_TRIPS * EAL_VMT;
   ESVMT_0   = EAL_VMT  * VMT;
PROC PRINT;
   TITLE 'ZERO';
PROC PRINT DATA = UGPT.ESAL0;
   TITLE 'UGPT ESAL0';
RUN;
%END;

%ELSE %DO;
%*******************************************************;
%*  B)  COMPUTE SCENARIO ANNUAL TRIPS AND ESALS       *;
%*******************************************************;
   DATA TEMP;
      MERGE RTAP.DLHWY UGPT.KIP&SCENARIO (IN=B);
      BY SECTION;
      IF B;
      %EAL
      ESAL_YR = AN_TRIPS * EAL_VMT;
   DATA UGPT.ESAL&SCENARIO;
   KEEP SECTION ROAD FUNCLASS SECLENG TRUCTYPE PSR PSR2
      SN T AN_TRIPS IC_TRIPS ESAL_YR IC_ESAL EAL_LVMT
      EAL_VMT ESALVMT IC_EVMT;
   MERGE TEMP ZERO;
   BY SECTION TRUCTYPE;
   IC_TRIPS = AN_TRIPS - TRIPS_0;
   IC_ESAL  = IC_TRIPS * EAL_VMT;
   ESALVMT  = EAL_VMT  * VMT;
   IC_EVMT  = ESALVMT  - ESVMT_0;
RUN;
%END;
%MEND ESALCAL;
```

```
%MACRO ESALIFE;
%*******************************************************;
%*               RTAP ESAL LIFE PROCEDURE              *;
%*******************************************************;
%*/////////////////////////////////////////////////////*;
%*******************************************************;
%*  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE    *;
%*  ESAL LIFETIMES OF SAMPLE HIGHWAY SECTIONS USING    *;
%*  BOTH THE TEXAS TRANSPORTATION INSTITUTE MODEL      *;
%*       AND THE HPMS DAMAGE FUNCTION.                 *;
%*******************************************************;
%*  COMPUTE THE VALUES OF "TAU" IN DAMAGE FUNCTION     *;
%*******************************************************;
   DATA TTI1;
      KEEP SECTION SN T PSR2 TAU;
      SET RTAP.DLHWY;
      %*********************************************;
      %*   SET VALUES FOR MAJOR MODEL INPUTS       *;
      %*********************************************;
      T1 = T;          /*  AC LAYER THICKNESS VARIABLE  */
      P = 90;          /*  TIRE PRESSURE PER TIRE       */
      L1 = 18;         /*  KIPS ON AXLE GROUP           */
      L2 = 1;          /*  NUMBER OF AXLES IN GROUP     */
      L3 = 2;          /*  NUMBER OF TIRES: "1" OR "2"  */
      L4 = 1;          /*  TIRE TYPE CODE: BIAS OR RAD. */
      ES = 4500;       /*  RESILIENT MODULUS OF SUBGRADE*/
      %*********************************************;
      %*  SET MODEL CONSTANTS AND COEFFICIENTS USING *;
      %*  VALUES FOR THE DRY-FREEZE ZONE EQUATIONS   *;
      %*********************************************;
      A0  =  8.54580997;
      A1  = -1.92636492;
      A2  =  0.00000000;
      A3  = -0.00000900;
      A4  = -0.00087092;
      A5  =  1.79275336;
      A6  =  0.00000000;
      A7  = -0.00001170;
      A8  =  0.00000000;
      A9  =  1.85872192;
      A10 =  0.00000000;
      A11 = -0.00000860;
      A12 =  0.00000000;
      A13 = -4.37832061;
      A14 =  0.67225250;
      A15 =  0.00000930;
      A16 =  0.00000000;
      A17 =  0.00000000;
      A18 = -0.12346038;
      A19 =  0.00000000;
```

```
      C =  0.00000000;
    RSQ =  0.93200000;
    %*********************************************;
    %*   COMPUTE THE VALUES OF MODEL EXPONENTS      *;
    %*********************************************;
    EXP1 = A1 + (A2 * T1) + (A3 * ES) + (A4 * P);
    EXP2 = A5 + (A6 * T1) + (A7 * ES) + (A8 * P);
    EXP3 = A9 + (A10 * T1) + (A11 * ES) + (A12 * P);
    EXP4 = A13 + (A14 * T1) + (A15 * ES) + (A16 * P);
    %*********************************************;
    %*  COMPUTE THE VALUE OF TAU IN DAMAGE FUNCTION  *;
    %*********************************************;
    TAU = (10**A0) * ((L1 + L2 + L3)**EXP1) *
          (L2**EXP2) *
          (L3**EXP3) *
          ((L4+1)**EXP4) *
          (T1**A17) * (ES**A18) * (P**A19) -
          C;
%****************************************************;
%*   COMPUTE THE VALUES OF "BETA" IN DAMAGE FUNCITON    *;
%****************************************************;
DATA TTI2;
   KEEP SECTION BETA;
   SET RTAP.DLHWY;
   %*********************************************;
   %*     SET VALUES FOR MAJOR MODEL INPUTS          *;
   %*********************************************;
   T1 = T;               /*  AC LAYER THICKNESS VARIABLE  */
   P = 90;               /*  TIRE PRESSURE PER TIRE       */
   L1 = 18;              /*  KIPS ON AXLE GROUP           */
   L2 = 1;               /*  NUMBER OF AXLES IN GROUP     */
   L3 = 2;               /*  NUMBER OF TIRES: "1" OR "2"  */
   L4 = 1;               /*  TIRE TYPE CODE: BIAS OR RAD. */
   ES = 4500;            /*  RESILIENT MODULUS OF SUBGRADE*/
   %*********************************************;
   %*   SET MODEL CONSTANTS AND COEFFICIENTS USING    *;
   %*   VALUES FROM THE DRY-FREEZE ZONE EQUATIONS     *;
   %*********************************************;
   A0  = -0.86987349;
   A1  =  0.00000000;
   A2  =  0.09442385;
   A3  = -0.00001860;
   A4  = -0.00022683;
   A5  =  0.00000000;
   A6  = -0.10482985;
   A7  =  0.00001300;
   A8  =  0.00000000;
   A9  =  0.00000000;
   A10 = -0.10122395;
   A11 =  0.00002340;
```

```
   A12 =  0.00000000;
   A13 = -0.08745997;
   A14 =  0.01632584;
   A15 = -0.00000080;
   A16 =  0.00000000;
   A17 = -0.84335410;
   A18 =  0.63703782;
   A19 =  0.00000000;
     C = 11.00000000;
   RSQ =  0.48800000;
   EXP1 = A1 + (A2 * T1) + (A3 * ES) + (A4 * P);
   EXP2 = A5 + (A6 * T1) + (A7 * ES) + (A8 * P);
   EXP3 = A9 + (A10 * T1) + (A11 * ES) + (A12 * P);
   EXP4 = A13 + (A14 * T1) + (A15 * ES) + (A16 * P);
   %*********************************************;
   %*  COMPUTE VALUE OF BETA IN THE DAMAGE FUNCTION *;
   %*********************************************;
   BETA = (10**A0) * ((L1 + L2 + L3)**EXP1) *
          (L2**EXP2) *
          (L3**EXP3) *
          ((L4+1)**EXP4) *
          (T1**A17) * (ES**A18) * (P**A19) -
          C;
   %***********************************************;
   %*   MERGE DATA SETS CONTAING "TAU AND "BETA"     *;
   %*   AND COMPUTE ESAL LIFETIMES OF HIGHWAY SECT.  *;
   %***********************************************;
   PROC SORT DATA = TTI1;
      BY SECTION;
   PROC SORT DATA = TTI2;
      BY SECTION;
   DATA TTI3;
      KEEP SECTION N;
      MERGE TTI1 TTI2;
      BY SECTION;
      PF = 1.5;
      PO = 4.2;
      C  = (PO - PF) / (PO - PSR2);
      GT = (PO - PSR2) / (PO - PF);
      B  = 1 / BETA;
      N  = TAU / (-LOG(GT/C)) ** (B);
RUN;
%MEND ESALIFE;
```

```
%MACRO BSOONER(SCENARIO);
%*****************************************************;
%*          RTAP BUILD-SOONER PROCEDURE              *;
%*****************************************************;
%*///////////////////////////////////////////////////*;
%*****************************************************;
%*  THE PURPOSE OF THIS PROCEDURE IS TO COMPUTE THE  *;
%*  SHORT-RUN INCREMENTAL COSTS DUE TO REDUCTIONS IN *;
%*  ESAL LIFETIMES CAUSED BY INCREMENTAL TRAFFIC.    *;
%*****************************************************;
PROC SORT DATA = UGPT.ESAL&SCENARIO;
    BY SECTION TRUCTYPE;
DATA BSP&SCENARIO;
   KEEP SECTION ROAD FUNCLASS N B_ESALS A_ESALS
      R_LIFE REPLACEM SECLENG BSC;
   MERGE RTAP.ESAL85 TTI3 UGPT.ESAL&SCENARIO (IN=A);
   BY SECTION;
   %*****************************************************;
   %* A)  COMPUTE THE ANNUAL ESALS UNDER THE BASELINE *;
   %*    AND ALTERED TRAFFIC STREAMS FOR EACH SECTION *;
   %*****************************************************;
   IF A;
   B_ESALS = AN_ESAL;
   A_ESALS = IC_ESAL + B_ESALS;
   %*****************************************************;
   %* B)  COMPUTE THE LIFE OF EACH HIGHWYA SECTION    *;
   %*   IN YEARS UNDER BOTH THE BASE & IMPACT CASES   *;
   %*****************************************************;
   B_LIFE  = ROUND(N / B_ESALS);
   A_LIFE  = ROUND(N /A_ESALS);
   %*****************************************************;
   %* C)  COMPUTE ANY REDUCTIONS IN PAVEMENT LIFE     *;
   %*****************************************************;
   R_LIFE = B_LIFE - A_LIFE;
   IF R_LIFE < 0 THEN R_LIFE = 0;
   %*****************************************************;
   %* D)  SET THE REPLACEMENT COST PER MILE, BY CLASS *;
   %*****************************************************;
   IF FUNCLASS = '02' THEN REPLACEM = 266000;
   IF FUNCLASS = '06' THEN REPLACEM = 119000;
   IF FUNCLASS = '07' THEN REPLACEM = 116000;
   IF FUNCLASS = '08' THEN REPLACEM = 116000;
   %*****************************************************;
   %* E)  COMPUTE REPLACEMENT COSTS FOR EACH SECTION  *;
   %*****************************************************;
   REPLACEX  =  REPLACEM  * SECLENG;
   %*****************************************************;
   %* F)  SET THE INTEREST RATE FOR PUBLIC CAPITAL    *;
   %*****************************************************;
   IR  = .09347;
```

```
   %*************************************************;
   %* G)  COMPUTE PRESENT VALUE OF REPLACEMENT OUTLAYS *;
   %*     UNDER BOTH THE BASELINE AND IMPACT CASES     *;
   %*************************************************;
   PVB = REPLACEX  / (1 + IR) ** B_LIFE;
   PVA = REPLACEX  / (1 + IR) ** A_LIFE;
   %*************************************************;
   %* H)  COMPUTE BUILD-SOONER COST FOR EACH SECTION   *;
   %*************************************************;
   BSC = PVB - PVA;
   IF BSC < 0 THEN BSC = 0;
RUN;
%MEND BSOONER;


%MACRO UPGRADE(SCENARIO);
%*****************************************************;
%*               RTAP UPGRADE PROCEDURE               *;
%*****************************************************;
%///////////////////////////////////////////////////*;
%*****************************************************;
%*  THE PURPOSE OF THIS PROCEDURE IS TO SIMULATE THE   *;
%*  LONG-RUN UPGRADING COSTS ON IMPACT HIGWAYS DUE TO  *;
%*  INCREMENTAL GRAIN TRUCK TRAFFIC.  THE PROCEDURE USES *;
%*  THE HPMS DAMAGE FUNCTION TO PREDICT ESAL LIFETIMES *;
%*  OF SECTIONS AND THE STRUCTURAL NUMBERS BEFORE AND  *;
%*  AFTER THE ALTERATION OF TRAFFIC PATTERNS.          *;
%*****************************************************;
DATA UPG1;
   MERGE UGPT.ESAL&SCENARIO (IN=A) RTAP.ESAL85;
   BY SECTION;
   %*************************************************;
   %* A)  COMPUTE "BEFORE" AND "AFTER" ANNUAL ESALS    *;
   %*************************************************;
   IF A;
   B_ESALS = AN_ESAL;
   A_ESALS = IC_ESAL + B_ESALS;
   %*************************************************;
   %* B)  COMPUTE ESAL LIFE UNDER BASELINE SCENARIO    *;
   %*************************************************;
   SNB = SN;
   LINK HLIFE;
   B_LIFE = E_LIFE;
   %*************************************************;
   %* C)  COMPUTE BASE CASE SECTION LIFE IN YEARS      *;
   %*************************************************;
   B_YEARS = FLOOR(B_LIFE/B_ESALS);
```

```
%*****************************************************;
%* D)  DEFINE A LOOP FOR RECOMPUTING SECTION LIFE    *;
%*****************************************************;
DO UNTIL(A_YEARS >= B_YEARS);
   %*************************************************;
   %* E)  INCREMENT THE VALUE OF SN IN ASSHTO EQU.   *;
   %*************************************************;
   SN = SN + .1;
   %*************************************************;
   %* F)  RECOMPUTE THE VALUE OF SECTION ESALLIFE    *;
   %*************************************************;
   LINK HLIFE;
   A_LIFE = E_LIFE;
   %*************************************************;
   %* G)  RECOMPUTE THE LIFE OF THE SECTION IN YRS.  *;
   %*************************************************;
   A_YEARS = FLOOR(A_LIFE/A_ESALS);
END;
%*****************************************************;
%* H)  COMPUTE THE INCREMENTAL THICKNESS REQUIRED    *;
%*****************************************************;
SNA = SN;
A1  = .44;
IT  = (SNA - SNB) / A1;
%*****************************************************;
%* I)  SET THE OVERLAY COST PER INCREMENTAL INCH     *;
%*****************************************************;
IF FUNCLASS =  '02' THEN OVERLAY = 18800;
IF FUNCLASS =  '06' THEN OVERLAY = 36600;
IF FUNCLASS =  '07' THEN OVERLAY = 35600;
IF FUNCLASS =  '08' THEN OVERLAY = 35600;
%**************************************;
%* J) COMPUTE LRIC FOR THE SECTION    *;
%**************************************;
UPGMILE = OVERLAY * IT;
UPGRADEX= UPGMILE * SECLENG;
RETURN;
HLIFE:
   SNZ = SN + (6/SN) ** 0.5;
   XB  = 0.4 + 1094/SNZ ** 5.19;
   XG  = LOG10((5 - PSR) / 3.5);
   XG2 = LOG10((5 - PSR2) / 3.5);
   XA  = 9.36 * LOG10(SNZ) - 0.2;
   LOGELA  = XA + XG  / XB;
   LOGELA2 = XA + XG2 / XB;
   CUM_ESAL= 10 ** LOGELA;
   E_LIFE  = 10 ** LOGELA2;
RETURN;
%MEND UPGRADE;
```

```
%ESALCAL(0,1)
%ESALCAL(1,2)
%ESALIFE
%BSOONER(1)
%UPGRADE(1)

%MEND MODULE2;
%MEND SHELL;
%SHELL
```