

**A COMMODITY BASED METHODOLOGY FOR
FREIGHT FORECASTING ON RURAL ROAD NETWORKS**

BY

KERRIN L. P. MRUSS, B.Sc., P.Eng.

**A Thesis Submitted to
the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements for the Degree of**

MASTER OF SCIENCE

**Department of Civil Engineering
University of Manitoba
Winnipeg, Manitoba**

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FACULTY OF GRADUATE STUDIES

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ABSTRACT

This research selects, develops, applies and evaluates a methodology for forecasting specific commodity movements of freight and related truck traffic on a rural highway network. The application of the methodology involves transportation engineering and planning considerations of grain movements by truck on provincial trunk highways and roads and selected municipal roads in Manitoba.

The thesis examines the importance of regional freight forecasting in transportation applications and identifies existing models available for forecasting freight movements on a regional basis. A freight forecasting methodology based on a modified version of the traditional four-step urban transportation planning procedure is selected for Manitoba. The freight forecasting model is comprised of three steps: (1) freight generation; (2) freight distribution; and (3) freight assignment.

The selected freight forecasting methodology is applied to estimate grain movements on the Manitoba rural road network. A geographic information system platform is developed and used to construct and implement the grain forecasting model. Freight generation, which includes freight production and freight attraction, is determined for grain movements in the province.

The gravity model is used in the freight distribution component to estimate grain tonnage moving between origin-destination pairs. Various measures of impedance are tested in the gravity model, and a combination of transport cost and distance is ultimately selected

for the grain application. The outcome of the freight distribution process is a matrix that identifies grain movements between all origins and destinations.

Freight volumes on individual road links are estimated by assigning freight to the road network based on the origin-destination results from the freight distribution component of the model. Various assignment methods are available, and the All-or-Nothing methodology is used to assign grain to the freight assignment network in this research.

The origin-destination and assignment results from the forecasting model are deemed to adequately represent the movement of grain from farm to elevator in Manitoba. The majority of grain travels to the closest delivery point available. However, grain is also transported longer distances to high throughput elevators that offer cost incentives to producers. Large volumes of grain are present on roads leading directly to major delivery points throughout the province.

The model developed in this research can be adapted to forecast freight movements for other commodity types in order to develop a better understanding of freight activity. Policy and decision makers can use the resulting freight forecasts to assist in making informed decision about transportation planning and engineering applications. The model developed in this research to forecast grain movements was used to identify grain routes for the Prairie Grain Roads Program.

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CHAPTER 1

INTRODUCTION

1.1 THE RESEARCH

This thesis selects, develops, applies and evaluates a methodology for forecasting specific commodity movements of freight and related truck traffic on a rural highway network. The application of the methodology involves transportation engineering and planning considerations of grain movements by truck on provincial trunk highways and roads and selected municipal roads in Manitoba.

1.2 BACKGROUND AND NEED

The safe and effective movement of freight is a major transportation policy issue in Canada and North America (Transportation Research Board, 2003). Moving goods efficiently, safely, and securely is vital to the national economy (Transport Canada, 2003), and freight movements on transportation networks play an important role in economic activities for all levels of government (U.S. DOT, 1998). An understanding of how freight moves through the transportation system is required to make decisions about infrastructure investments and policy issues (U.S. DOT, 1998 and Transportation Research Board, 1998). Methods for estimating freight movements are important tools that can be used by decision makers to help make choices about where to spend limited infrastructure and maintenance funds. Informed decisions are not possible without reliable freight transportation data.

Information on truck movements is especially important, as almost all freight is transported by truck at some point in its journey (Nix, 2003). Truck freight information is critical for the planning and provision of transportation infrastructure and facilities necessary for the efficient movement of both goods and people. Reliable data on truck freight movements is necessary to answer the questions facing jurisdictions today. Key questions for Manitoba that require freight information include:

- How do changes in size and weight regulations affect truck flows in the province? For example, what are the impacts of extended spring weight restrictions on freight movements in Manitoba? What are the impacts on grain movements and pavement deterioration associated with an increase in truck size and weight regulations?
- How does the addition or removal of major freight generating facilities affect truck flows? For example, how are freight movements impacted by the consolidation of grain elevators and the construction of new high throughput terminals in Manitoba?
- Which highways on the provincial network should receive funding in order to maximize the benefits of limited infrastructure investments? For example, which roads should receive funding under the Prairie Grain Roads Program, a federal initiative that provides financial assistance to upgrade roadways used for grain transportation?
- What is the impact on truck flows of the addition of a new link in the road network? For example, how have grain movements around Winnipeg changed since the construction of the northeast link of Perimeter Highway 1A?
- How are truck flows affected by the temporary or permanent removal of a link in the provincial road network? For example, what is the impact on grain movements of a construction project on PTH 5 that results in lane closures and speed limit reductions for an extended period? PTH 5 leads directly to the Dauphin grain delivery point and is the primary route for grain movements to the facility.

Engineering and planning questions require reliable freight information and forecasts in order to make informed decisions about transportation policies and investments. “Without good data, decisions will be arbitrary, options overlooked, and solutions reactive” (Transportation Research Board, 2003).

1.3 OBJECTIVES

Specific objectives of this thesis are:

- 1) To research and understand the importance of truck freight movements in the overall transportation planning process. This objective requires documentation of the requirement for and use of freight movement information in the decision making process.
- 2) To understand, compare, and contrast methodologies available to forecast freight movements in North America. This objective requires a comprehensive environmental scan of both the literature and freight forecasting practices.
- 3) Based on the comparison of models currently in practice, to determine an appropriate methodology that can be used to forecast freight movements in Manitoba. This requires a critical consideration of the various freight forecasting models available and selection of a methodology that is appropriate for Manitoba.
- 4) To use the selected methodology from Objective 3 to develop and apply a freight forecasting model to the grain industry to forecast grain movements on the road network in Manitoba. The model uses a Geographic Information System for Transportation (GIS-T) platform developed using TransCAD GIS Software.
- 5) To critically evaluate the results of the freight forecasting model developed for Manitoba and applied to the grain industry.

1.4 RESEARCH CONSIDERATIONS

The following requirements were necessary for this research:

- 1) Experience with freight transportation planning and engineering work in Western Canada and North America. Experience was obtained through analysis of the highway freight transportation system for the Transport Canada *Prairie Provinces Transportation System Study*, and as primary researcher for the study update. Similar projects were conducted for the Atlantic Provinces and Ontario. A study of people and goods movement in Manitoba examined economic activities, traffic trends, and the highway, rail, and air systems. This experience provides an understanding of freight movements and related issues.

- 2) Working experience with the analysis and integration of domestic and international freight databases, including the following:
- Statistics Canada For-Hire Truck Survey;
 - Canadian Council of Motor Transport Administrators (CCMTA) Roadside Survey;
 - Transborder Surface Freight Databases developed by the United States Bureau of Transportation Statistics;
 - United States Commodity Flow Survey;
 - University of Manitoba Transportation Information Group freight surveys; and
 - border crossing statistics.

This work has resulted in additional knowledge of freight activity in North America.

- 3) Educational and working knowledge in the planning, design, operation and application of GIS-T platforms. GIS-T work has been conducted for Transport Canada, Manitoba Transportation and Government Services, Saskatchewan Highways and Transportation, Alberta Economic Development, City of Winnipeg Public Works Department, and others. Experience with GIS-T applications is critical to the design and development of an appropriate platform for the freight forecasting model.
- 4) Knowledge of the Manitoba road network and working experience with the provincial highway inventory database. An understanding of the type of data available for the highway network is essential for the development of a freight assignment network for the forecasting model.
- 5) Working experience with studies involving grain movements in the Prairies. This work provides a practical understanding of the current issues facing the grain industry in Manitoba.
- 6) Field and analysis experience with vehicle classification surveys in the Prairie Provinces. A survey was conducted at the Moosomin Weigh Scale on Trans Canada Highway 1 west of the Manitoba border, and cross-border surveys were conducted at the Emerson Weigh Scale (Manitoba), Estevan Weigh Scale (Saskatchewan), and Coutts Vehicle Inspection Station (Alberta). During each survey, axle weight, vehicle configuration, and body type information was recorded and drivers were interviewed to collect data on commodities, origins and destinations, and routing choices.

1.5 THESIS ORGANIZATION

This thesis consists of eight chapters. Chapter 2 describes the importance of regional freight forecasting in transportation engineering and planning applications. The various methodologies currently available for forecasting freight movements on a regional basis are discussed and the results of an environmental scan of freight related initiatives and programs in jurisdictions throughout North America are presented.

Chapter 3 discusses the selection of a methodology for freight forecasting in Manitoba and describes the components of the three-step freight forecasting model. The forecasting model predicts freight movements by commodity type and the grain industry in Manitoba is selected for the application of the forecasting model.

Chapter 4 describes the development of a GIS-T platform for the freight forecasting model for Manitoba. Data requirements for the development of the grain application are also discussed.

Chapter 5 describes the freight generation step for the selected freight forecasting methodology. Freight production and attraction estimates are developed for the grain industry in Manitoba.

Chapter 6 develops the freight distribution component for the selected freight forecasting methodology. The use of the gravity model and the estimation of appropriate friction

factors for the grain forecasting model are discussed. The determination of the origin-destination results and the subsequent calibration of the gravity model are also provided.

Chapter 7 describes the freight assignment step for the selected freight forecasting methodology. The development of a freight assignment network for the grain industry in Manitoba is discussed. The All-or-Nothing freight assignment method is used to assign grain movements to the freight network and the results are evaluated.

Chapter 8 discusses and evaluates the application of the selected methodology for forecasting grain movements on the Manitoba freight assignment network. Potential applications of the grain forecasting model are suggested and lessons learned during the research are presented. Conclusions developed during the course of the research are provided and future considerations for additional research involving regional freight forecasting are discussed.

CHAPTER 2

FREIGHT FORECASTING METHODOLOGIES

This Chapter discusses the importance of regional freight forecasting in transportation engineering and planning applications. Key freight related initiatives in North America are identified and the methodologies currently available for forecasting freight movements on a regional basis are described. Information on existing freight forecasting programs in the United States and Canada are also provided.

2.1 IMPORTANCE OF REGIONAL FREIGHT FORECASTING

Financial constraints require decision-makers to carefully consider every investment decision. Transportation engineers and planners rely on information about the movement of both people and goods, and comprehensive, reliable and timely freight data are essential for making logical and informed decisions about policy and infrastructure investments (Huang, 1998, Pendyala, 2002, and Transportation Research Board, 2003). Lack of freight data may result in inappropriate allocation of scarce investment funds.

Regional models that forecast freight movements are useful for a wide range of transportation engineering and planning applications:

- Freight forecasts can be used to determine the appropriate capacity for new infrastructure facilities as well as for existing facilities in the future. Overestimating freight movements can result in underutilized facilities, while underestimating freight movements can result in congested facilities or a failure to build needed facilities (Cambridge, 1997 and Pendyala et al., 2000).

- Freight forecasting models can simulate usage of potential highway networks in order to evaluate the viability of alternative road improvement scenarios (Cambridge, 1997, Huang, 1998, and Pendyala et al., 2000).
- Forecasts of freight movements can be used to assess the adequacy of existing facilities and services in a specified corridor, and can also be used to determine the need for expanding corridor facilities and services in the future (Cambridge, 1997 and Pendyala et al., 2000).
- The results of a freight forecasting model can be used to identify congested and problem locations on a highway network and evaluate proposed improvements (Transportation Research Board, 2003).
- Freight forecasts are important for pavement design, as pavement damage increases rapidly with increasing axle weights (Park and Smith, 1997 and Sorratini, 1999). In 2001, trucks in the United States accounted for just 17 percent of total traffic on rural Interstate highways, but were responsible for 89 percent of the pavement loadings (BTS, 2003).
- Freight forecasting models can be used to evaluate the impacts of major changes in the highway network, such as the completion of new highway facilities or changes in speed and weight limits (Park and Smith, 1997 and Sorratini, 1999). Forecasting models can also be used to determine the effects of road closures or major detours during prolonged construction periods.
- Estimates of freight movements can enhance transportation safety and security by ensuring that appropriately designed facilities and structures are constructed to meet forecast transportation requirements (Park and Smith, 1997 and Sorratini, 1999),
- Freight forecasts can be used to evaluate different Intelligent Transportation Systems for Commercial Vehicle Operations (Sorratini, 1999).
- Estimates of freight forecasts can be used in environmental impact and air quality studies to help reduce fuel consumption and improve air quality (Park and Smith, 1997, Sorratini, 1999 and Transportation Research Board, 2003).

Freight forecasts can also be used to evaluate truck routes and restrictions, analyze truck size and weight regulations, plan truck/rail intermodal facilities, facilitate effective land use planning, promote economic development, and provide important information on commercial vehicle operations (Cambridge, 1997, Huang, 1998 and Transportation Research Board, 2003).

Unfortunately, available freight data is not always sufficient to support the requirements of decision makers. Freight information can be disjointed and out of date, and attempts to combine information from different sources result in problems in terms of modal coverage, data collection strategies, and concerns about the quality of the combined data (Transportation Research Board, 2003). Freight data users consistently note important gaps in freight information, including origins and destinations, freight flows, commodities, transit times, shipment costs, intermodal connections, and the infrastructure, vehicles, vessels, airplanes and pipelines used (BTS, 2003). The most significant gap in freight data is truck commodity flows, specifically information on truck contents and freight movements from origin to destination (Coogan, 1996 and Transportation Research Board, 2003).

Ideally, all freight information would be “real” data gathered through a combination of surveys and data collection techniques. However, because data collection, processing, and distribution are expensive activities, analytical models are used to fill in data gaps. Modeling techniques can be used to generate missing freight data in a timely manner and avoid the expense of data collection (Transportation Research Board, 2003).

2.2 FREIGHT DATA AND FORECASTING INITIATIVES

The requirement for freight data has received more attention in recent years. Conferences and meetings have been held to discuss the need for freight related information and research aimed specifically at the collection and analysis of freight information has been published.

- The National Cooperative Highway Research Program (NCHRP) is currently sponsoring *Project 8-43: Methods for Forecasting Statewide Freight Movements and Related Performance Measures* to develop an analytical framework for forecasting freight movements at the state level. The primary issue driving this project is the large gaps in data required to estimate freight movements, especially truck freight movements. According to the project overview, the framework will include: (1) a tool kit of data collection techniques, analytical procedures, and computer models; (2) management approaches and decision-making procedures; and (3) performance evaluation methods to guide states in establishing priorities for improving their transportation systems to best accommodate increased freight demand. The project is scheduled for completion in December 2004 (Cambridge, 2004).
- The Transportation Research Board published *Special Report 276, A Concept for a National Freight Data Program*, in 2003. The purpose of this report is to guide the development of a national freight database and associated data collection and synthesis activities in the United States. The conceptual plan for a national freight data program is comprised of five components: (1) national freight data framework; (2) integrated program of freight surveys; (3) freight informatics initiative; (4) freight data synthesis to fill data gaps (particularly in the short term before the proposed data sources are fully established); and (5) standard survey methodologies (Transportation Research Board, 2003).
- The New York State Department of Transportation hosted the *Data Needs in the Changing World of Logistics and Freight Transportation Conference* in 2001, which was organized by the New York State Department of Transportation and the Transportation Research Board, and jointly sponsored by the American Association of State Highway and Transportation Officials, the Bureau of Transportation Statistics, the Federal Highway Administration, and the Northeast Association of State Transportation Officials. Participants agreed that currently available freight data are inadequate to support the needs of decision makers and recommended the development of a strategic freight data business plan to direct data collection efforts and an associated freight data framework (Transportation Research Board, 2003).
- The Transportation Research Board sponsored the *Statewide Travel Demand Forecasting Conference* in December of 1998. The objective of the conference was to review existing statewide travel demand forecasting practices, identify critical issues in developing and applying forecasting procedures, and discuss research needs in the forecasting field (Transportation Research Board, 1998).
- The goal of *NCHRP Report 388: A Guidebook for Forecasting Freight Transportation Demand*, published in 1997, is to assist transportation planners and policy analysts to effectively integrate freight planning and demand forecasting into the broader transportation planning process. The Guidebook is intended as a reference document for transportation planners who require forecasts of freight transportation demand for facility, corridor, or strategic planning decisions. The Guidebook includes analyses to support decisions that are directly impacted by changes in freight transportation demand; diversion of freight flows to new or

expanded facilities; diversion of freight flows across modes due to regulatory actions, pricing policies, capacity changes or changes in service levels; and analyses of future freight scenarios (Cambridge, 1997).

- The *Quick Response Freight Manual* from the U.S. Department of Transportation was released in 1996 to assist states and other agencies with freight planning. Objectives of the manual are to: (1) provide background information on the freight transportation system and factors affecting freight demand to planners; (2) help planners locate available data and freight-related forecasts compiled by others, and to apply this information in developing forecasts for specific facilities; (3) provide simple techniques and transferable parameters that can be used to develop commercial vehicle trip tables that can be merged with passenger vehicle trip tables developed through the conventional four-step planning process; and (4) provide techniques and transferable parameters for site planning, which can be used by planners in anticipating local commercial vehicle traffic caused by new facilities (U.S. DOT, 1996).
- *NCHRP Report 260: Application of Freight Demand Forecasting Techniques*, published in 1983, presents a methodology for states to use in conducting freight studies to meet a wide range of needs including facility, service or regulatory problems; state policies toward infrastructure investment, energy use, and life cycle costs; and freight components of statewide master plans. The manual recommends the use of three steps for freight forecasting: freight generation and distribution; mode choice; and traffic/route assignment (Cambridge, 1997).

2.3 EXISTING FREIGHT FORECASTING MODELS

Approaches to forecasting freight movements have been developed and implemented in recent years, but no standard approach has emerged (Huang, 1998). An analysis of available methodologies separates freight forecasting procedures into two basic approaches:

- ***Structured Approach:*** The structured approach to freight forecasting recognizes that freight movements are directly linked to the economic activities of a particular region. The relationships between economic activities and freight transportation are modeled and used to forecast freight movements (Sorratini, 1999). The structured approach is used for more comprehensive freight forecasting studies than the direct approach and often requires origin-destination survey data for calibration (Sorratini, 1999).

- **Direct Approach:** Direct freight forecasting methods do not consider the economic relationships modeled in the structured approach. Direct techniques are single-step approaches designed to solve a specific forecasting issue. In general, the direct approach involves collecting data about actual freight flows on roadways and using these observations to forecast future freight movements (Sorratini, 1999). An example of direct forecasting is the growth factor method, which involves calculating a growth factor based on historical trends in freight activity and applying the factor to forecast future freight movements (Huang, 1998, Park and Smith, 1997, Pendyala, 2000, Sorratini, 1999 and U.S. DOT, 1996).

Many public agencies use direct forecasting techniques such as growth factor analyses to estimate and forecast freight movements at the regional level (Huang, 1998, Park and Smith, 1997, and Sorratini and Smith, 1998). These methods do not take into account the fact that the demand for freight transportation is directly related to changes in economic activities and related variables (U.S. DOT, 1996). As well, the direct approach does not account for interactions among links in the transportation network (Park and Smith, 1997, Sorratini and Smith, 1998) and cannot effectively estimate future freight movements for planning purposes (Huang, 1998).

2.4 FREIGHT FORECASTING IN THE UNITED STATES

In the United States, the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991 resulted in additional data requirements for freight transportation activities (Jack Faucett, 1997). The Act required agencies to address transportation infrastructure needs other than those required for passenger travel and include freight transportation in the planning and policy processes (Sorratini, 1999). ISTEA introduced requirements for statewide transportation plans to include intermodal freight transportation issues in order to facilitate the efficient movement of both people and

goods (Cambridge, 1997, Pendyala, 2002, and Scales, 1997). ISTEA also required states to have an ongoing planning process and transportation improvement program (Cambridge, 1997) that specifically considers ways to enhance the efficiency of commercial motor vehicles and addresses access to ports, airports, and intermodal transportation facilities (Coogan, 1996 and Scales, 1997). The importance of freight transportation in the engineering and planning process was further reinforced with the enactment of the Transportation Equity Act for the 21st Century (TEA-21) in 1998 (Pendyala, 2002).

2.4.1 U.S. Department of Transportation

The Office of Freight Management and Operations of the U.S. Department of Transportation initiated the *Freight Analysis Framework* to develop a comprehensive database of transportation flows on the nation's infrastructure (U.S. DOT, 2002). The *Freight Analysis Framework* estimates commodity flows and freight activity throughout the United States and forecasts shifts in flows and activity based on changes in economic conditions, transportation facilities, and various other factors (U.S. DOT, 2002). The *Freight Analysis Framework Highway Capacity Analysis* was conducted to identify and assess freight related capacity deficiencies on the nation's highway system. The purpose was to develop a tool that can be used to analyze potential policy, operational and planning issues, examine the ability of the system to meet forecast trucking demand, and provide estimates of transportation system capacity (Battelle, 2002).

The project methodology for the *Freight Analysis Framework Capacity Analysis* involves four major components (Battelle, 2002):

- 1) The National Highway Planning Network was selected as the freight analysis network. Attributes including travel impedance functions, free flow speeds, and link capacities were included for each link in the freight analysis network and were used during the assignment process.
- 2) Traffic demand analysis requires the formation of traffic analysis zones that define the areas from which traffic originates from and is destined for. United States counties were selected as the freight analysis zones.
- 3) In the freight demand analysis component, a national traffic flow map was developed based on traffic counts collected by the states and used to calibrate the freight flows from the study. Annual freight tonnage production was collected for each county and converted to equivalent daily truck trips. Truck trips were assigned to the freight analysis network, which was pre-loaded with passenger and non-freight truck traffic.
- 4) The final step was to determine existing and future capacity deficiencies on the freight analysis network. Various performance measures were generated to assess infrastructure deficiencies, including levels of service, volume to capacity ratios, travel times, link speeds, and total delay.

The resulting maps illustrating existing and forecast future national freight flows have been used to raise awareness of freight issues among policy makers in the United States. (U.S. DOT, 2002)

2.4.2 Southern California Association of Governments

Forecasting truck travel has become an increasingly important part of the regional transportation planning process in Southern California. To address the growing need for truck travel information, a study was commissioned by the Southern California Association of Governments to develop a truck travel forecasting model that can be integrated with the existing regional travel demand model. The truck travel forecasting

model is based on commodity flow forecasts and economic input-output modeling techniques. Commodity flows are converted to truck trips using estimates of average truck payloads by weight class on a commodity by commodity basis (Fisher, 1998).

The Southern California truck travel forecasting model consists of six components: (1) trip generation for internal trips; (2) trip distribution for internal trips; (3) trip generation and distribution for external trips; (4) special generator trip generation and distribution; (5) time of day factoring; and (6) traffic assignment (Fisher, 1998).

2.4.3 Indiana Department of Transportation

A project was undertaken for the Indiana Department of Transportation to forecast commodity traffic on the state transportation network. The model was developed using TransCAD Transportation GIS Software and estimates future commodity traffic flows on Indiana's transportation networks. The model is the first step in the development of a general transportation model for the state, which will be used by decision-makers to evaluate transportation infrastructure investment alternatives for Indiana (Black, 1999).

The Indiana model uses multiple regression analysis to develop production and attraction estimates by commodity type. The production and attraction data are input to a gravity model, which estimates commodity flows between origins and destinations. Commodity flows are allocated to different travel modes using historical patterns of mode use by commodity type, and the forecast commodity flows are assigned to Indiana's rail and highway networks (Black, 1999).

2.4.4 Kentucky Transportation Cabinet

The Kentucky Statewide Traffic Model developed by the Kentucky Transportation Cabinet (Department of Transportation in other states) is designed for use in major statewide highway projects such as corridor studies, alternative analysis, and investigation of new rural highways. The Kentucky model is based on the traditional four-step urban transportation planning model. Truck movements are included in the statewide traffic model as a separate trip purpose and are forecast as part of overall traffic volumes. Additional research is planned in the area of freight modeling (Bostrom, 1998).

2.4.5 Maine Department of Transportation

The Maine Department of Transportation developed a statewide travel demand model to forecast traffic growth for use in evaluating capital improvement projects. The model is linked to a Geographic Information System (GIS) (U.S. DOT, 1998).

The first step in the development of the statewide travel demand model was the definition of traffic analysis zones based on the location of towns and refined using population and other socioeconomic data. Statewide producers and attractors were identified during the trip generation process. The gravity model was used to estimate where trips begin and end based on existing traffic volumes, link capacities, and several other roadway characteristics. Goods movement and mode split components were developed and incorporated into the overall statewide travel demand model (U.S. DOT, 1998).

2.4.6 Michigan Department of Transportation

The Michigan Statewide and Urban Travel Demand Models were developed by the Travel Demand and Intermodal Services Section of Michigan's Department of Transportation. The purpose of the Statewide and Urban Travel Demand Models is to provide a framework for assessing transportation system performance and deficiencies, long-range plan development, and systems level project analysis (Nellet, 1998).

The Statewide and Urban Travel Demand Models include a truck model that estimates flows by commodity group using a TransCAD Transportation GIS software platform. The truck model includes trip generation, trip distribution and traffic assignment components. The model was developed using Customs Data, Michigan Department of Transportation truck surveys, U.S. Input Output Account, and the National Commodity Flow Survey (Nellet, 1998).

2.4.7 Minnesota Department of Transportation

The Minnesota Department of Transportation collects vehicle classification counts for cars, pickups, motorcycles, two-axle single units, three or more axle single units, three-axle semis, four-axle semis, five or more axle semis, buses, heavy single unit trucks with heavy trailers, and twin trailer semis. Vehicle classification information is collected through manual counts conducted for 16 hour periods, tube counts conducted for 48 hour periods, and five permanent weigh-in-motion (WIM) sites. Approximately 200 tube sites and 40 manual sites are counted each year. Additional vehicle classification counts are conducted at 95 trend sites on a two year cycle and approximately 1,000 update sites on a

six-year cycle. Minnesota DOT plans to add 19 permanent vehicle classification installations to their program. These permanent locations will collect continuous vehicle classification data (Mn/DOT, 2003).

Minnesota DOT addresses traffic and truck forecasting in the *Mn/DOT Procedure Manual for Forecasting Traffic on Minnesota's Highway Systems*. The document is a guide for preparing traffic and load projections on Minnesota's road network. The basic steps in forecasting traffic include the following: (1) determine what information is needed; (2) check the forecast database for previous forecasts; (3) assemble the appropriate data; (4) determine base/design year average annual daily traffic volumes; (5) calculate vehicle type percentages; and (6) create an ESAL report and documentation (Mn/DOT, 2003).

2.4.8 Oregon Department of Transportation

The Oregon Department of Transportation addressed travel demand modeling in their document entitled *Travel Demand Model Development and Application Guidelines*. The report includes guidelines for the estimation, calibration, validation, and application of travel demand models on a statewide basis. The forecasting of commercial vehicles on the Oregon highway network is addressed in the report. The guidelines state that the truck travel forecasting process should consist of the following four components (Parsons, 1995):

- 1) Trip generation should relate the production and attraction of commercial vehicle trips to the land use and socioeconomic characteristics of a particular area. The guidebook suggests that employment data can be used when estimating truck trip production and attraction.

- 2) The guidebook notes that the gravity model technique is considered the “best practice” for trip distribution, the second component in the commercial vehicle forecasting process.
- 3) Daily truck travel estimates obtained from the trip distribution process should be converted to peak hour forecasts for each trip purpose through the use of survey data and classification counts. An iterative assignment process is used to adjust the initial peak hour factors until the estimated vehicle miles traveled on the road network are within five percent of the observed vehicle miles traveled on the network.
- 4) The guidebook suggests using the basic highway network as the truck assignment network for the trip assignment process, providing links prohibiting truck movements are removed or adequately identified. A statistical comparison of observed and estimated truck traffic volumes is recommended to verify the commercial vehicle trip assignment.

2.4.9 Centre County, Pennsylvania

A traditional four-step traffic demand model was developed for Centre County in Pennsylvania. The model predicts truck traffic separately and combines truck and passenger trip forecasts into one assignment to produce combined traffic volumes. The three-step procedure discussed in the *Quick Response Freight Manual* is used to generate estimates of truck traffic volumes (Goulias and Eom, 2003).

In the truck trip generation component, individual trip generation rates are developed based on socio-economic data including the type of business, number of employees, and number of households. The trip generation rates are used to estimate the number of truck trips originating in and destined for each traffic analysis zone. A gravity model is used to perform the truck trip distribution and estimates the number of truck trips moving between traffic analysis zones. Link truck traffic volumes are estimated by assigning truck trips to the road network. Control data, including truck counts and estimates of vehicle miles of travel, are used to calibrate the model (Goulias and Eom, 2003).

2.4.10 Wisconsin Department of Transportation

A statewide truck travel demand model was developed for Wisconsin using an adjusted version of the standard four-step urban transportation planning model (Sorratini and Smith, 1997). Truck trip rates are developed during the trip generation component of the model based on population data and measures of economic activity. The gravity model is used for the trip distribution component to estimate truck movements between traffic analysis zones and the standard All-or-Nothing trip assignment method is used to allocate truck trips to the road network. The All-or-Nothing minimum path assignment method is considered reasonable as very few links in the Wisconsin statewide road network are congested (Park and Smith, 1997).

The Wisconsin model includes a selected-link analysis procedure to calibrate the results of the truck travel demand model (Park and Smith, 1997). Selected-link analysis is used to adjust trip productions and attractions so the assigned truck traffic volumes from the model closely match actual truck counts on the network.

2.5 FREIGHT FORECASTING IN CANADA

In Canada, there is no legislation similar to ISTEA or TEA-21 in the United States that requires public agencies to address freight transportation issues or include freight transportation in their planning and policy processes. However, there is increasing recognition that freight transportation issues need to be integrated into the planning process because of the impacts freight activities have on economic growth and development (Pendyala, 2002). Given the critical role that trucks play in moving freight

and the importance of freight activity to the Canadian economy, the analysis of freight transportation should be included as a basic component of the provincial and national transportation planning processes (Sorratini and Smith, 1998).

2.5.1 Ontario Ministry of Transportation

The Ontario Ministry of Transportation collects traffic volumes on Provincial Highways (King's, Secondary, Tertiary Roads and 700 series highways) throughout the province. The Provincial Highway network is divided into approximately 1,900 sections for reporting purposes and one third of the sections are counted each year. Counts are conducted at permanent counting stations (permanent locations where counts are taken every hour of the year), inventory counting stations (designated locations where counts are counted on a cyclical basis), and request counting stations (random locations requested to address operational or planning concerns) (Ontario MTO, 2002).

The Ministry also collects vehicle classification information at permanent count stations. However, the number of permanent stations is fairly small, and the majority of truck information comes from roadside interviews conducted on an approximately five-year cycle. The last series of interviews was completed in 1999 and 2000 as part of the CCMTA roadside survey, when approximately 40,000 interviews with truck drivers were conducted in Ontario. The interviews collect information on vehicle characteristics such as truck type, number of axles, and vehicle lengths and weights. Drivers are interviewed to determine commodities, origins and destinations, last stop, next stop, route taken and other related information. This information is used to build truck flows on primary

highways and main trade corridors throughout Ontario. Future truck flows are forecast using estimates of growth in various commodity sectors, such as forestry, agriculture, etc. (Smith, 2004).

2.5.2 Saskatchewan Highways and Transportation

Saskatchewan Highways and Transportation collects truck information on a continuous basis at 16 automatic vehicle classifiers (AVC) and 14 length vehicle classifiers (LVC) in the province. The AVC sites are located on paved roads and the LVC sites are located on low volume roads. In addition to the permanent count sites, approximately 1,200 48-hour coverage classification counts are conducted each year. Approximately 3,000 coverage classification locations are included in the program and counted on a rotating basis. Saskatchewan Highways and Transportation have conducted coverage classification counts for a number of years and have a fairly extensive database of truck information. Three to eight historical truck counts are available for all locations included in the program (Anderson, 2004).

In addition, Saskatchewan Highways and Transportation sometimes conduct vehicle weight surveys, with the last survey conducted in 2003. The department recently received funding to implement annual weight surveys (Anderson, 2004).

2.5.3 Alberta Transportation

Alberta Transportation is responsible for collecting traffic data on Alberta highways. Information is available for traffic volumes, vehicle classifications, and travel. Vehicles

are classified into passenger vehicles (cars, pickup trucks, sport utility vehicles, vans, and motorcycles), recreation vehicles (cars or pickup trucks with trailers and campers), buses (school, inter city, transit, and disabled transportation), single unit trucks (single non-articulated trucks greater than three tonnes in weight), and tractor trailer combinations (articulated tractor and trailer combinations). One day turning movement counts are conducted at 2,200 intersections over five years (approximately 440 counts per year) and are used to determine truck traffic volumes. Information on single unit trucks and tractor trailer combinations is presented as a percentage of total traffic. Growth in truck volumes is assumed to be the same as total traffic growth at permanent count stations, and is used to forecast future truck volumes (Kilburn, 2004).

Alberta Transportation plans to install six weigh-in-motion (WIM) sites in 2004 to improve the quality of provincial truck information. Weigh-in-motion sites are permanent locations that continually collect and store axle weight data. This information will help address transportation planning and weight and compliance issues in Alberta (Kilburn, 2004).

2.5.4 Manitoba Transportation and Government Services

Manitoba Transportation and Government Services (MTGS) is responsible for the province's transportation system and services and currently collect detailed traffic data through their Traffic Information System. The Traffic Information System is maintained by the University of Manitoba Transport Information Group and collects traffic counts and classification data at numerous permanent and temporary stations throughout the

province each year. Truck traffic information for Manitoba provincial highways and roads is collected at automated vehicle classifiers (AVC), weigh-in-motion devices, and manual 14-hour classification counts at intersections (Tan, 2002 and Tang, 2003). Truck information is provided as estimates of average annual daily truck traffic (AADTT).

There is currently a project underway to develop a Truck Traffic Information System to collect detailed information about truck traffic on Manitoba highways and roads. The purpose of the project is to design, develop and implement a new truck traffic information system for MTGS. According to MTGS, many current planning, engineering and management issues are dependent on knowledge and understanding of past, present and future truck traffic volumes and characteristics. The primary focus of the initial stage of development of the truck traffic information system is the collection and analysis of current truck volumes and information. Forecasting issues will only be addressed at the conceptual level, although the department acknowledges the need for accurate truck traffic forecasts for Manitoba (UMTIG, 2002).

2.6 COMPARISON OF REGIONAL FREIGHT FORECASTING PROGRAMS

The investigation of regional freight forecasting programs in North America reveals several types of initiatives. Differences are especially apparent between Canada and the United States, where freight transportation analysis is required in the planning process by ISTEA and TEA-21. Most regional freight forecasting programs can be grouped into three levels.

- 1) The first level of freight forecasting involves the use of traditional direct approach models. Truck volumes are generally provided as a percentage of total traffic and forecasts are made based on historical growth in overall traffic volumes. These types of programs are common throughout Western Canada. However, all three Prairie Provinces recognize the need for freight information and have plans to specifically address truck movements through the implementation of a Truck Traffic Information System in Manitoba, annual weight surveys in Saskatchewan, and additional classification counts in Alberta.

- 2) The second level of freight forecasting involves modeling freight and truck volumes as part of a regional traffic forecasting model. In these models, truck movements are usually included as an additional trip type in the existing regional traffic demand model. Programs of this nature are used in a number of states including Kentucky, Maine, Pennsylvania, and Minnesota to address the freight requirements of ISTEA and TEA-21.

- 3) The third level of freight forecasting involves the development and implementation of models specifically designed for forecasting freight and truck movements. These models are more advanced than second level models, and consider various factors that influence freight and truck movements in a region, such as loading and unloading procedures, delivery requirements, type of vehicles, and commodity types. Models of this type have been developed in states including Southern California, Indiana, Michigan, Oregon, and Wisconsin in response to ISTEA and TEA-21 requirements.

CHAPTER 3

DEVELOPMENT OF A METHODOLOGY FOR A FREIGHT FORECASTING MODEL FOR MANITOBA

This Chapter involves the selection of a freight forecasting methodology for Manitoba and describes in detail the components of the selected freight forecasting model. The model is based on a modified version of the traditional four-step urban transportation planning procedure and is comprised of three steps: freight generation, freight distribution and freight assignment. Methodologies and procedures currently in use are described for each step.

3.1 FREIGHT FORECASTING METHODOLOGY

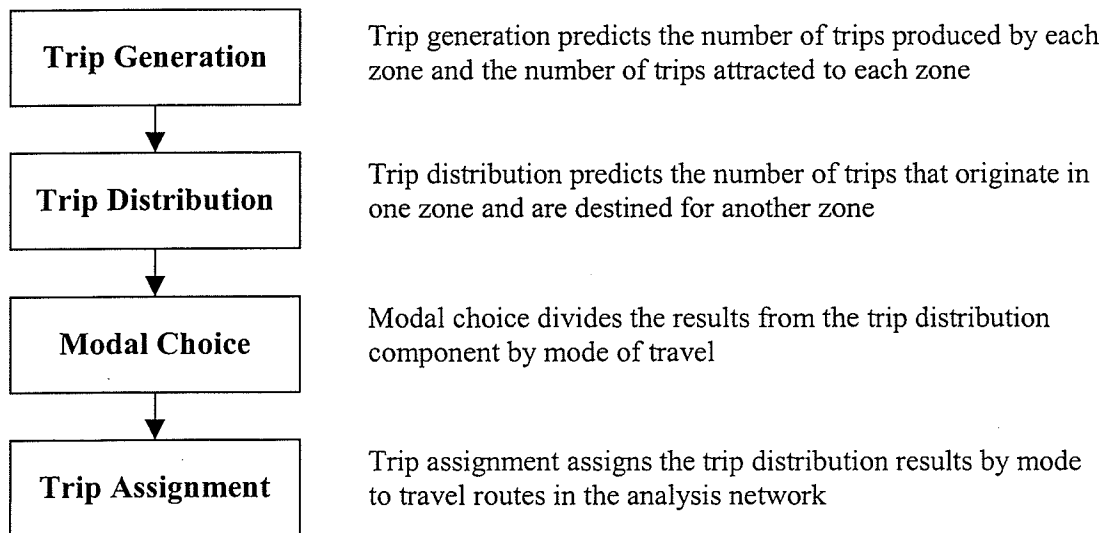
As previously noted, there is currently no recognized standard model for forecasting regional freight movements (Friesz and Tobin, 1983, Huang, 1998, and Pendyala et al., 2000). Each jurisdiction has developed its own model (Coogan, 1996), and a variety of approaches to forecast freight movements have emerged (Crevo, 1998).

There has been debate among transportation professionals about applying methods developed to forecast urban passenger flows to the task of forecasting freight movements (Coogan, 1996). Critics argue that freight movements are more complex than passenger movements because of the numerous economic activities and variables that affect freight transportation (Battelle, 2002, Cambridge, 1997, Sorratini, 1999 and Transportation Research Board, 2003). The loading and unloading process, value of time, type of vehicles, delivery requirements, commodity type, measures of cost, and the large number

of decisions makers (shippers, carriers and receivers) are all factors that influence freight transportation (Battelle, 2002, Cambridge, 1997, Sorratini, 1999 and U.S. DOT, 1996).

Despite the differences between freight and passenger transportation, a modified version of the urban transportation planning procedure is emerging as the most effective and commonly used approach to regional freight forecasting (Huang, 1998). The urban transportation planning procedure was developed to forecast passenger trips in urban areas but can be adapted to serve as a framework to forecast freight movements. The four-step urban transportation planning process is illustrated in Figure 3.1 and involves trip generation, trip distribution, modal choice, and trip assignment (Huang, 1998, Mao and Demetsky, 2002 and Sorratini, 1999).

Figure 3.1: Four-Step Urban Transportation Planning Procedure



Forecasting regional freight movements on rural road networks involves removing the modal choice component from the four-step process (Huang, 1998 and Parsons, 1995), which means that the model estimates regional freight movements without considering

modal competition or multi-modal transportation (Huang, 1998 and Sorratini, 1999). As well, freight movements within analysis zones are not considered in the regional freight forecasting model (Huang, 1998).

3.2 THREE STEP FREIGHT FORECASTING MODEL

3.2.1 Freight Generation

Freight generation is the first step in the freight forecasting model. Freight generation estimates the volume of goods produced and consumed within a region and the actual locations of the production and consumption (Cambridge, 1997). Freight generation requires the establishment of traffic, or freight, analysis zones, which are areas where freight originates from and is destined for. Analysis zones are areas with similar population and economic characteristics that are used in transportation planning activities and are generally estimated based on existing area boundaries and refined using population information and economic data (U.S. DOT, 1998 and Pendyala et al., 2000).

The Canadian For-Hire Truck Survey conducted by Statistics Canada uses census divisions to report origin-destination movements. Freight movements are reported in the U.S. commodity flow survey by National Transportation Analysis Region areas, which are based on the relative density of economic and commercial activity levels. Several freight data sources, including the U.S. Transborder freight origin-destination surveys, the CCMTA roadside commercial vehicle survey, and the University of Manitoba Transport Information Group border crossing freight origin-destination surveys, report origin-destination movements by province in Canada and Mexico and by state in the U.S.

(DS-Lea et al., 1998). The analysis zones used in freight forecasting are selected depending on the freight generation information available and the level of detail required for the model.

Estimates of goods production and consumption by analysis zone are frequently not available and freight generation information is often estimated. Most estimates of freight production and attraction are based on land use and the regional economy (Park and Smith, 1997, Parsons, 1995 and Sorratini, 1999). Relationships between the production and attraction of commodities and the various economic factors are determined and used to estimate freight generation rates (Black, 1999). These freight generation rates are applied to estimate freight production and attraction for each analysis zone (Pendyala et al., 2000).

3.2.2 Freight Distribution

Freight distribution is the second step in the freight forecasting model. Freight distribution estimates the amount of freight moving between analysis zones or origin-destination pairs (Goulias and Eom, 2003 and Holguin-Veras and Thorson, 1998). The result of the freight distribution process is a table or matrix that identifies the origins and destinations of all freight movements in a region (U.S. DOT, 1996).

Several different types of distribution models can be used to forecast freight movements, including the following:

- The gravity model assumes that freight flow between two analysis zones is directly proportional to the freight activity in each zone and inversely proportional to a

function of the spatial separation, known as the impedance, between the same two analysis zones (Goulias and Eom, 2003, Huang, 1998, Mao and Demetsky, 2002 and Sorratini, 1999).

- Trade models assume that every producer and consumer has a market share directly proportional to his or her share of total production or consumption. Trade models can overstate freight movements and are more appropriate for small areas and for short average haul distances (Sorratini, 1999).
- Linear programming models assume that all producers attempt to minimize their transport costs, which results in low estimates of freight movements. Linear programming models are generally more appropriate for a limited number of producers and consumers and a limited number of commodities (Sorratini, 1999).

The gravity model is used in the majority of regional freight distribution initiatives (Mao and Demetsky, 2002). The gravity model is simple and effective and is considered the best freight distribution model currently available (Huang, 1998, Mao and Demetsky, 2002, Park and Smith, 1997, Parsons, 1995 and Pendyala et al., 2000).

The gravity model for transportation planning and freight forecasting is based on Newton's gravitational law, which states that the attraction between two objects is directly proportional to their mass and inversely proportional to their respective distance (Rodrigue, 2004 and Huang, 1998). The gravity model for freight forecasting assumes that freight movements between two analysis zones are directly proportional to the amount of freight production and attraction in each zone and inversely proportional to the impedance between the same two zones (Huang, 1998 and Sorratini, 1999). Different measures of impedance between analysis zones can be used in the gravity model for freight forecasting, including travel distance, travel time, and travel cost (Caliper, 2001 and U.S. DOT, 1996).

The gravity model can be doubly-constrained to both productions and attractions or singly-constrained to either productions or attractions. The production and attraction information available determines how the gravity model is constrained. Reliable production and attraction data for an analysis means that the gravity model can be doubly-constrained. If production data are more reliable than attraction data, the gravity model is singly-constrained to productions, and if attraction data are more reliable than production data, the gravity model is singly-constrained to attractions.

In the doubly-constrained gravity model, freight flow between productions and attractions is based on the following equation (Caliper, 2001):

$$T_{ij} = t_{ij} * a_i * b_j \quad \text{subject to:} \quad \begin{aligned} \sum T_{ij} &= P_i \\ \sum T_{ij} &= A_j \end{aligned}$$

where: T_{ij} = the forecast flow produced by zone i and attracted to zone j
 t_{ij} = the base year flow produced by zone i and attracted to zone j
 a_i = the balancing factor for row i
 b_j = the balancing factor for column j
 P_i = the number of trips produced by zone i
 A_j = the number of trips attracted to zone j

In the singly-constrained gravity model, freight flow between productions and attractions is based on the following equation (depending on whether the model is constrained to productions or attractions) (Caliper, 2001):

$$T_{ij} = P_i \frac{A_j * f(d_{ij})}{\sum A_z * f(d_{iz})} \quad \text{(constrained to productions)}$$

$$T_{ij} = A_j \frac{P_i * f(d_{ij})}{\sum P_z * f(d_{zj})} \quad \text{(constrained to attractions)}$$

where: T_{ij} = the forecast flow produced by zone i and attracted to zone j
 P_i = the forecast number of trips produced by zone i
 A_j = the forecast number of trips attracted to zone j
 d_{ij} = the impedance between zone i and zone j
 $f(d_{ij})$ = the friction factor between zone i and zone j

Friction factors are measures of the attractiveness between each pair of analysis zones and are inputs to the gravity model (Caliper, 2001 and Huang, 1998). Friction factors are estimated using the impedance between analysis zones together with an impedance function and are discussed in more detail in Chapter 6.

3.2.3 Freight Assignment

Freight assignment is the final step in the freight forecasting model. Freight volumes on individual road links are estimated by assigning freight to a predefined road network based on the origin-destination information developed in the freight distribution component (Goulias and Eom, 2003, Huang, 1998, Pendyala et al., 2000 and Sorratini, 1999). The assignment process determines the travel routes between origins and destinations, and hence the estimated freight volumes on road links (U.S. DOT, 1998).

Numerous assignment methods are available to estimate freight movements between origins and destinations and forecast freight volumes on a road network (Black, 1999 and Battelle, 2002). Assignment methods vary in terms of whether they allow multiple paths from a particular origin to a particular destination and whether traffic volumes and road capacity are considered in the assignment process. Assignment methods currently used in transportation planning and freight forecasting are discussed below (Caliper, 2001).

- The simplest assignment method is the All-or-Nothing assignment procedure. This assignment method assigns freight to the minimum path between each origin-destination pair (Black, 1999 and Sorratini, 1999). The All-or-Nothing assignment method selects the minimum path between each origin-destination pair without considering capacity limitations or congestion on the road network (Huang, 1998). The method assumes that only one route between each origin-destination pair is used for all trips.
- The STOCH assignment method distributes freight moving between origin-destination pairs to a number of alternative paths. The portion of freight assigned to a particular path is based on the “choice probability” of that path. The lower the travel time for a path between an origin-destination pair as compared to other available paths, the higher that path's choice probability. In the STOCH assignment method, link travel time is a fixed input and is not impacted by fluctuations in traffic or freight volumes on the road network.
- Fractions of freight movements are assigned to multiple paths for each origin-destination pair in a series of steps in the Incremental assignment method. A fixed portion of the total freight flow is distributed in each step based on the All-or-Nothing assignment procedure. After the assignment in each step, travel times are recalculated based on the new link volumes. The assignment and recalculation of link travel times are repeated until all freight has been assigned to the network. The results of the Incremental assignment method are directly influenced by the order that freight movements for different origin-destination pairs are assigned to the road network.
- The Capacity Restraint assignment method alternates between assigning freight to the network according to the All-or-Nothing assignment method and recalculating link travel times in the road network. Link travel times are recalculated based on a congestion function that reflects link capacity. The Capacity Restraint method does not converge and freight volumes can oscillate back and forth on some road links. The results of the Capacity Restraint assignment method are directly dependent on the number of iterations performed.
- The User Equilibrium assignment method uses an iterative procedure to reach a convergent freight assignment solution. Each iteration involves computing link flows for the entire road network. The convergent solution is achieved when no freight moving between any origin-destination pair can improve its travel time by shifting to an alternate route.
- The Stochastic User Equilibrium assignment method is similar to the User Equilibrium procedure described above, but instead assumes that drivers do not have access to information concerning the road network and/or that they value travel costs in different ways. Freight movements are assigned to less attractive routes as well as to the most attractive routes between origin-destination pairs. In the User Equilibrium method, less attractive routes between origin-destination pairs will be assigned zero freight flow.

- The System Optimum assignment method assigns freight to the road network in order to minimize the total travel time of all freight movements between origin-destination pairs. In the final System Optimum assignment, a change in the route for a movement between an origin-destination pair may reduce the travel time for that individual trip, but will always result in an increase of total travel time for all freight movements on the overall road network.

The All-or-Nothing assignment method has critics who are against its use in transportation planning because the procedure does not consider the capacity of road links or the effects of congestion during the assignment process (Black, 1999). Link capacities and road congestion are not problems for freight movements on many regional road networks (Park and Smith, 1997 and Sorratini, 1999), especially those in Western Canada. A 2001 survey of Manitoba cereal producers indicated that approximately 95 percent move their grain to delivery points by the shortest route possible (UMTI, 2001). Almost all regional freight assignments are based on the All-or-Nothing assignment methodology (Huang, 1998).

3.2.4 Model Calibration

Calibration of a freight forecasting model is generally an iterative process that occurs during the trip distribution and/or trip assignment steps (Sorratini, 1999). The most common method used to evaluate the results is the comparison of forecast truck volumes on road links with actual truck volumes obtained from truck count and classification data (Huang, 1999, Mao and Demetsky, 2002, Park and Smith, 1997 and Parsons, 1995).

For commodity based freight forecasting models, it is difficult to determine the amount of freight flow on a road link for a specific commodity using truck count and classification

data (Mao and Demetsky, 2002). Instead, commodity based forecasting models should be calibrated using origin-destination data by commodity (Huang, 1998, Mao and Demetsky, 2002 and Sorratini, 1999). Existing data sources such as the For-Hire Truck Survey, the CCMTA Roadside Survey, and the Transborder Surface Freight Database provide origin-destination information by commodity. As well, the Truck Traffic Information System currently in development for Manitoba will provide information by truck body type and weight for locations on the Manitoba road network.

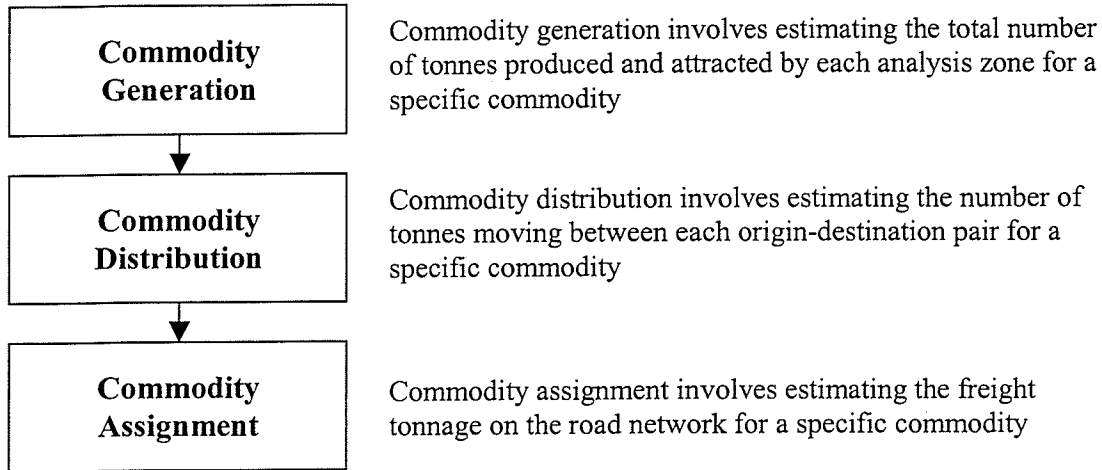
3.3 COMMODITY VERSUS TRIP BASED FORECASTING

In contrast to passenger forecasting, in which the primary measure of travel is the number of passenger trips, several different measures of freight movements can be estimated, including freight vehicle trips, freight weight or tonnage, and freight volume. This has resulted in two freight forecasting approaches: one based on commodity movements and a second based on trip movements (Holguin-Veras and Thorson, 1998 and Mao and Demetsky, 2002).

3.3.1 Commodity Based Forecasting Models

Commodity based freight forecasting models estimate the movement of freight tonnage (or any other unit of weight) by commodity type. A commodity based forecasting model includes three components and is illustrated below in Figure 3.2 (Holguin-Veras and Thorson, 1998).

Figure 3.2: Commodity Based Three Step Freight Forecasting Model



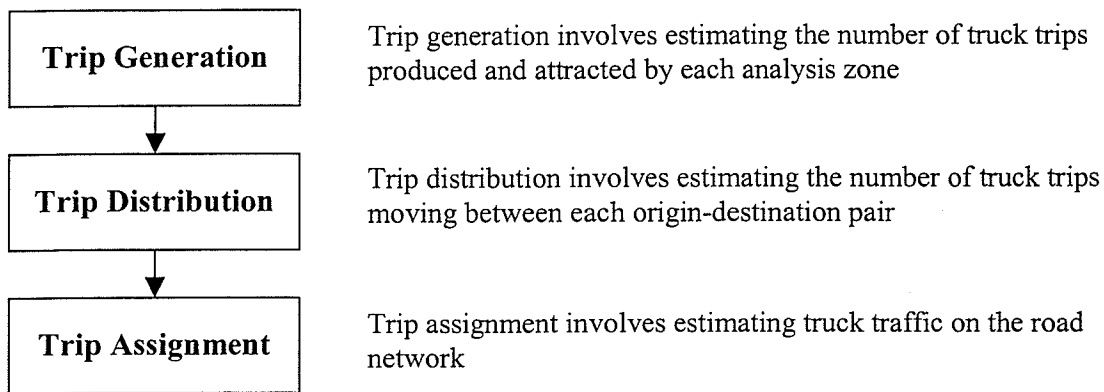
Commodity based forecasting models incorporate the economic factors that impact freight demand and are dependent on the type of commodities being transported (Holguin-Veras and Thorson, 1998 and Mao and Demetsky, 2002). The primary disadvantage of commodity based models is the lack of empty trips included in the forecasts. Because the model is based on commodity movements, there is no way to forecast empty trip movements. As well, freight movement information by commodity is required to calibrate the model, and this type of information is primarily estimated through origin-destination surveys (Holguin-Veras and Thorson, 1998).

The commodity based approach requires the development of multiple freight forecasting models to estimate movements of different commodities. However, the majority of freight and truck movements in a region can generally be attributed to a limited number of commodity types. It is likely that the majority of freight movements in Manitoba are the result of a small number of commodity types. An understanding of the majority of freight movements is sufficient for most engineering and planning requirements.

3.3.2 Trip Based Forecasting Models

Trip based freight forecasting models estimate truck trips and are similar to traditional passenger forecasting models. A trip based forecasting model includes three components and is illustrated below in Figure 3.3 (Holguin-Veras and Thorson, 1998).

Figure 3.3: Trip Based Three Step Freight Forecasting Model



One advantage of trip based forecasting models is the fact that the measure of freight movements is truck trips and there is a significant amount of data available for calibration purposes from truck counts, screen line counts, and classification counts (Holguin-Veras and Thorson, 1998). As well, because the trip based model focuses on truck trips, empty trips are included in the forecasts (Holguin-Veras and Thorson, 1998). The major disadvantage of trip based forecasting models is that the types of commodities being transported are not considered and therefore the economic factors that drive freight demand are not incorporated in the model (Holguin-Veras and Thorson, 1998 and Mao and Demetsky, 2002).

3.3.3 Measure of Freight Movements

As noted above, both the commodity based and the trip based freight forecasting models have advantages and disadvantages, and neither approach is able to completely address all aspects of freight movements (Holguin-Veras and Thorson, 1998). The commodity based approach incorporates the economic factors that impact freight demand, but fails to address the issue of empty truck trips. The trip based approach includes empty trips in the truck forecasts and uses readily available truck classification data for calibration purposes, but does not consider the economic factors that affect freight movements (Holguin-Veras and Thorson, 1998 and Mao and Demetsky, 2002).

Previous applications of the commodity based and trip based methodologies in forecasting freight movements have both proven successful. However, several studies have concluded that the commodity approach based on the economic activities of a region results in a more powerful freight forecasting tool than models based on truck traffic data alone (Sorratini, 1999 and Transmanagement, 1998). The commodity based model is also expected to provide better forecasts of future freight flows, since growth rates vary by commodity type (Huang, 1998). As well, modeling individual commodities increases awareness of the specific needs of different commodity types and improves understanding of how different commodity movements affect roadway facilities (Transmanagement, 1998).

3.4 COMMODITY SELECTION

The commodity based approach requires estimates of freight generation, distribution and assignment on a commodity specific basis. For the development of a commodity-based freight forecasting model for Manitoba, selection of a specific commodity to test the freight forecasting methodology is necessary.

Rail line abandonment and grain elevator consolidation has resulted in major impacts on roadways in Manitoba and other grain producing areas of Western Canada. Increases in truck volumes have occurred on grain haul routes and are expected to continue with additional elevator consolidation and construction of new high throughput facilities. Sections of the road network in Manitoba were not designed for the types of trucks and the amount of grain haul that are now common across the province (ND LEA, 2002).

The Prairie Grain Roads Program is a federal program to improve municipal and provincial grain roads in the Prairie Provinces and the Peace River region of British Columbia. The program was initiated in response to traffic increases resulting from changing transportation policies and the restructuring of grain handling systems. The program provides financial assistance to upgrade roadways used for grain transportation. An understanding of grain movements on Manitoba roadways is critical to determine where to invest financial resources available through the program (Agriculture and Agri-Food Canada, 2004).

The application of the freight forecasting methodology to the grain industry in Manitoba was completed for the Transportation Systems Planning and Development Branch of Manitoba Transportation and Government Services in conjunction with Agriculture and Agri-Food Canada and the Prairie Farm Rehabilitation Administration, with funding from the Prairie Grain Roads Programs.

CHAPTER 4

GIS-T PLATFORM FOR MANITOBA

This Chapter describes the geographic information system for transportation (GIS-T) platform developed and the type of software used to construct and implement the freight forecasting model for Manitoba. Specific GIS data requirements for the development of the grain forecasting model are also discussed.

4.1 GEOGRAPHIC INFORMATION SYSTEMS

A Geographic Information System (GIS) is defined as a system of hardware, software, data, and people for collecting, storing, analyzing, manipulating, and presenting information that is tied to a spatial location (Jack Faucett, 1997 and ESRI, 2004). GIS software is designed for the storage, retrieval, and analysis of spatial data and has proven to be a powerful tool for the compilation, management and display of geographic information (Jack Faucett, 1997). The fact that almost all transportation data can be geographically referenced suggests that GIS provides an effective way to manage transportation spatial data, and GIS technology is now used for transportation modeling, planning, reporting and decision-making throughout North America (Jack Faucett, 1997 and Transportation Research Board, 1993). The City of Winnipeg Public Works Department, Manitoba Transportation and Government Services (MTGS), and Transport Canada all use GIS software.

Geographic Information Systems manage and integrate spatial data necessary for the planning, design, construction, analysis, operation, maintenance, and administration of

transportation systems and facilities. Queries of transportation information can be made at the spatial level, and data stored in a GIS environment can be visually displayed to easily identify problems areas and locations where additional data are needed (Jack Faucett, 1997). The union of an enhanced Transportation Information System (TIS) and a GIS is known as GIS-T, Geographic Information Systems for Transportation.

In terms of forecasting freight movements, GIS-T software is an efficient tool that can enhance the modeling process (U.S. DOT, 1998). Some GIS software includes distribution models, and GIS databases can be used to develop assignment networks (Crevo, 1998). The display capabilities of GIS-T software can also be used to communicate the forecasting results through freight flow maps or other visual displays of the analysis results, (Battelle, 2002) which enables more effective review and model calibration (U.S. DOT, 1998).

4.2 TRANSCAD TRANSPORTATION GIS SOFTWARE

There is a variety of transportation modeling software available to forecast freight movements. TransCAD Transportation GIS Software is a Geographic Information System developed by Caliper Corporation that is designed for planning, managing, and analyzing the characteristics of transportation systems and facilities. TransCAD combines tools for travel demand modeling with digital mapping, geographic database management, presentation graphics, and application of transportation, operations research and statistical models (Caliper, 2001).

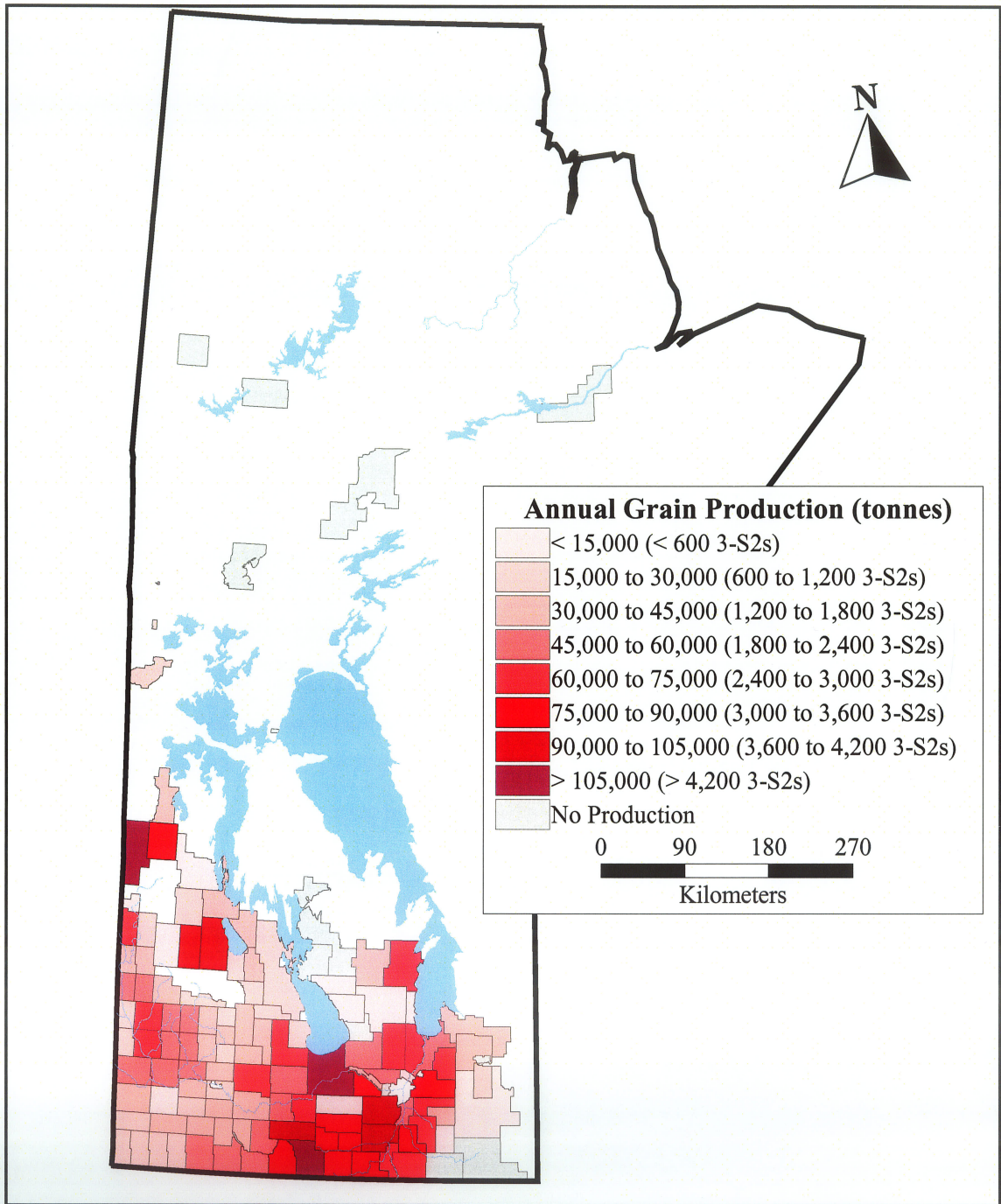
Numerous transportation planning procedures are also included in TransCAD, as well as an extensive set of traffic assignment models. TransCAD modeling procedures can be used to forecast passenger and freight movements at the provincial, national and international level (Caliper, 2000) TransCAD has been used with success in Indiana and Michigan to forecast freight movements (Black, 1999 and Nellet, 1998).

4.3 DATA REQUIREMENTS AND SOURCES

A variety of information is required for the GIS-T platform in order to forecast grain movements in Manitoba. Data is available from numerous sources and must be spatially referenced in order to be incorporated into the GIS-T platform for the model. Information required includes grain production locations, grain attraction locations, and information regarding the road transportation network in Manitoba.

Grain production information is available for 1999 from the Canadian Grain Commission for rural municipalities in Manitoba. A geographic database of rural municipality boundaries was obtained from MTGS. There are 130 rural municipalities in Manitoba, which range in size from 1,700 acres for the rural municipality of Kelsey to approximately 923,000 acres for the rural municipality of Mystery Lake. The average rural municipality in Manitoba is approximately 217,000 acres in size. Grain production information is linked to the geographic database of rural municipalities and is illustrated in Figure 4.1.

Figure 4.1: 1999 Grain Production by Rural Municipality

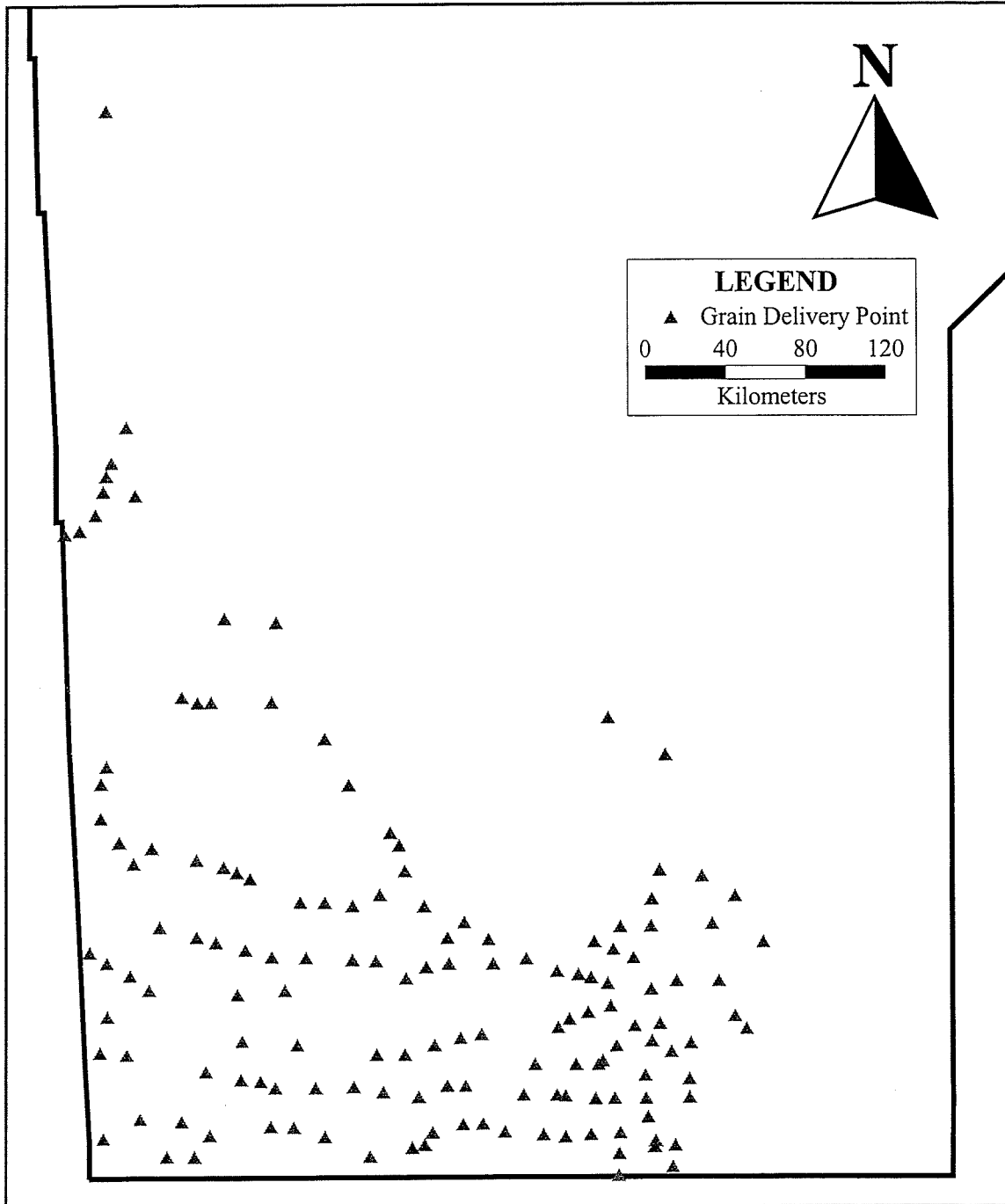


Source: Canadian Grain Commission, 1999.

Delivered tonnage (attraction) information is available for grain delivery points in Manitoba from the Canadian Grain Commission. The data used in the model represents the 1999/2000 fiscal year (end of the fiscal year is March 31). Grain deliveries to elevators can occur throughout the year, as most producers now have the capability to store grain themselves. However, large volumes of grain are still transported to elevators each fall. Delivered tonnage information is available by grain delivery point and not by individual elevator (there can be multiple elevators located at a delivery point). A geographic database of grain delivery points for the year 2000 was obtained from MTGS and is illustrated in Figure 4.2.

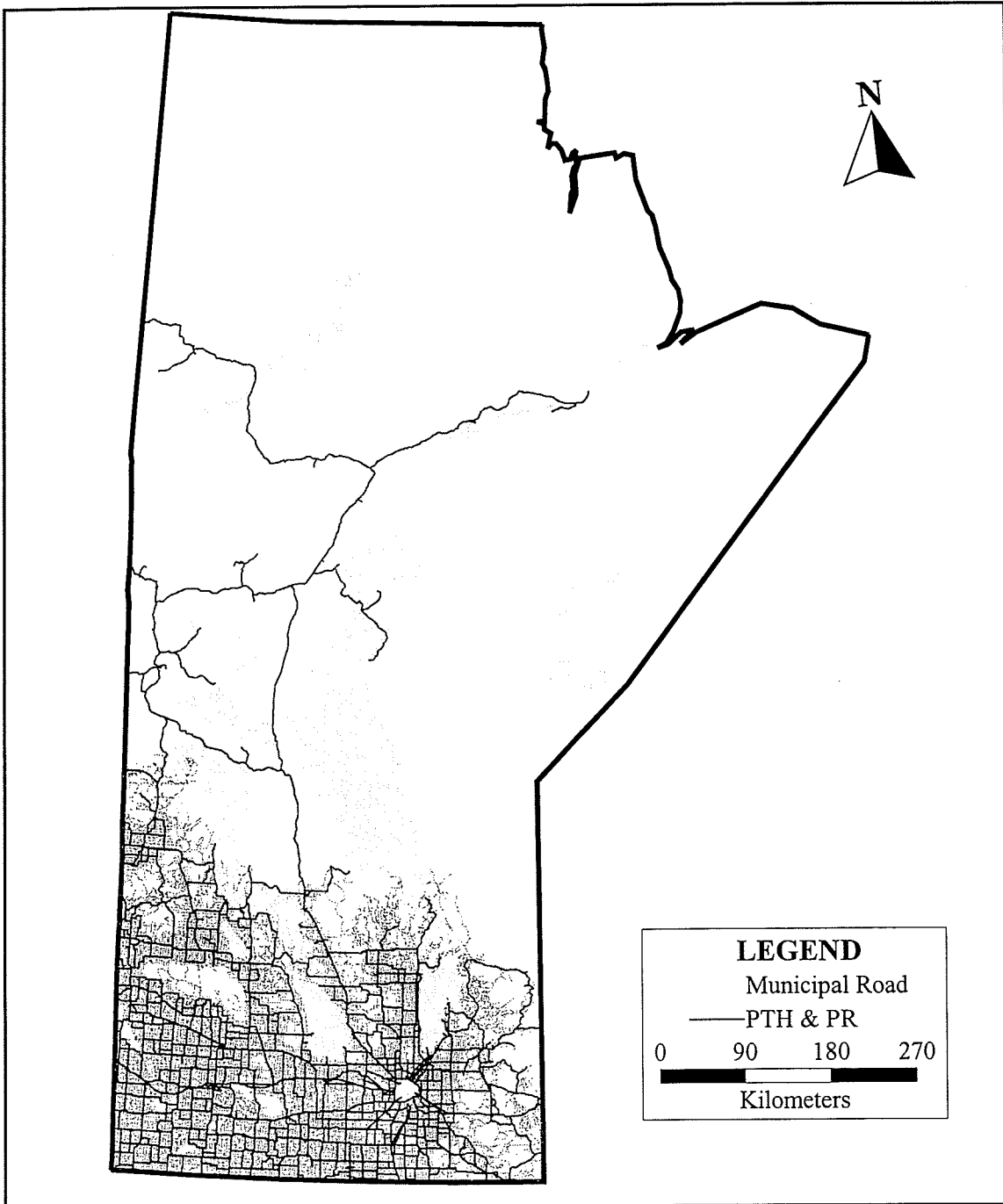
The Manitoba road network consists of provincial trunk highways (PTH) and roads (PR) under the jurisdiction of MTGS and municipal roads under the jurisdiction of rural municipal authorities. There are approximately 18,000 kilometres of provincial trunk highways and roads and over 65,000 kilometres of municipal roads in Manitoba. A geographic file of the Manitoba road network was obtained from MTGS and is illustrated in Figure 4.3.

Figure 4.2: Year 2000 Manitoba Grain Delivery Points



Source: Canadian Grain Commission, 2000.

Figure 4.3: 2001 Manitoba Road Network



Source: Manitoba Transportation & Government Services, 2001.

CHAPTER 5

FREIGHT GENERATION

This Chapter describes freight generation, the first step in the development of the Manitoba freight model for forecasting grain movements. Freight generation is comprised of two distinct components, freight production and freight attraction. The sources of information and methodologies used to estimate freight production and attraction for grain movements in Manitoba are described.

5.1 FREIGHT PRODUCTION

Lack of freight generation data for forecasting models is a common problem (Huang, 1998). When actual production data is unavailable, information is estimated based on economic indicators of freight activity. For the grain industry in Manitoba, grain production information is available by rural municipality from the Canadian Grain Commission.

For the purpose of forecasting grain movements in Manitoba, rural municipalities are too large to act as origin freight analysis zones as they do not provide a sufficient level of detail. However, any new analysis zones selected for the model should be compatible with rural municipalities, as the grain production information must be distributed from the rural municipalities to the new origin freight areas. As noted in Chapter 4, Manitoba analysis zones previously used in freight research include census divisions and provincial boundaries. Unfortunately, these areas are not compatible with rural municipality

boundaries or do not provide a sufficient level of detail for the forecasting model. Alternate origin freight analysis zones are required.

Manitoba is divided into a series of townships and ranges. From west to east, the province is divided into ranges from 29 west to 16 east. From south to north, the province is divided into townships from one to 56. The intersection of a range and township forms a square area approximately 23,000 acres in size (93 square kilometers), which is described by the intersecting range and township names. For example, in the southwest corner of the province, the intersecting range and township form area 01-29-W. Although the intersection of both a range and a township, these areas are generally referred to as townships, and will be called townships for the remainder of this research. There are over 1,300 townships in Manitoba, which are illustrated in Figure 5.1.

Each township area is further divided into 36 sections (six sections by six sections), each approximately 640 acres in size. Each section is further divided into four quarter sections, called the northeast, northwest, southeast and southwest quarter sections. There are approximately 49,000 sections and over 197,000 quarter sections in the province, a sample of which is illustrated in Figure 5.2. Areas of land along bodies of water generally do not follow the traditional section and quarter section divisions, but are instead comprised of river lots. A sample of river lots is illustrated in Figure 5.3.

Figure 5.1: Manitoba Townships

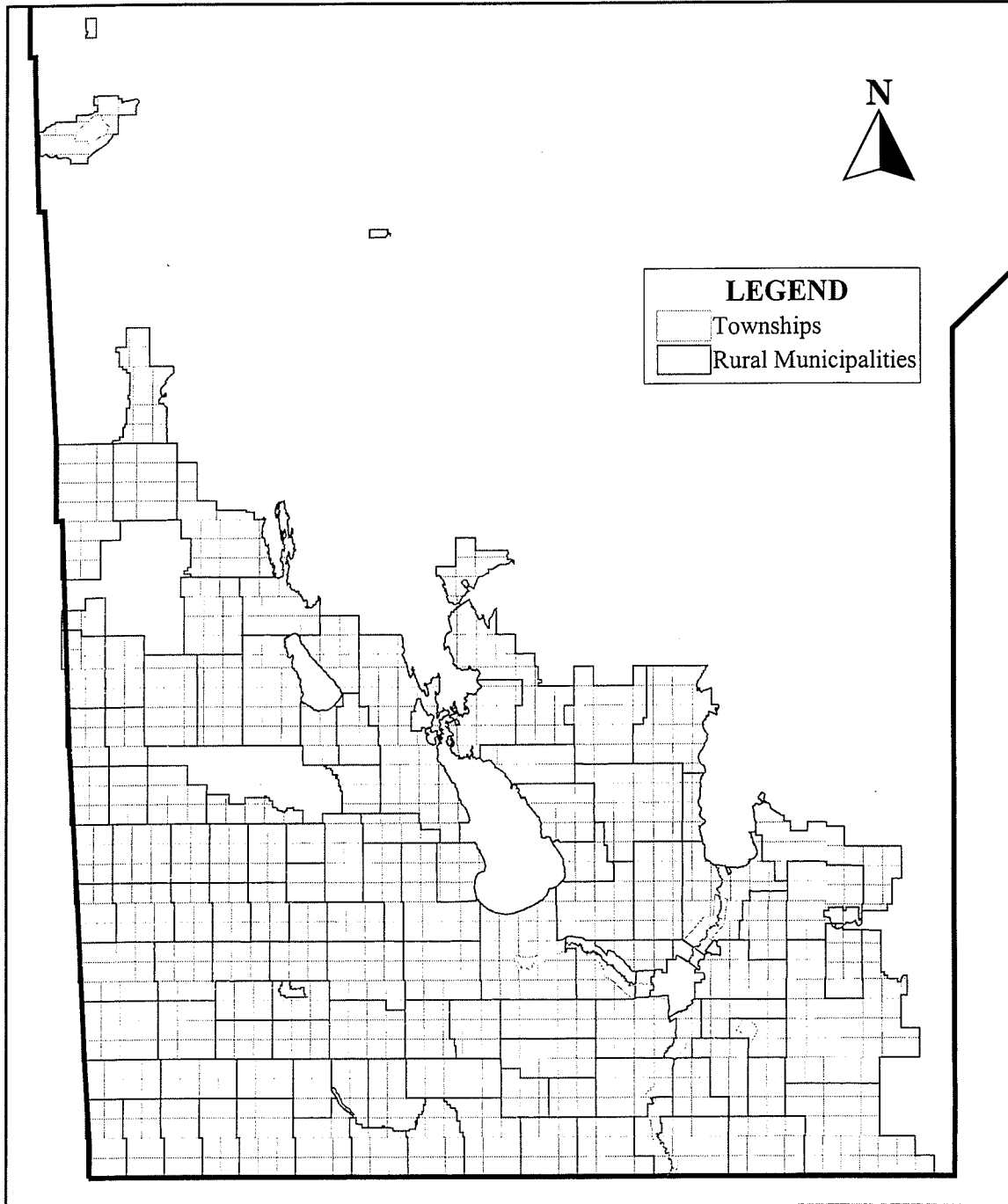
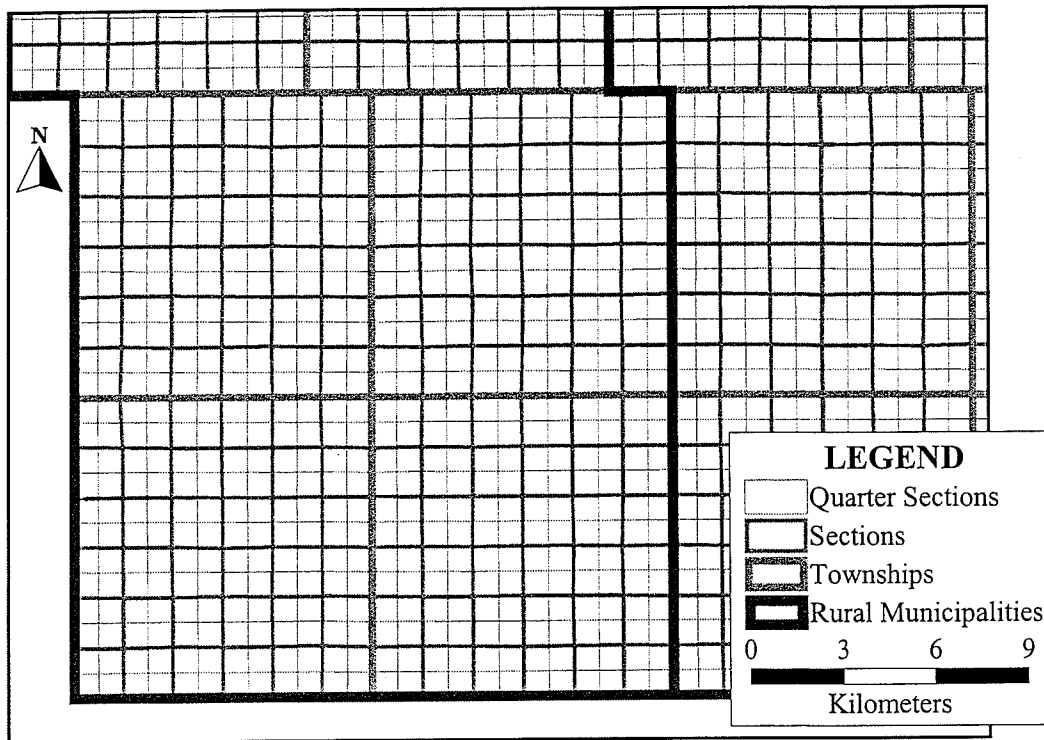
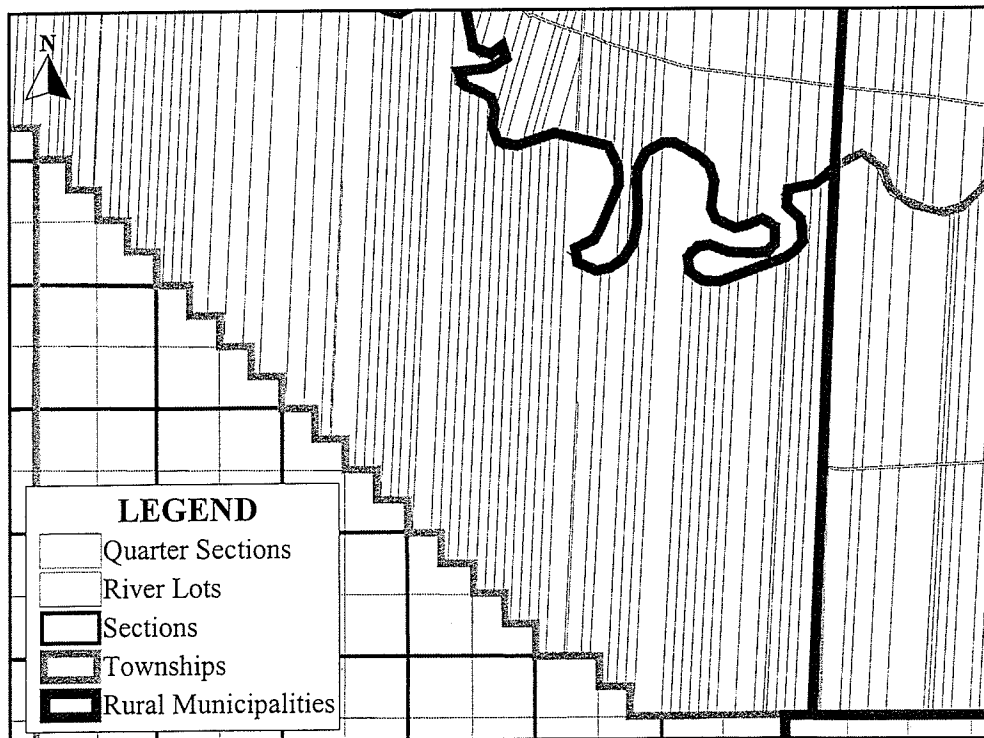


Figure 5.2: Manitoba Sections and Quarter Sections



Source: Manitoba Transportation & Government Services, 2001.

Figure 5.3: Manitoba River Lots



Source: Manitoba Transportation & Government Services, 2001.

Townships, sections, and quarter sections are all possible origin freight analysis zones for the grain forecasting model. Townships are smaller and provide more detail than rural municipalities, but are large enough to keep the information requirements for the model management. Townships are therefore selected as the origin freight production zones for this research.

A geographic file of Manitoba townships is created based on the section locations and rural municipality boundaries and contains 1,321 townships. It should be noted that townships do not always follow rural municipality boundaries, and a single township sometimes falls into two or more rural municipalities. For the purposes of freight production in this research, townships are divided along rural municipality boundaries to facilitate the distribution of the grain production information.

Grain production information is distributed from the rural municipality level to the township level using information about the potential grain productivity of individual townships. Due to the detailed and complicated nature of the productivity information, the allocation of grain production from rural municipality to township was completed by the Department of Agriculture and Food (now the Department of Agriculture, Food and Rural Initiatives) of the Province of Manitoba. 1994 Land Use Imagery (obtained from Landsat.org) and Manitoba Crop Insurance Corporation soil rating maps were used to allocate grain produced in a rural municipality to individual townships (U.S. Geological Survey, 2004). Townships within each rural municipality were assigned a percentage of the total grain production for that rural municipality. Minor land areas, due to partial townships or very small acreages of cropland, are allocated to an adjacent township

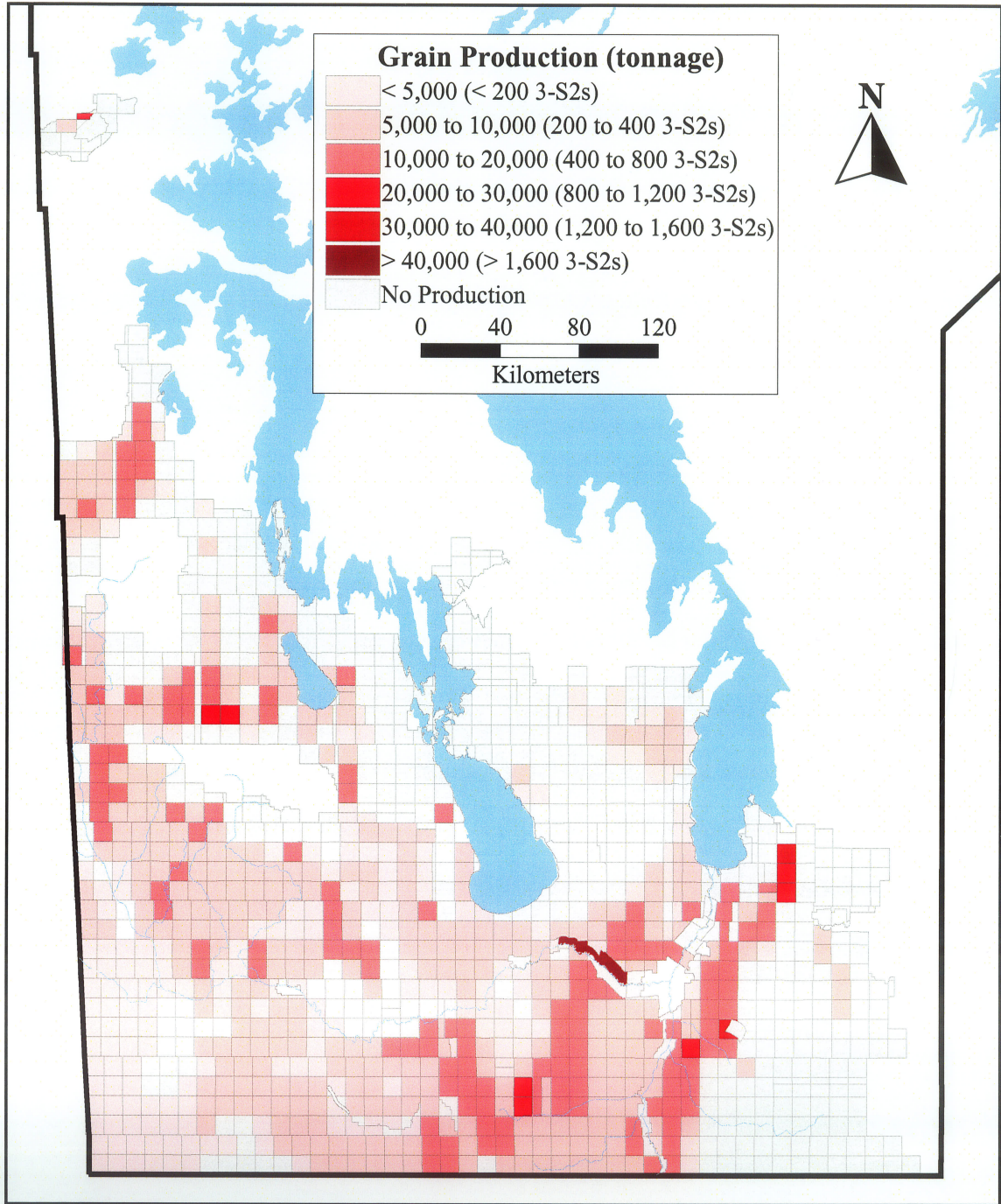
having substantial cropland area. The resulting grain production information by township used in the forecasting model is illustrated in Figure 5.4.

Although townships are relatively large areas of land that can include a number of farms, all grain produced in each township originates from a single point in the freight forecasting model. Centroids are locations that represent the geographic centre of analysis zones (Caliper, 2000) and are used in transportation modeling to describe the geographic locations at which freight flows begin and end (Battelle, 2002). Township centroids are used in this research as the origin locations for grain produced in each township.

5.2 FREIGHT ATTRACTION

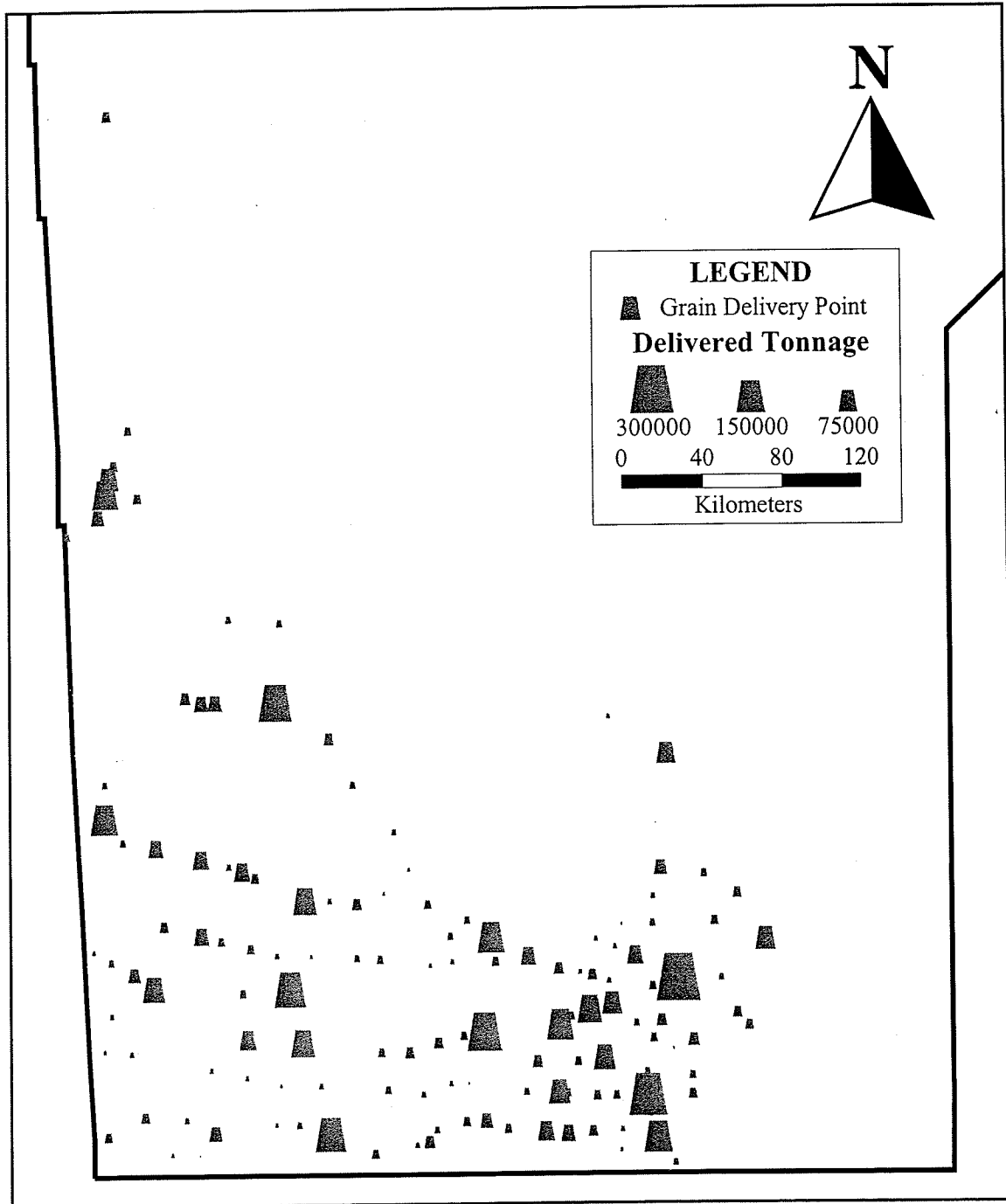
Freight attraction is the second component of the freight generation process. Similar to freight production, freight attraction information is estimated when actual attraction data is unavailable. For Manitoba, delivered tonnage information is available for grain delivery points from the Canadian Grain Commission. Unlike freight production, grain is not attracted to analysis zones but is delivered to specific locations, grain delivery points. Delivered tonnage information (grain attraction data) for the 152 grain delivery points in the freight forecasting model is illustrated in Figure 5.5.

Figure 5.4: 1999 Grain Production by Manitoba Township



Source: Canadian Grain Commission, 1999.

Figure 5.5: 1999/2000 Delivered Tonnage at Manitoba Grain Delivery Points



Source: Canadian Grain Commission, 1999/2000.

5.3 BALANCING FREIGHT PRODUCTION AND ATTRACTION

Upon review of the grain production and attraction information obtained for the forecasting model, it is discovered that total grain production does not equal total grain attraction (delivered tonnage). This can be primarily attributed to the fact that not all grain produced in the province is destined for grain delivery points in Manitoba. Some grain is also delivered to other types of locations, including local needs and hog farms. As well, a portion of grain produced in Manitoba moves to neighbouring jurisdictions, and some grain produced in surrounding jurisdictions is delivered to locations in Manitoba.

For the purpose of the freight forecasting model, grain production must equal grain attraction. Since not all grain produced in the province is destined for Manitoba grain elevators, delivered tonnage (freight attraction) information at the grain delivery points is selected as the total freight tonnage for use in the model. The percentage of grain produced in each township in the province is determined from the original grain production information, and total delivered tonnage is then distributed to the origin townships based on the estimated percentage of grain production.

CHAPTER 6

FREIGHT DISTRIBUTION

This Chapter describes the freight distribution procedure used in the Manitoba forecasting model for grain movements. The purpose of the freight distribution component is to estimate the freight tonnage moving between analysis zones or origin-destination pairs (Goulias and Eom, 2003 and Holguin-Veras and Thorson, 1998). The result of the freight distribution process is a matrix that identifies the origins and destinations of all freight movements (U.S. DOT, 1996). Calibration of the freight distribution component of the forecasting model is also described.

6.1 GRAVITY MODEL

The gravity model is used in the majority of regional freight distribution initiatives (Mao and Demetsky, 2002) and is considered to be the most appropriate model available for freight distribution (Mao and Demetsky, 2002, Park and Smith, 1997, Parsons, 1995 and Pendyala et al., 2000). The gravity model for forecasting grain movements in Manitoba is singly-constrained to attractions because the delivered tonnage (attraction) total was used to balance freight productions and attractions in Chapter 5. Friction factors are key inputs to the gravity model and are measures of the attractiveness between origin-destination pairs (Caliper, 2001 and Huang, 1998). Friction factors are estimated using the impedance between origin-destination pairs and an impedance function.

6.2 MEASURE OF IMPEDANCE

There are several different measures of impedance that can be used for forecasting freight movements, including transport distance, transport time, and transport cost. Previous research has shown that grain is generally delivered to elevators within a short distance of the field (Transmanagement, 1998). However, elevator companies in Manitoba sometimes offer trucking incentives to attract grain to specific facilities. Trucking incentives result in grain being hauled to facilities that are farther away in order for producers to benefit from cost savings. A 2001 survey of Manitoba farmers indicated that over one-third of producers deliver grain to locations that are not the closest facility. The primary reason cited for choosing not to ship grain to the nearest site was better prices at other facilities (UMTI, 2001). Transport cost is an important consideration in the movement of grain and is selected to test as the measure of impedance for the freight distribution component of the grain forecasting model.

Selection of transport cost as the measure of impedance requires the collection of transport cost information for grain movements. Numerous costs are involved in transporting grain, including haul rates charged by trucking companies to move grain from townships to grain delivery points, rail costs charged by rail companies to ship grain from delivery points, various costs charged at elevators to store and maintain grain, and trucking incentives offered at high throughput elevators to attract grain to those facilities.

A number of charges are levied at elevators, including elevation costs, storage costs, cleaning costs, and drying costs. Some of these charges depend on factors such as the

number of days of storage required for the grain, whether the grain is returned to the owner, and the condition of the grain. These factors vary for each individual shipment of grain and are difficult to estimate. Therefore, of the charges levied at elevators, only elevation charges are included in the grain forecasting model.

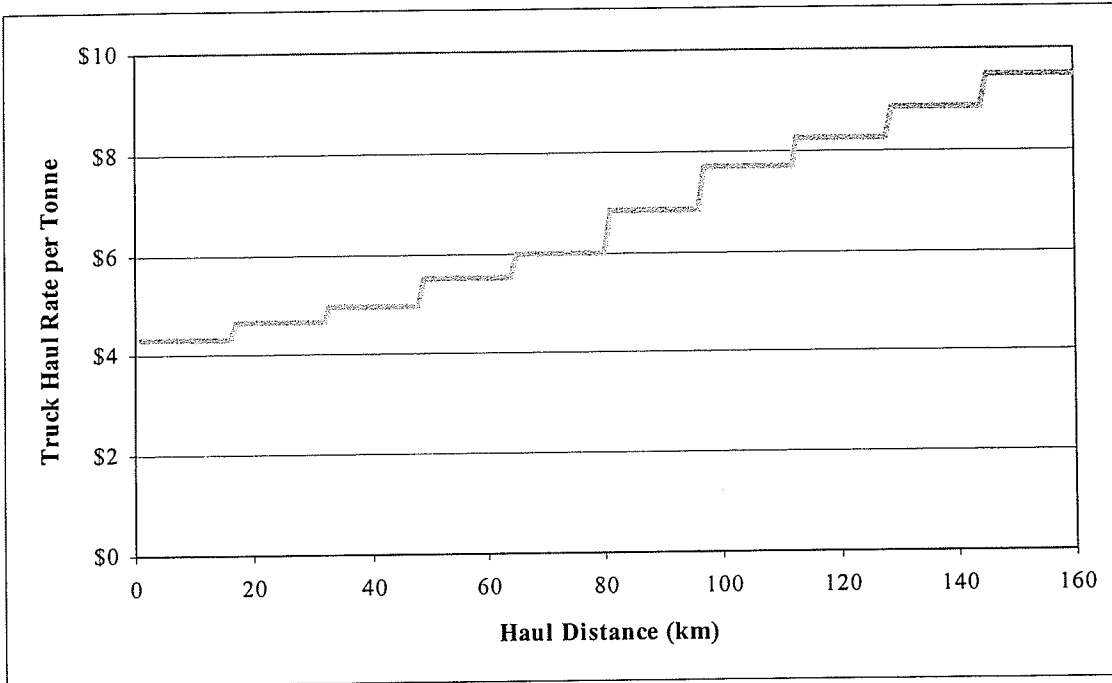
The costs for transporting grain used in this research are truck haul rates, rail costs, elevation charges, and trucking incentives. Trucking incentives are actually negative costs or savings offered at high throughput elevators to reduce producers' transport costs. The cost to transport grain from an origin township to a destination grain delivery point is the sum of the costs for that origin-destination pair.

6.2.1 Truck Haul Rates

Truck haul rates vary depending on the distance traveled and the type of truck. Haul rates for larger commercial vehicles are available from several sources; however, rates for smaller, producer-owned vehicles are difficult to estimate. The haul rates in this research are commercial haul rates used by Saskatchewan Wheat Pool for 2001. Rates are similar for Manitoba as cost inputs are comparable for the two provinces. The rates are also consistent with truck rates developed by Trimac Consulting Services. Truck haul rates are illustrated in Figure 6.1.

Table 6.1 lists average gross vehicle weights and payloads for various truck types used to deliver grain, including two and three-axle straight trucks, five-axle 3-S2s, and seven and eight-axle B-trains.

Figure 6.1: 2001 Commercial Truck Haul Rates



Source: Saskatchewan Wheat Pool, 2001.

Table 6.1: Common Truck Types Used for Grain Delivery

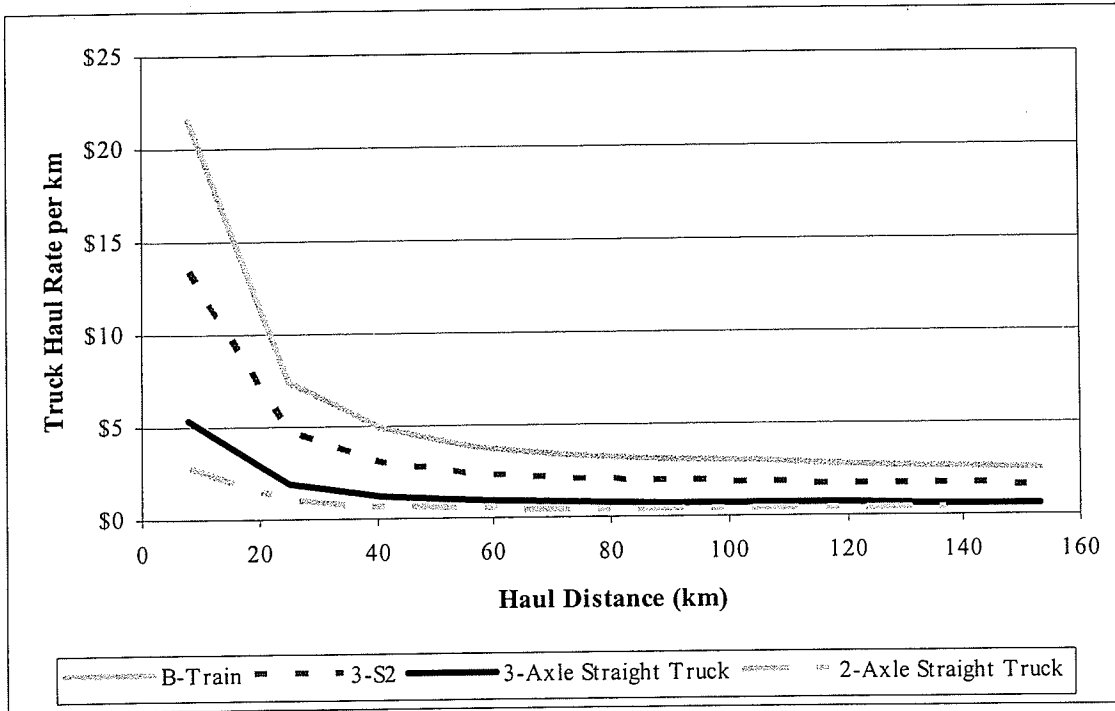
| Truck Type | Maximum Allowable Gross Vehicle Weight (GVW) on RTAC Basic Routes | Typical Maximum Payload |
|-----------------------|---|-------------------------|
| 2-axle straight truck | 17.6 tonnes | 5 tonnes |
| 3-axle straight truck | 24.3 tonnes | 10 tonnes |
| 5-axle 3-S2 | 39.5 tonnes | 25 tonnes |
| 7 and 8-axle B-train | 62.5 tonnes | 40 tonnes |

Source: ND LEA Engineers & Planners Inc., *Prairie Provinces Transportation System Study Update*, Transport Canada, March 2001.

Figure 6.2 illustrates truck haul rates per kilometre by truck type and is derived from the truck haul rates shown in Figure 6.1 and the typical maximum payloads listed in Table 6.1. As delivery distance increases, truck haul rates per kilometre decrease rapidly for

the first 25 kilometres, and then level out. Truck haul rates per kilometre for all truck types are less than \$5 per kilometre once the delivery distance is greater than 40 kilometres.

Figure 6.2: Derived Truck Haul Rates per Kilometre for Different Payloads



Truck haul rates vary by distance, and so in order to determine the haul rate between a particular origin and destination, the travel distance between the two points is required. Travel distances between each origin-destination pair are determined using the Multiple Shortest Path function in TransCAD. Based on the travel distance between each township centroid and grain delivery point, a truck haul rate is determined for each origin-destination (township-grain delivery point) pair in dollars per tonne.

6.2.2 Freight Consideration Rates

Freight consideration rates (FCR) are charged by railway companies to ship grain from delivery points and are based on railway tariffs. FCR information is obtained from the Canadian Wheat Board and data from August 1, 2001 and November 10, 2000 is used in this research (Dutka, 2002). Freight consideration rates vary by type of crop shipped and no average rate for grain is available. The FCR for wheat falls midway between the high and low rates for the various grain crops and is utilized in the model.

FCR information is available for each grain delivery point in dollars per tonne. FCR rates used in the model vary from a low of \$28.93 per tonne to a high of \$43.06 per tonne. Detailed freight consideration rate information for each grain delivery point is included in Appendix A. All grain delivered to a particular grain delivery point, no matter where the grain originates, is charged the same freight consideration rate. Freight consideration rates are determined for each origin-destination (township-grain delivery point) pair in dollars per tonne.

6.2.3 Elevation Charges

Elevation charges are available by company for the 2001-2002 crop year from the Canadian Grain Commission (Dutka, 2002). Information about the companies operating elevators and their respective capacities at each grain delivery point is also provided (Mudry, 2002). A weighted average of the elevation charges is determined for each delivery point based on the elevator capacity by company. Weighted elevation charges vary from a low of \$10.50 per tonne to a high of \$12.63 per tonne. Detailed elevation

charge information for each grain delivery point is included in Appendix A. All grain delivered to a particular grain delivery point, no matter where the grain originates, is subject to the same elevation charge. Elevation charges are determined for each origin-destination (township-grain delivery point) pair in dollars per tonne.

6.2.4 Trucking Incentives

Trucking incentives are sometimes offered by elevator companies to reduce producers' transport costs and are included in the grain forecasting model as negative costs. Rail companies offer elevator companies incentive rates to order and ship blocks of 25, 50, or 100 rail cars. According to the Canadian Wheat Board, incentives of \$1 per tonne, \$4 per tonne, and \$6 per tonne are offered by the rail companies for a minimum of 25 cars, 50 cars, or 100 cars of grain, respectively (Canadian Wheat Board, 2002). Elevator companies pass on some or all of these rail incentives as trucking incentives to producers to deliver grain to their facilities. Trucking incentives are offered as required to attract grain to facilities. Depending on market conditions, elevator companies may not offer any trucking incentives, while at other times, trucking incentives can exceed rail incentives.

Based on analysis of the trucking incentives used in the Saskatchewan Road Impact Analysis (Government of Saskatchewan, 1999) and information obtained from Manitoba grain companies, incentive rates of \$1 per tonne at locations with 25 car loaders, \$3 per tonne at locations with 50 car loaders, and \$5 per tonne at locations with 100 car loaders are selected for the model (ND LEA, 2002). The incentive rates are less than actual

trucking incentives obtained from the Canadian Wheat Board to reflect the fact that incentives are not always offered to producers at high throughput facilities.

Locations that can handle 25, 50 and 100 car shipments were obtained from the Canadian Wheat Board and are listed in Table 6.2 (Canadian Grain Commission, 2002). All grain delivered to a facility that offers a trucking incentive, no matter where the grain originates, is offered the same incentive. Trucking incentives are determined for each origin-destination (township-grain delivery point) pair in dollars per tonne.

6.2.5 Transport Costs

The four input costs, truck haul rates, freight consideration rates, elevation charges, and trucking incentives, are added together to get the total transport cost in dollars per tonne charged to a producer to transport grain from each origin township to every destination grain delivery point.

Transport costs for a sample origin township (Township 36-27-W in the rural municipality of Swan River) are illustrated in Figure 6.3 for ten possible destination grain delivery points. Truck haul rates, freight consideration rates and elevation charges are all positive costs, while trucking incentives are cost savings and are illustrated in the figure as negative costs. Transport costs to deliver grain from Township 36-27-W range from \$46.58 per tonne at the Swan River grain delivery point to \$67.47 per tonne at The Pas grain delivery point. Freight consideration rates and elevation charges are relatively constant for deliveries to most potential grain delivery points. However, haul rates and

trucking incentives vary considerably for movements from Township 36-27-W to potential grain delivery points and have a major impact on total transport costs.

Table 6.2: 2001 Grain Delivery Points Offering Trucking Incentives

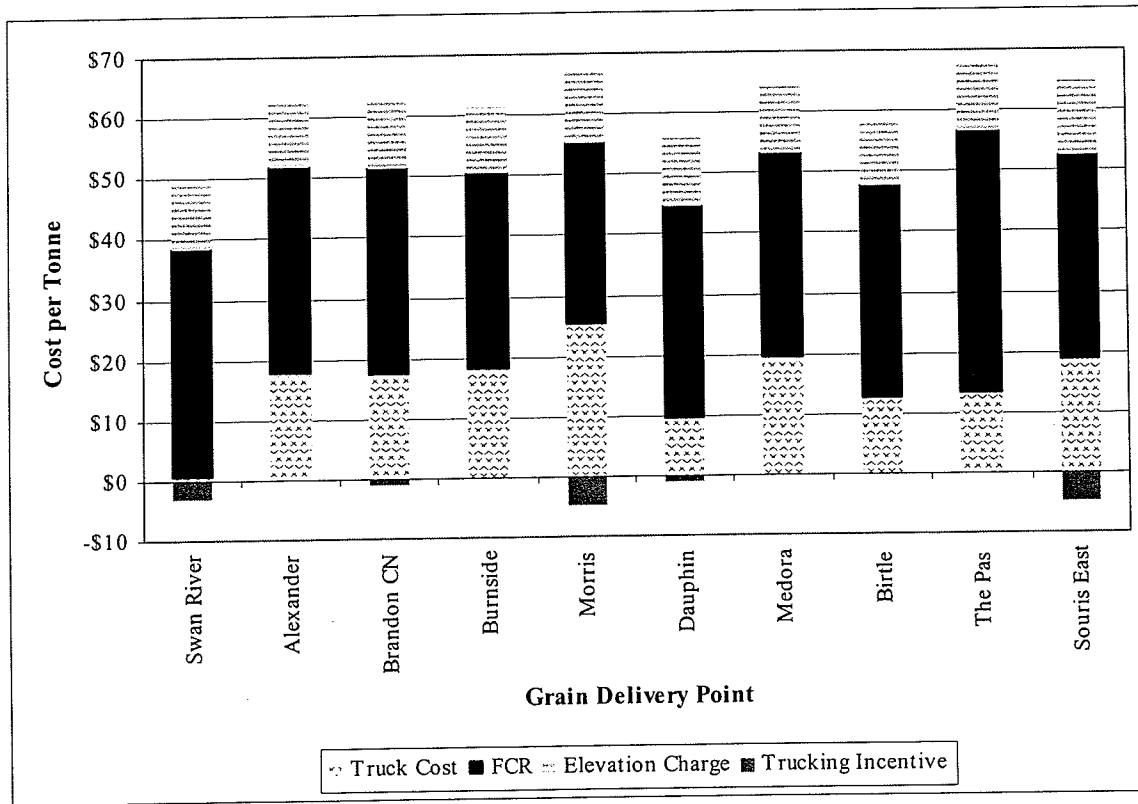
| 25-Car Loaders | | | 50-Car Loaders | | | 100-Car Loaders | | |
|----------------|------|---------|-------------------|------|---------|-----------------|------|---------|
| Location | Rail | Company | Location | Rail | Company | Location | Rail | Company |
| Arborg | CP | ACR | Binscarth | CP | ACR | Boissevain | CP | SWP |
| Beausejour | CP | ACR | Binscarth | CP | PAT | Morris | CN | PAT |
| Bowsman | CN | CAR | Dauphin | CN | ACR | Red River South | CN | ACR |
| Brandon | CP | ACR | Dundonald | CP | UGG | Souris East | CP | UGG |
| Brandon | CN | CAR | Elgin | CN | ACR | Virden | CP | LDL |
| Deloraine | CP | UGG | Elm Creek | CP | CAR | | | |
| Dutton | CN | UGG | Fannystelle | CP | UGG | | | |
| Glenboro | C; | ACR | Glossop | CP | PIO | | | |
| Grandview | CN | ACR | Killarney | CP | ACR | | | |
| Graysville | CN | ACR | Minnedosa | CP | ACR | | | |
| Hargrave | CP | UGG | Mollard | CN | PIO | | | |
| Morden | CP | UGG | Rathwell | CP | LDL | | | |
| Morris | CN | CAR | Rosser | CP | ACR | | | |
| Oakner | CN | ACR | Shoal Lake | CP | UGG | | | |
| Quadra | CN | ACR | Starbuck | CP | ACR | | | |
| Solsgirth | CP | ACR | Swan River | CN | ACR | | | |
| Swan River | CN | CAR | Swan River Valley | CN | PIO | | | |
| Somerset | CN | ACR | Tucker | CP | ACR | | | |
| Winnipeg | CO | SWP | | | | | | |
| Winnipeg | CN | CAR | | | | | | |

Source: Canadian Wheat Board, 2002.

Note: ACR – Acricore Cooperative Ltd.
 CAR – Cargill Ltd.
 LDL – Louis Dreyfus Canada Ltd.
 PAT – N. M. Paterson & Sons Ltd.

PIO – Pioneer Grain Company Ltd.
 SWP – Saskatchewan Wheat Pool
 UGG – United Grain Growers Ltd.

Figure 6.3: Transport Costs for Origin Township 36-27-W



6.3 FRICTION FACTORS

Friction factors are measures of the attractiveness between origins and destinations and are inversely proportional to impedances. Impedances in this research are the transport costs developed in Section 6.2. As the cost to transport goods between an origin and destination increases, the friction factor decreases. In other words, as the cost to transport goods from an origin to a destination increases, the attractiveness of delivering goods from that origin to that destination decreases, along with the friction factor (Caliper, 2001 and Serratini, 1999). The volume of grain estimated to move between an origin-destination pair depends on the size of the friction factor, the higher the friction factor, the more grain moves from township to delivery point.

Impedance functions relate the impedance, or transport cost, to the attractiveness, or friction factor, between origins and destinations (Caliper, 2001 and Huang, 1998). Exponential, inverse power, and gamma functions can be used as impedance functions in the gravity model. The *Quick Response Freight Manual* recommends an exponential function as the impedance function to determine friction factors for the gravity model (U.S. DOT, 1996). The exponential function has been used previously in studies to forecast freight movements and is as follows (Caliper, 2001):

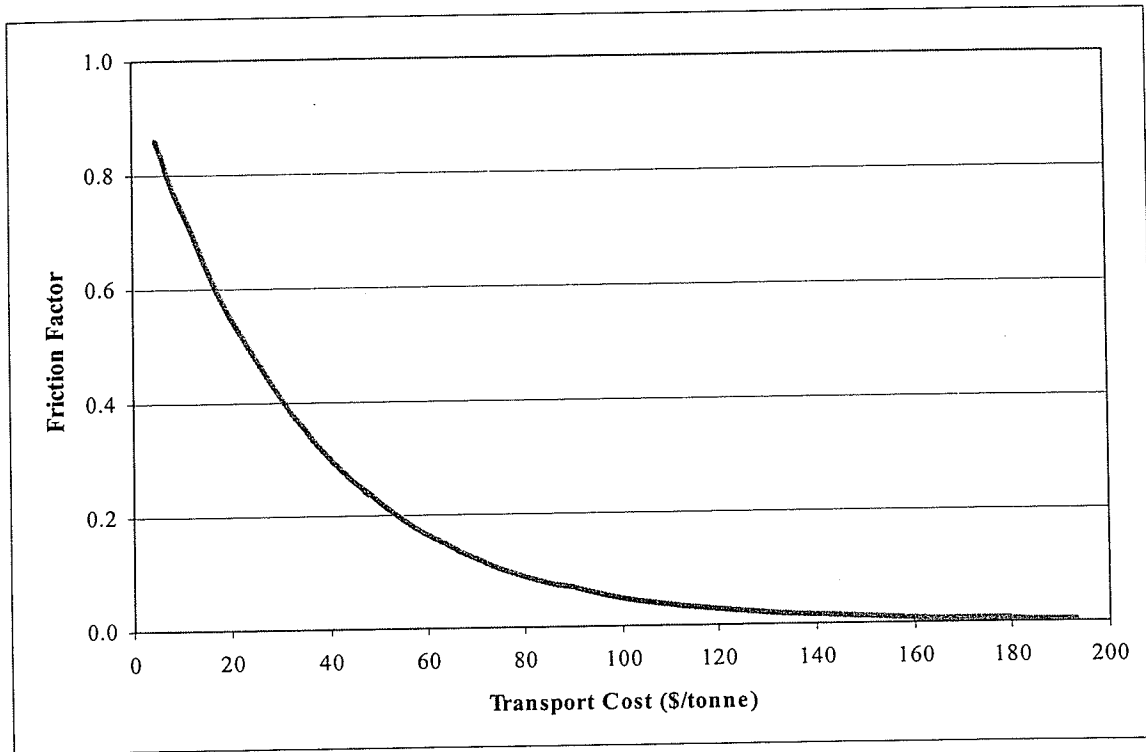
$$f(d_{ij}) = e^{-c(d_{ij})}$$

where:

- $f(d_{ij})$ = the friction factor between each i, j pair
- d_{ij} = the impedance (transport cost in this research) between each i, j pair
- i = origin location
- j = destination location
- c = parameter
- e = 2.71828

Values for the c parameter are available for commercial vehicles in the United States and are based on past analyses and calibration of impedance functions. No values are available for commercial vehicles operating in Manitoba. The *Quick Response Freight Manual* recommends a c parameter of 0.03 for commercial vehicles (U.S. DOT, 1999). The exponential friction factor curve for transport cost is illustrated in Figure 6.4. The smaller the transport cost for an origin-destination pair, the higher the friction factor and the more likely it is that grain will be transported from that origin township to that destination grain delivery point.

Figure 6.4: Transport Cost Impedance Friction Factor Curve



For example, the friction factor to transport grain from Township A to Grain Delivery Point #1, based on a transport cost of \$36.50 per tonne, is 0.33. The friction factor to transport grain from Township A to Grain Delivery Point #2, based on a transport cost of \$57.30 per tonne, is 0.20. Grain Delivery Point #1 is more attractive and has a higher friction factor than Grain Delivery Point #2 for grain movements from Township A.

Using the exponential impedance function and the estimated transport costs, friction factors are determined for transporting grain between each origin township and destination grain delivery point in the model.

6.4 GRAVITY MODEL RESULTS

6.4.1 Origin-Destination Results Based on Transport Costs

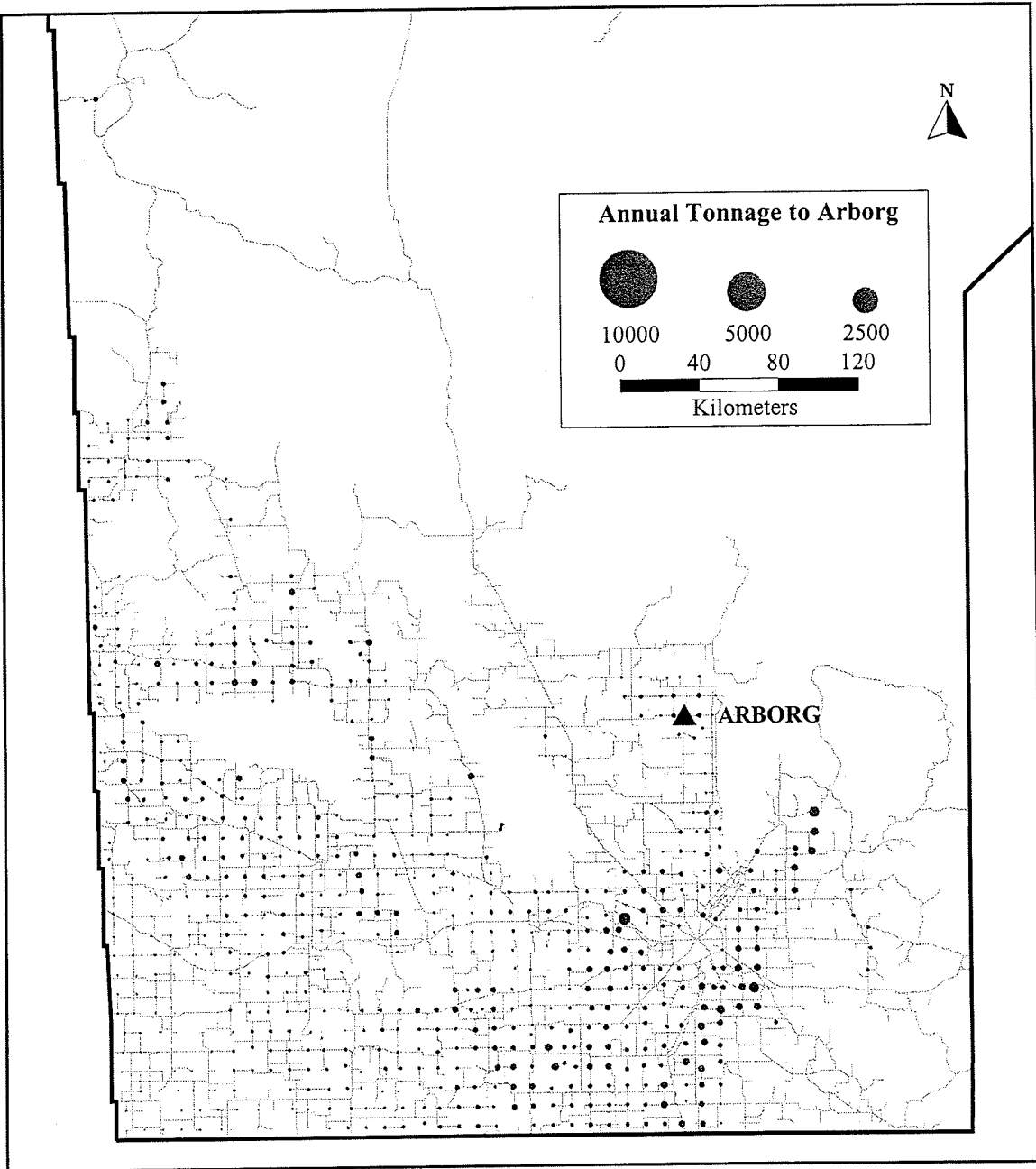
The friction factors based on transport costs and the grain production and attraction information developed during the trip generation component are input to the gravity model in TransCAD. The gravity model yields estimates of the freight flow between all origins and destinations (Black, 1999). The results are stored in an origin-destination matrix that lists the volume of grain moving between each township and grain delivery point. A single township does not necessarily coincide with a single grain producer. In general, there is more than one producer per township, and the model allows grain originating in one township to be delivered to more than one delivery point.

Traditionally, origin-destination results from the gravity model are compared to existing truck and vehicle classification counts, origin-destination surveys, or in the case of a commodity-based model such as this one, to commodity flow survey data, and calibrated to match (Huang, 1998, Mao and Demetsky, 2002 and U.S. DOT, 1996). No commodity flow information describing grain movements from origin townships to destination grain delivery points is available for Manitoba. Vehicle classification information from automatic weigh scale surveys is available at approximately 35 locations in the province (Tang, 2003). However, this information does not provide the commodity detail required to calibrate the forecasting model for grain movements. Therefore, the calibration procedure for this research will involve manual analysis of the origin-destination matrix in an iterative process to improve the gravity model results.

Ten grain delivery points of various sizes located throughout Manitoba are selected at random for analysis. The delivery points selected are Arborg, Dauphin, Killarney, Melita, Minnedosa, Rathwell, Red River South, Swan River, Virden, and Winnipeg CN. The origin-destination results based on the transport cost friction factors are analyzed using thematic maps that illustrate the locations of townships where grain originates and the associated volume of grain destined for the selected delivery point from each origin township. The origin-destination results for the Arborg grain delivery point are shown in Figure 6.5. Figures for the remaining grain delivery points are included in Appendix B.

Analysis of the figures indicates that grain destined for delivery points originates throughout Manitoba, no matter where the delivery point is located. In some cases, the results show grain moving hundreds of kilometers across the province to a particular delivery point. In reality, this is not the case. The survey of Manitoba grain producers indicated that just 36 percent of producers deliver to grain delivery points that are not closest to their place of origin (UMTI, 2001). Transport cost is therefore not appropriate as the measure of impedance in the gravity model for forecasting grain movements in Manitoba.

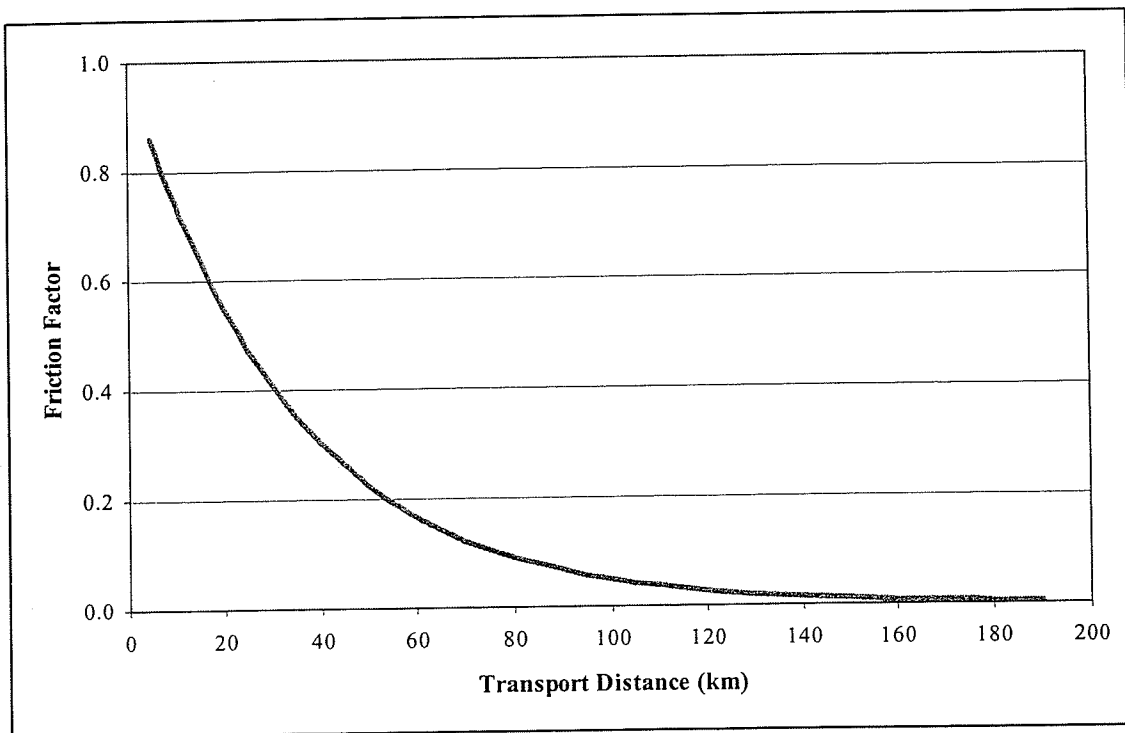
**Figure 6.5: Arborg Grain Delivery Point
Origin-Destination Results Based on Cost**



6.4.2 Origin-Destination Results Based on Distance

The survey of Manitoba grain producers concluded that most producers deliver to the nearest grain delivery point (UMTI, 2001), and transport distance is therefore selected as the second measure of impedance to test in the gravity model to forecast grain movements. A second set of friction factors is developed based on the distance between townships and grain delivery points, which was determined in Section 6.2.1. The exponential friction factor curve for transport distance is illustrated in Figure 6.6. The smaller the transport distance for an origin-destination pair, the higher the friction factor and the more likely it is that grain will be transported from that origin township to that destination grain delivery point.

Figure 6.6: Transport Distance Impedance Friction Factor Curve

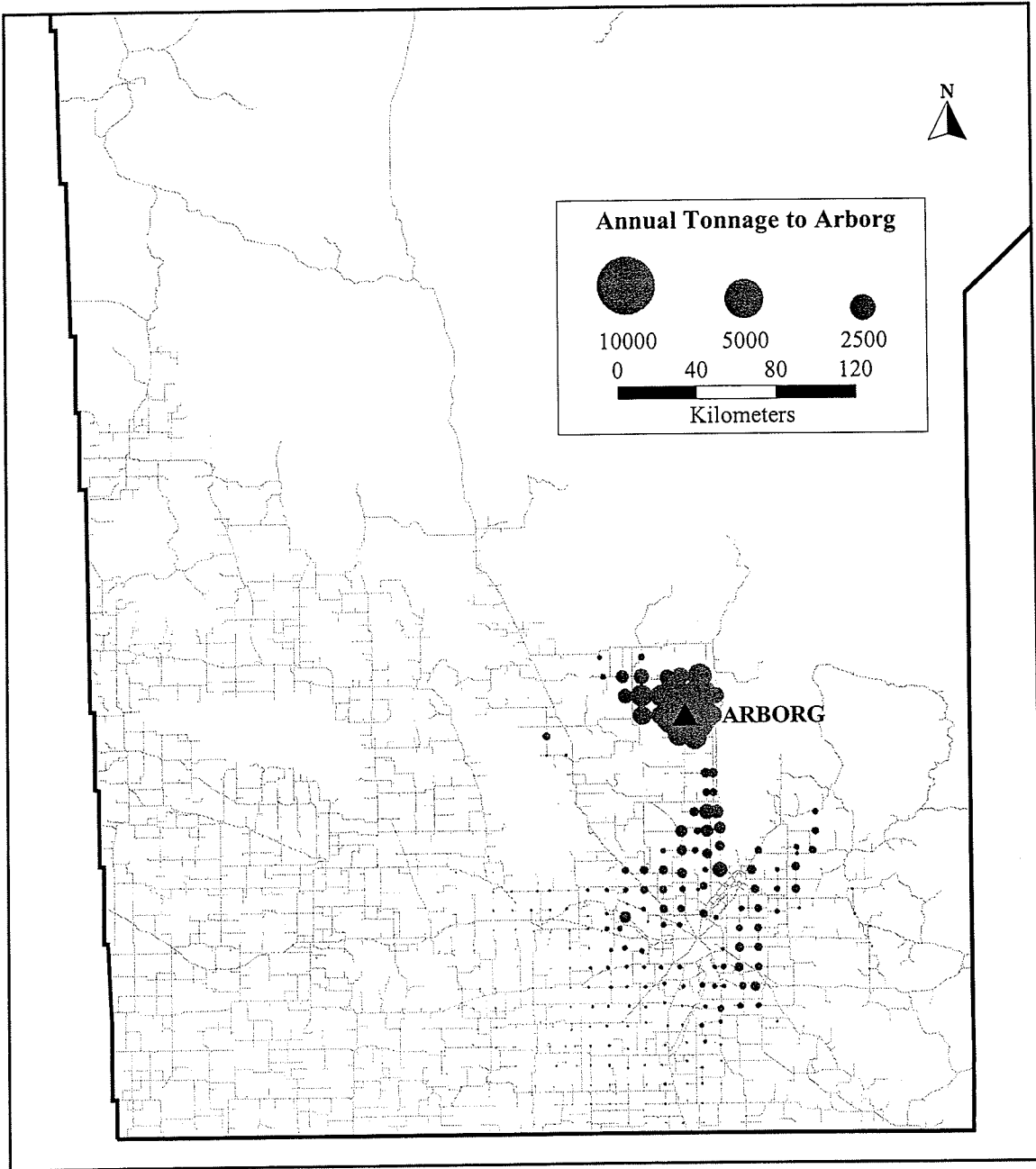


For example, the friction factor to transport grain from Township B to Grain Delivery Point #3, based on a transport distance of 93 kilometre, is 0.06. The friction factor to transport grain from Township B to Grain Delivery Point #4, based on a transport distance of 48 kilometres, is 0.24. Grain Delivery Point #4 is more attractive and has a higher friction factor than Grain Delivery Point #3 for grain movements from Township B.

A second origin-destination matrix is produced from the gravity model using the distance friction factors and the ten delivery points previously selected are again analyzed. The origin-destination results for the Arborg grain delivery point are illustrated in Figure 6.7. Figures for the remaining grain delivery points based on the distance friction factors are included in Appendix C.

The origin-destination results indicate that the majority of grain destined for delivery points originates at townships in the immediate vicinity. Large volumes of grain originate at nearby townships as compared to townships located farther distances from the grain delivery points. The origin-destination results based on transport distance are more realistic than the origin-destination results based on transport cost. However, the distance friction factors do not address the fact that producers deliver to high throughput elevators located farther away that offer trucking incentives. Distance by itself is not sufficient for use as the measure of impedance in the gravity model for forecasting grain movements.

Figure 6.7: Arborg Grain Delivery Point
Origin-Destination Results Based on Distance



6.4.3 Origin-Destination Results Based on Transport Cost and Distance

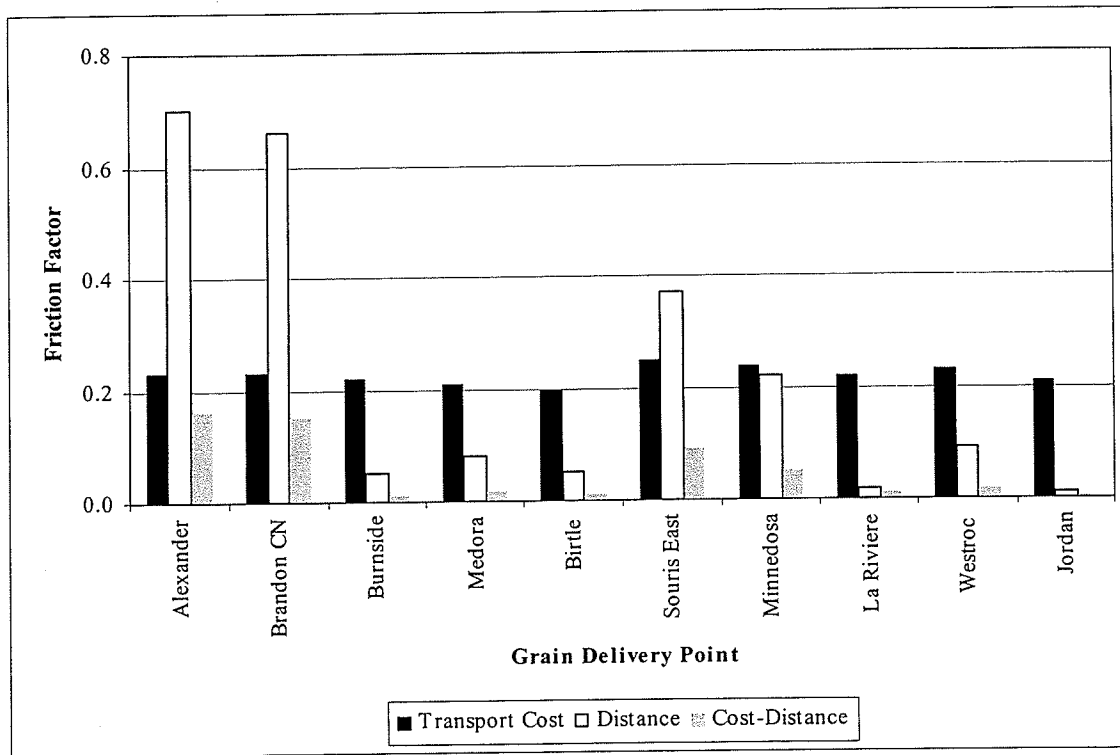
The survey of Manitoba grain producers concluded that most producers deliver to nearby facilities (UMTI, 2001), however; lower cost is the primary reason producers choose to ship to facilities that are not closest to their place of origin (UMTI, 2001). Transport cost and distance are both important considerations for producers deciding where to deliver grain, and each was tested independently in this research as the measure of impedance to predict grain movements in Manitoba. Neither proved sufficiently accurate on its own, and a combination of transport cost and distance is therefore selected as the third measure of impedance to test in the gravity model to forecast grain movements.

Transport costs are measured in dollars per tonne and transport distances are measured in kilometres, which makes it difficult to merge transport cost and distance together for use in the gravity model. Friction factors, however, are unitless and can therefore be combined relatively easily. Friction factors are measures of attraction between origins and destinations. These attractions can also be thought of as probabilities; the probability that a producer originating in a certain township will travel to a certain destination to deliver grain. The higher the friction factor, the higher the probability that a producer will deliver to that grain delivery point. Friction factors based on transport cost can be thought of as the probabilities that a producer will deliver to various destinations if transport cost is the only consideration. Friction factors based on distance can be thought of as the probabilities that a producer will deliver to various destinations if distance is the only consideration. To obtain friction factors that consider both transport cost and distance, it was decided to multiply the transport cost friction factors for each origin-

destination pair by the distance friction factors for the same origin-destination pair to obtain combined cost-distance friction factors. This method is similar to how multiple probabilities are considered at the same time.

Transport cost, distance, and combined cost-distance friction factors for a sample origin township (Township 10-20-W in the rural municipality of Whitehead) are compared in Figure 6.8 for ten possible destination grain delivery points.

Figure 6.8: Comparison of Friction Factors for an Origin Township



Transport cost friction factors for Township 10-20-W are relatively consistent and range from 0.20 to 0.25, which means that the potential delivery points have similar levels of attractiveness from a transport cost perspective. The friction factors based on distance

are much more varied, and range from 0.01 to 0.70. The combined cost-distance friction factors range from a low of less than 0.01 at the Jordan grain delivery point to a high of 0.16 at the Alexander grain delivery point. Because the friction factors based on transport cost are relatively similar to one another, the differences in the combined cost-distance friction factors primarily represent differences in the distance friction factors. However, transport costs are still considered in the combined friction factors.

Origin-destination results are produced using the combined cost-distance friction factors and the ten delivery points previously selected are again analyzed. The origin-destination results for the Arborg grain delivery point based on the cost-distance friction factors are illustrated in Figure 6.9. Figures for the remaining grain delivery points are included in Appendix D. As well, six townships with varying tonnages of originating grain located throughout Manitoba are selected for analysis. The townships selected are 05-23-W, 08-06-E, 12-09-W, 16-24-W, 21-02-E, and 29-19-W. The grain delivery points each township delivers to and the associated volume of delivered grain are illustrated using thematic maps. A sample of the origin-destination results for Township 08-06-E, located in the rural municipality of Sainte Anne, is illustrated in Figure 6.10. Figures for the remaining townships are also included in Appendix D.

Figure 6.9: Arborg Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

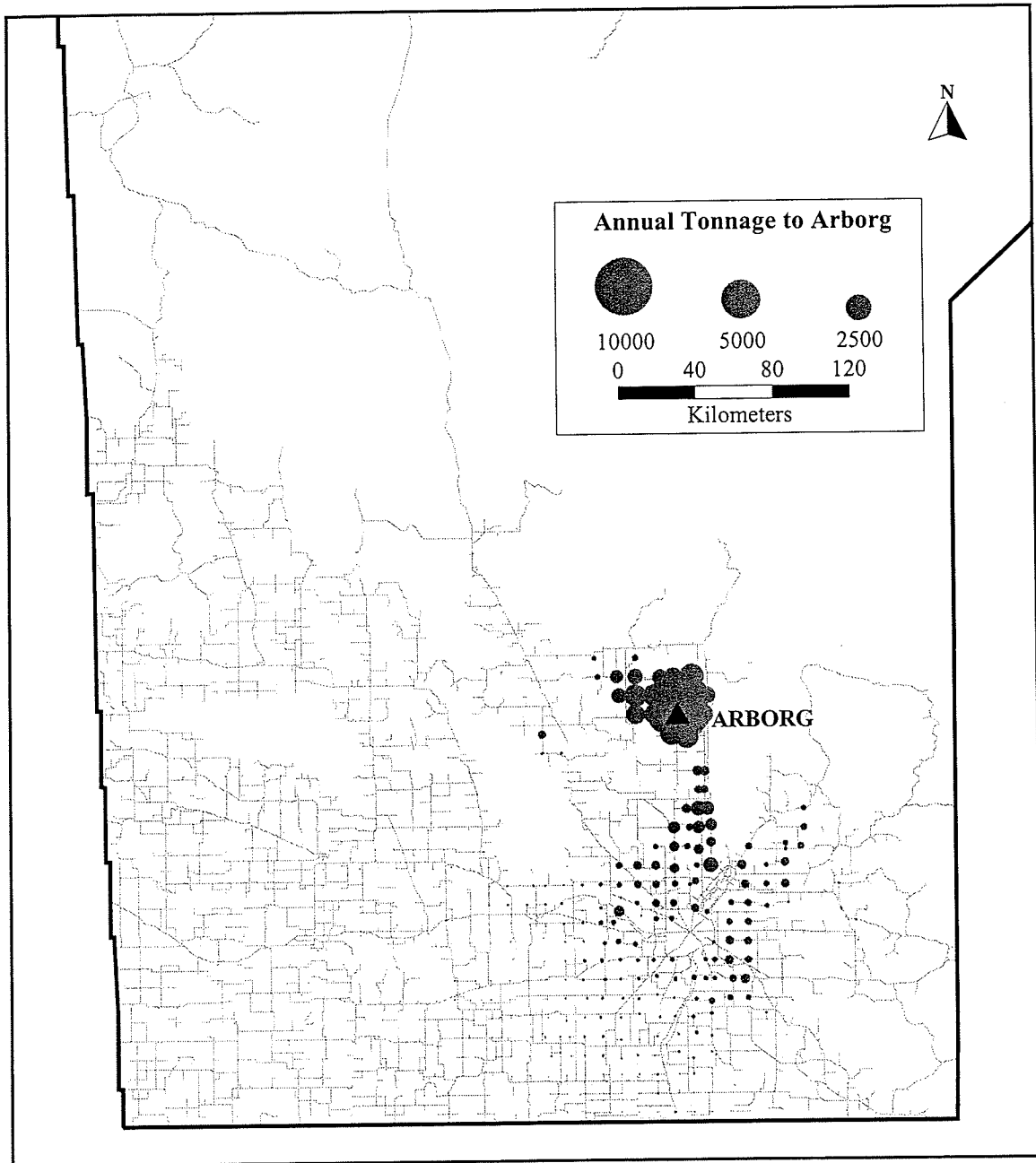
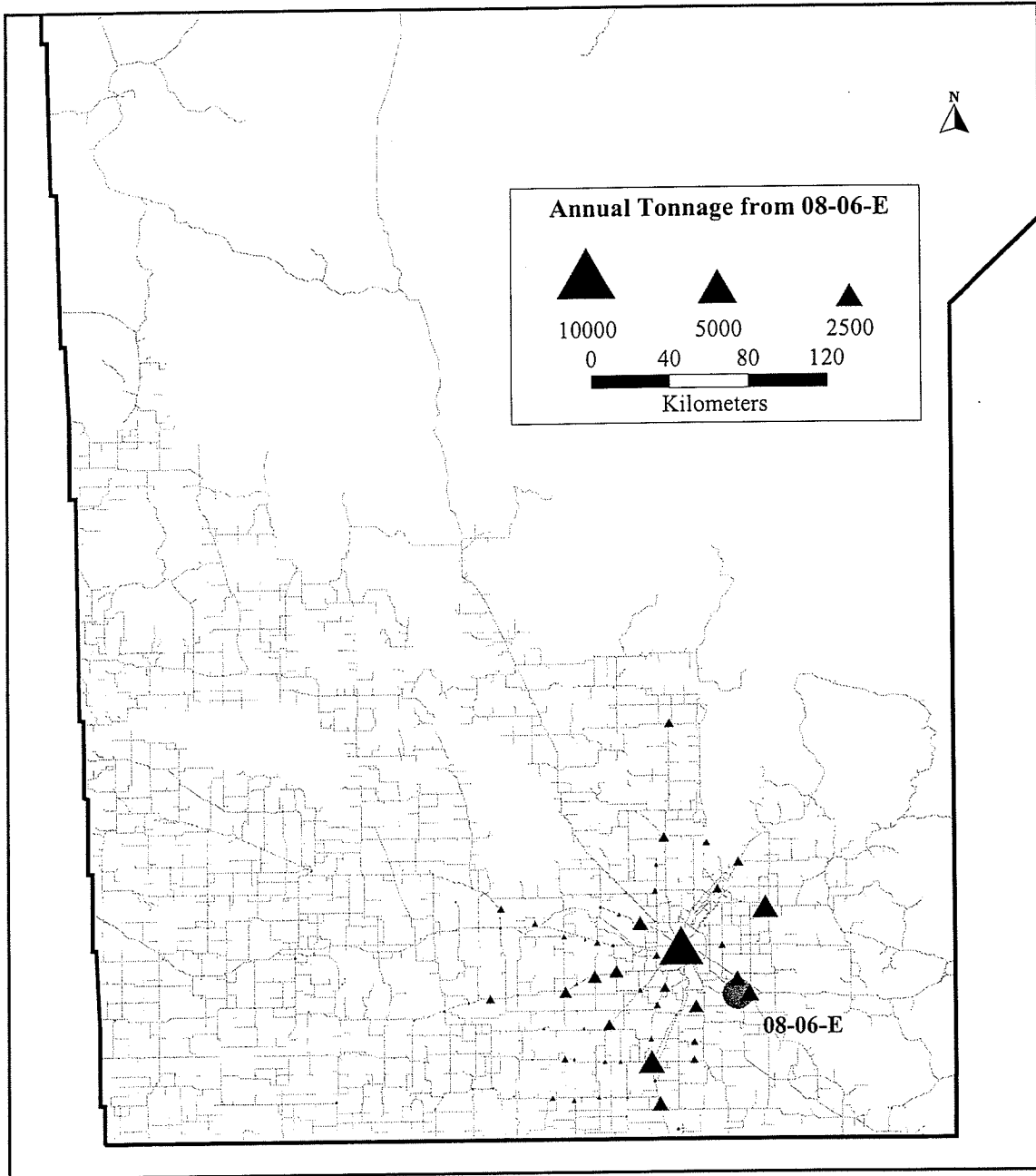


Figure 6.10: Township 08-06-E
Origin-Destination Results Based on Cost and Distance



The cost-distance origin-destination results from the gravity model appear realistic. The majority of grain originating in townships is delivered to nearby grain elevators as well as locations that offer lower costs. From a delivery point perspective, large volumes of grain originate in nearby townships. The volume of grain destined for a delivery point decreases as the distance from township to elevator increases. High throughput delivery points offering trucking incentives receive grain from a larger surrounding area as compared to smaller delivery points that do not offer incentives. Smaller delivery points receive the majority of grain from nearby locations. Combined transport cost and distance is therefore selected as the impedance in the gravity model for forecasting grain movements in Manitoba.

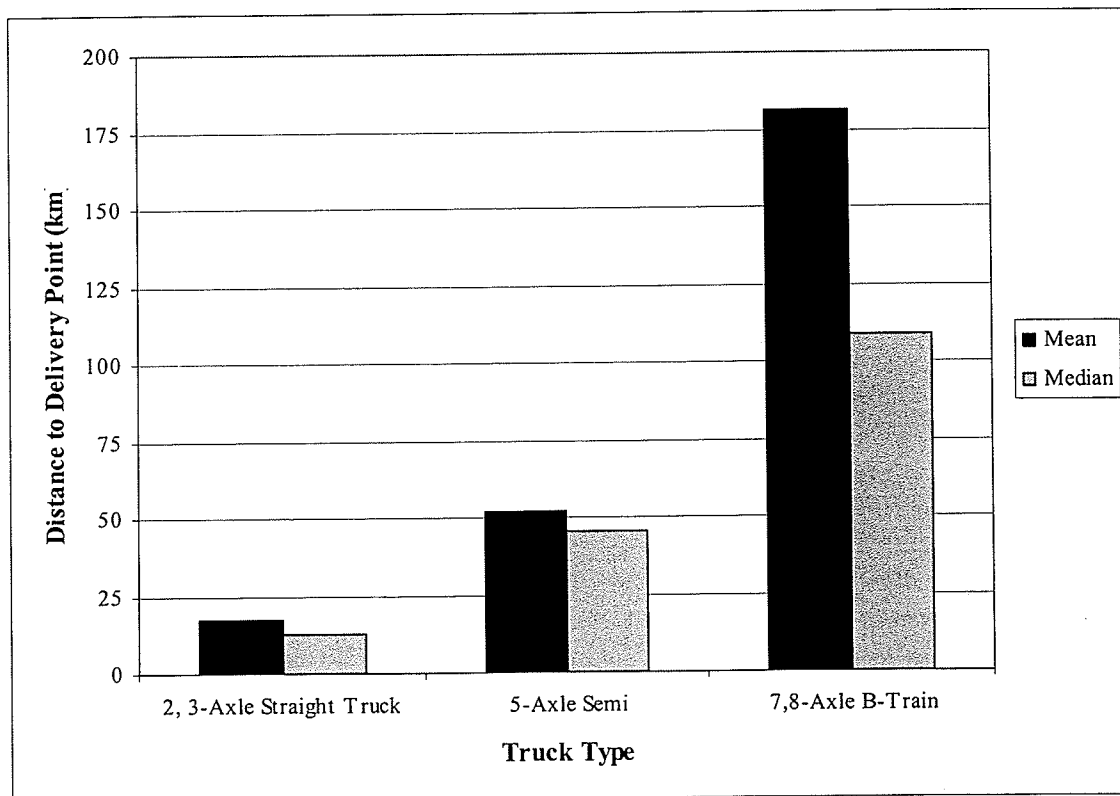
6.5 CALIBRATION OF THE COST-DISTANCE FRICTION FACTORS

The origin-destination results from the gravity model based on transport cost and distance are realistic; however, there are minor concerns that should be addressed. Grain from individual townships is delivered to a large number of grain delivery points, and a number of shipments involve tiny amounts of grain travelling long distances across the province. Most of the small grain volumes moving between origins and destinations are less than ten tonnes, or less than one three-axle straight truck per year. Calibration of the friction factors is required to discourage deliveries to distant grain delivery points and encourage deliveries to nearby and low cost facilities.

Calibration of the combined cost-distance friction factors is based on a survey of Manitoba cereal growers who reported distances to their main drop-off point (UMTI,

2001). The results of the survey are illustrated in Figure 6.11. Smaller trucks are used to transport grain to delivery points located less than 20 or 30 kilometres from the producer. Deliveries to facilities located at greater distances from the producer are made using commercial vehicles, primarily five-axle semi-trailers and seven and eight-axle B-trains. Thirty-eight percent of grain is delivered by two and three-axle straight trucks and the remaining 62 percent is delivered by tractor-trailer combinations (UMTI, 2001).

Figure 6.11: Truck Type versus Distance to Grain Delivery Point



Source: University of Manitoba Transport Institute, *Agricultural Transportation Infrastructure Study Final Report*. Manitoba Transportation and Government Services, March, 2001

The calibration of the cost-distance friction factors considers the distance between townships and grain delivery points and the estimated tonnage of grain moving between

an origin-destination pair from the gravity model. The grain tonnages selected and used for the calibration represent average payloads for trucks used to deliver grain to facilities at various distances. Deliveries to facilities located more than 75 kilometres from the origin township are made using B-trains with 40-tonne payloads, deliveries to facilities located 25 to 75 kilometres from the origin township are made using 3-S2s with 25-tonne payloads, deliveries to facilities located 15 to 25 kilometres from the origin township are made using three-axle straight trucks with 10-tonne payloads, and deliveries to facilities located less than 15 kilometres from the origin township are made using two-axle straight trucks with five-tonne payloads. The calibration process involves manually reducing the cost-distance friction factors for estimated grain movements of less than one truckload.

The first and second calibrations of the cost-distance friction factor are illustrated in Table 6.3. Friction factors for origin-destination movements of less than one truckload per year are reduced to 0.000001 in the first calibration. The value of 0.000001 was selected for the friction factor reduction to discourage small shipments of grain. However, the results of the first calibration suggest that if a friction factor exists, no matter how small, some volume of grain will move between that origin-destination pair. Therefore, the second calibration sets cost-distance friction factors for origin-destination movements of less than one truckload per year to zero to eliminate the small movements of grain.

Table 6.3: Cost-Distance Friction Factor Calibration

| Transport Distance | Estimated Grain Movement from Gravity Model based on Cost and Distance | Friction Factor Calibration #1 | Friction Factor Calibration #2 |
|---------------------------|---|---------------------------------------|---------------------------------------|
| > 75 km | < 40 tonnes (less than one B-train) | Reduce to 0.000001 | Reduce to 0 |
| 25 to 75 km | < 25 tonnes (less than one 3-S2) | | |
| 15 to 25 km | < 10 tonnes (less than one 3-axle truck) | | |
| < 15 km | < 5 tonnes (less than one 2-axle truck) | | |

Origin-destination results are produced from the gravity model using the first and second calibrations of the cost-distance friction factors. The ten delivery points and six township origins previously analyzed are again examined. The origin-destination results for the first calibration of the cost-distance friction factors for the Arborg grain delivery point and Township 08-06-E are illustrated in Figure 6.12 and Figure 6.13, respectively (figures for the remaining grain delivery points and townships are included in Appendix E). Figure 6.14 and Figure 6.15 illustrate the origin-destination results for the second calibration of the cost-distance friction factors for the Arborg grain delivery point and Township 08-06-E, respectively (figures for the remaining grain delivery points and townships are included in Appendix F).

Figure 6.12: Arborg Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

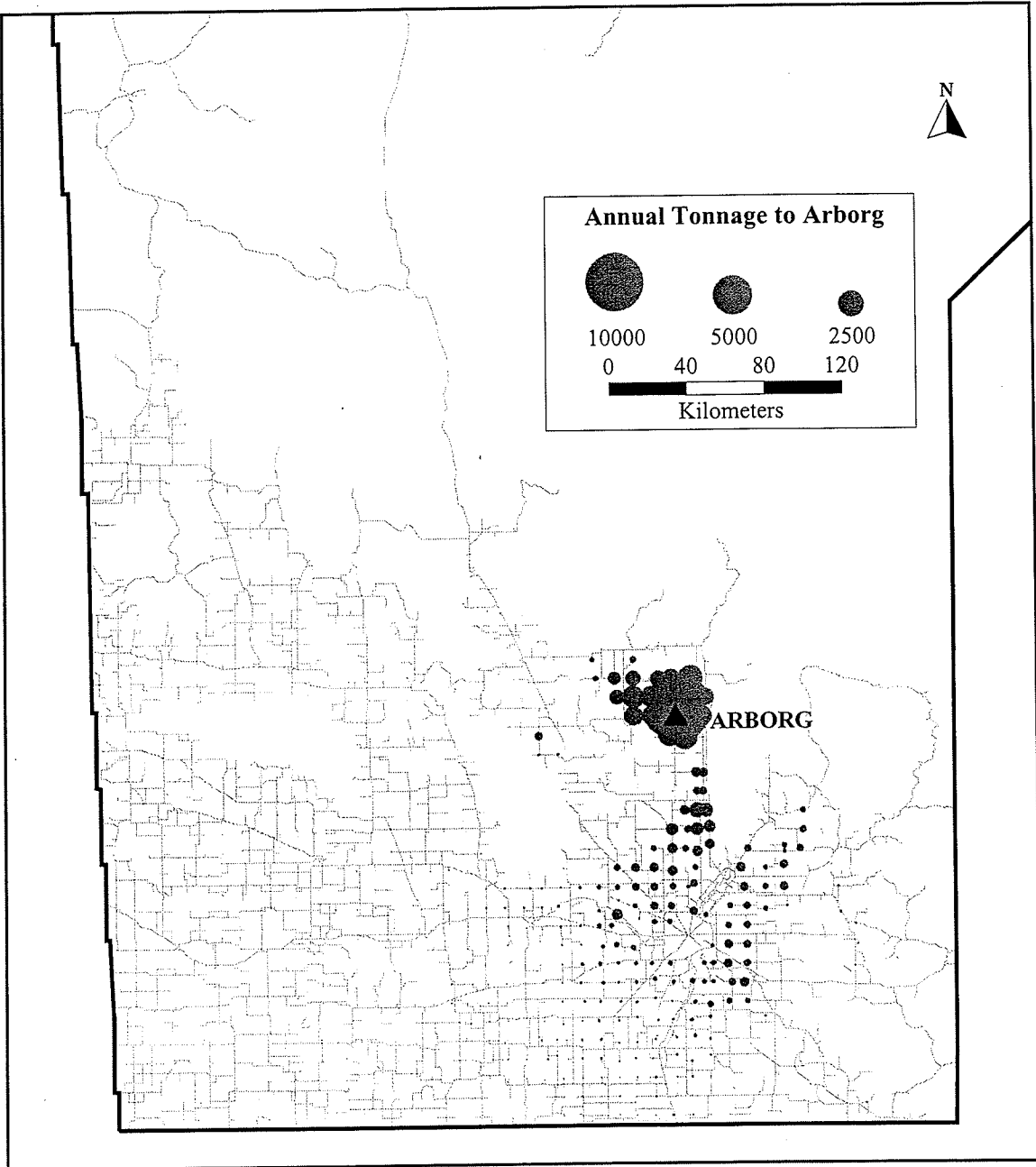


Figure 6.13: Township 08-06-E
Origin-Destination Results Based on Cost and Distance Calibration #1

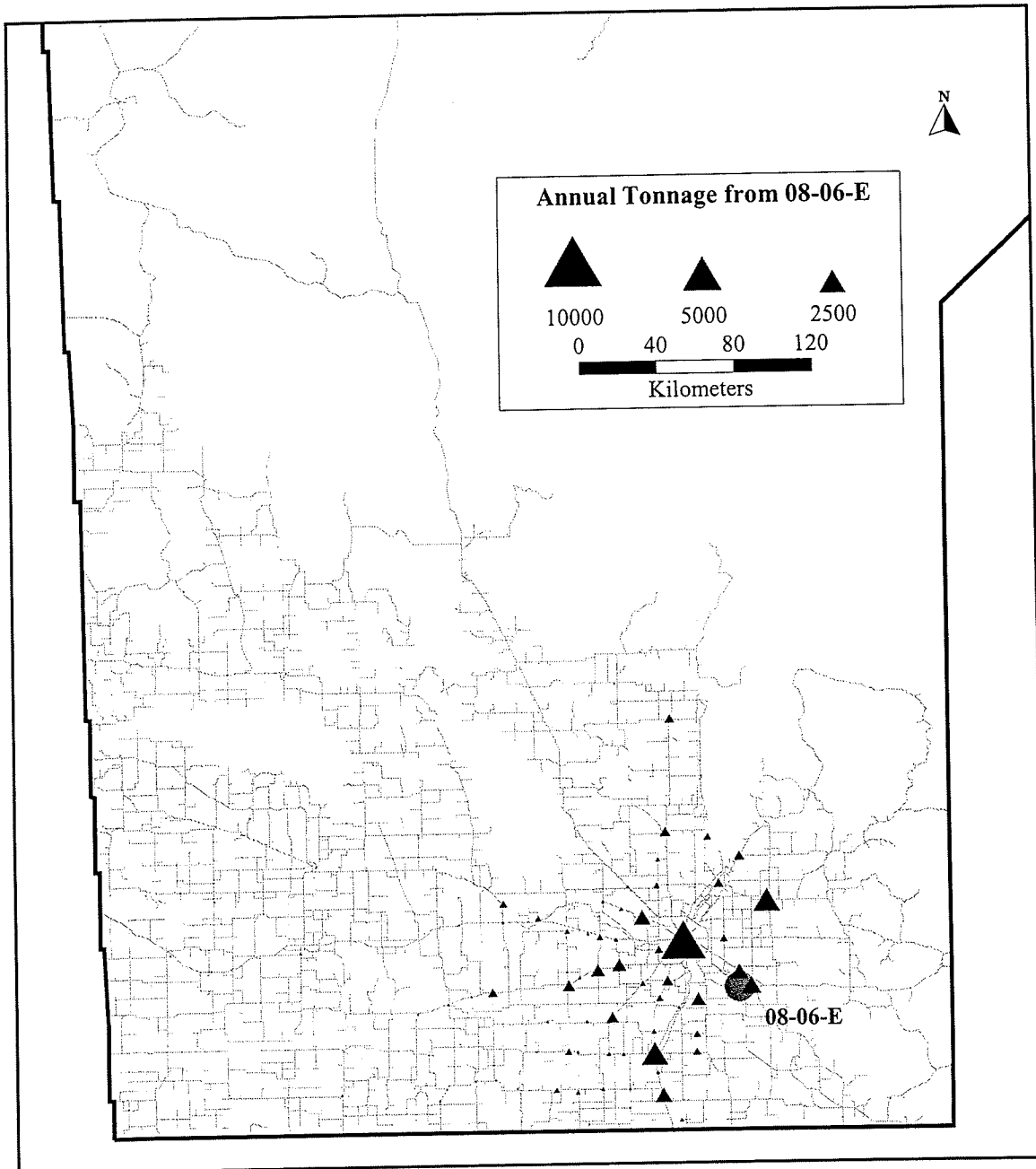


Figure 6.14: Arborg Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

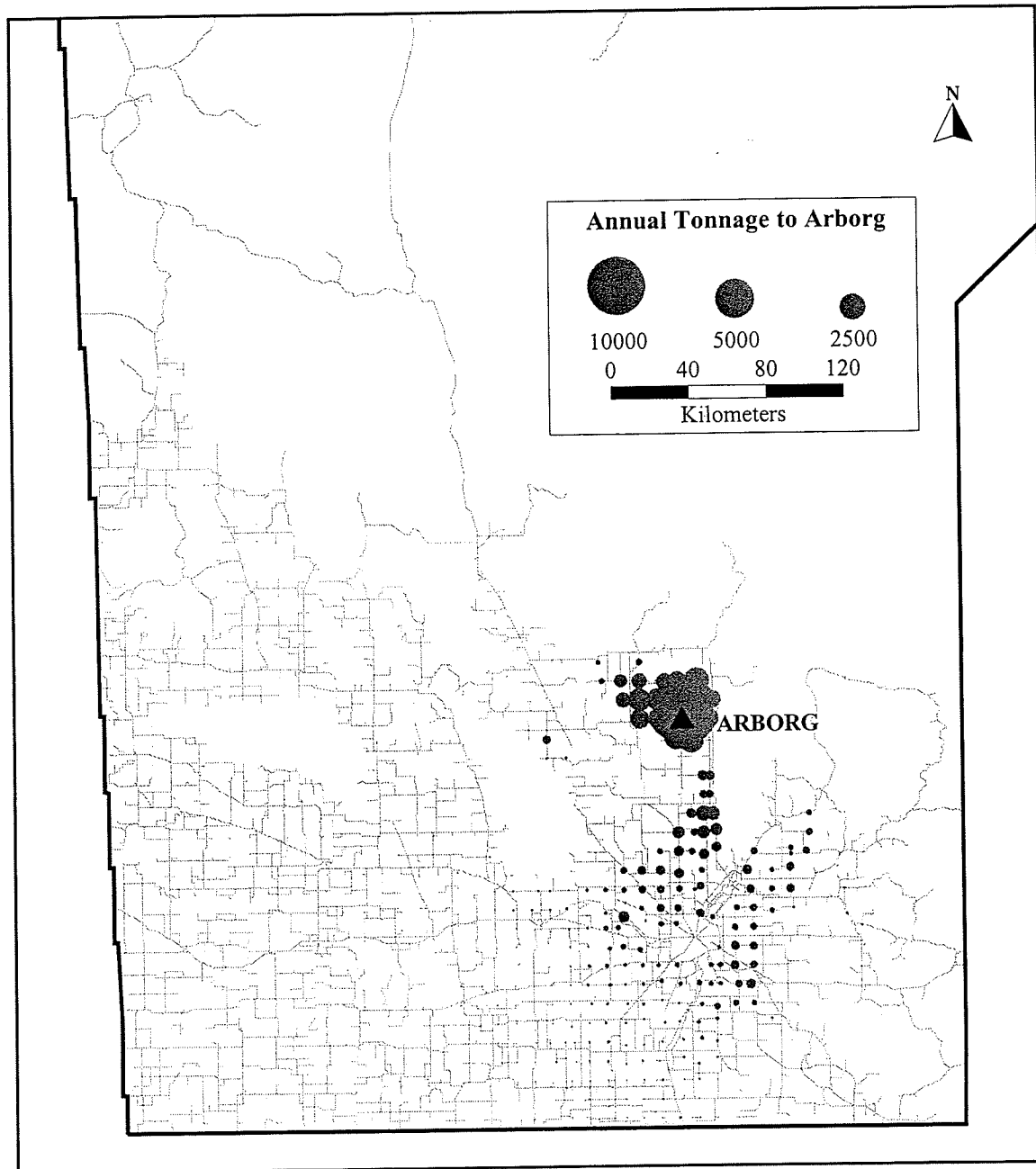
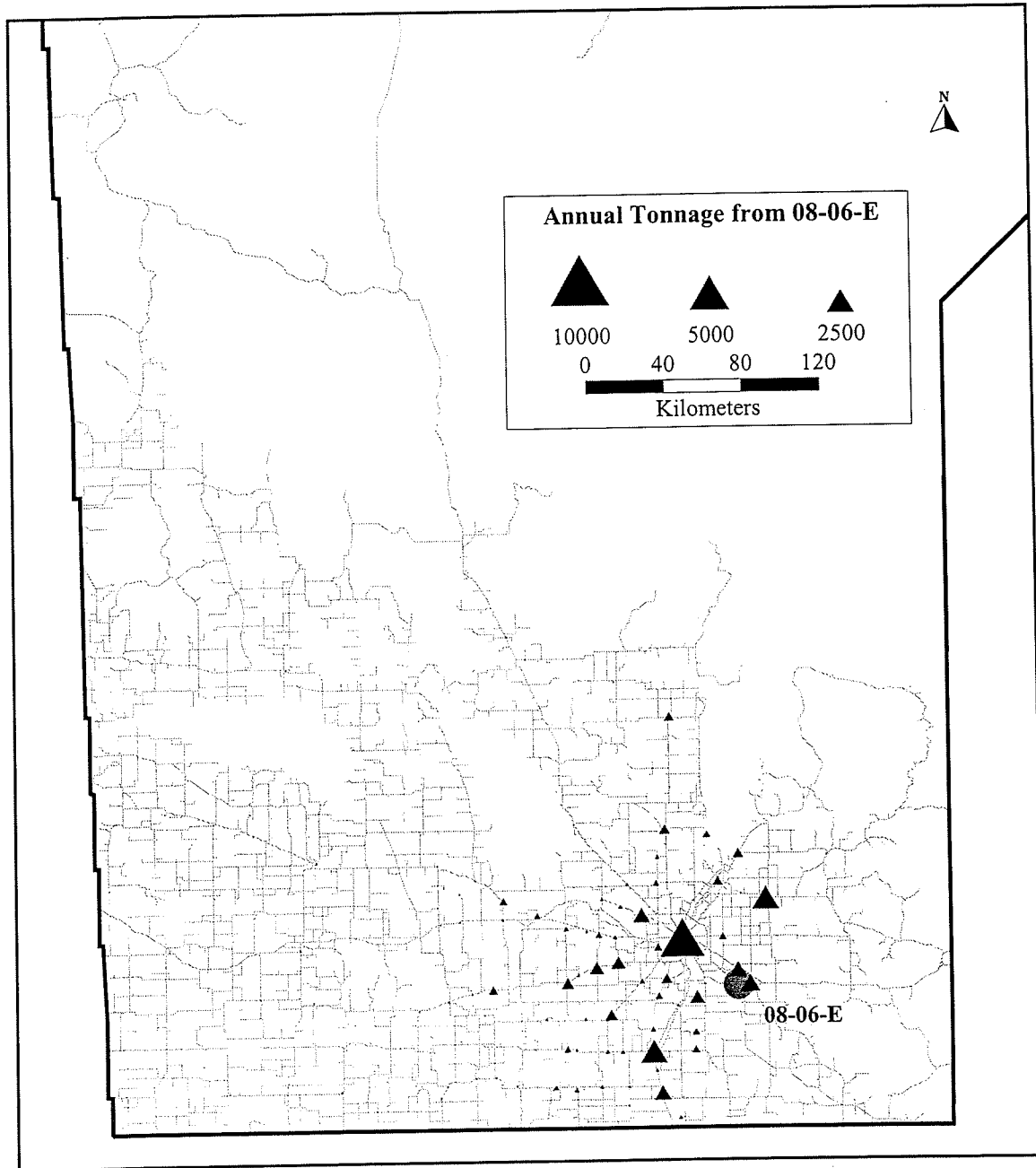


Figure 6.15: Township 08-06-E
Origin-Destination Results Based on Cost and Distance Calibration #2



The results of the first and second calibration of the cost-distance friction factors confirm that if a friction factor exists for an origin-destination pair, some volume of grain will move between the origin township and the destination grain delivery point. Therefore, the number of friction factors included in the gravity model for each origin township is the number of delivery points where grain from that township will be delivered. In reality, a producer deciding where to deliver grain does not consider every possible grain delivery point in the province. Instead, a producer decides between delivery points located in the surrounding area. The number of potential grain delivery points for each township must be reduced in order to better estimate grain movements in Manitoba.

For the third calibration, the number of destination grain delivery points for each origin township is limited to five. The five grain delivery points selected for each township are locations that are most attractive (largest friction factors). All other friction factors for each township are set to zero.

An origin-destination matrix is produced from the gravity model using the third calibration of the cost-distance friction factors. The ten delivery points and six township origins are again examined. The origin-destination results for the Arborg grain delivery point and Township 08-06-E are illustrated in Figure 6.16 and Figure 6.17, respectively. Figures for the remaining grain delivery points and townships are included in Appendix G.

Figure 6.16: Arborg Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

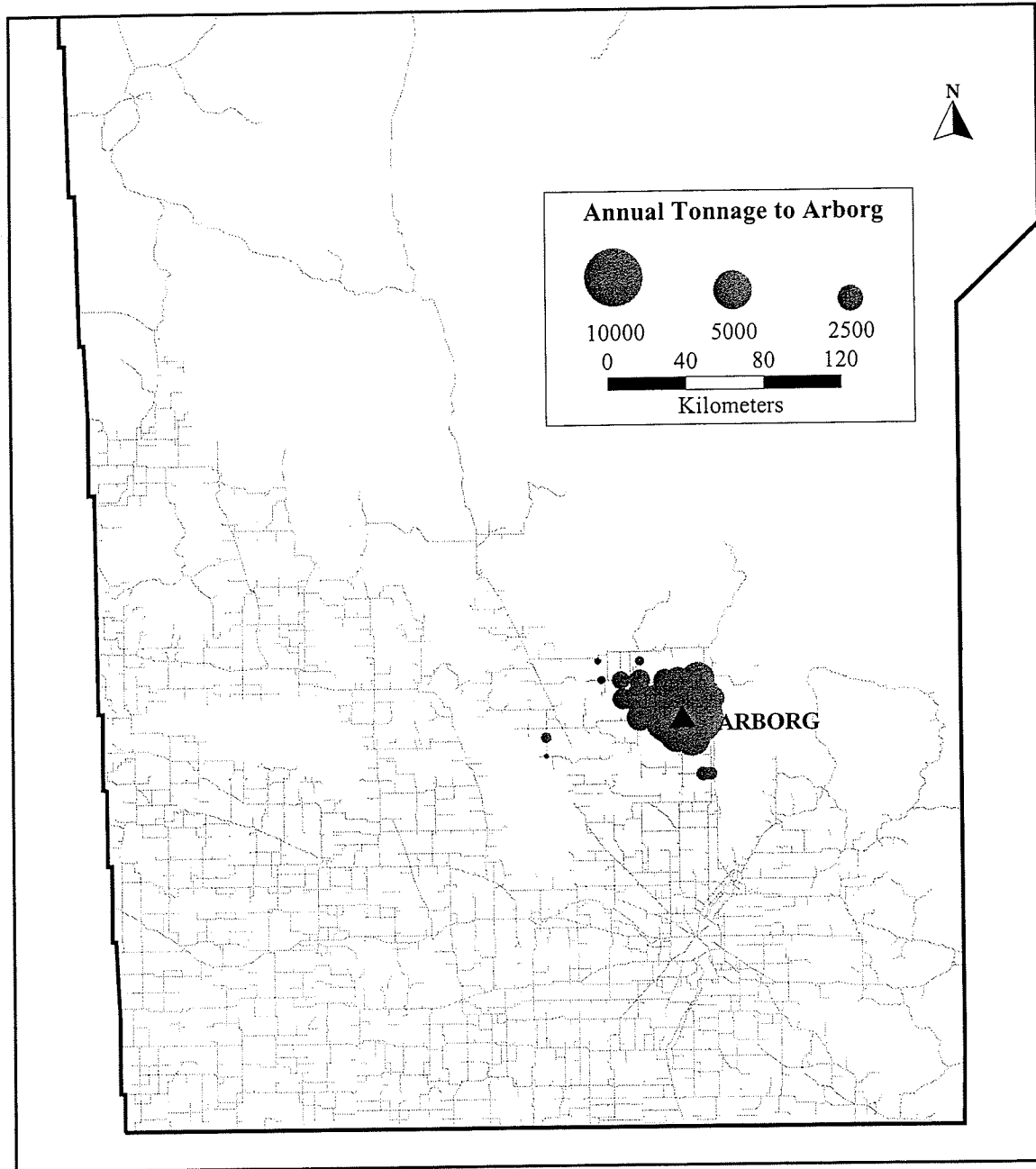
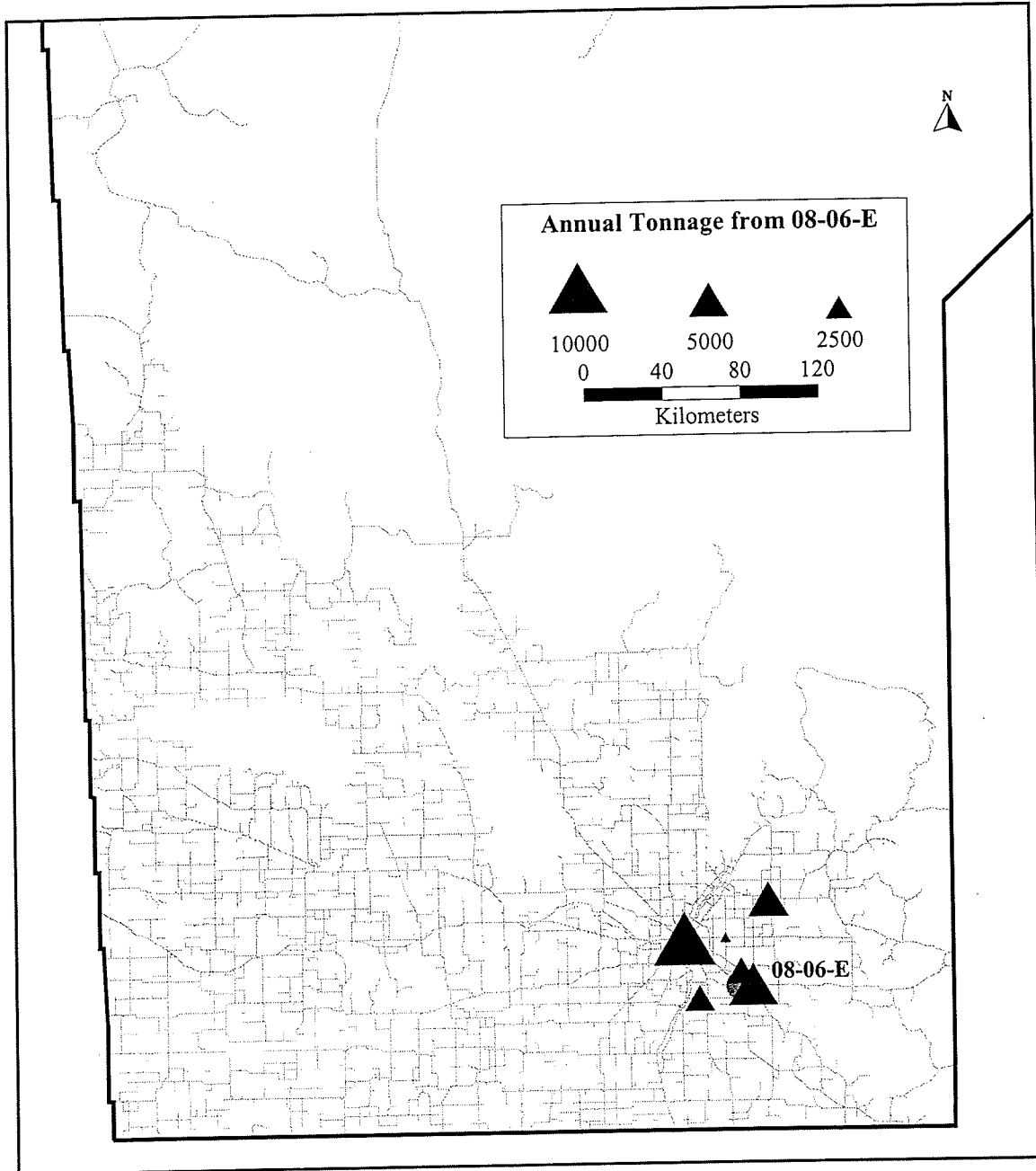


Figure 6.17: Township 08-06-E
Origin-Destination Results Based on Cost and Distance Calibration #3



Analysis of the origin-destination results for the third calibration of the cost-distance friction factors illustrates that there are no longer tiny volumes of grain travelling large distances across the province. Grain from each township is delivered to the most attractive delivery points, which include locations close to the origin township as well as locations that offer cost savings. The third calibration of the cost-distance friction factors is determined to be adequately predicting grain movements in Manitoba.

CHAPTER 7

FREIGHT ASSIGNMENT

This Chapter describes freight assignment, the final step in the freight forecasting model. Grain volumes on individual road links are estimated by assigning freight to the road network based on the origin-destination results from the freight distribution component of the model (Goulias and Eom, 2003 and Huang, 1998). The formation of a freight assignment network is described, and the results of the assignment process are evaluated.

7.1 MANITOBA FREIGHT ASSIGNMENT NETWORK

Freight assignment requires the construction of a network on which freight movements take place and freight flows are allocated (Black, 1999). The assignment network must connect all freight origins (townships) to all freight destinations (grain delivery points) (Black, 1999 and Sorratini, 1999). The highway network for a region is typically used as the freight assignment network, provided links where truck movements are prohibited or limited are removed from the assignment network or properly identified (Parsons, 1998).

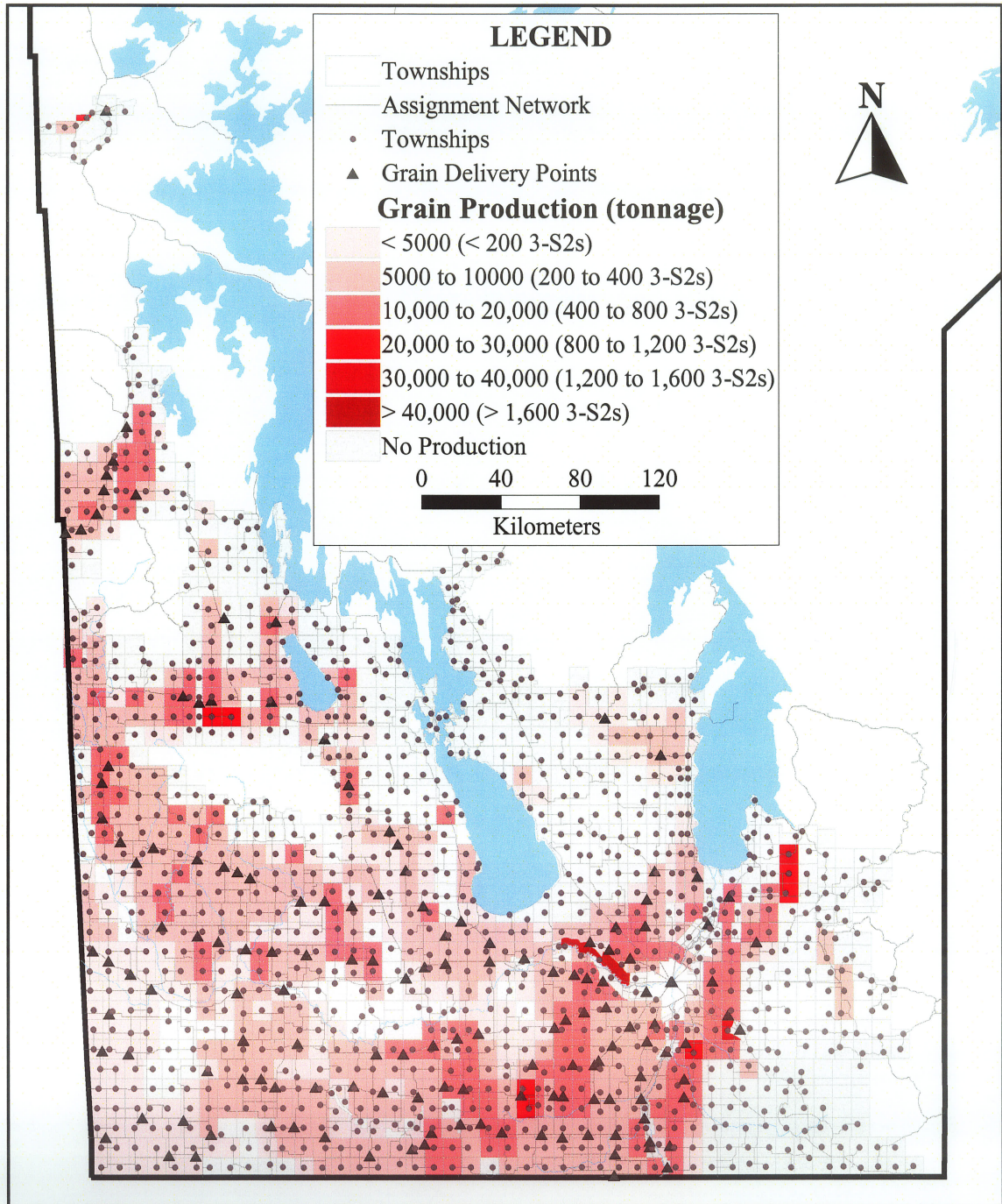
A detailed inventory of highway characteristics is available from Manitoba Transportation and Government Services (MTGS) for provincial trunk highways and roads in the province, including information on surface type, surface condition, number of lanes, divided or undivided, weight limits, traffic volumes, and bridge restrictions. Little to no information is available for the majority of municipal roads in Manitoba, which means there is no data to use to select between municipal roads and no way of determining a preferred route for grain haul on the municipal network. Most Manitoba

producers use paved roads for a large portion of their delivery trip, which indicates that the majority of the trip takes place on the provincial network (UMTI, 2001). Provincial trunk highways and roads are included in the freight assignment network for this research.

Although municipal roads are not included in the freight assignment network, select municipal roads are required to connect township centroids and grain delivery points to the freight assignment network. All township centroids and grain delivery points are examined to determine their locations with respect to the freight assignment network and the municipal road system. Municipal roads that offer the shortest route to the freight assignment network are selected and added to the assignment network.

Multiple municipal road connections are provided for township centroids or grain delivery points with more than one freight assignment network road link located within close proximity. Multiple connections are added so that the municipal links included in the network do not influence the assignment route chosen. The municipal links are identified as connections and are not used as through routes in the assignment process. Over 2,100 municipal road links totaling approximately 5,000 kilometres are added to the freight assignment network. The final freight assignment network, including the municipal connection links, is illustrated in Figure 7.1. Grain production by township along with origin township centroids and destination grain delivery points are also illustrated in Figure 7.1.

Figure 7.1: Manitoba Freight Assignment Network



Source: Canadian Grain Commission, 2000.

Certain areas in the province have little to no grain production and no grain delivery points. Although roads in these regions are included in the freight assignment network, these roads are not likely to be used to transport grain movements. Assignment of freight volumes should be concentrated on roads leading from and to townships centroids and grain delivery points.

7.2 FREIGHT ASSIGNMENT

Volume to capacity ratios are examined on a link-by-link basis for the freight assignment network to ensure that the All-or-Nothing assignment method is suitable for grain movements in Manitoba. The majority of roads in Manitoba are operating well below capacity (volume to capacity ratio less than 0.8), and there are few traffic volume or capacity issues in the province that would cause a shift from the shortest, quickest and most direct route between origin-destination pairs.

The assignment of grain flows from the origin-destination results to the Manitoba freight assignment network is based on the travel "cost" of moving from an origin to a destination within the network. Travel costs can be a function of a number of variables, including distance, travel time, and capacity (Black, 1999).

As previously discussed, there are few, if any, capacity constraints on the Manitoba freight assignment network, and link capacities are not expected to affect the freight assignment process. Therefore, capacity is not selected as the travel cost in this research. Specific link travel times are not known for the Manitoba freight assignment network,

however, they can be calculated based on the link distance and average travel speed. Speed limits are often used in place of average travel speed to calculate travel times, however, this can result in an overestimation of travel times, as the average travel speed is often higher than actual speed limits on rural road networks.

Information on road lengths are readily available and travel distance on the Manitoba freight assignment network is selected as the link travel cost for this research. However, there are differences between road links besides travel distance that can make one route more attractive than another. Whether the roadway is divided or undivided, the surface type, the surface condition, allowable weight limits, and bridge restrictions all impact the selection of a grain delivery route. Link travel costs must be adjusted to account for the differences in road characteristics on the freight assignment network.

7.2.1 Link Adjustments for the Freight Assignment Network

Road characteristics can make one travel link more or less attractive than other road links in the network. If a road link is more attractive than a second road link, travel is more likely to take place on the first link. Link travel costs are modified to account for different road characteristics through the use of link adjustment factors. Link adjustment factors are estimated based on the characteristics that impact the selection of a travel route and are determined for each individual road link in the freight analysis network. Travel costs for municipal road links included in the assignment network are not adjusted.

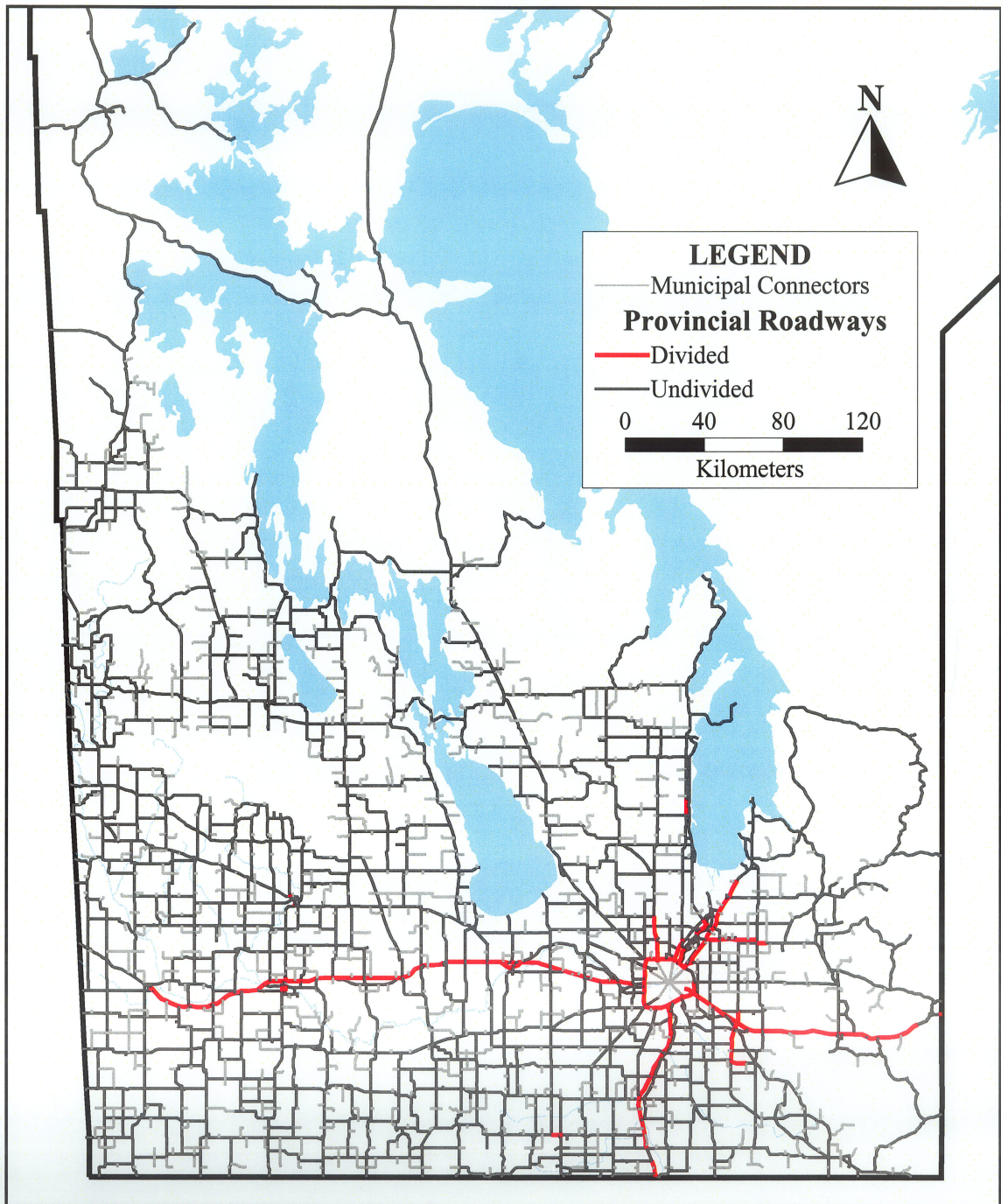
Road characteristics that impact travel route selection and are used to adjust link travel costs in this research include divided versus undivided roadway, surface type, surface condition of the road, weight class, and bridge restrictions. The link adjustments for the freight analysis network are summarized in Table 7.1 and described below. All link adjustments factors are greater than or equal to 1.0

Table 7.1: Link Travel Distance Adjustments

| Road Characteristic | Rating | Distance Adjustment |
|----------------------------|--|----------------------------|
| Divided versus Undivided | Divided | -- |
| | Undivided | + 10 % |
| Surface Type | Paved | -- |
| | Unpaved | + 15 % |
| Surface Condition | Good | -- |
| | Moderate | + 4 % |
| | Poor | +8 % |
| Weight Class | RTAC | -- |
| | Class A1 | + 25 % |
| | Class B1 | + 50 % |
| Bridge Restriction | Determined on an individual basis for each bridge location | |

- Provincial trunk highways and roads are classified as divided or undivided roadways. The distribution of divided and undivided roads is illustrated in Figure 7.2. Divided roadways are higher class facilities with additional lanes and are more desirable and attractive than undivided roadways. Link travel distances for all undivided roadways are increased by 10 percent. Any links in the freight assignment network with no divided/undivided information are assumed to be undivided.

Figure 7.2: Divided Versus Undivided Roadways



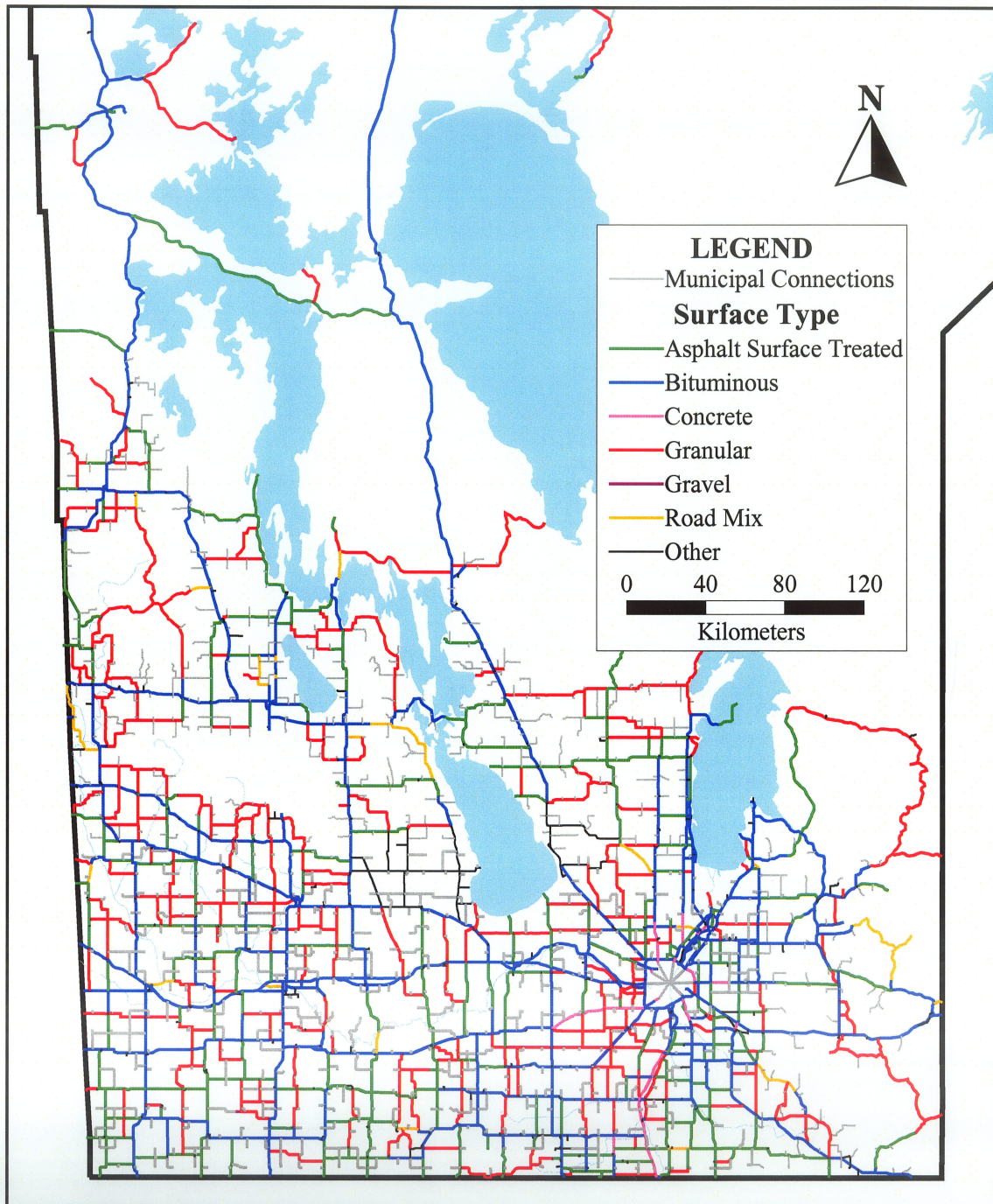
Source: 1999 Highway Inventory Database, Manitoba Transportation & Government Services, 2001.

- Surface types for provincial trunk highways and roads are illustrated in Figure 7.3 and include asphalt surface treated, bituminous, concrete, road mix, granular, and gravel. Paved roadways (asphalt surface treated, bituminous, concrete, and road mix) are more desirable and attractive than unpaved roadways (granular and gravel). Link travel distances for all unpaved roadways are increased by 15 percent. Any links in the freight assignment network with no surface type information are assumed to be unpaved roadways.
- MTGS measures pavement quality in Manitoba in terms of the smoothness of the pavement surface. The International Roughness Index (IRI) is used to measure pavement roughness on a scale of 0.0 to 5.0. IRI ratings were previously converted into three broad categories of pavement conditions for the *Prairie Provinces Transportation System Study* (DS-Lea et al., 1998), and these same classifications will be used in this research and are as follows:
 - Roadway links with IRI values less than 2.5 ($IRI < 2.5$) are considered to be in good condition.
 - Roadway links with IRI values between 2.5 and 3.5 ($2.5 \leq IRI < 3.5$) are considered to be in moderate condition.
 - Roadway links with IRI values greater than or equal to 3.5 ($IRI \geq 3.5$) are considered to be in poor condition.

The surface condition of roadways in the freight assignment network is illustrated in Figure 7.4. To account for different surface conditions, travel distances are increased by four percent for roads in moderate condition and increased by eight percent for roads in poor condition. Any links in the freight assignment network with no surface condition information are assumed to be in moderate condition.

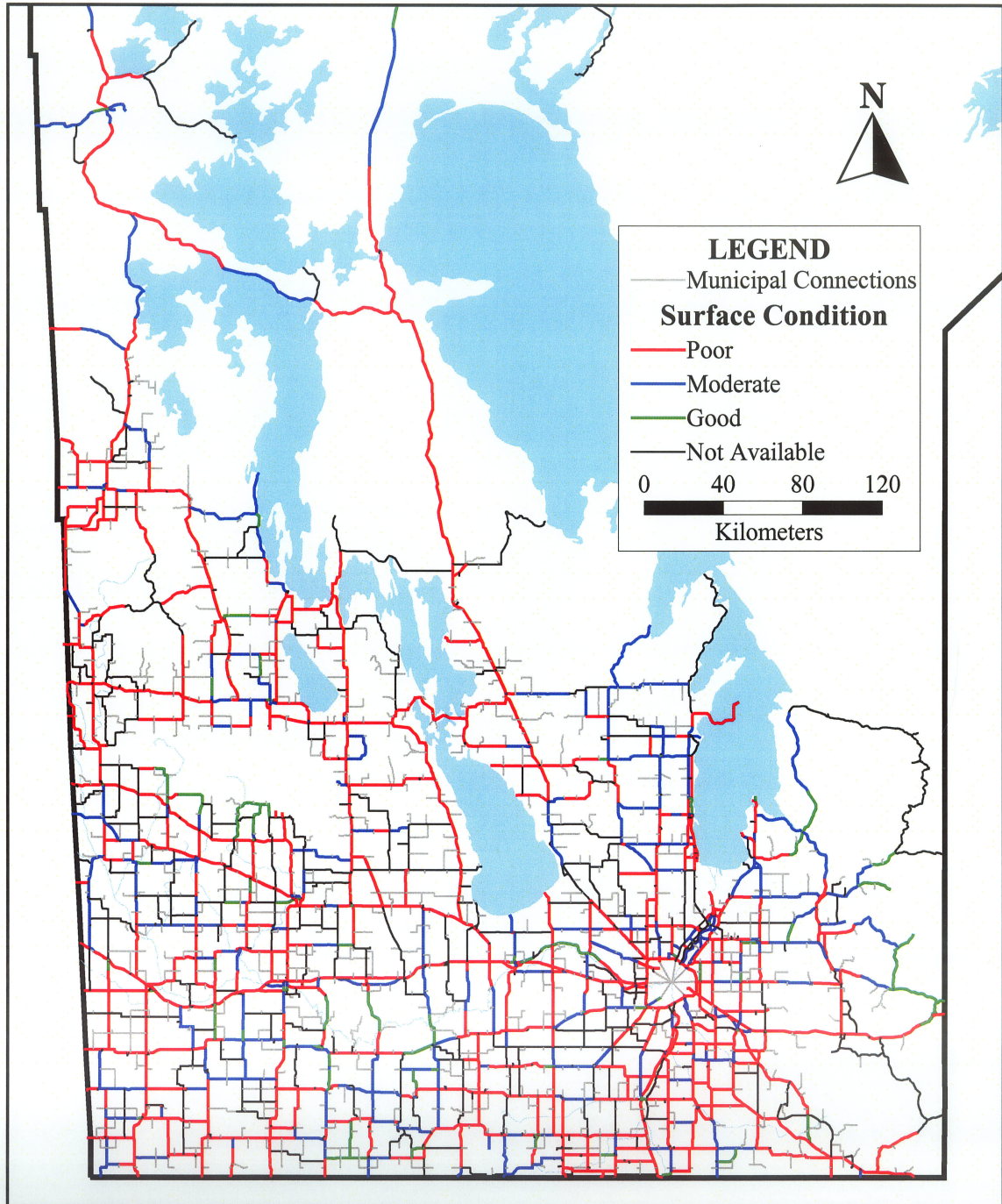
- Provincial trunk highways and roads are classified by the maximum number of truck loadings they can accommodate on a year-round basis (some roadways have seasonal loadings restrictions) (DS-Lea et al., 1998). Weight classes in Manitoba are defined according to their maximum allowable gross vehicle weight limits and include the following:
 - Roadways classified as RTAC facilities allow the highest weight loadings and permit vehicles with a maximum gross vehicle weight up to 62.5 tonnes.
 - Class A1 facilities allow medium weight loadings and permit vehicles with a maximum gross vehicle weight up to approximately 55 tonnes.
 - Class B1 facilities allow the lowest weight loadings and permit vehicles with a maximum gross vehicle weight up to approximately 47 tonnes.

Figure 7.3: 1999 Surface Types



Source: 1999 Highway Inventory Database, Manitoba Transportation & Government Services, 2001.

Figure 7.4: 1999 Surface Condition



Source: 1999 Highway Inventory Database, Manitoba Transportation & Government Services, 2001.

Weight classes on the Manitoba freight assignment network are illustrated in Figure 7.5. RTAC routes are considered the most attractive roadways as they allow the largest and heaviest vehicles. Link travel distances are increased by 25 percent for Class A1 roads and increased by 50 percent for Class B1 roads. Any links in the freight assignment network with no weight information are assumed to be Class B1 roads.

- Bridges in Manitoba have specific weight limits that are dependant on the structural capacity of the bridge. All 2,656 bridge locations on the Manitoba freight assignment network are examined and compared to the allowable weight limit on the affected link to determine if the bridge weight limit is more restrictive than the weight class of the road link. Roadways with restrictive bridge limits are illustrated in Figure 7.6. Link travel distances are adjusted on an individual basis depending on how much more restrictive the bridge limit is as compared to the weight class of the road link.

The link adjustments are applied to actual travel distances through a link impedance function to estimate the adjusted travel distance for each road link. The link impedance function is as follows:

$$L_j = l_j * r_j$$

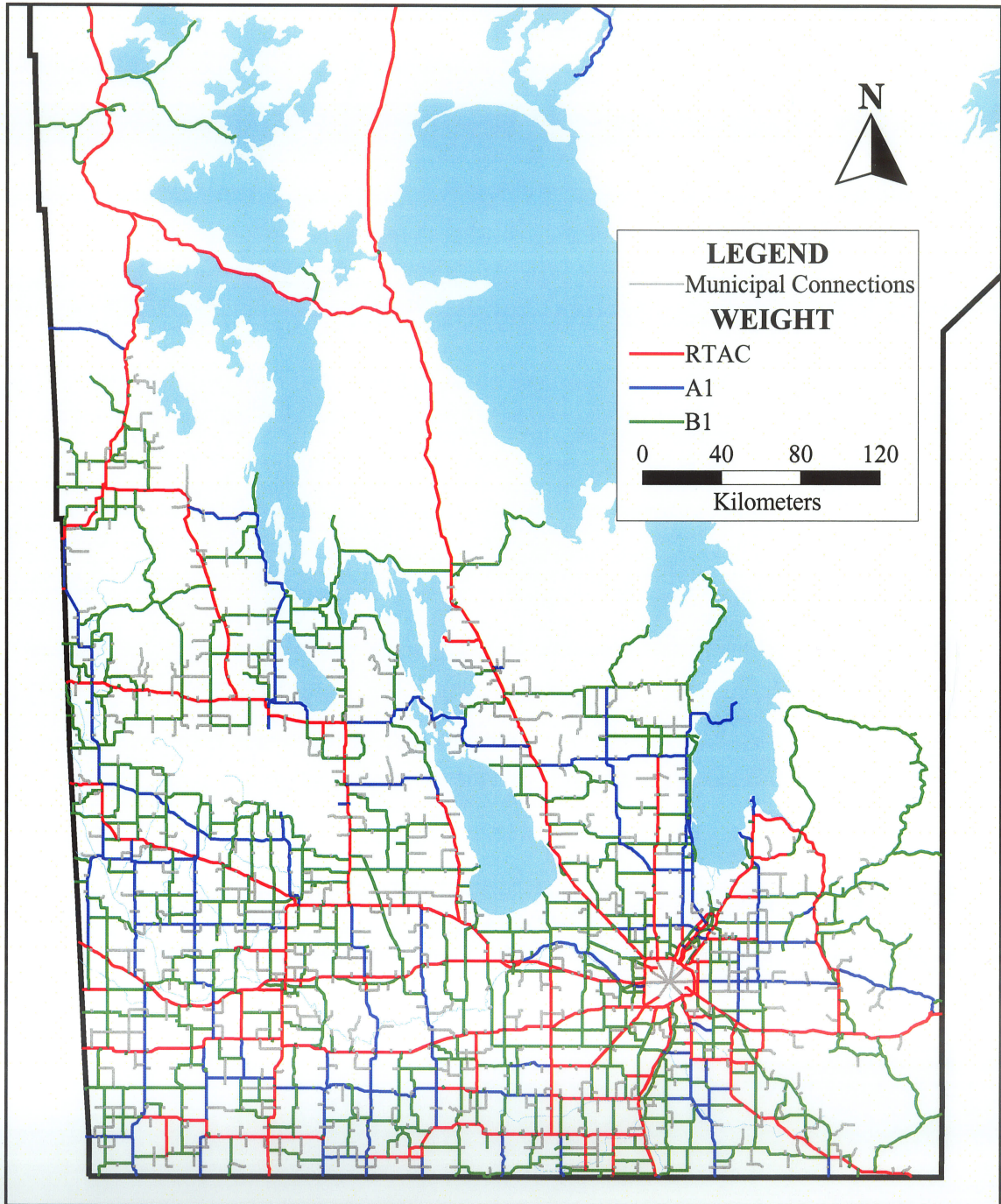
$$r_j = r_{\text{divided/undivided}} * r_{\text{surface type}} * r_{\text{surface condition}} * r_{\text{weight class}} * r_{\text{bridge restriction}}$$

where

- L_j = adjusted length of link j in kilometres
- l_j = actual length of link j in kilometres
- r_j = total travel distance adjustment factor for link j; function of divided versus undivided, surface type, surface condition, weight class, and bridge restrictions

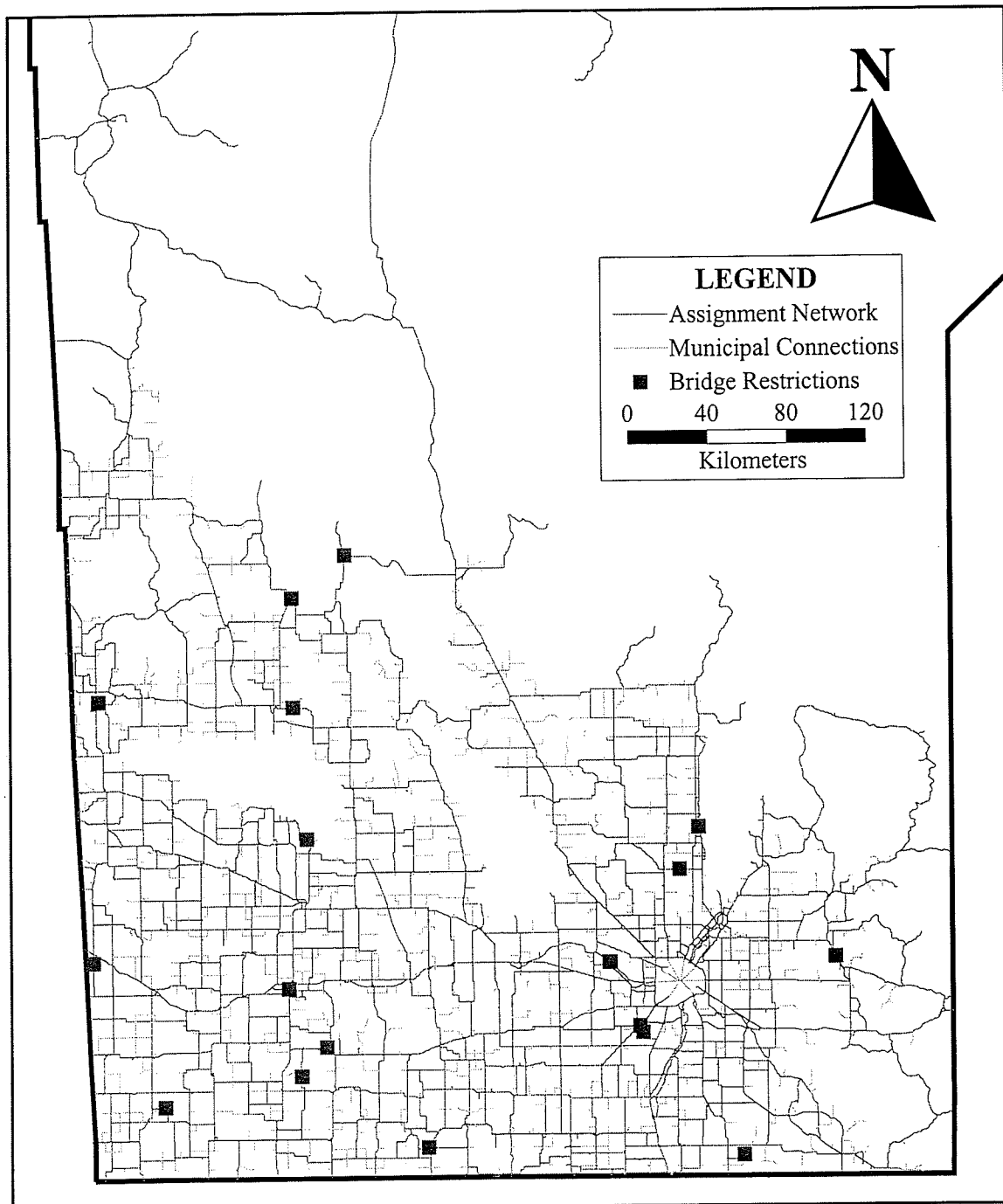
For example, consider two alternative routes from an origin township to a destination delivery point. The first route is approximately 20 kilometres in length and consists of undivided gravel road links with moderate surface conditions and Class A1 weight restrictions. There are no additional bridge restrictions on the travel route. The adjusted length of the first route is calculated as follows:

Figure 7.5: 1999 Weight Classes



Source: 1999 Highway Inventory Database, Manitoba Transportation & Government Services, 2001.

Figure 7.6: 2001 Bridge Restrictions



Source: Manitoba Transportation & Government Services, 2001.

$$L_1 = l_1 * r_1 = l_1 * (r_{1div/undiv} * r_{1surface\ type} * r_{1surface\ condition} * r_{1weight\ class} * r_{1bridge})$$

$$L_1 = 20 * (1.10 * 1.15 * 1.04 * 1.25 * 1.00)$$

$$L_1 = 32.89 \text{ kilometres}$$

The second route is 50 percent longer than the first route (approximately 30 kilometres), but consists of divided, paved, RTAC roadways in good surface conditions. There are no additional bridge restrictions on the travel route. The adjusted length of the second route is calculated as follows:

$$L_2 = l_2 * r_2 = l_2 * (r_{2div/undiv} * r_{2surface\ type} * r_{2surface\ condition} * r_{2weight\ class} * r_{2bridge})$$

$$L_2 = 30 * (1.00 * 1.00 * 1.00 * 1.00 * 1.00)$$

$$L_2 = 30.00 \text{ kilometres}$$

Although the first route is substantially shorter than the second route, the surface type, condition and weight restrictions associated with the first route make it less attractive as a delivery path than the second route. Grain moving from the origin township to the grain delivery point would travel on the second route.

7.2.2 Freight Assignment Results

Once the adjusted link travel distances are determined, the origin-destination results from the freight distribution component are used to distribute grain flows to the freight assignment network using the All-or-Nothing assignment process. All grain moving from an origin township to a destination grain delivery point travels via the same route.

The resulting assignment of grain tonnages on the Manitoba freight assignment network is illustrated in Figure 7.7.

Evaluation of the freight assignment results is not a straightforward process. Transportation engineers and planners often look at the forecast distribution of movements and retain the freight assignment if it is relatively close to the observed distribution (Black, 1999). There is no information available that specifically describes the distribution of grain haul movements from townships to delivery points on roadways in Manitoba to compare with the assignment results. Existing average annual daily truck traffic (AADTT) volumes are available for the provincial network in Manitoba and are illustrated in Figure 7.8.

Total truck volumes are not considered to be a good measure of commodity flows on highways. Total truck volumes include all commodity movements, delivery and large service vehicles, as well as empty vehicles, which means that truck counts are considerably larger than individual commodity flows (Black, 1999). When the freight assignment results in Figure 7.8 are compared to the daily truck volumes in Figure 7.9, differences in the distribution of movements are obvious. In the freight assignment figure, grain volumes are highest on roadways leading directly to major grain delivery points. Comparatively, daily truck volumes in the truck traffic figure are highest on major inter-provincial roadways including Trans Canada Highway 1, Highway 16, and Highway 75. Daily truck volumes are relatively low on certain roadways leading to major grain destinations, including roadways around the Dauphin, Rathwell, and Killarney delivery points.

Figure 7.7: Grain Assignment

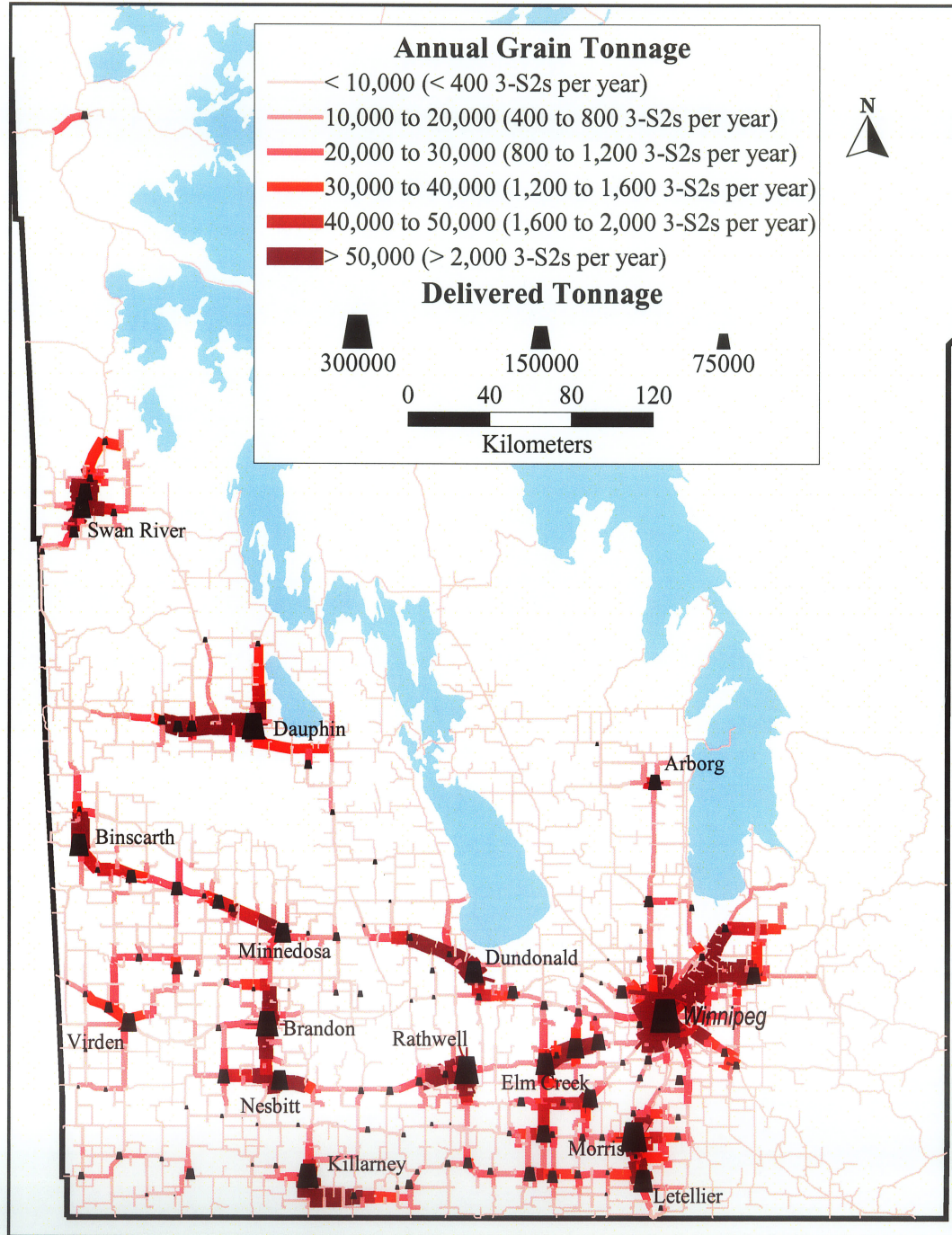
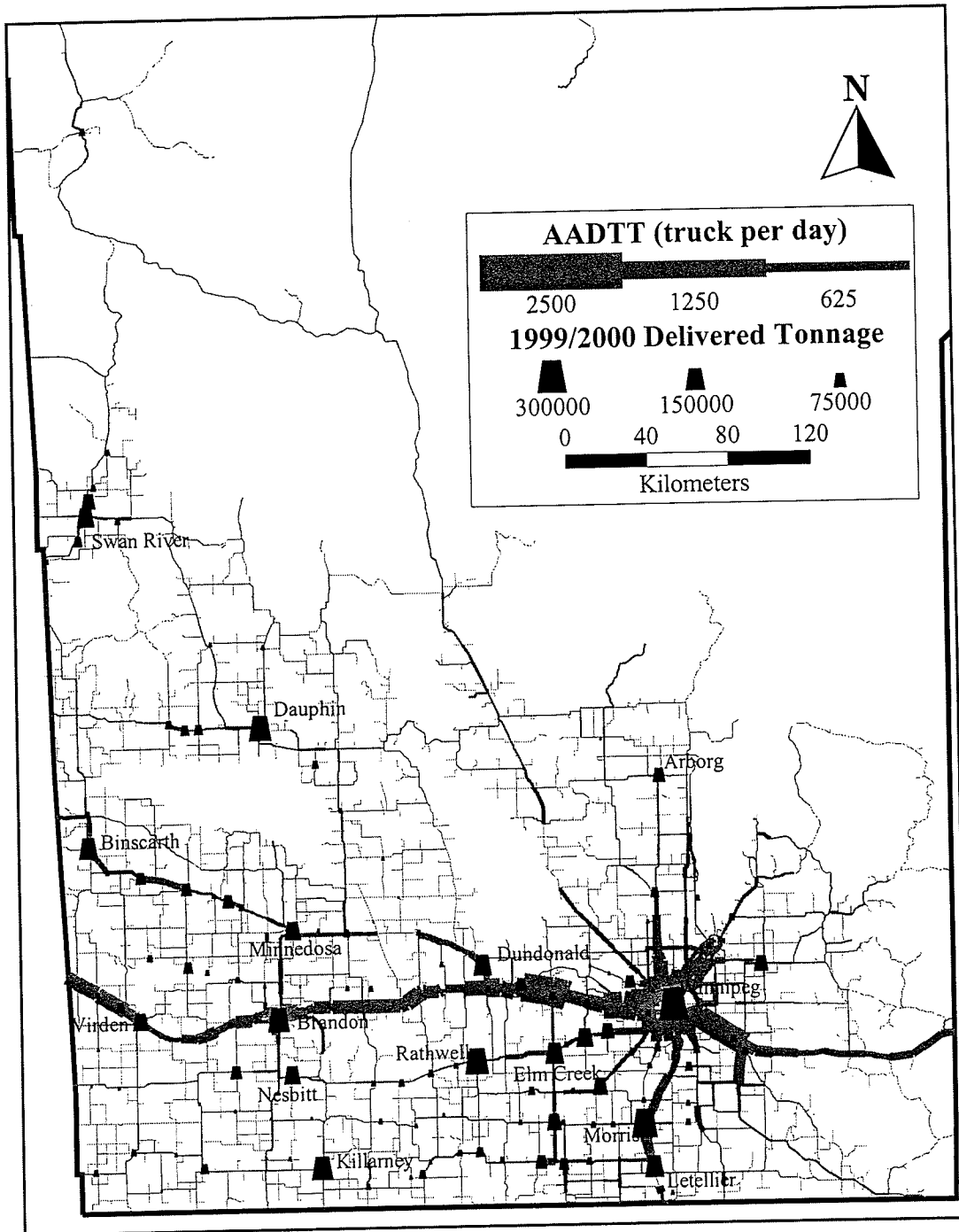


Figure 7.8: 2000 Average Annual Daily Truck Traffic (AADTT)



Source: Manitoba Transportation & Government Services, 2001.

Representatives of Manitoba Transportation and Government Services, Manitoba Agriculture and Food, Prairie Farm Rehabilitation Administration, and the Association of Manitoba Municipalities reviewed the grain assignment patterns to confirm the results of the forecasting model. Based on their experience, the reviewers agreed that the assignment results were reasonable and are adequately representing the movement of grain from farm to elevator in Manitoba. The vast majority of grain travels to the closest delivery point available. However, grain is also transported longer distances to high throughput elevators that offer cost incentives to producers. Large volumes of grain are present on roads leading directly to major delivery points throughout the province.

7.3 APPLICATION OF THE MANITOBA GRAIN FORECASTING MODEL

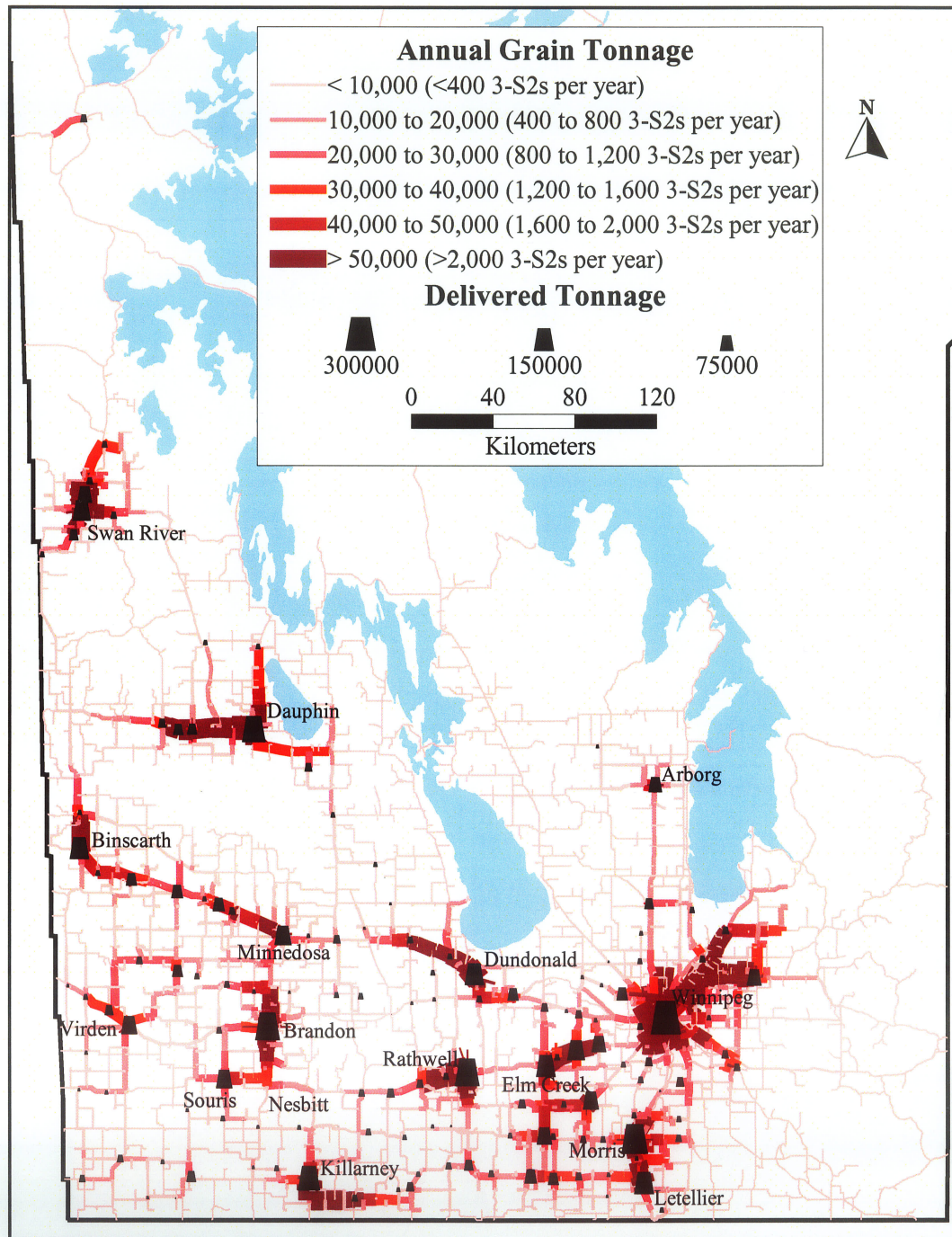
Once the freight forecasting model developed for the grain industry in Manitoba was determined to be accurately predicting grain movements from township to grain delivery point, the model was used to investigate the removal of a grain delivery point from the network. A large grain delivery point was selected for the analysis as the results of the closure of a major delivery location are expected to be more obvious in the subsequent traffic assignment. The Nesbitt grain delivery point, located south of Brandon on Highway 2, was selected at random for closure. Approximately 114,4000 tonnes of grain were delivered to the Nesbitt grain delivery point during the 1999/2000 crop year.

Grain attraction at the Nesbitt delivery point was set to zero and all friction factors associated with Nesbitt were also set to zero. Grain attracted to the Nesbitt delivery point in the base model was shifted to other delivery points based on the friction factors for

townships that delivered to Nesbitt in the base model, as well as the volume of grain destined for the other delivery points in the area surrounding Nesbitt. New origin-destination results were generated from the gravity model and used to distribute grain flows to the freight assignment network using the All-or-Nothing assignment process. The resulting assignment of grain tonnages on the Manitoba freight assignment network with the closure of the Nesbitt grain delivery point is illustrated in Figure 7.9.

The assignment results illustrate that grain delivery points in the area surrounding Nesbitt are receiving more grain than in the base grain assignment. Grain originally destined for Nesbitt is being delivered to nearby delivery points, including Souris East, Brandon (CN), Elgin, and Cypress River. Grain volumes on roadways around Nesbitt confirm that grain is being transported to alternate delivery points. Grain volumes on roadways in unaffected parts of Manitoba, such as the areas around Winnipeg or north of Highway 16, remain unchanged from the base grain assignment.

Figure 7.9: Grain Assignment - Nesbitt Grain Delivery Point Closure



CHAPTER 8

DISCUSSION AND CONCLUSIONS

This research selects, develops, applies and evaluates a model for forecasting freight movements by commodity on a rural road network. The selected methodology is applied to forecast grain movements in Manitoba. The research creates a model that can be adapted to forecast freight movements for other commodity types in order to develop a better understanding of freight activity. Policy and decision makers can use the resulting freight forecasts to assist in making informed decisions about transportation planning and engineering applications.

This Chapter presents regional freight forecasting methodologies and discusses the selection and application of a methodology to forecast grain movements on the Manitoba freight assignment network. Further applications of the grain forecasting model are suggested and lessons learned during the research are identified. Requirements for future research in the area of regional freight forecasting are also provided.

8.1 REGIONAL FREIGHT FORECASTING

Existing regional freight forecasting methodologies were compared during the course of this research. A modified version of the traditional four-step urban transportation planning process -- the three-step freight forecasting method -- is the most widespread methodology in use. The three-step freight forecasting method involves freight generation, freight distribution, and freight assignment. The model estimates freight movements for a single travel mode without considering modal competition or multi-

modal transportation. This is a reasonable assumption for the grain application, as all grain movements from field to elevator in Manitoba are transported using trucks.

Freight generation estimates the location and volume of goods produced and consumed within a particular region. The amount of freight moving between origins and destinations in the study region is estimated during the freight distribution process. The gravity model is the most commonly used freight distribution method and is the procedure utilized in this research. Freight assignment, the final component in the three-step freight-forecasting model, assigns actual freight volumes to individual road links in the assignment network. Various assignment methods are available; however, the All-or-Nothing assignment procedure is the one most frequently used in regional freight forecasting models and is the approach applied here. This is a reasonable assignment procedure for the grain application since link capacities and road congestion, which are not considered in the All-or-Nothing method, do not affect truck movements on the Manitoba rural road network.

Commodity-based and trip-based methodologies were considered for the forecasting model. Both methodologies have been used for regional freight forecasting. However, the commodity based methodology is based on the economic activities of a region and results in a more powerful freight forecasting model, and is therefore the methodology adopted in this research.

8.2 MANITOBA GRAIN FORECASTING METHODOLOGY

The first step in the application of the three-step freight forecasting methodology to the grain industry in Manitoba is the development of a GIS-T platform. Grain production and attraction freight analysis areas were defined and the Manitoba road transportation network was obtained.

Information on grain production and attraction was available from various sources and was linked to the geographic files developed in the GIS-T platform. After considering the options of transport cost and then distance, a combination of transport cost and distance was ultimately selected as the measure of impedance for the gravity model. Friction factors (measures of attractiveness) were determined based on the combination of transport cost and distance. The friction factors were calibrated based on prior research of grain haul behaviour and movements from production areas to grain elevators. The calibration of the friction factors considered the distance between townships and grain delivery points and the estimated tonnage of grain traveling between townships and grain delivery points. The final calibration of the gravity model limits the number of potential destination grain delivery points for each origin township to five. The five grain delivery points selected for each township are those locations with the highest level of attractiveness (highest friction factors).

The origin-destination information developed in the gravity model is assigned to the freight assignment network developed for the grain industry in Manitoba. Development of the assignment network requires road characteristic information in order to make

choices between available travel routes. Information on divided or undivided links, surface type, surface condition, weight class, and bridge restrictions are included in the freight assignment network. The final assignment results from the freight forecasting model represent grain movements from farm to elevator in Manitoba. Most grain is hauled to the closest delivery point available; however, some grain is also transported longer distances to high throughput elevators that offer cost incentives to producers. Large volumes of grain are forecast on roads leading to major delivery points throughout the province.

8.3 FURTHER APPLICATIONS OF THE GRAIN FORECASTING MODEL

Potential uses for the freight forecasting model developed for the grain industry in Manitoba are:

- The results of the model can provide a technical foundation for decision makers. The freight assignment results can be used to assist policy makers in making decisions on where to allocate funds for road improvements and maintenance.
- The freight assignment results generated by the model can be compared to current road improvement projects. A GIS layer showing proposed or completed projects can be added to the figure illustrating traffic volumes for comparison purposes.
- The freight assignment results can be compared to road characteristics included in the Manitoba highway inventory database. Forecast grain volumes on provincial trunk highways and roads can be compared with traffic volumes, surface type, surface condition, maintenance history, weight restrictions, speed limits, or any other characteristic included in the database.
- The model can be used to conduct detailed analysis of a selected area, such as a specific rural municipality. This type of analysis would involve adding municipal roads to the freight assignment network and restricting the analysis to production areas and grain delivery points within and surrounding the study area. For a smaller area, additional production locations could also be included in the model for grain assignment results at a more detailed level.

- The effects of adding or eliminating grain delivery points can be investigated using the model. Grain is redistributed and reassigned based on a revised origin-destination matrix. The results can be used to assess potential road impacts due to grain movements shifting to other roads to access alternate delivery points.
- Changes in grain haul patterns due to the closure of a section of road, either permanently or temporarily during construction, periods of flooding, or for other reasons, can be investigated using the model. The affected link can be disabled in the freight assignment network and the grain reassigned to the modified assignment network.
- The effects of changes in weight restrictions on the freight assignment network can be investigated using the model. Grain can be assigned to the road network for various provincial weight restriction scenarios (e.g., increase weight restrictions on selected roads to RTAC limits, increase weight restrictions on selected roads to A1 limits, reduce weight restrictions on selected roads to reflect spring restrictions, etc.) to determine the impacts on grain haul patterns.
- The freight forecasting methodology developed for grain movements in Manitoba can also be adapted to examine products such as potatoes, dairy products, oil seeds, manufactured goods, or value-added commodities. A similar process to determine the applicable costs and distances to transport other commodities can be used to develop friction factors and generate origin-destination information.

8.4 LESSONS LEARNED

Throughout the research, a number of items were discovered and identified that would be of use in similar future research and would make future freight forecasting initiatives easier. Lessons learned during the course of this research include:

- No commodity flow data is available at the township and grain delivery point level for grain movements in Manitoba. Origin-destination information collected by commodity type could be used to calibrate the friction factors and verify the freight assignment results for forecasting models. For this research, a manual iterative process was used to calibrate the gravity model.
- Grain production data does not equal grain attraction information for the forecasting model. This may occur during similar research for other commodities, as production and attraction information are often obtained from different sources. Evaluation of the quality and reliability of data sources is necessary to determine the appropriate information for use in the model.

- The grain forecasting model assumes that all grain produced in Manitoba is destined for grain delivery points in the province, and vice versa. In reality, grain produced and delivered in Manitoba moves from and to the province. Integrating freight movements within, through, and to and from an analysis region would enhance the forecasting model and provide better estimates of total freight movements.
- Friction factors were determined for movements between all townships and grain delivery points in the model. However, grain originating in a township is shipped to a limited number of grain delivery points located in the surrounding area, and many frictions factors were set to zero during the calibration process. It is not necessary to determine friction factors for all origin-destination pairs in the forecasting model.
- The calibration process involved modifying friction factors in order to eliminate tiny movements of grain (less than one or two 3-S2's per year). The end result of the forecasting model is directed at pragmatic engineering considerations and plus or minus one or two trucks per day is not significant. Freight movements of this magnitude do not provide an increased understanding of freight activity in Manitoba, and calibration to this level of detail is not required.
- Adjustments were made to link travel distances in the freight assignment network to account for divided versus undivided roadways, surface type, surface condition, weight class, and bridge restrictions. The adjustments for divided versus undivided, surface type and surface condition are relatively small, increases of 15 percent or less. However, the adjustments for weight classes and bridge restrictions are much larger, with increases up to 50 percent for Class B1 roads. The assignment process and the route selection are primarily driven by weight class and bridge restrictions, and minor adjustments for other road characteristics are not always necessary.
- All provincial trunk highways and roads in Manitoba are included in the freight assignment network for this research. However, there are regions in the province that are not involved in grain production or delivery as well as portions of the provincial network that are not used for transporting grain. These regions and roadways are not required in the freight analysis network for the model.

8.5 FUTURE CONSIDERATIONS

The following issues were identified for future consideration:

- Grain production information for Manitoba is available by rural municipality and was distributed to townships based on 1994 Land Use Imagery data and Manitoba Crop Insurance Corporation soil rating maps. Changes in production areas can occur that may modify the grain distribution and impact the freight forecasting results.

- Trucking incentives used in the model are based on analysis of incentives used in the Saskatchewan Road Impact Analysis and discussions with Manitoba grain companies. Additional information on the actual incentives offered by elevator companies would ensure that the trucking incentives used in the modeling process are accurate.
- Production areas selected for use in the model are townships, not individual farms. These origin locations provide adequate freight assignment results on a province-wide basis; however, the level of detail may not be adequate for smaller areas or when municipal roads are included in the assignment network.
- Cost information used in the model represents a single point in time. Truck haul rates, freight consideration rates, elevation charges, and trucking incentives all vary over time. Trucking incentives can change from one shipment to the next, while the other factors shift gradually over time. Significant changes in cost information can impact the model results.
- Grain is transported from production areas to delivery points in smaller producer-owned trucks as well as larger commercial vehicles. While haul rates are available for commercial vehicles, there is less information available for producer transport costs, as the perceived costs for producers using their own vehicles for delivery are more difficult to quantify. Haul rates used in the model are representative of commercial vehicles.
- In this research, transport cost, distance, and finally a combination of cost and distance were used to determine grain movements from townships to grain delivery points. Additional information about what factors producers consider when making their delivery decisions could improve the origin-destination and subsequent grain assignment results.
- Municipal roads are not included in the freight assignment network, as characteristic information is not available and there is no basis for choosing between municipal roads. Select municipal roads are used to connect townships centroids and grain delivery points to provincial trunk highways and roads, but they are not part of the actual freight assignment network. This means that all grain haul movements occur on the provincial network, while in reality, delivery trucks can also use municipal roads. Municipal roads can be included in the assignment network to increase the accuracy of the model as characteristic information becomes available.
- Transportation related industrial intelligence, such as interviews with producers or grain terminal operators to review the grain assignment results, would provide real-life input to verify that the forecasting model is accurately predicting grain movements in Manitoba.

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APPENDIX A

Charges at Manitoba Grain Delivery Points

Table A.1: Freight Consideration Rates at Grain Delivery Points

| Delivery Point | FCR | Delivery Point | FCR | Delivery Point | FCR | Delivery Point | FCR | Delivery Point | FCR | Delivery Point | FCR |
|----------------|---------|----------------|---------|-----------------|---------|----------------|---------|----------------|---------|-------------------|---------|
| Alexander | \$33.94 | Culross | \$31.36 | Fredensthalwest | \$29.35 | Letellier | \$29.58 | Ninga | \$32.89 | Somerser | \$32.08 |
| Altona | \$29.47 | Cypress River | \$32.65 | Gilbert Plains | \$35.87 | Libau | \$32.01 | Niverville | \$30.16 | Souris | \$33.94 |
| Arborg | \$32.00 | Dacotah | \$31.36 | Gladstone | \$32.65 | Lowe Farm | \$30.58 | Norman | \$33.57 | Souris East | \$33.94 |
| Arden | \$33.29 | Darlingford | \$30.61 | Glenboro | \$33.29 | MacGregor | \$32.00 | Oakner | \$33.57 | Sperling | \$31.33 |
| Austin | \$32.65 | Dauphin | \$35.22 | Glenella | \$33.93 | Makinak | \$34.58 | Oakville | \$32.01 | St. Jean | \$30.18 |
| Baldur | \$32.83 | Deloraine | \$33.64 | Glossop | \$34.58 | Manitou | \$30.64 | Pierson | \$34.76 | Starbuck | \$30.72 |
| Balmoral | \$30.72 | Domain | \$30.11 | Goodlands | \$32.81 | Mariapolis | \$32.79 | Pilot Mound | \$31.36 | Ste. Agathe | \$30.66 |
| Beausejour | \$29.37 | Dominion City | \$28.93 | Grandview | \$35.87 | Marquette | \$30.72 | Plum Coulee | \$29.85 | Ste. Anne | \$30.07 |
| Belmont | \$33.51 | Dufresne | \$30.07 | Graysville | \$31.50 | McCreary | \$34.58 | Plumas | \$33.29 | Stonewall | \$30.72 |
| Benard | \$31.49 | Dufrost | \$39.93 | Gregg | \$33.29 | McTavish | \$30.23 | Quadra | \$35.22 | Strathclair | \$34.58 |
| Benito | \$38.49 | Dugald | \$30.72 | Gretna | \$32.81 | Meadows | \$30.72 | Rathwell | \$32.00 | Swan Lake | \$32.11 |
| Binscarth | \$35.87 | Dundonald | \$32.00 | Hargrave | \$35.22 | Medora | \$33.79 | Red River S | \$29.58 | Swan River | \$37.87 |
| Birch River | \$32.81 | Dunrea | \$33.53 | Harte | \$33.29 | Melita | \$33.99 | Reston | \$35.22 | Swan River Valley | \$37.87 |
| Birtle | \$35.22 | Durban | \$32.81 | Hartney | \$33.95 | Miami | \$31.36 | Rivers | \$33.57 | Tenby | \$32.81 |
| Boissevain | \$33.57 | Dutton | \$35.87 | Holland | \$32.65 | Mile 10.6 | \$30.72 | Roland | \$31.30 | Teulon | \$31.36 |
| Bowsman | \$38.49 | Elgin | \$32.97 | Homewood | \$31.38 | Mintonas | \$37.87 | Rosenfeld | \$29.77 | The Pas | \$43.06 |
| Brandon CN | \$33.94 | Elie | \$31.36 | Jordan | \$31.32 | Minnedosa | \$33.94 | Rosser | \$30.07 | Treherne | \$32.00 |
| Brandon CP | \$33.94 | Elkhorn | \$35.22 | Justice | \$33.93 | Minto | \$34.20 | Russell | \$35.87 | Tucker | \$31.36 |
| Brunkild | \$30.81 | Elm Creek | \$31.36 | Kane | \$30.61 | Mollard | \$30.71 | Sanford | \$30.95 | Virden | \$34.58 |
| Burnside | \$32.00 | Ethelbert | \$32.81 | Katrimie | \$32.65 | Morden | \$30.54 | Selkirk | \$30.83 | Warren | \$32.81 |
| Carey | \$30.11 | Fairfax | \$34.22 | Kenville | \$37.87 | Morris | \$29.94 | Shoal Lake | \$34.58 | Waskada | \$34.20 |
| Cartwright | \$32.13 | Fannystelle | \$31.36 | Killarney | \$32.84 | Neepawa | \$33.29 | Sidney | \$32.65 | Westroc | \$32.00 |
| Clearwater | \$32.07 | Fisher Branch | \$32.00 | Kirkella | \$35.22 | Nesbitt | \$33.94 | Sinclair | \$35.22 | Winkler | \$29.87 |
| Cracknell | \$32.81 | Fork River | \$32.81 | La Riviere | \$31.31 | Netley | \$31.36 | Smart Siding | \$32.81 | Winnipeg CN | \$30.07 |
| Cromer | \$35.87 | Foxwarren | \$35.22 | La Salle | \$30.34 | Newdale | \$33.94 | Solsgirth | \$35.22 | Winnipeg CP | \$30.07 |
| Crystal City | \$31.39 | Franklin | \$33.29 | | | | | | | | |

Source: Canadian Wheat Board, 2000/2001.

Table A.2: Elevation Charges at Grain Delivery Points

| Delivery Point | EC | Delivery Point | EC | Delivery Point | EC | Delivery Point | EC | Delivery Point | EC | Delivery Point | EC |
|----------------|---------|----------------|---------|-----------------|---------|----------------|---------|----------------|---------|-------------------|---------|
| Alexander | \$11.00 | Culross | \$11.49 | Fredensthalwest | \$11.00 | Letellier | \$11.00 | Ninga | \$11.00 | Somerser | \$11.00 |
| Altona | \$11.00 | Cypress River | \$11.18 | Gilbert Plains | \$11.00 | Libau | \$11.00 | Niverville | \$11.00 | Souris | \$11.00 |
| Arborg | \$11.03 | Dacotah | \$11.49 | Gladstone | \$10.50 | Lowe Farm | \$11.00 | Norman | \$12.20 | Souris East | \$12.20 |
| Arden | \$11.00 | Darlingford | \$11.00 | Glenboro | \$11.00 | MacGregor | \$11.00 | Oakner | \$11.36 | Sperling | \$11.49 |
| Austin | \$11.00 | Dauphin | \$11.21 | Glenella | \$11.00 | Makinak | \$11.00 | Oakville | \$11.00 | St. Jean | \$11.00 |
| Baldur | \$11.00 | Deloraine | \$11.61 | Glossop | \$11.25 | Manitou | \$12.20 | Pierson | \$11.49 | Starbuck | \$11.00 |
| Balmoral | \$11.49 | Domain | \$11.00 | Goodlands | \$11.00 | Mariapolis | \$10.50 | Pilot Mound | \$11.00 | Ste. Agathe | \$11.00 |
| Beausejour | \$11.75 | Dominion City | \$12.20 | Grandview | \$11.00 | Marquette | \$11.49 | Plum Coulee | \$12.20 | Ste. Anne | \$12.20 |
| Belmont | \$12.20 | Dufresne | \$11.00 | Graysville | \$11.00 | McCreary | \$12.20 | Plumas | \$12.20 | Stonewall | \$11.00 |
| Benard | \$11.00 | Dufrost | \$11.00 | Gregg | \$11.00 | McTavish | \$11.00 | Quadra | \$11.00 | Strathclair | \$11.00 |
| Benito | \$11.00 | Dugald | 11.00 | Gretna | \$11.00 | Meadows | \$11.49 | Rathwell | \$11.25 | Swan Lake | \$11.49 |
| Binscarth | \$11.00 | Dundonald | 12.20 | Hargrave | \$12.20 | Medora | \$11.00 | Red River S | \$11.00 | Swan River | \$11.19 |
| Birch River | \$11.49 | Dunrea | \$11.00 | Harte | \$11.00 | Melita | \$11.00 | Reston | \$11.00 | Swan River Valley | \$11.25 |
| Birtle | \$11.00 | Durban | \$11.50 | Hartney | \$11.00 | Miami | \$11.00 | Rivers | \$11.93 | Tenby | \$11.50 |
| Boissevain | \$11.19 | Dutton | \$12.20 | Holland | \$11.24 | Mile 10.6 | \$11.00 | Roland | \$12.20 | Teulon | \$11.49 |
| Bowsman | \$11.00 | Elgin | \$11.00 | Homewood | \$11.00 | Minitonas | \$11.00 | Rosenfeld | \$11.00 | The Pas | \$11.00 |
| Brandon CN | \$11.23 | Elie | \$11.00 | Jordan | \$10.50 | Minnedosa | \$11.00 | Rosser | \$11.00 | Treherne | \$11.00 |
| Brandon CP | \$11.17 | Elkhorn | \$11.00 | Justice | \$11.00 | Minto | \$11.49 | Russell | \$11.00 | Tucker | \$11.00 |
| Brunkild | \$11.49 | Elm Creek | \$11.00 | Kane | \$11.49 | Mollard | \$11.25 | Sanford | \$11.00 | Virден | \$11.22 |
| Burnside | \$11.00 | Ethelbert | \$11.00 | Katrimie | \$11.00 | Morden | \$12.20 | Selkirk | \$11.00 | Warren | \$11.00 |
| Carey | \$11.25 | Fairfax | \$11.49 | Kenville | \$11.25 | Morris | \$11.49 | Shoal Lake | \$12.03 | Waskada | \$11.49 |
| Cartwright | \$11.00 | Fannystelle | \$12.20 | Killarney | \$11.26 | Neepawa | \$11.66 | Sidney | \$11.50 | Westroc | \$11.00 |
| Clearwater | \$11.00 | Fisher Branch | \$11.00 | Kirkella | \$11.00 | Nesbitt | \$11.77 | Sinclair | \$11.00 | Winkler | \$11.26 |
| Cracknell | \$11.49 | Fork River | \$11.00 | La Riviere | \$11.00 | Netley | \$11.00 | Smart Siding | \$11.00 | Winnipeg CN | \$12.63 |
| Cromer | \$11.00 | Foxwarren | \$12.20 | La Salle | \$11.49 | Newdale | \$11.00 | Solsgirth | \$11.00 | Winnipeg CP | \$11.09 |
| Crystal City | \$11.28 | Franklin | \$11.00 | | | | | | | | |

Source: Canadian Grain Commission, 2001-2002.

APPENDIX B

Origin-Destination Results Based on Cost

Figure B.1: Dauphin Grain Delivery Point
Origin-Destination Results Based on Cost

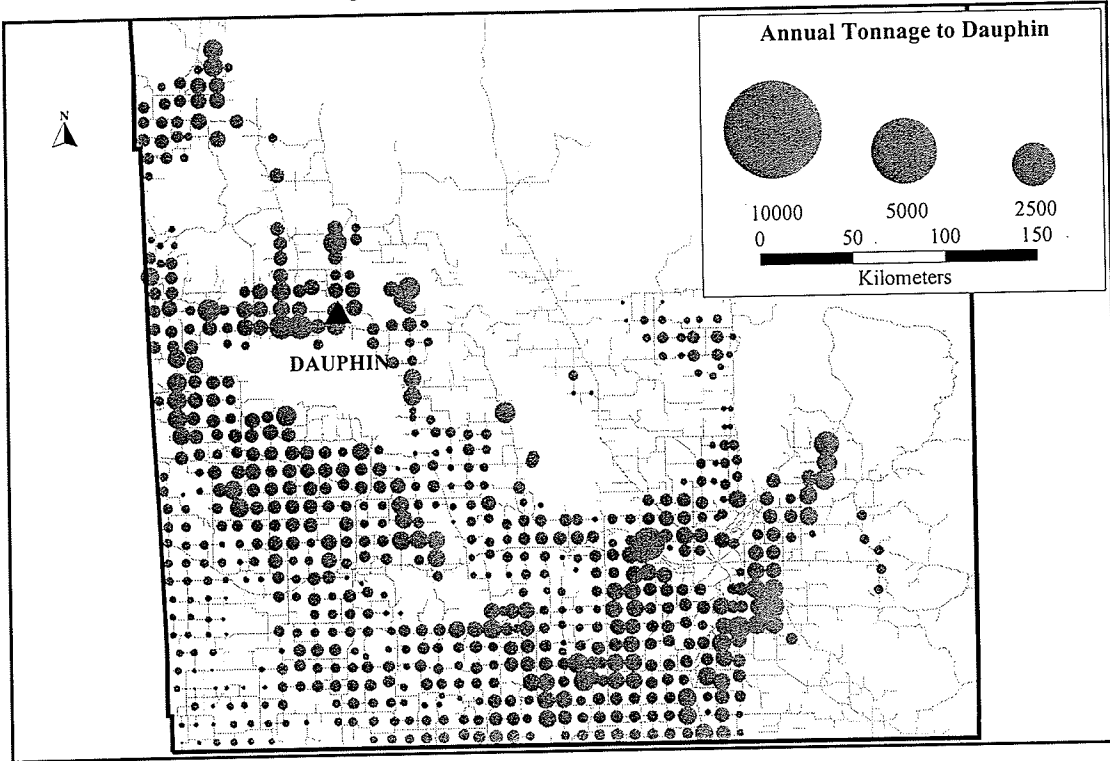


Figure B.2: Killarney Grain Delivery Point
Origin-Destination Results Based on Cost

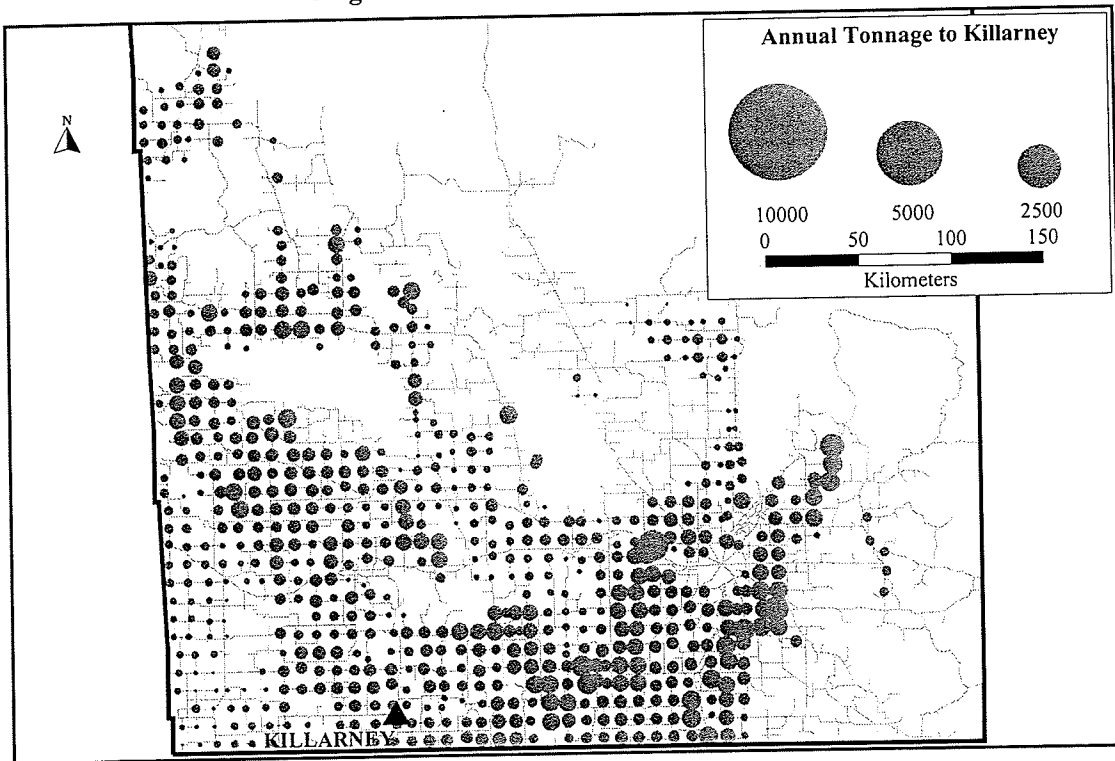


Figure B.3: Melita Grain Delivery Point
Origin-Destination Results Based on Cost

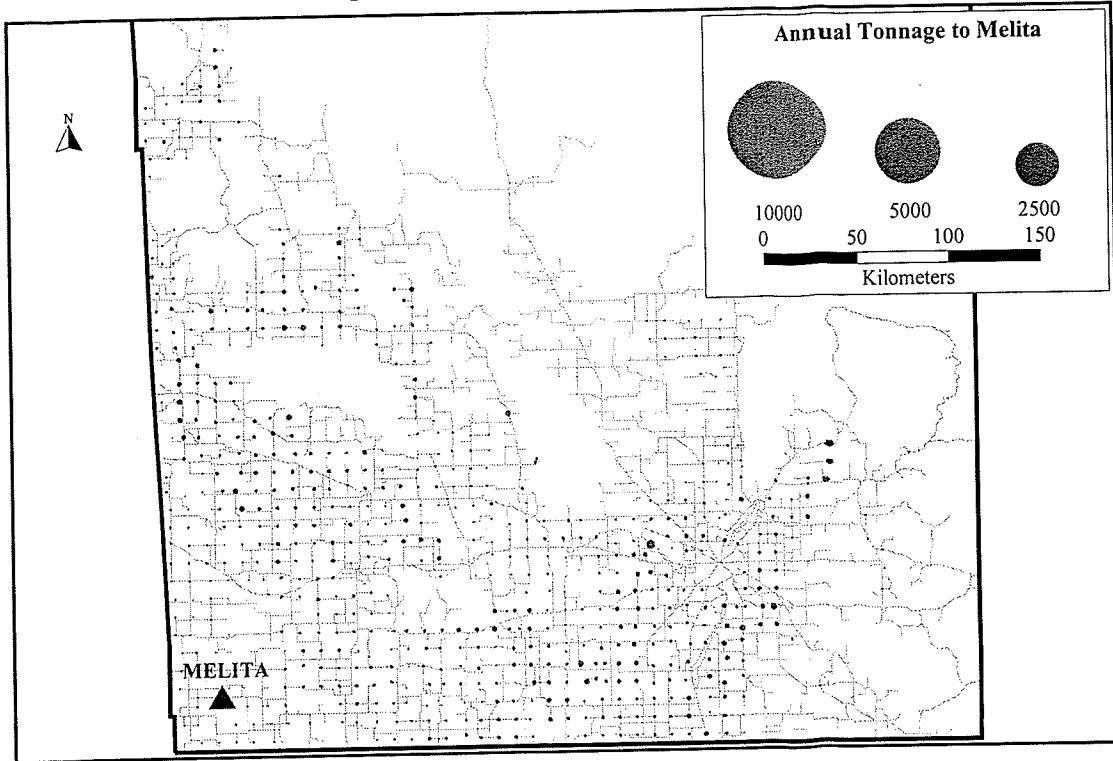


Figure B.4: Minnedosa Grain Delivery Point
Origin-Destination Results Based on Cost

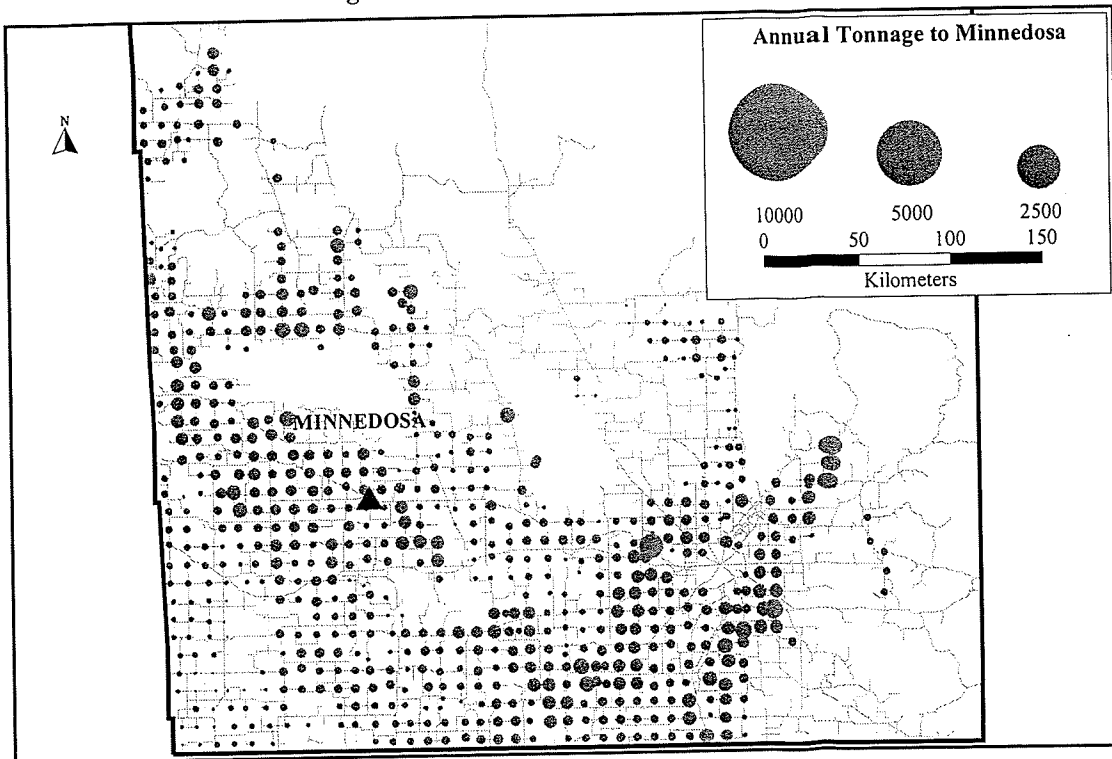


Figure B.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Cost

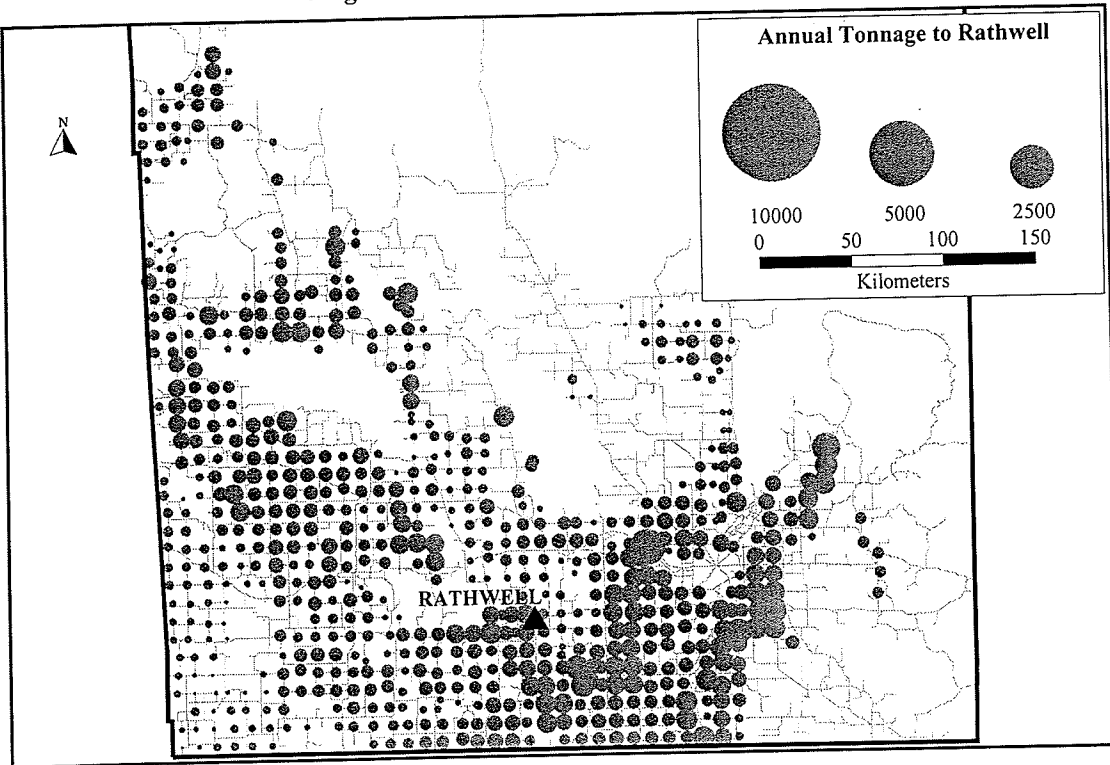


Figure B.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Cost

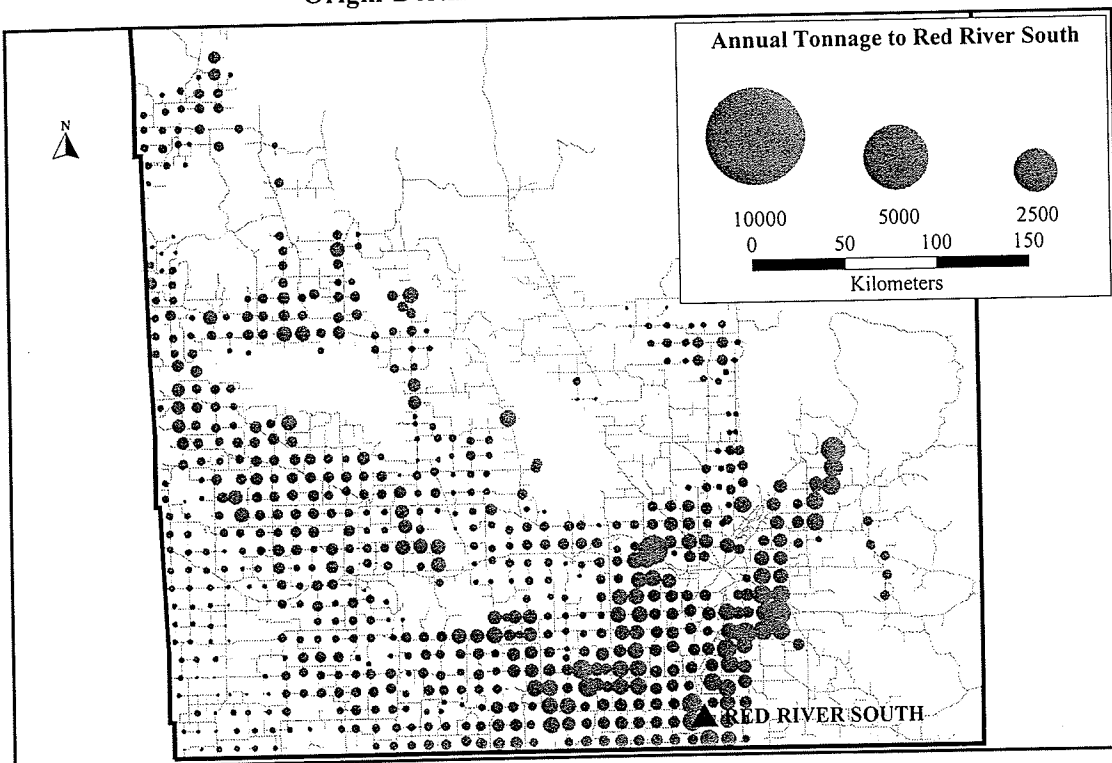


Figure B.7: Swan River Grain Delivery Point
Origin-Destination Results Based on Cost

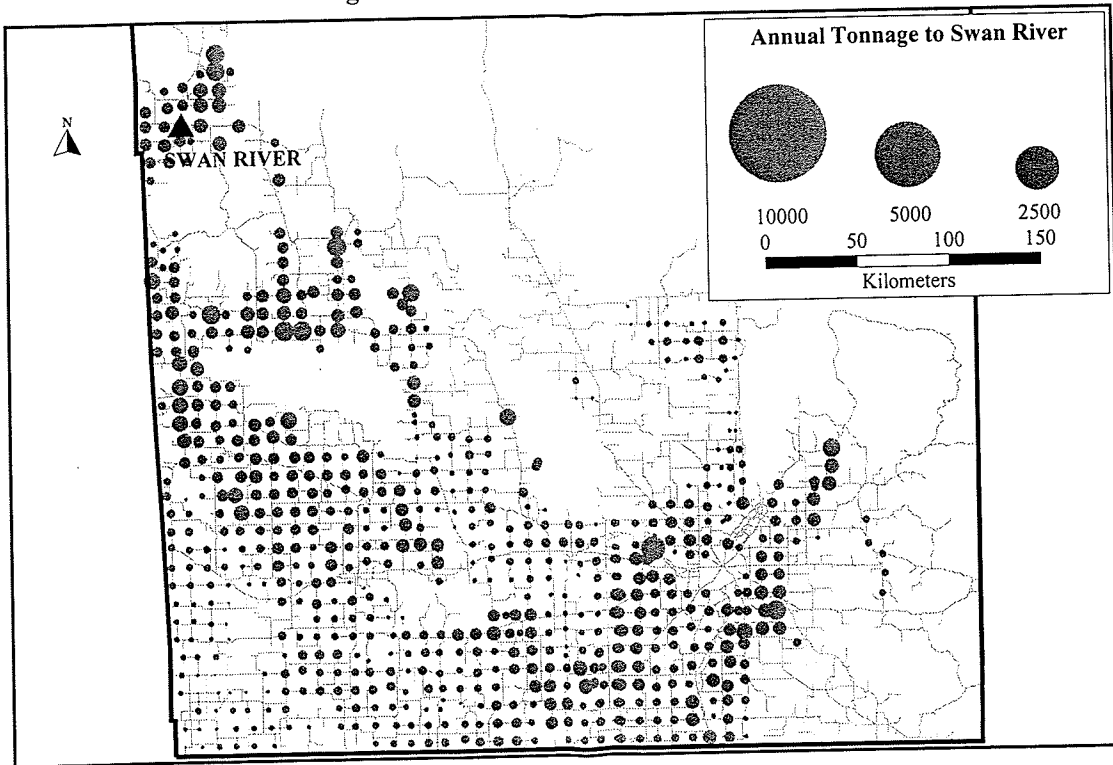


Figure B.8: Virden Grain Delivery Point
Origin-Destination Results Based on Cost

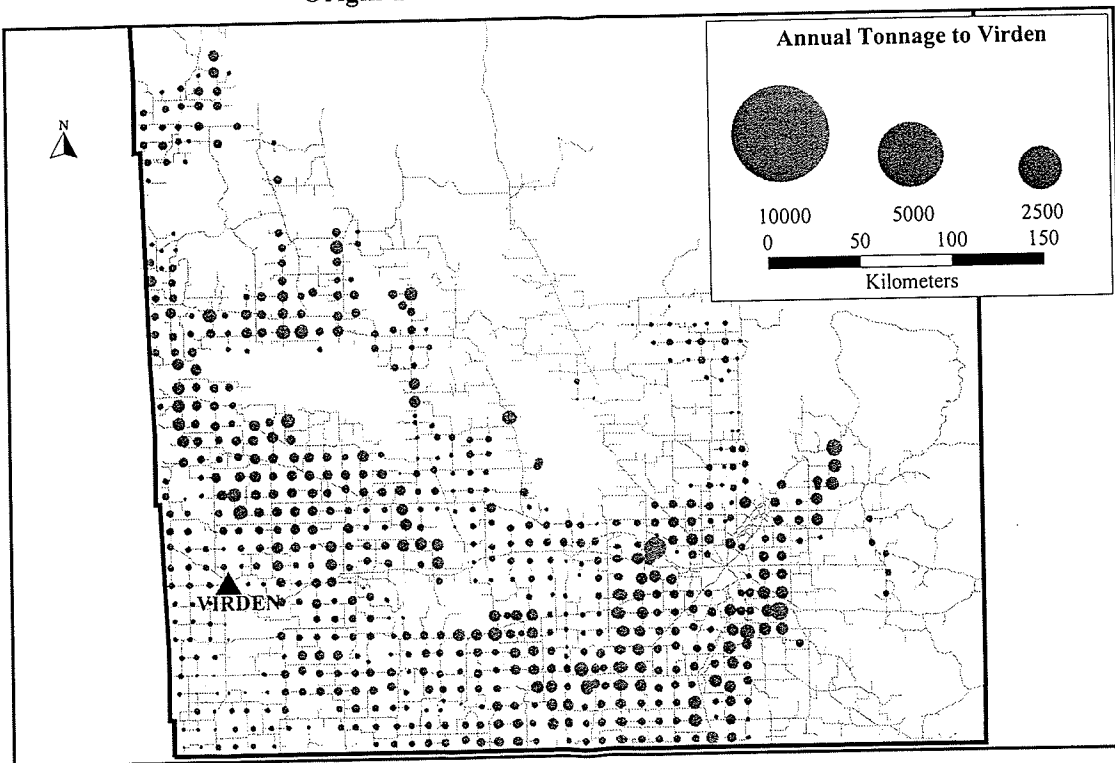
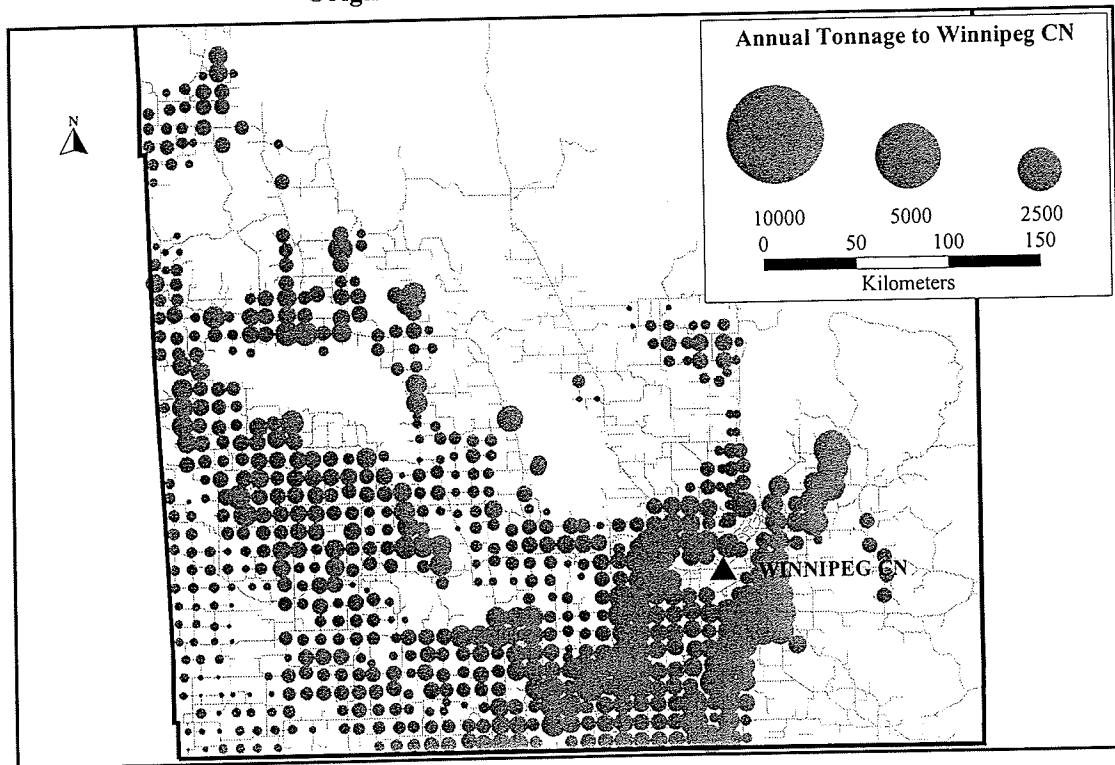


Figure B.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Cost



APPENDIX C

Origin-Destination Results Based on Distance

Figure C.1: Dauphin Grain Delivery Point
Origin-Destination Results Based on Distance

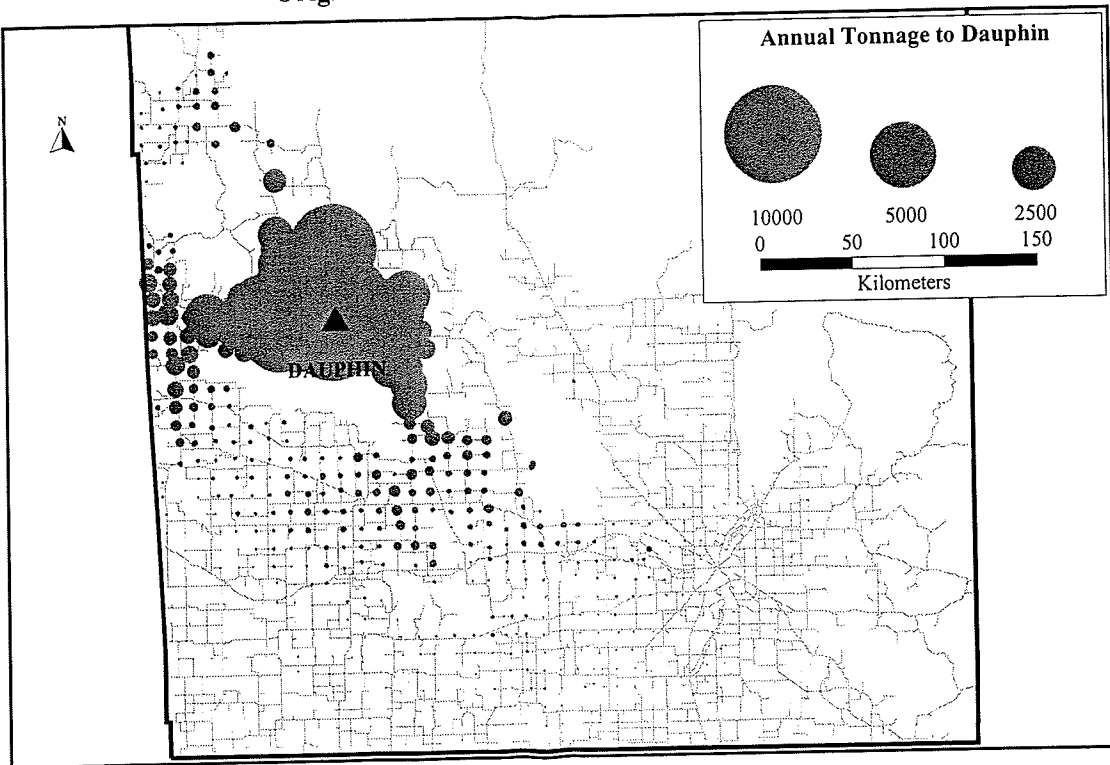


Figure C.2: Killarney Grain Delivery Point
Origin-Destination Results Based on Distance

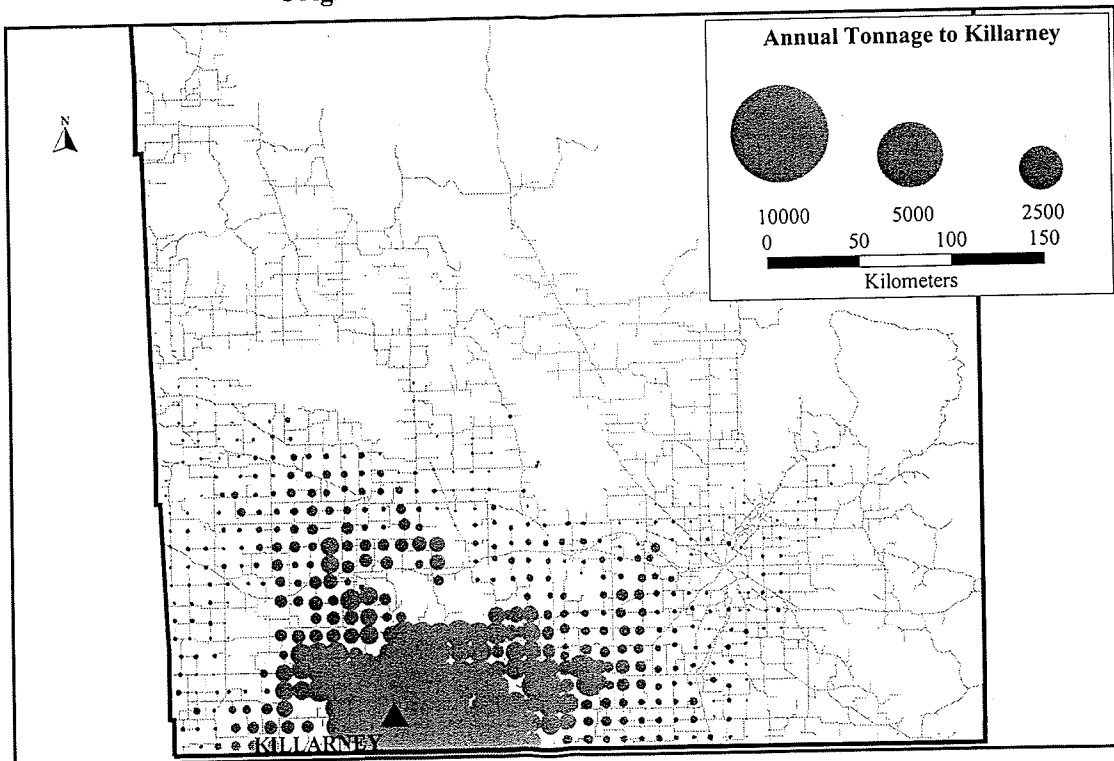


Figure C.3: Melita Grain Delivery Point
Origin-Destination Results Based on Distance

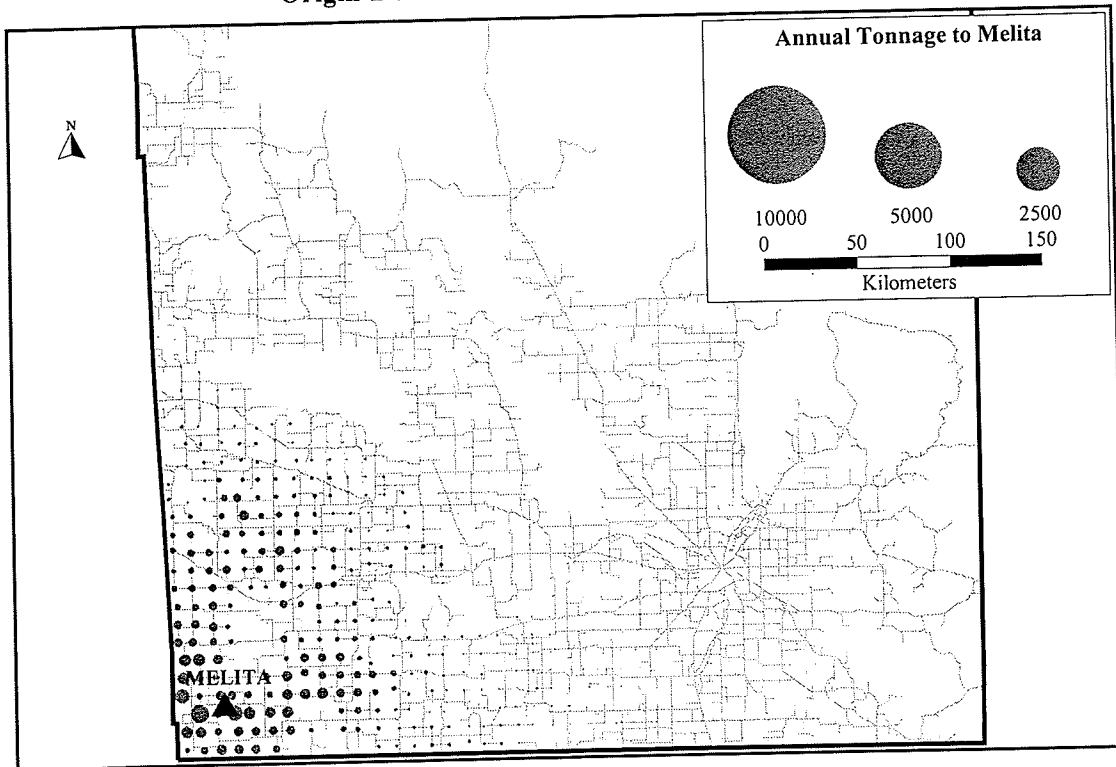


Figure C.4: Minnedosa Grain Delivery Point
Origin-Destination Results Based on Distance

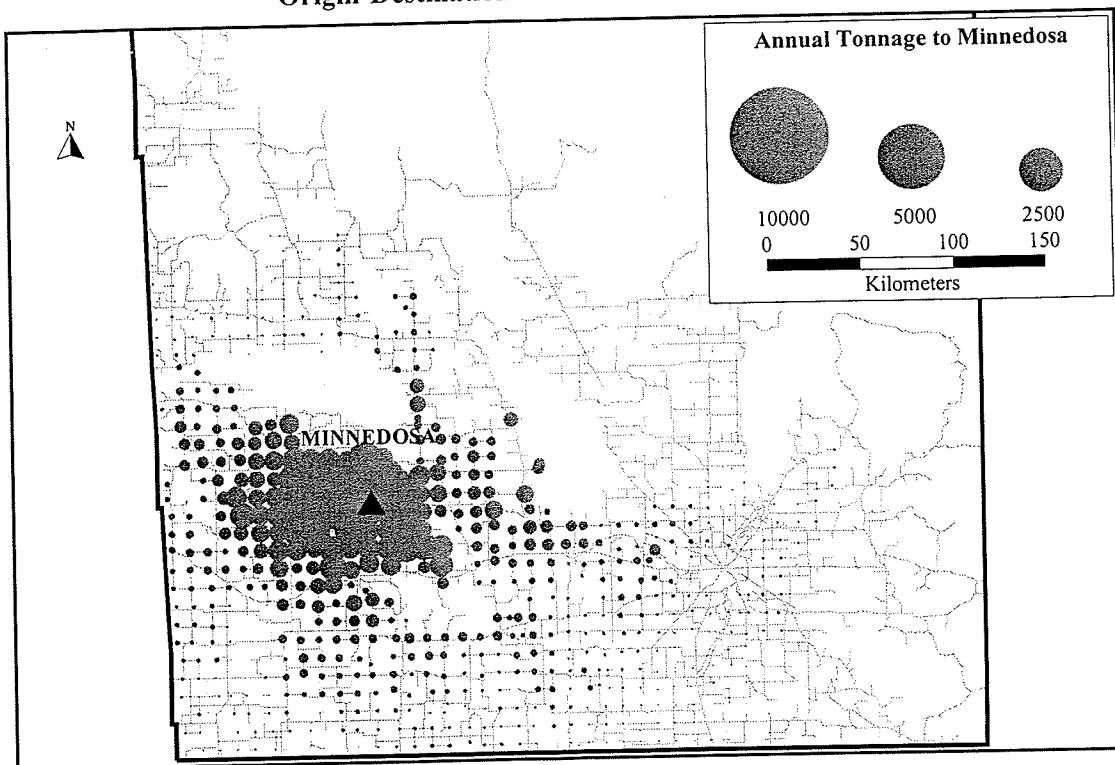


Figure C.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Distance

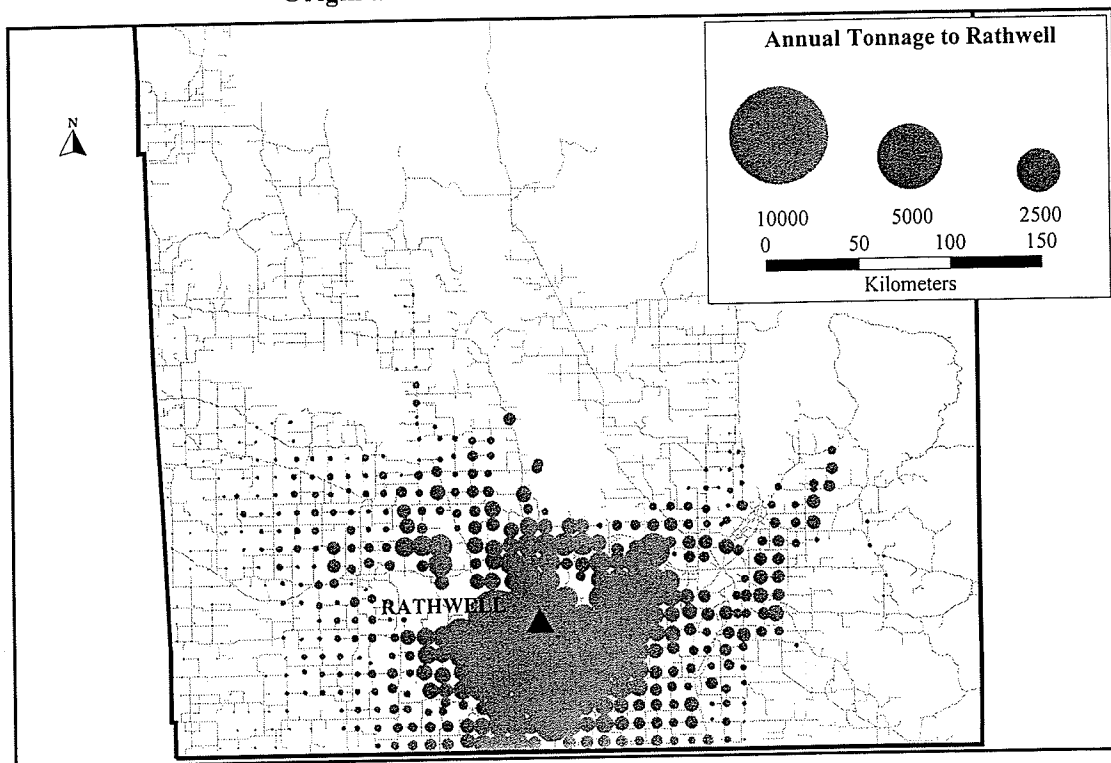
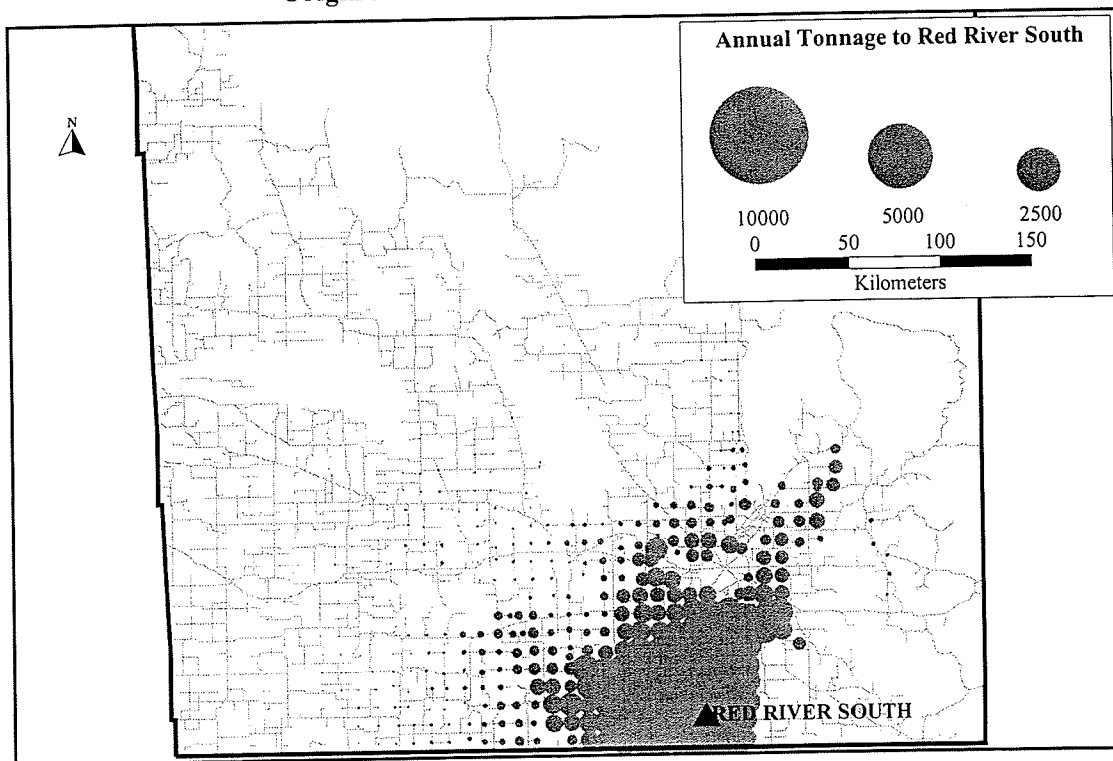
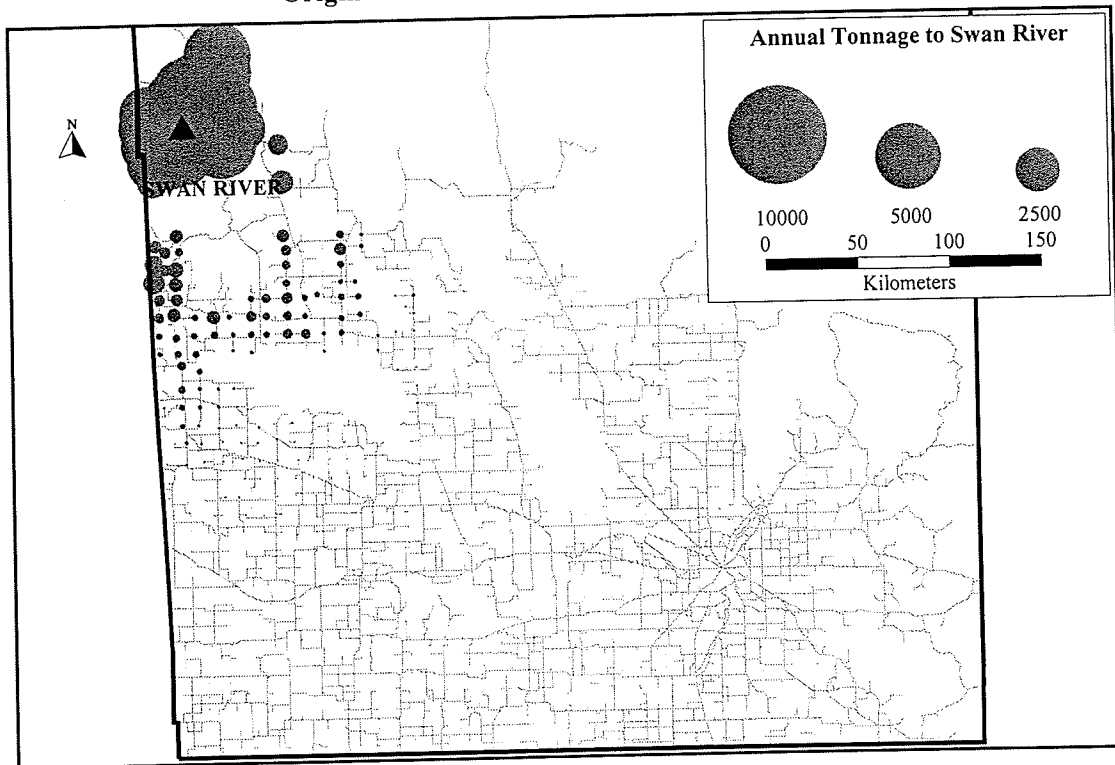


Figure C.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Distance



**Figure C.7: Swan River Grain Delivery Point
Origin-Destination Results Based on Distance**



**Figure C.8: Virden Grain Delivery Point
Origin-Destination Results Based on Distance**

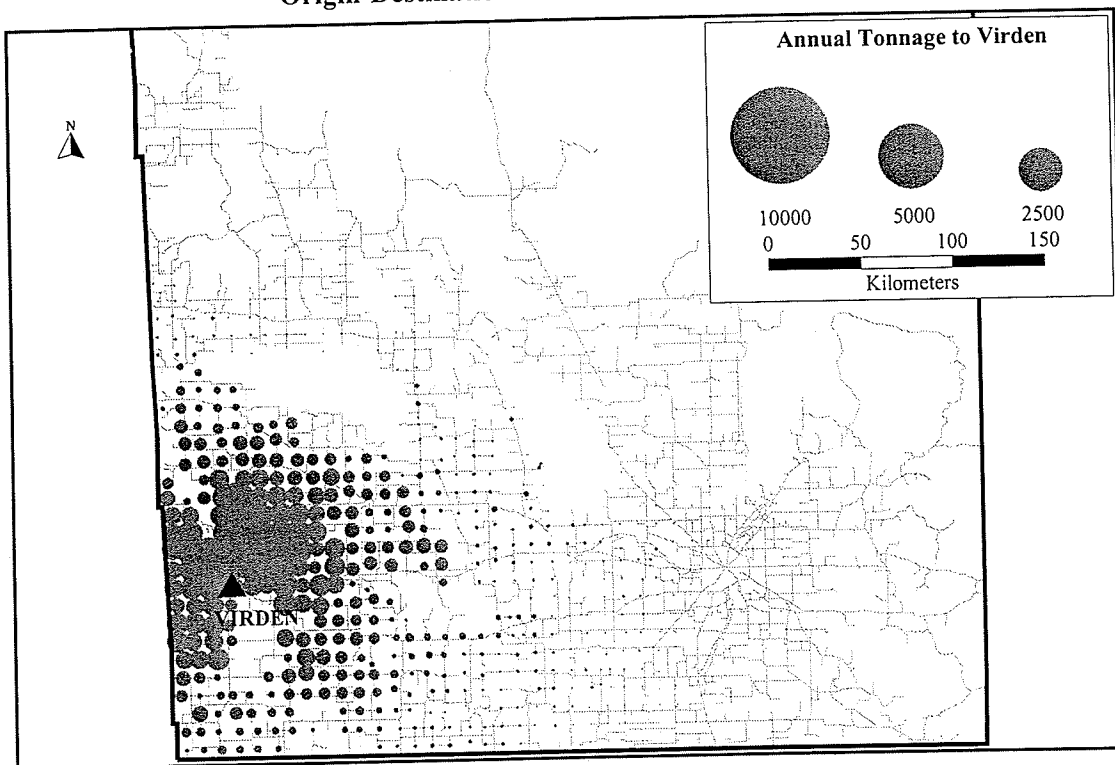
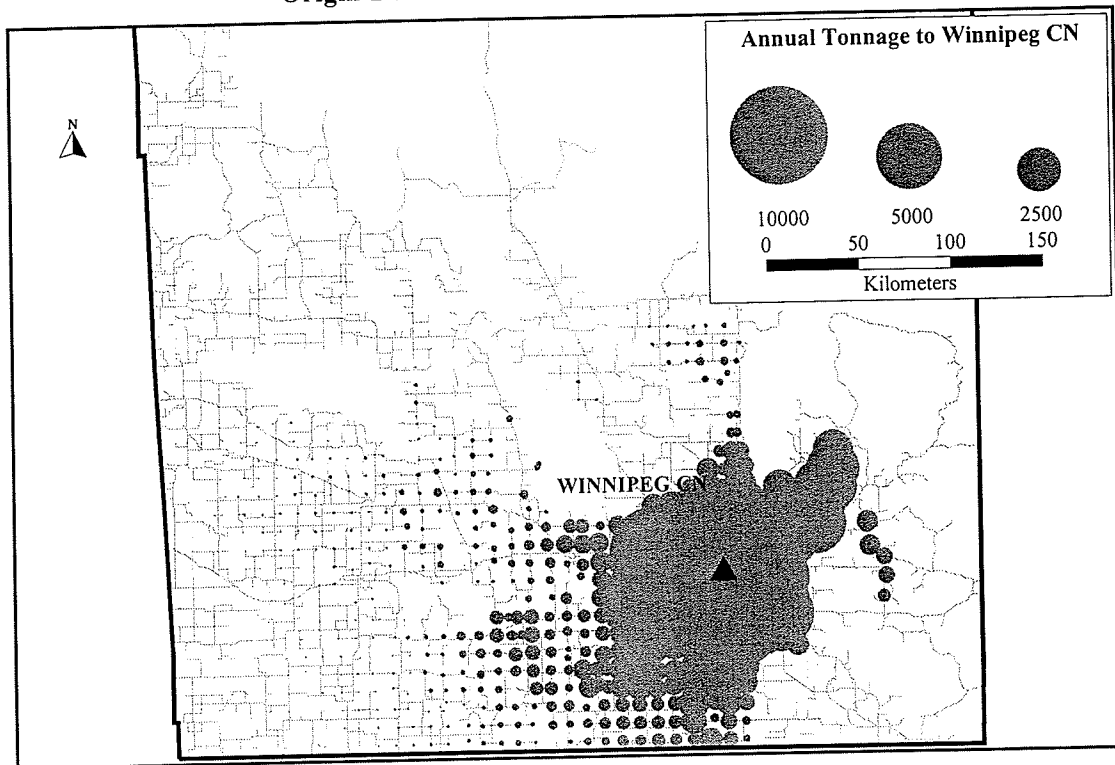


Figure C.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Distance



APPENDIX D

Origin-Destination Results Based on Cost and Distance

Figure D.1: Dauphin Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

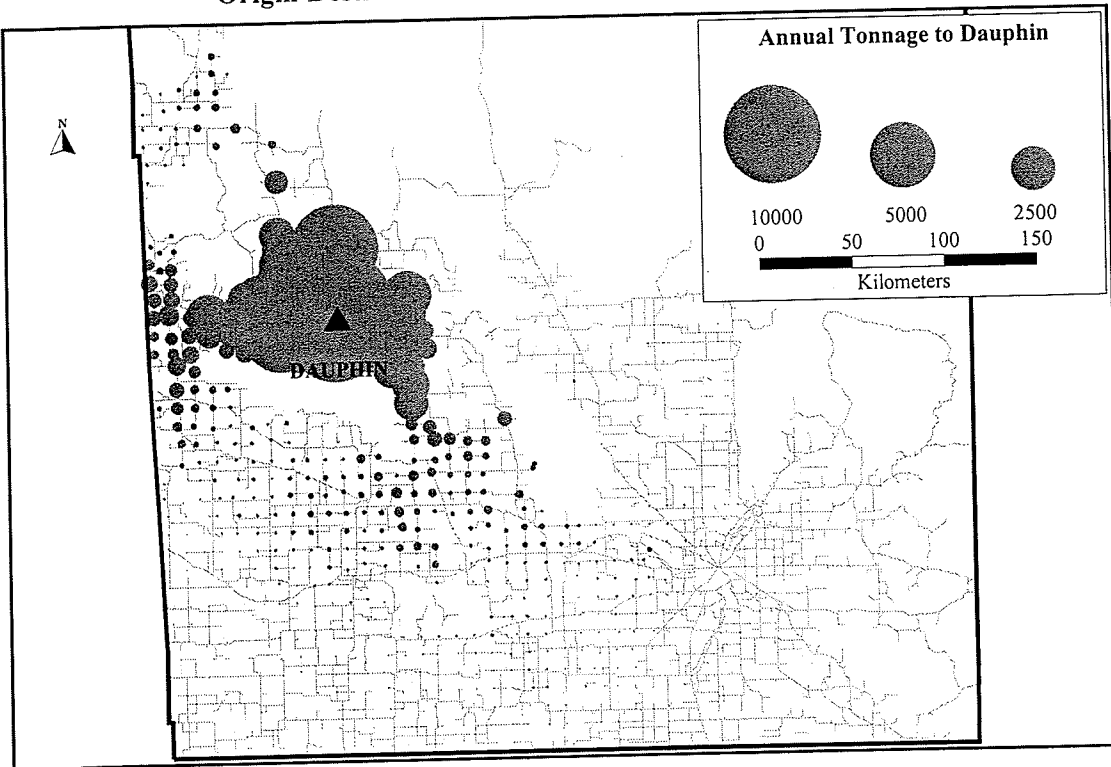


Figure D.2: Killarney Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

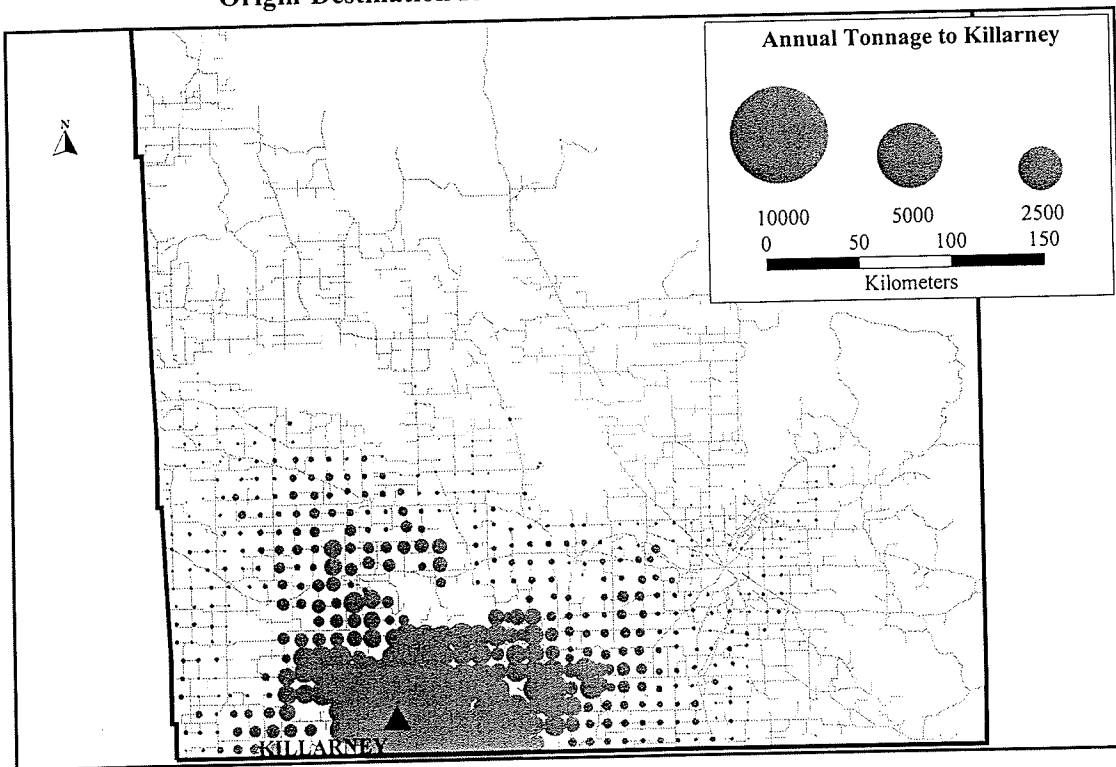


Figure D.3: Melita Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

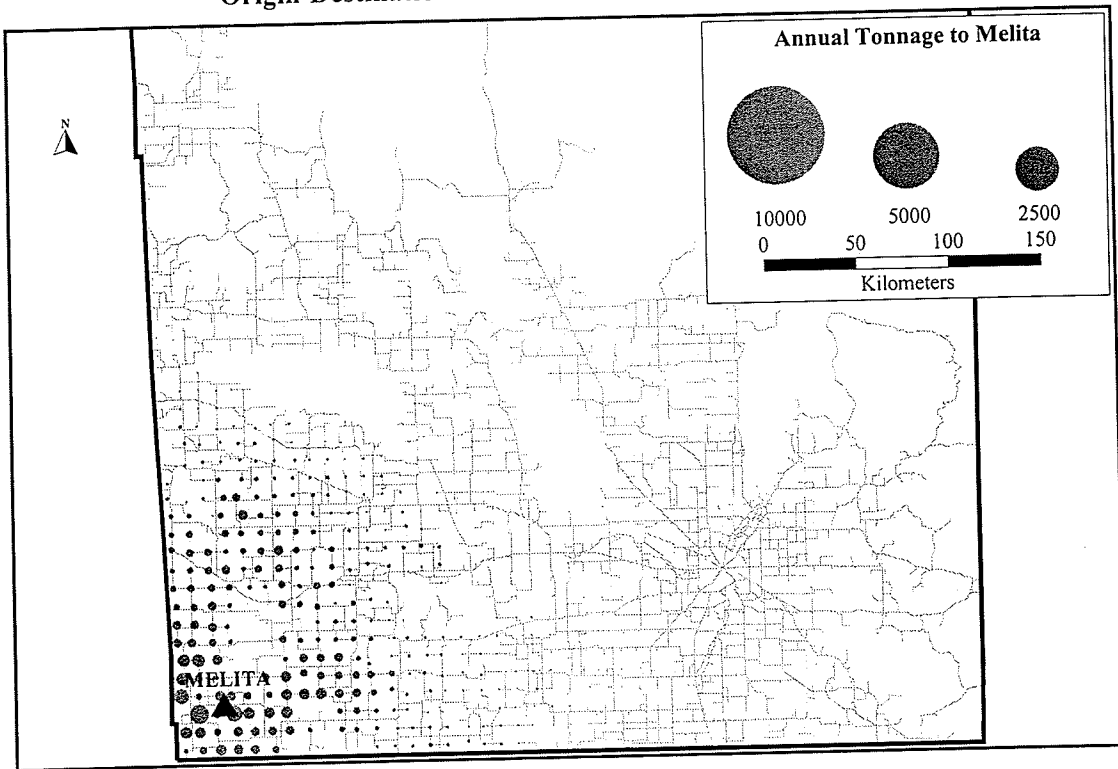


Figure D.4: Minnedosa Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

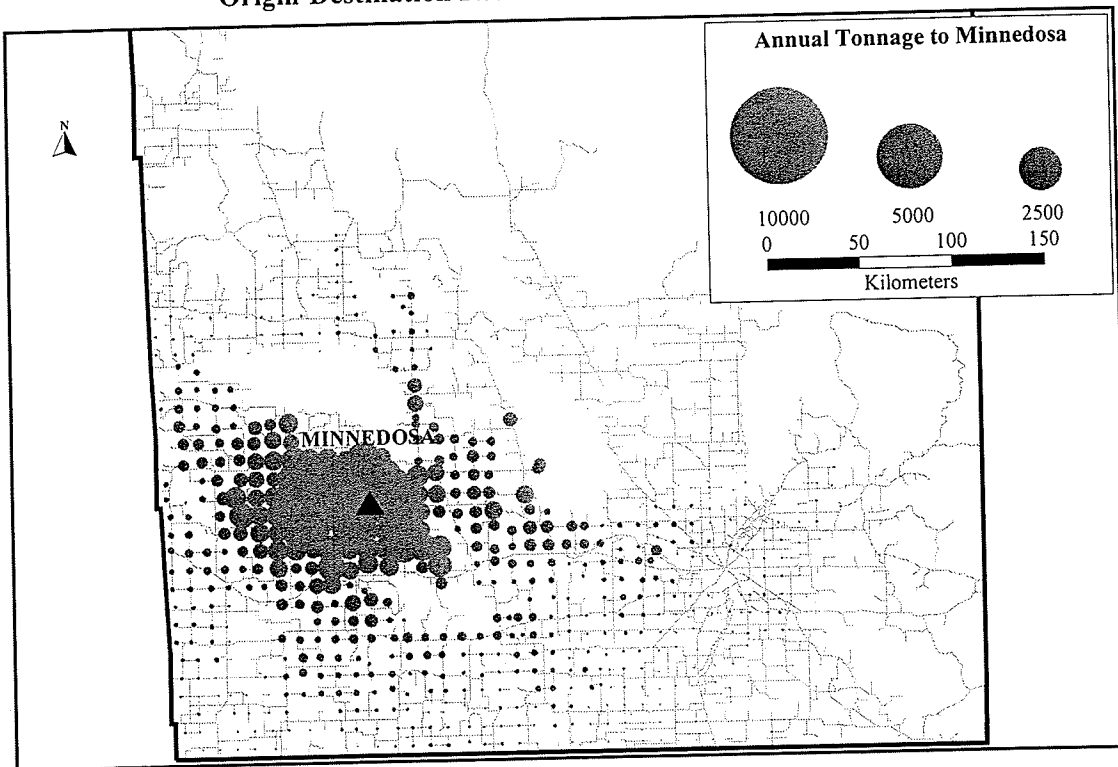


Figure D.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

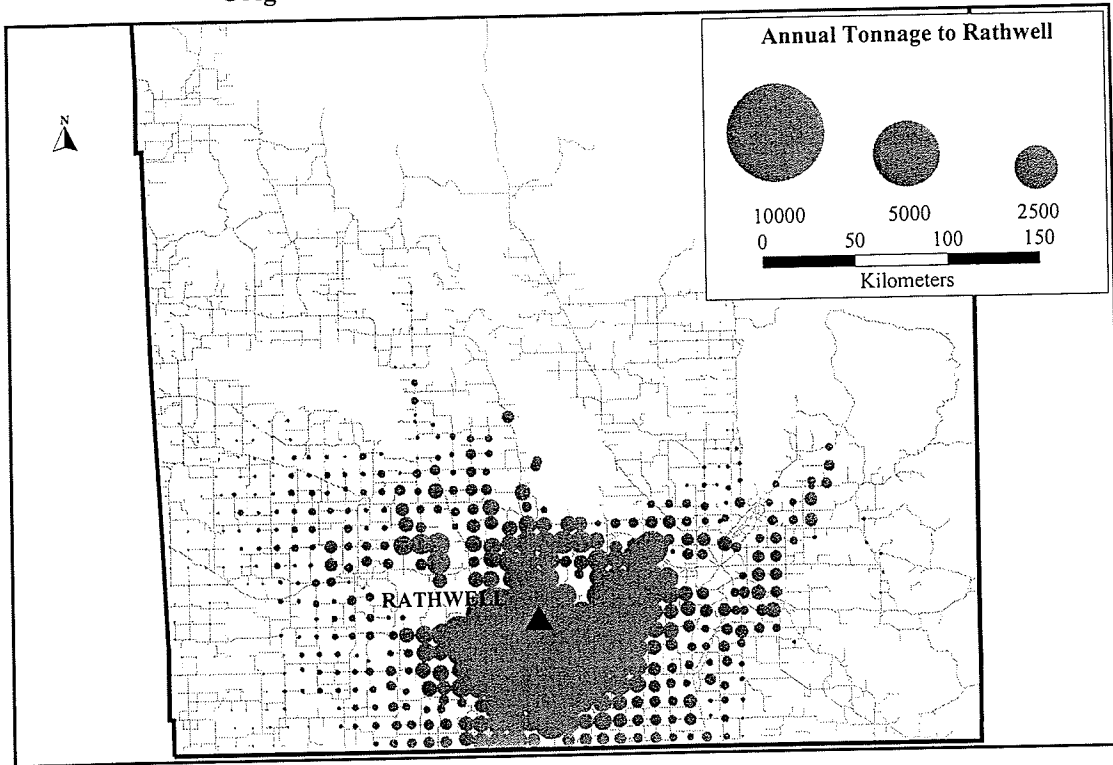


Figure D.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

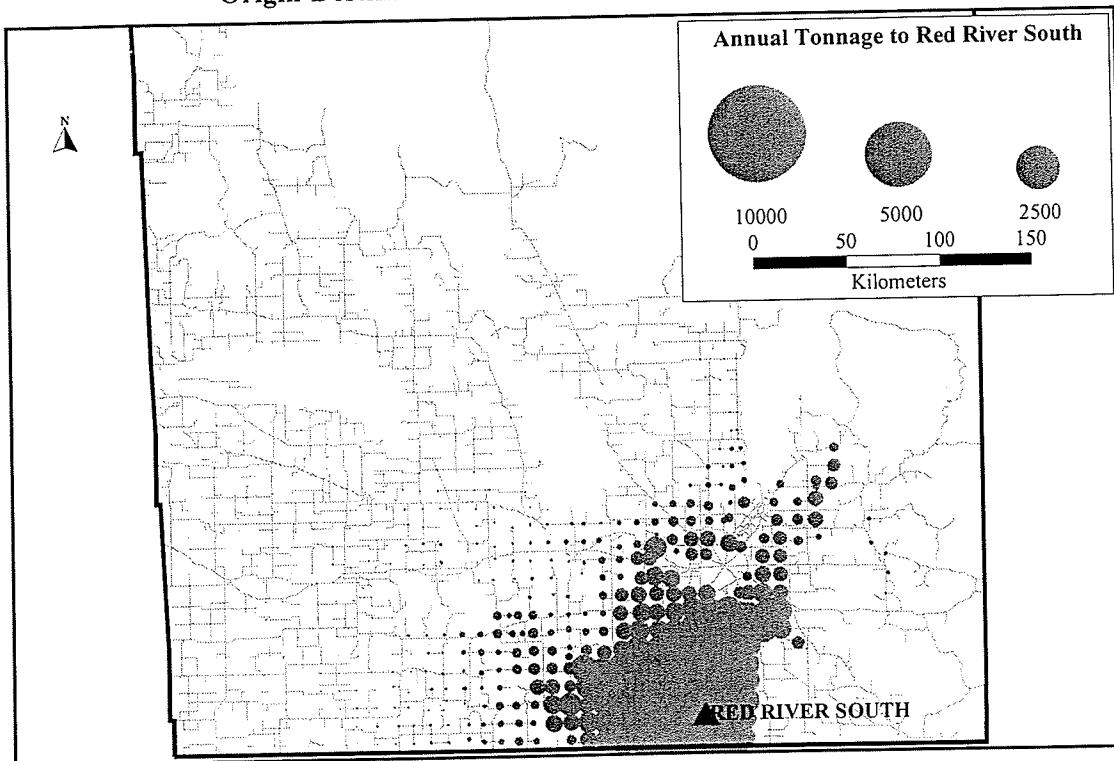


Figure D.7: Swan River Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

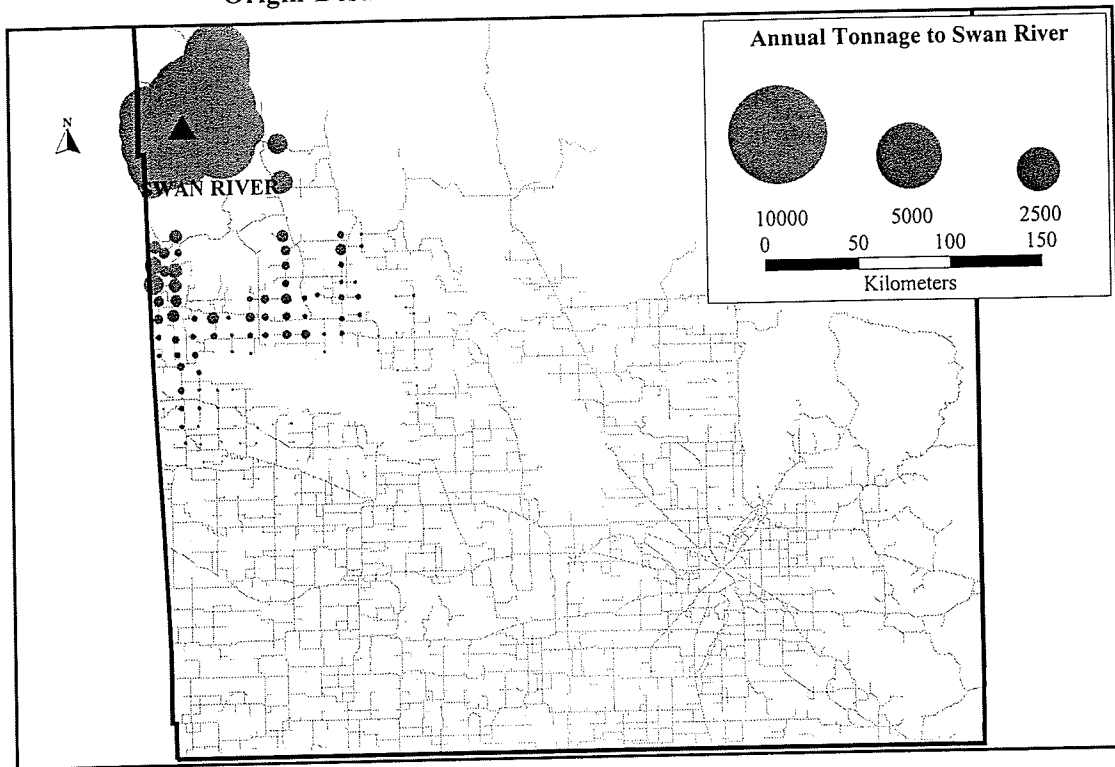


Figure D.8: Virden Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

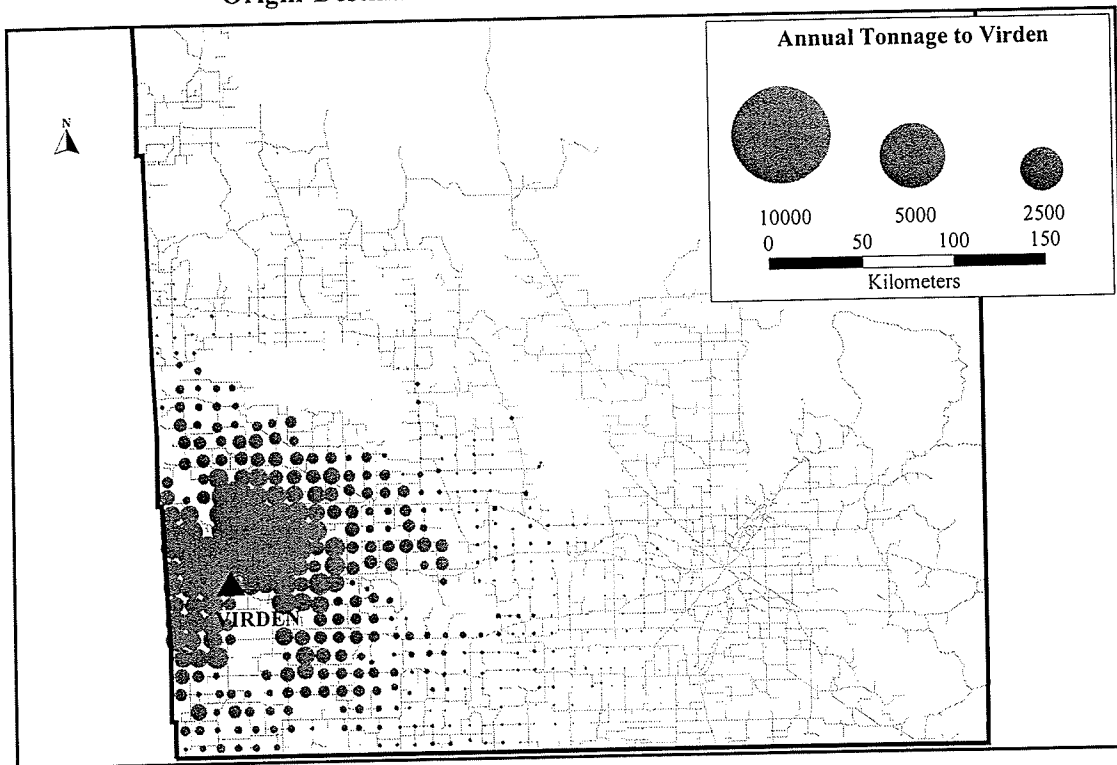


Figure D.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Cost and Distance

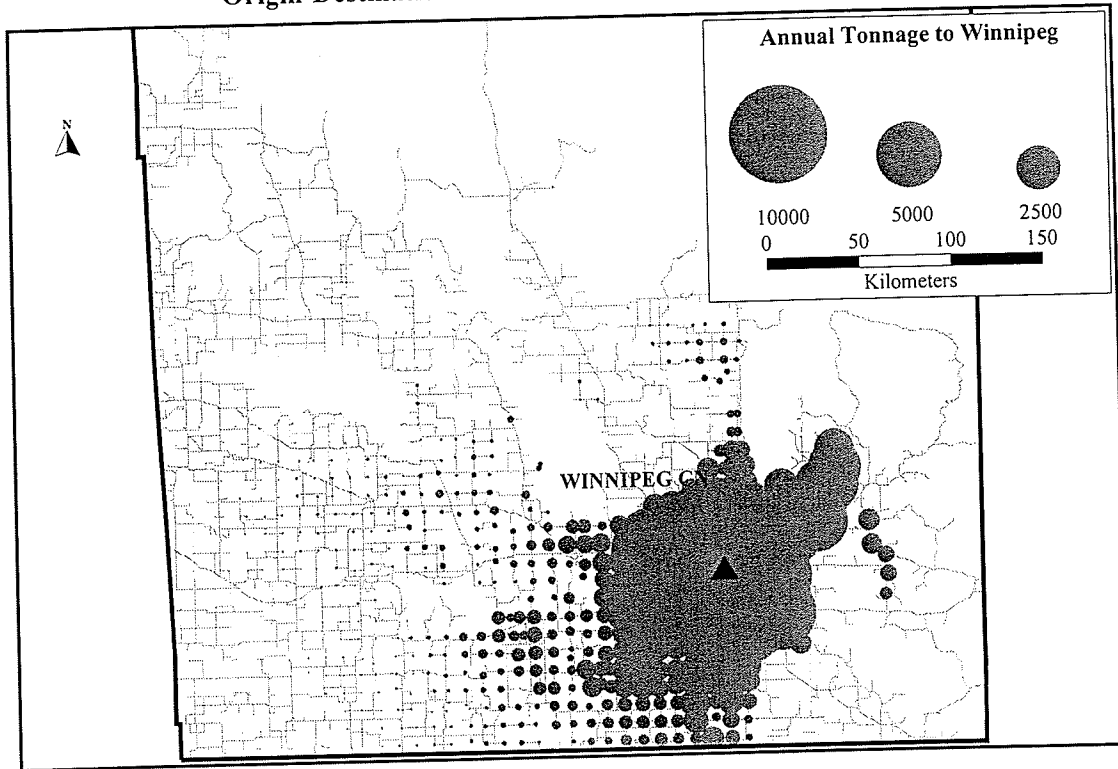


Figure D.10: Township 05-23-W
Origin-Destination Results Based on Cost and Distance

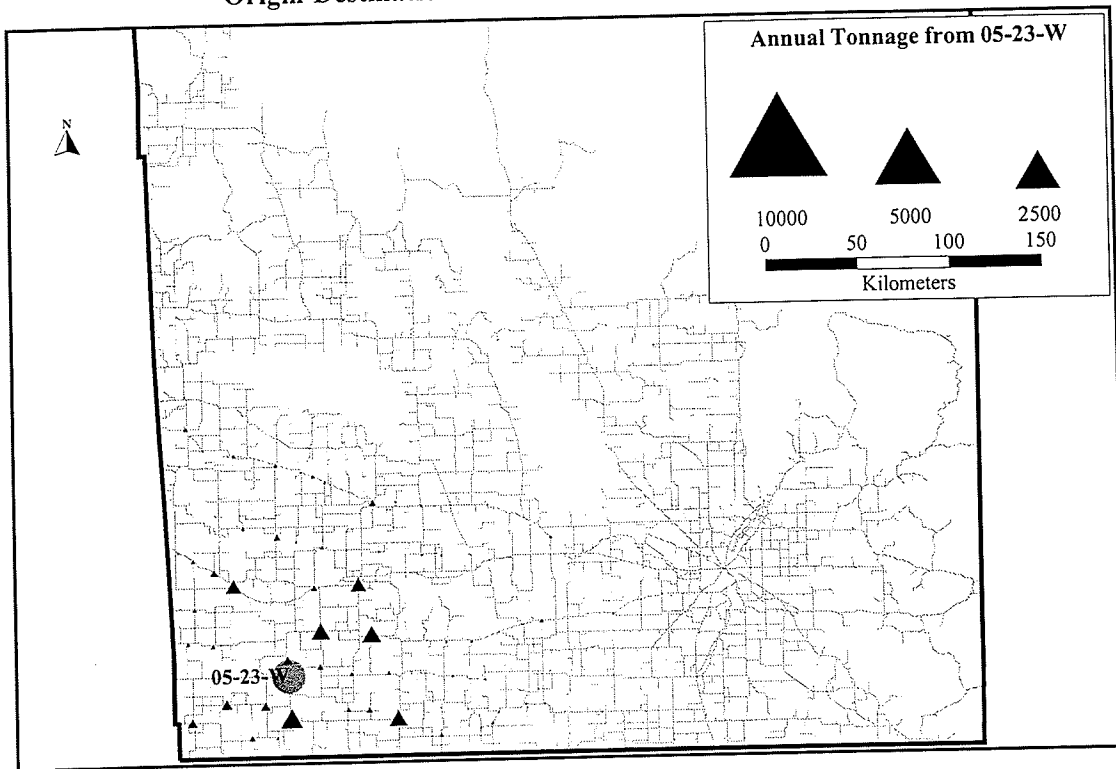


Figure D.11: Township 12-09-W
Origin-Destination Results Based on Cost and Distance

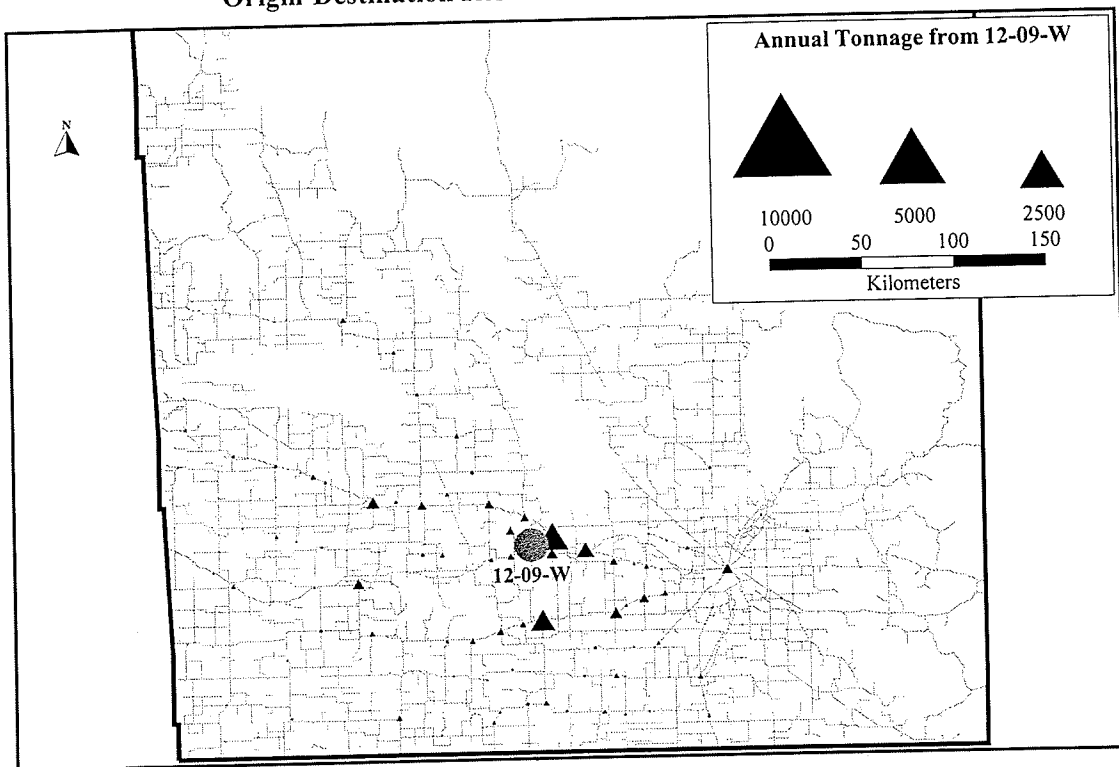


Figure D.12: Township 16-24-W
Origin-Destination Results Based on Cost and Distance

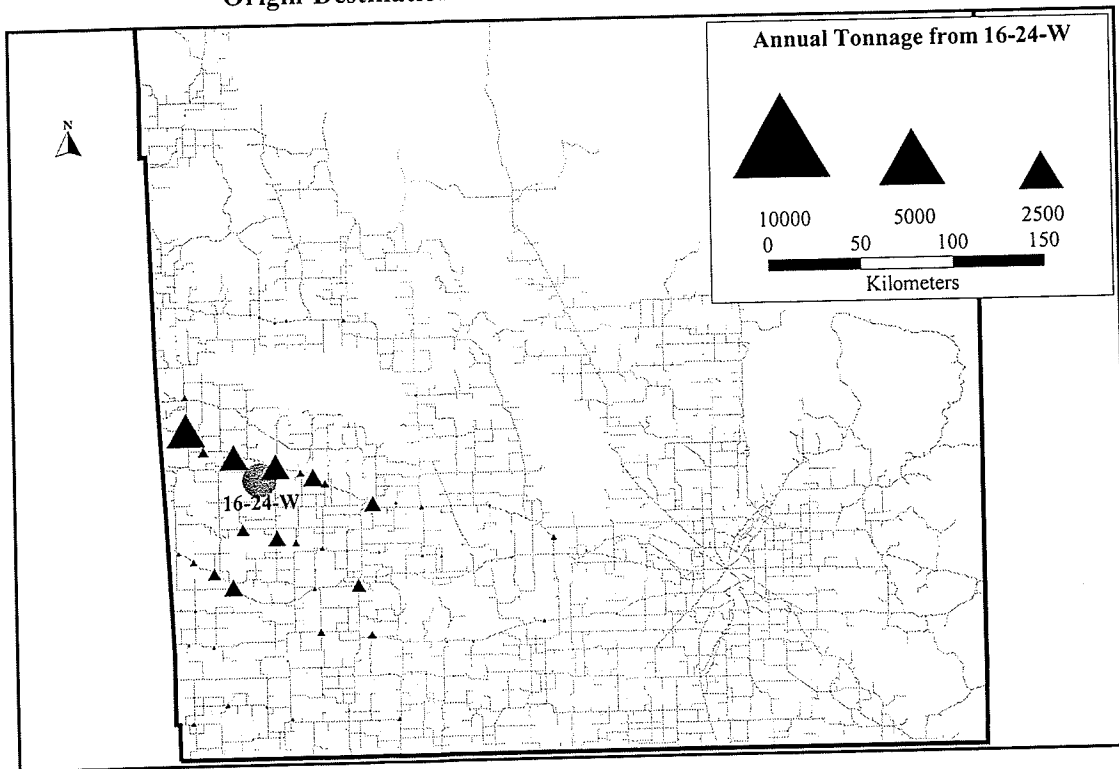


Figure D.13: Township 21-02-E
Origin-Destination Results Based on Cost and Distance

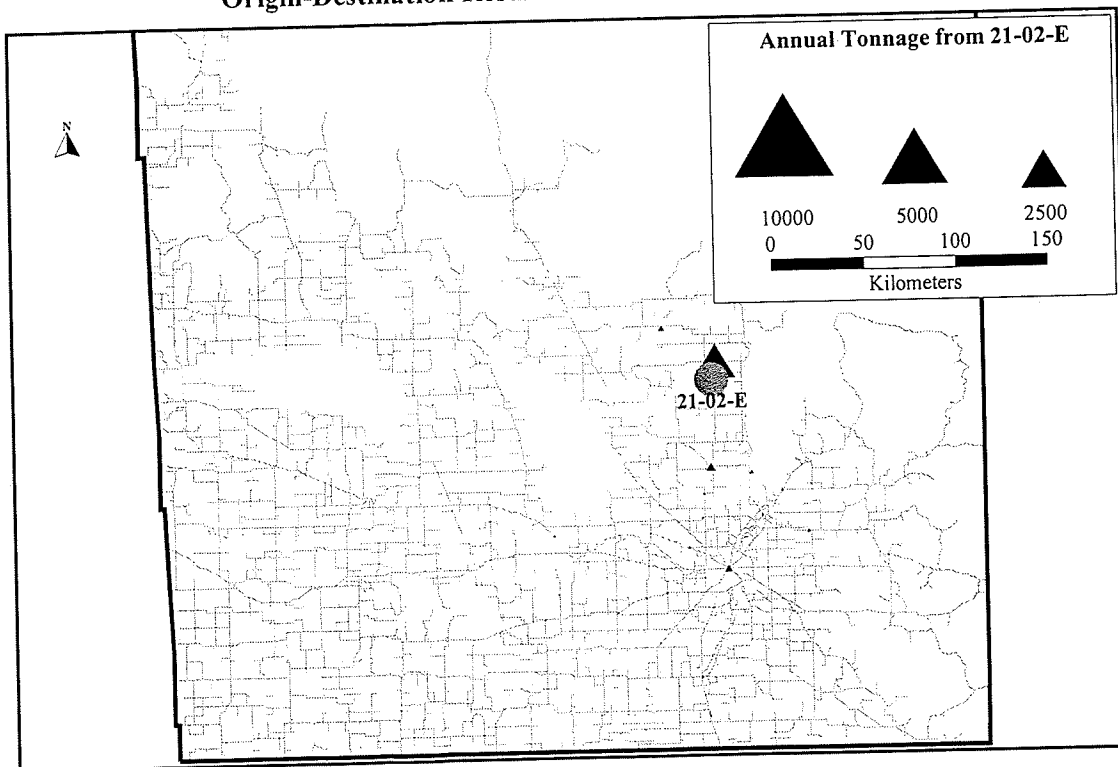
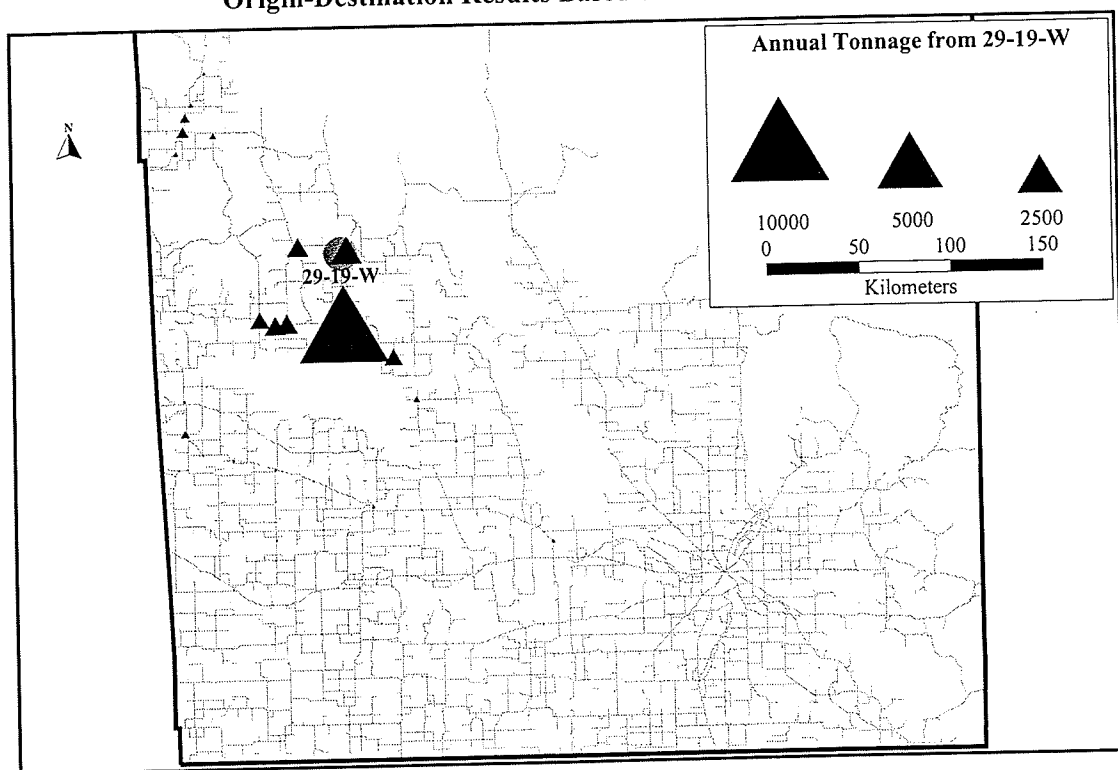


Figure D.14: Township 29-19-W
Origin-Destination Results Based on Cost and Distance



APPENDIX E

Origin-Destination Results Based on Cost and Distance Calibration #1

Figure E.1: Dauphin Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #1

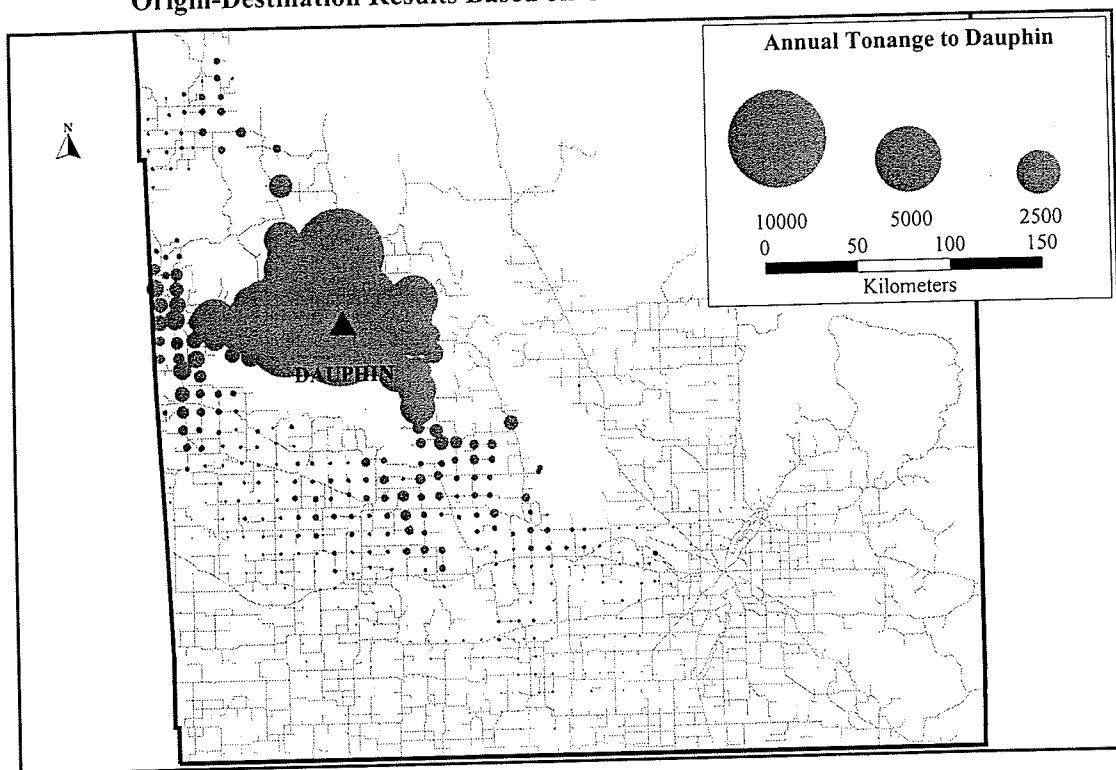


Figure E.2: Killarney Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #1

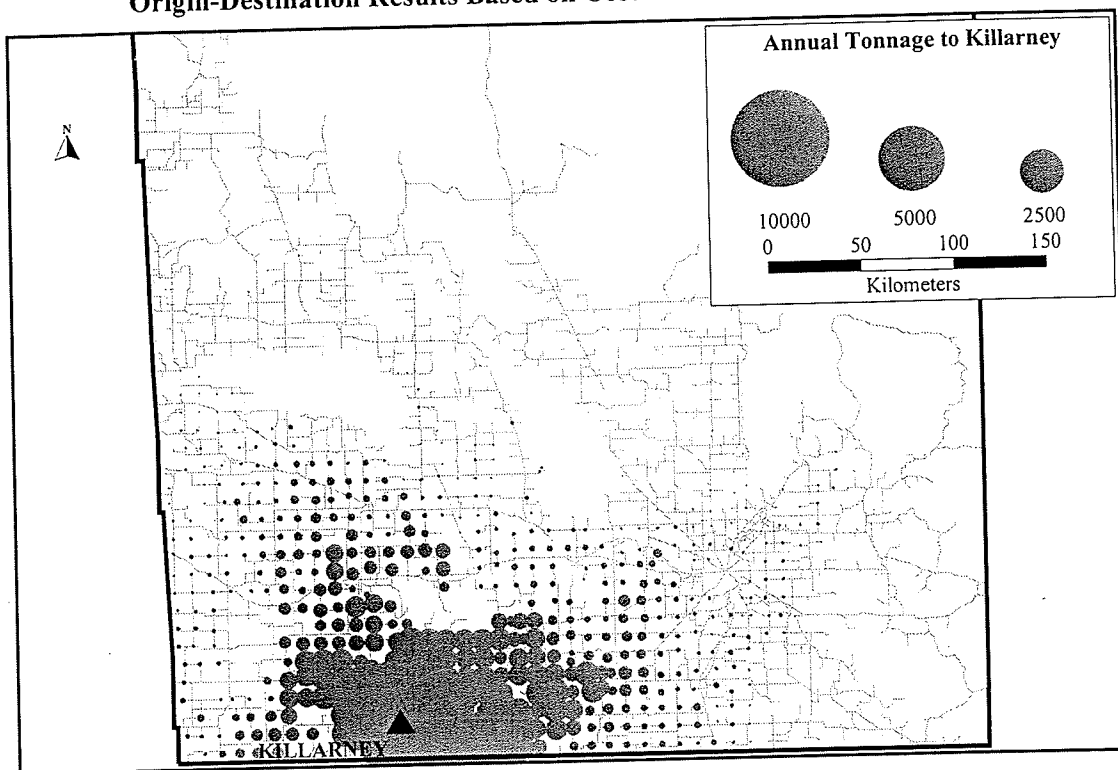


Figure E.3: Melita Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

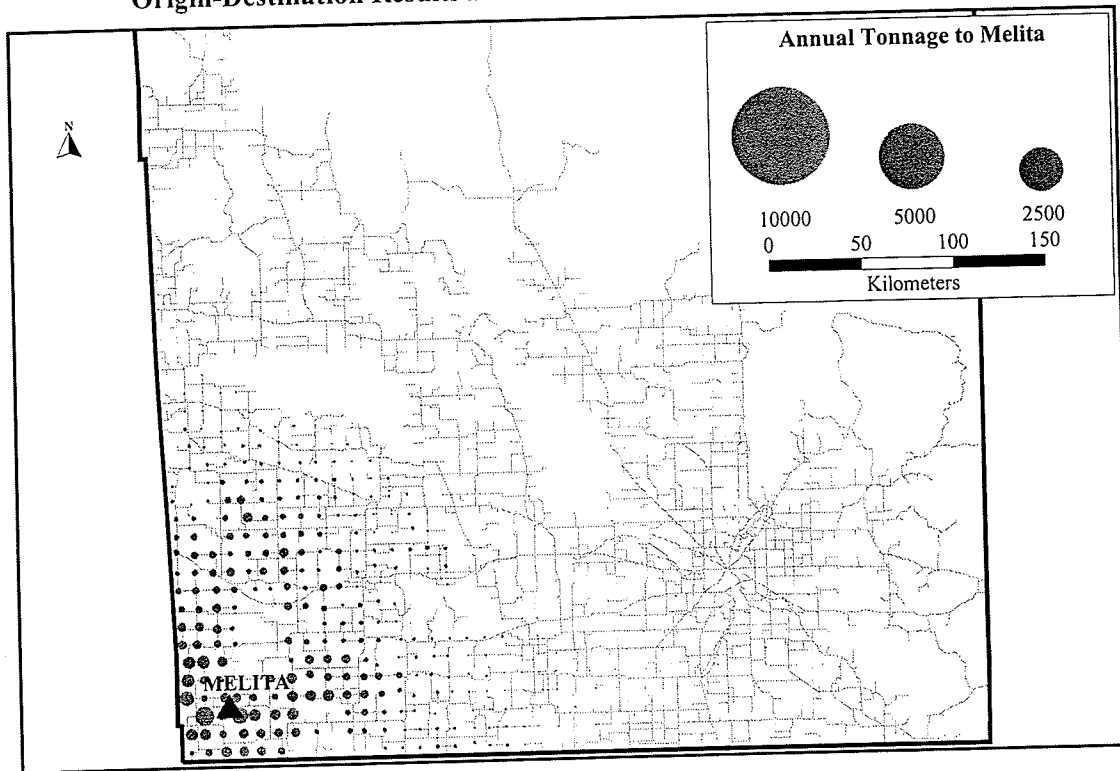


Figure E.4: Minnedosa Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

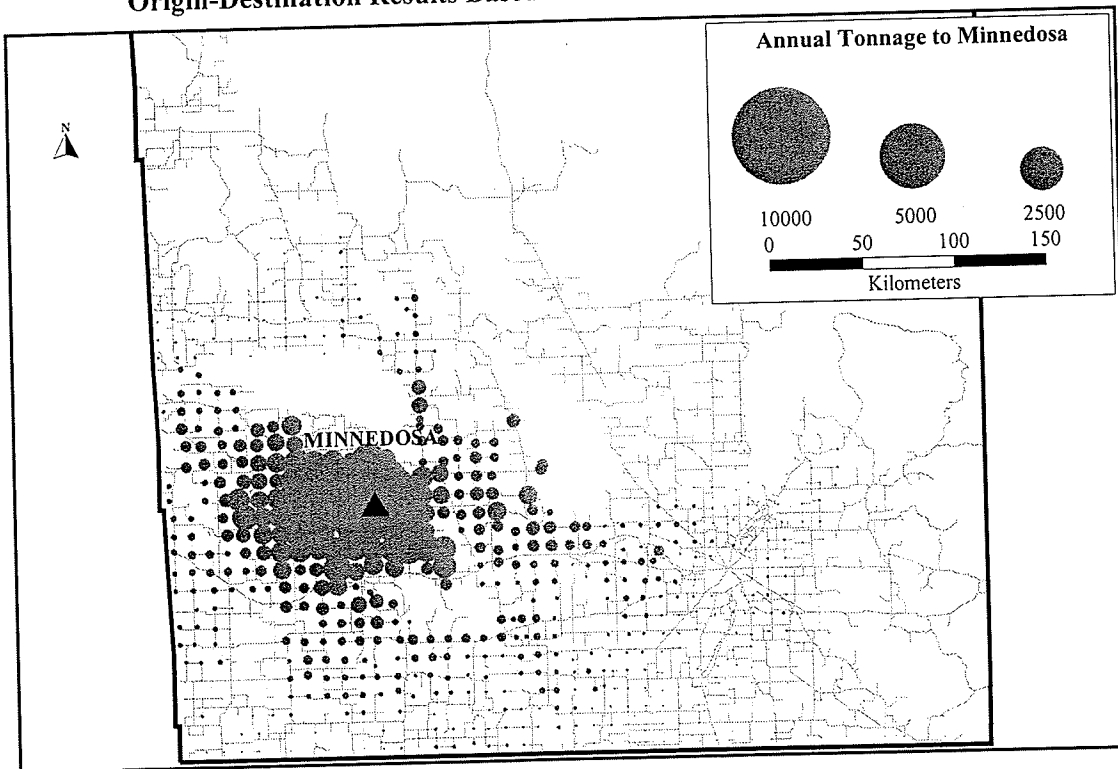


Figure E.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

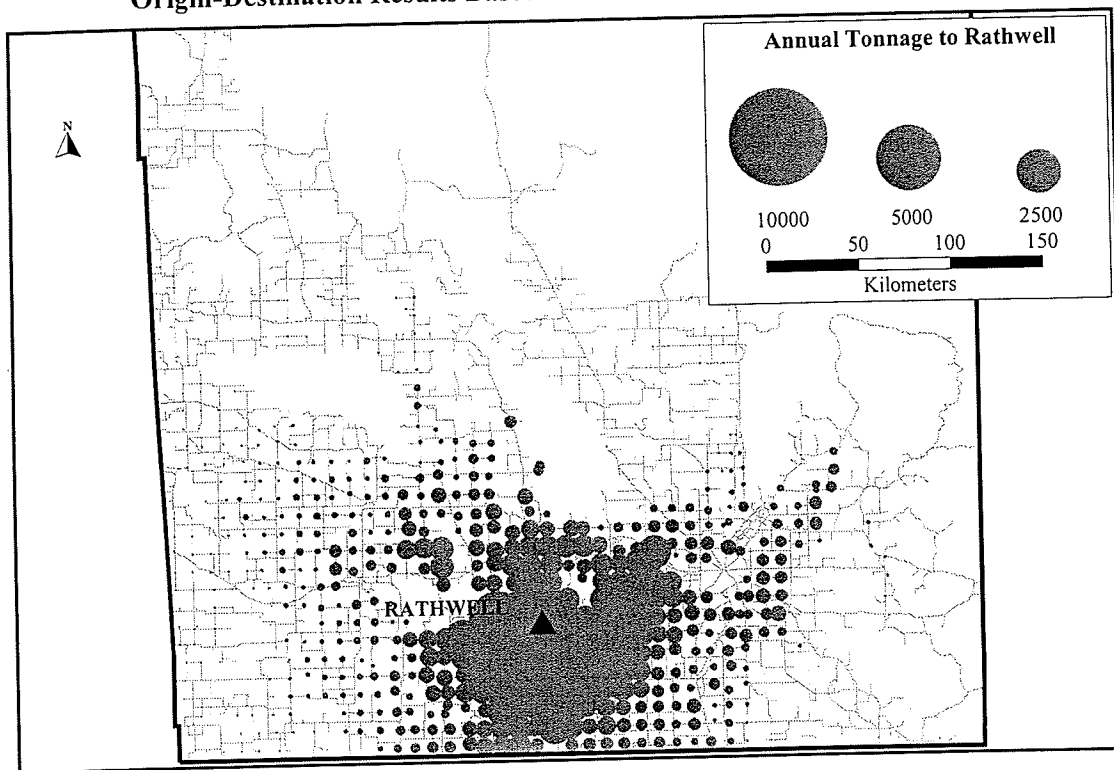


Figure E.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

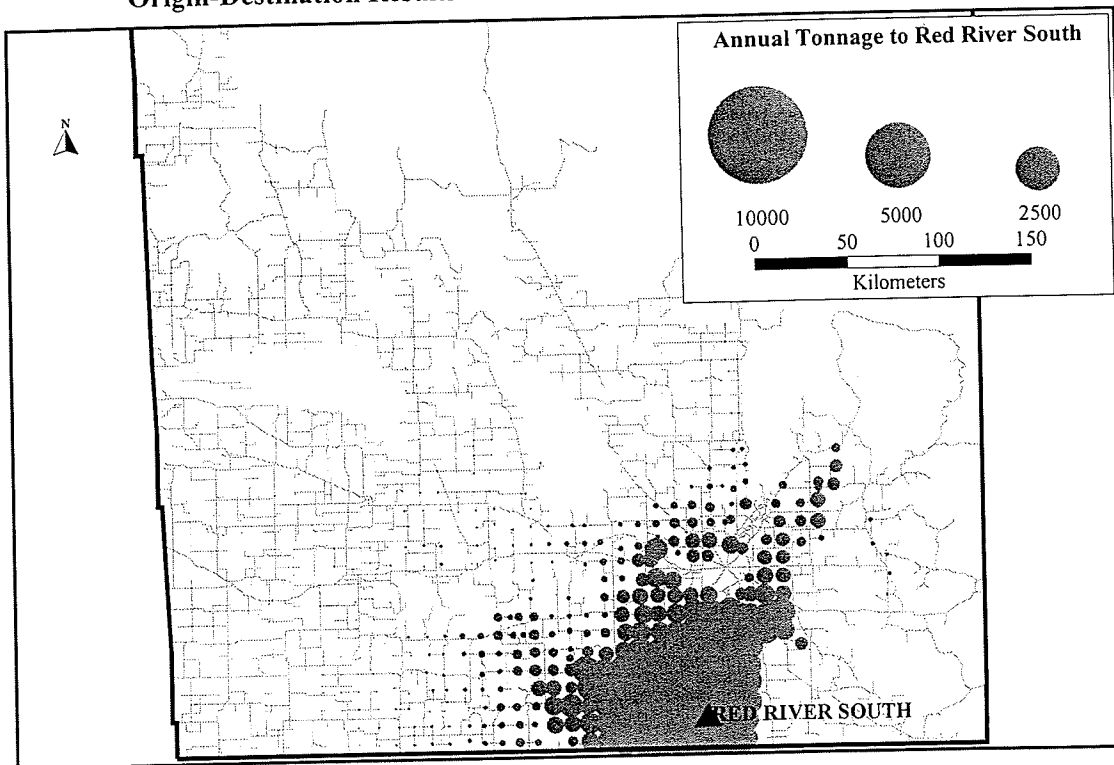


Figure E.7: Swan River Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #1

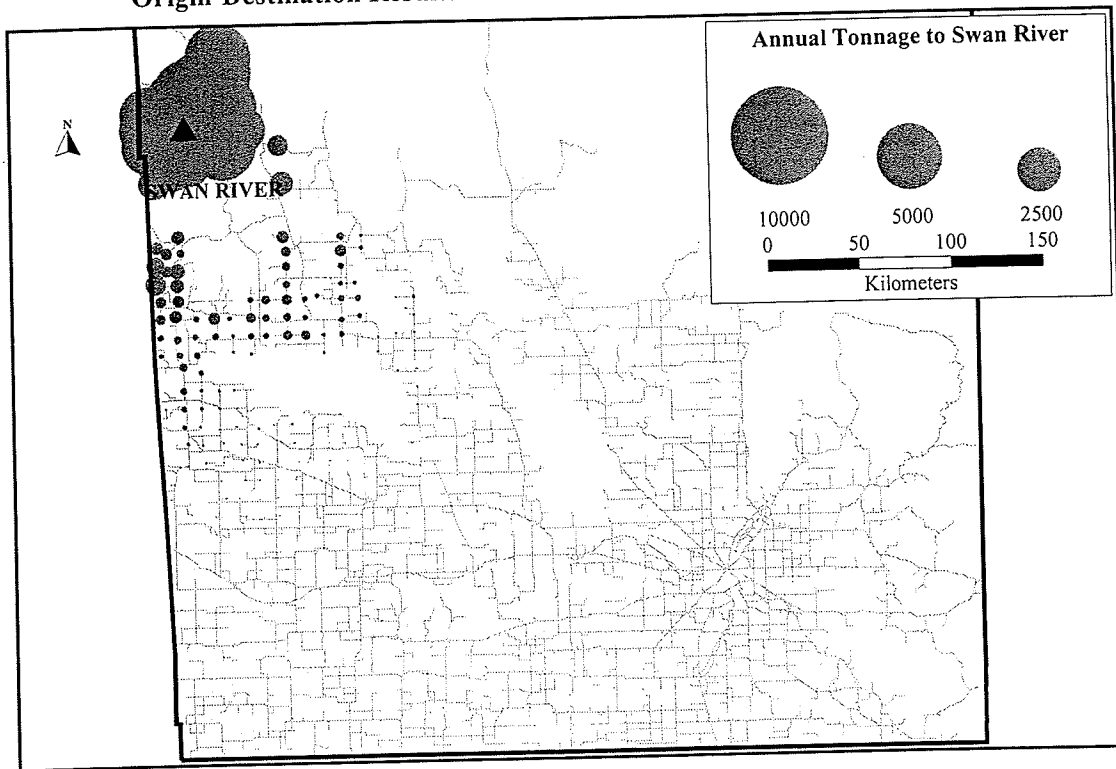


Figure E.8: Virden Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #1

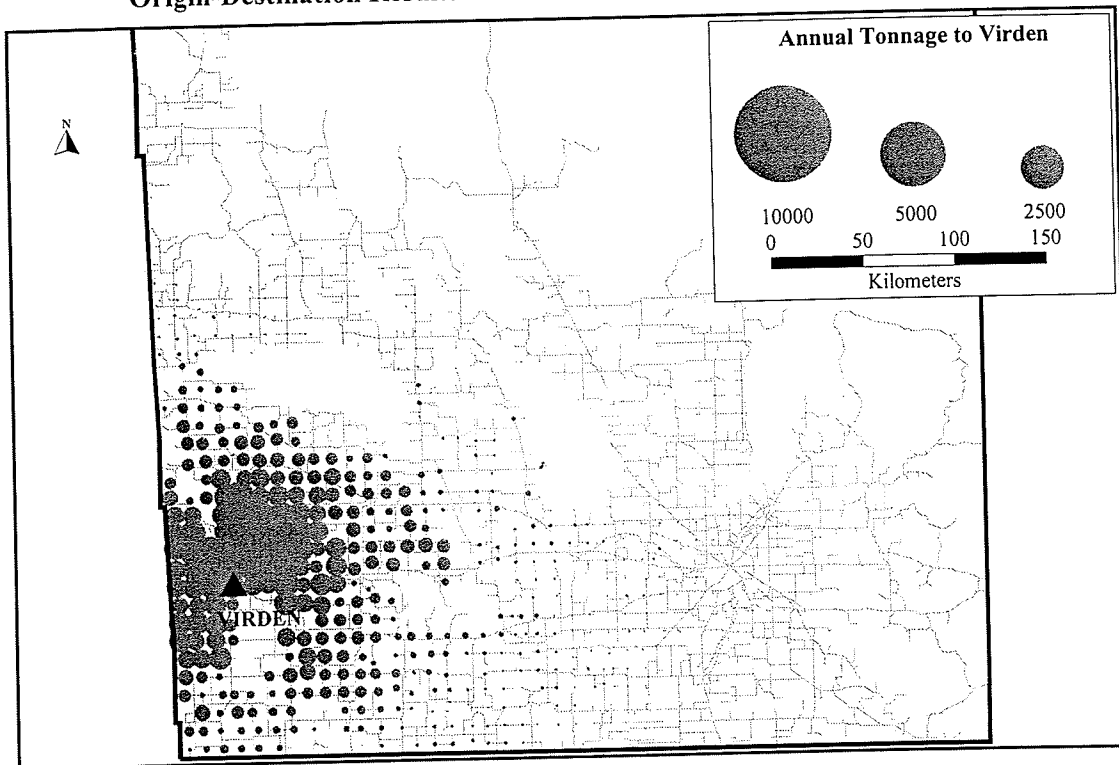


Figure E.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #1

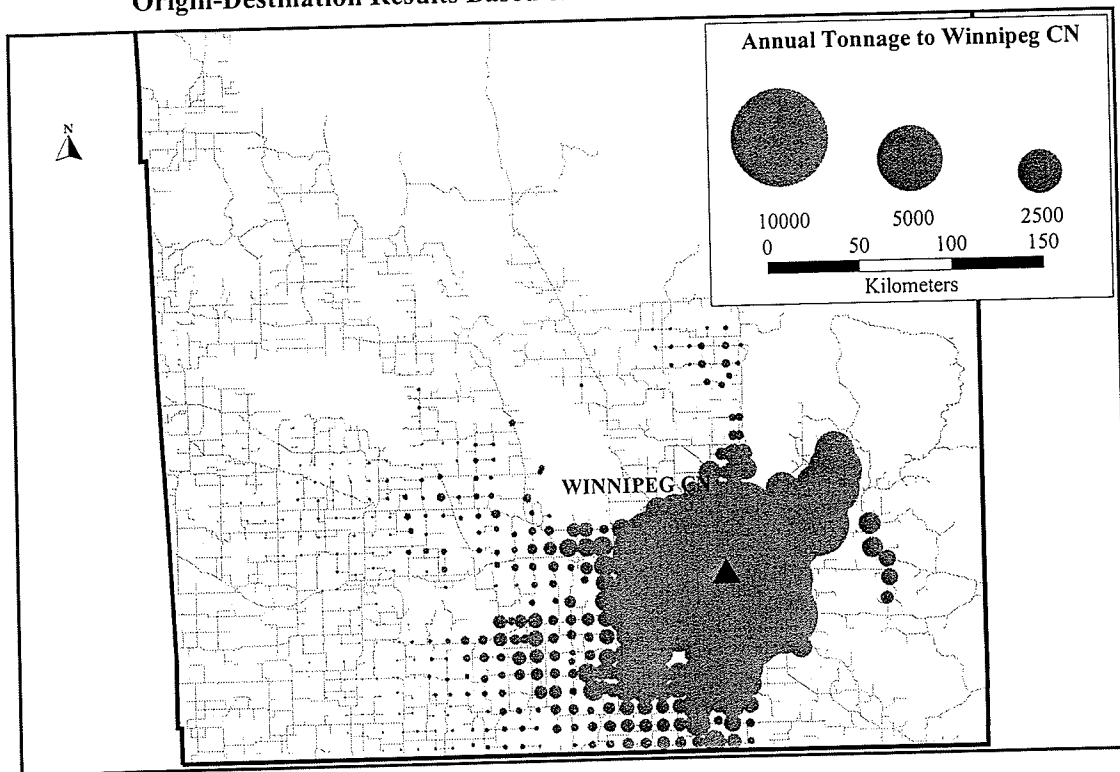


Figure E.10: Township 05-23-W

Origin-Destination Results Based on Cost and Distance Calibration #1

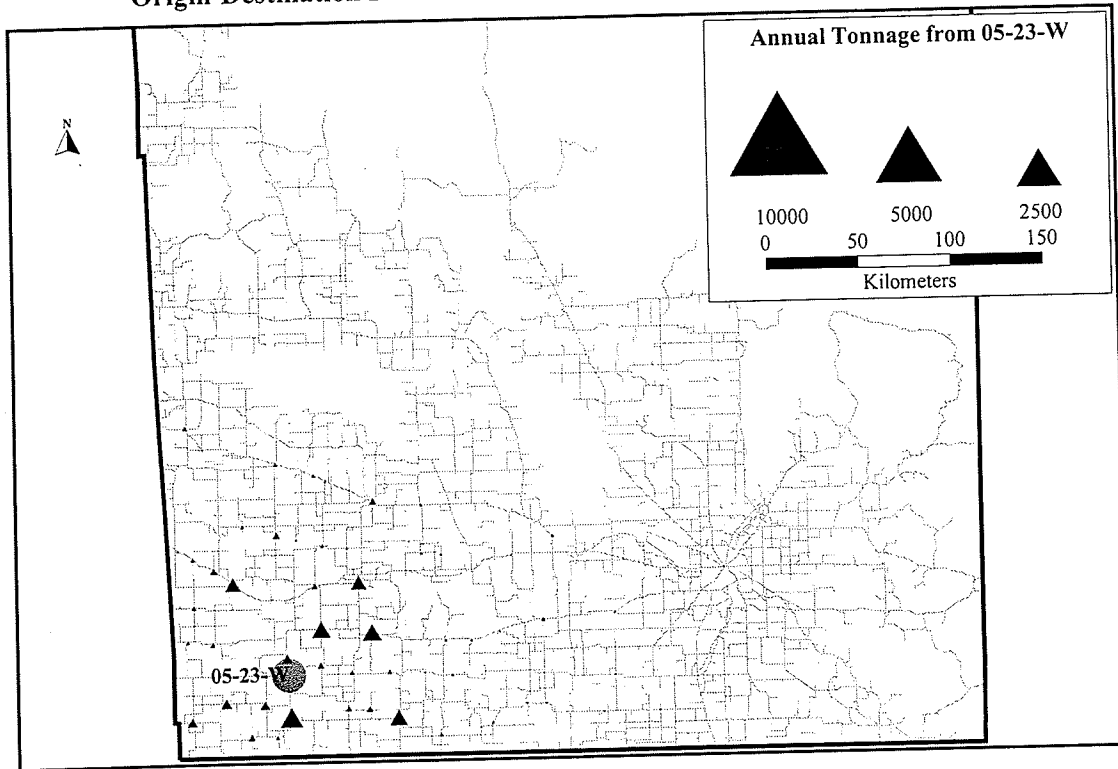


Figure E.11: Township 12-09-W

Origin-Destination Results Based on Cost and Distance Calibration #1

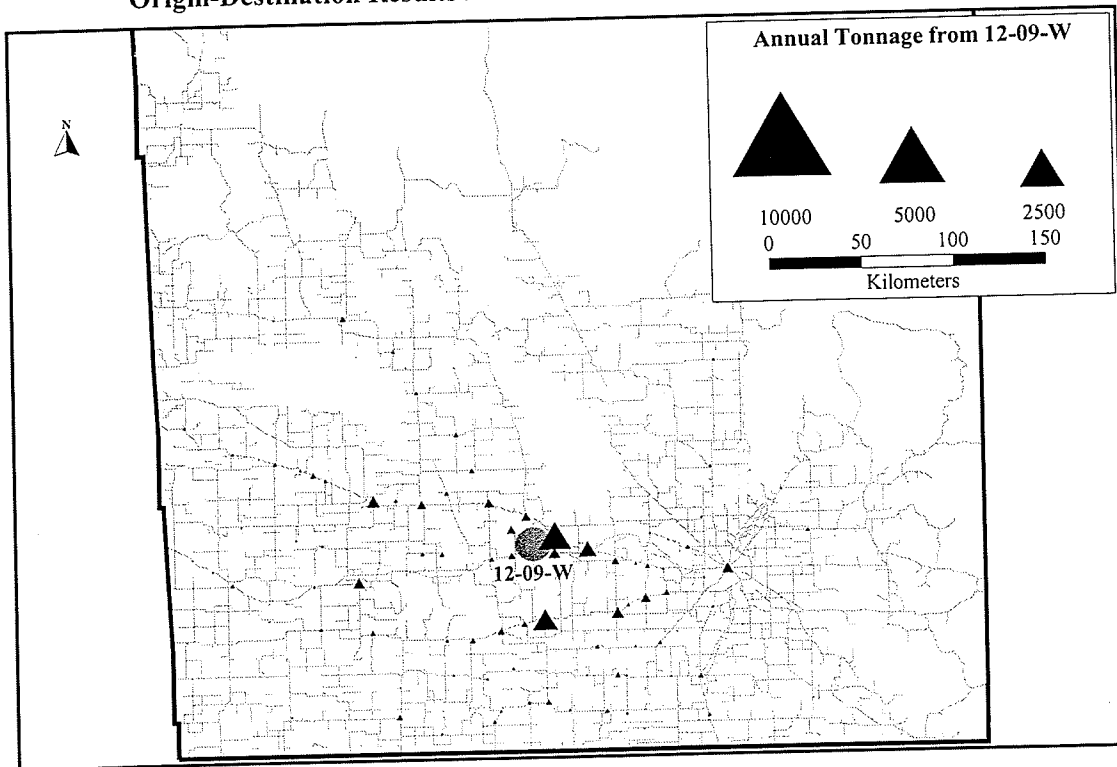


Figure E.12: Township 16-24-W

Origin-Destination Results Based on Cost and Distance Calibration #1

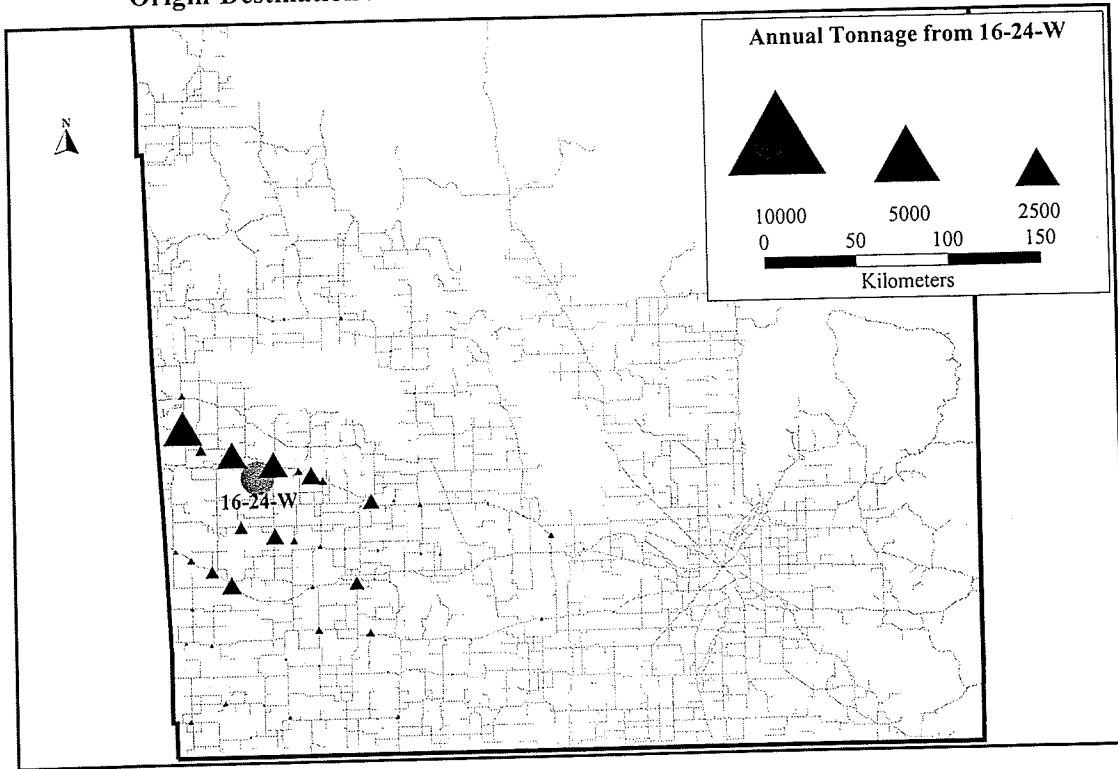


Figure E.13: Township 21-02-E

Origin-Destination Results Based on Cost and Distance Calibration #1

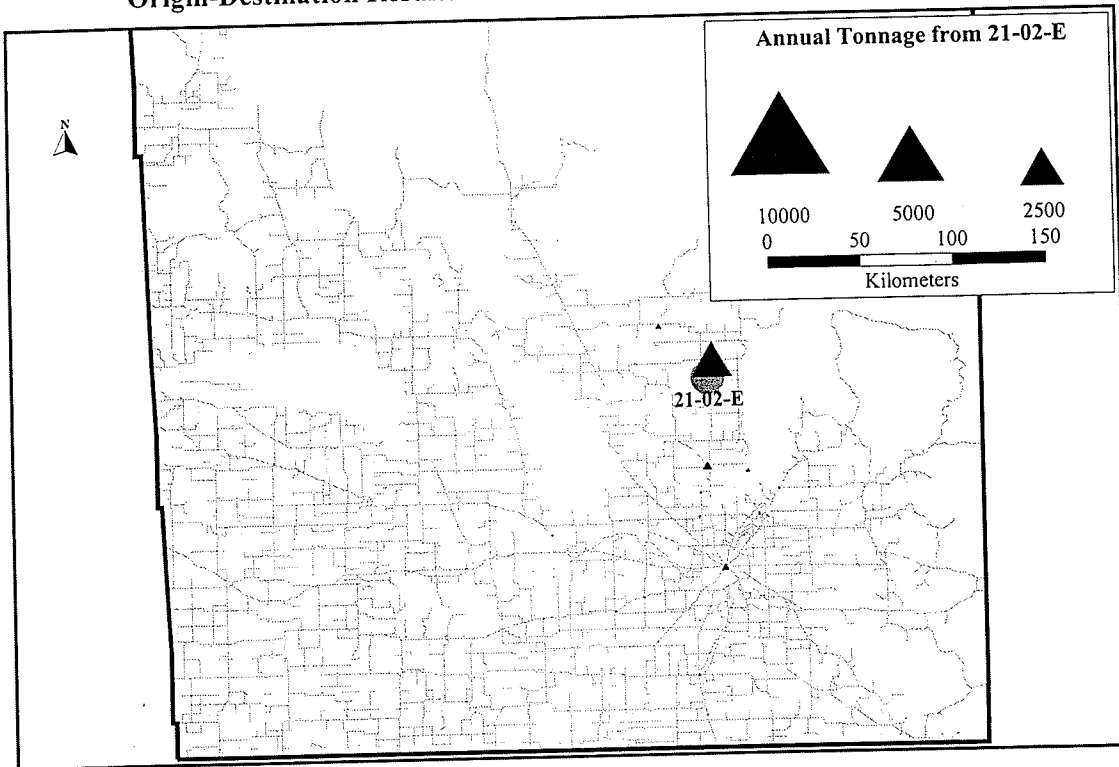
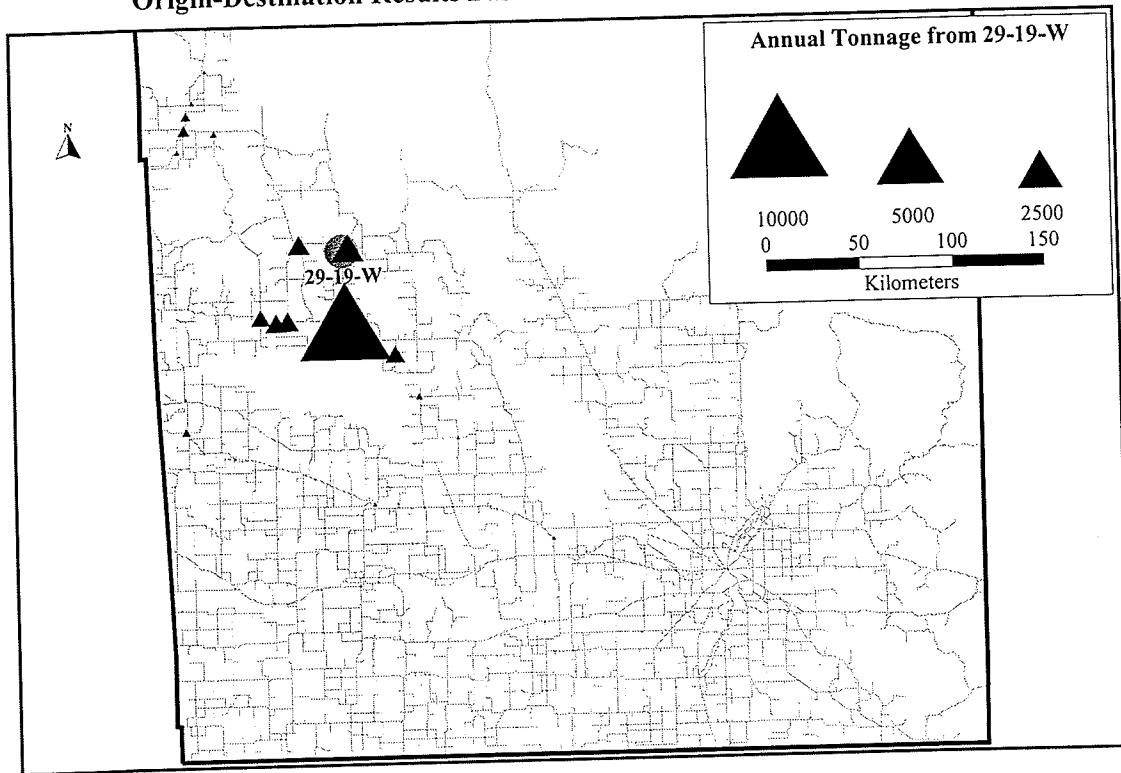


Figure E.14: Township 21-19-W

Origin-Destination Results Based on Cost and Distance Calibration #1



APPENDIX F

Origin-Destination Results Based on Cost and Distance Calibration #2

Figure F.1: Dauphin Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

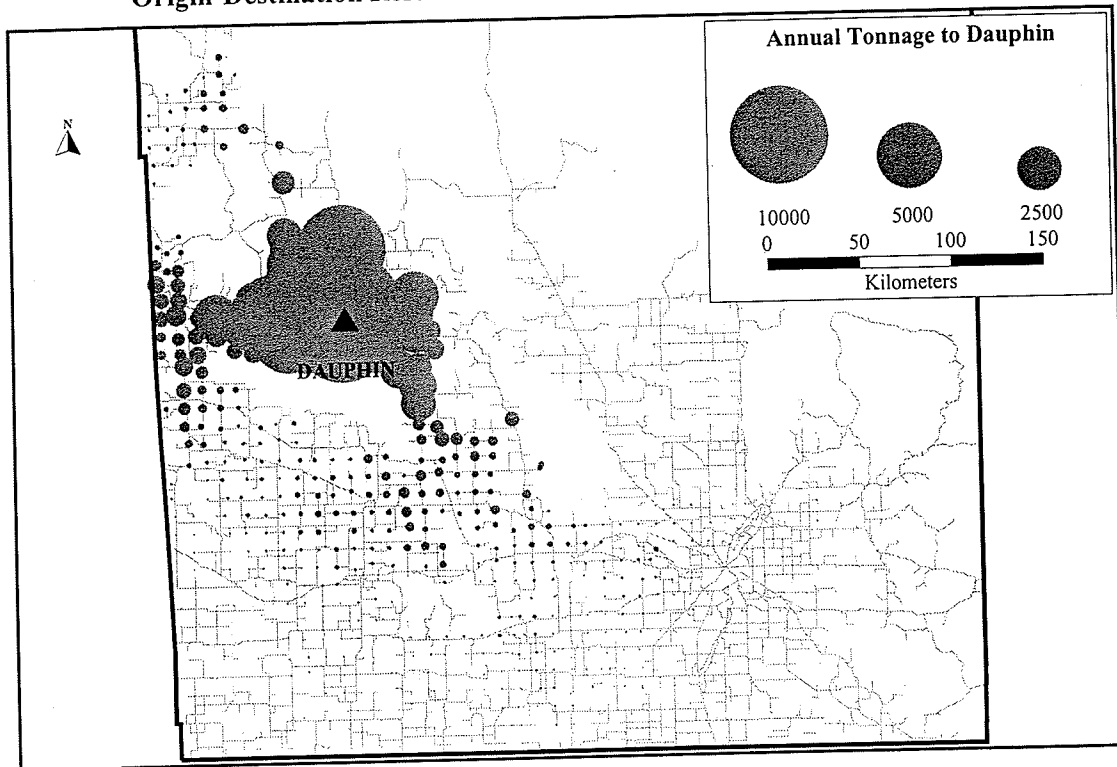


Figure F.2: Killarney Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

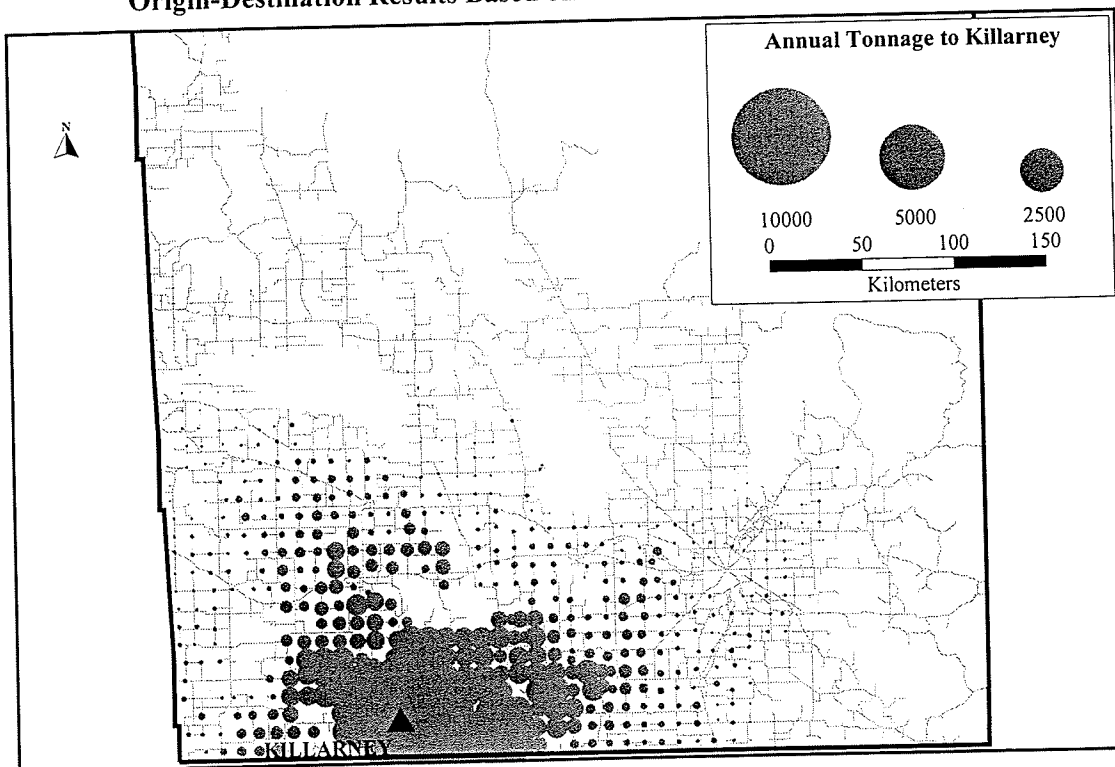


Figure F.3: Melita Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

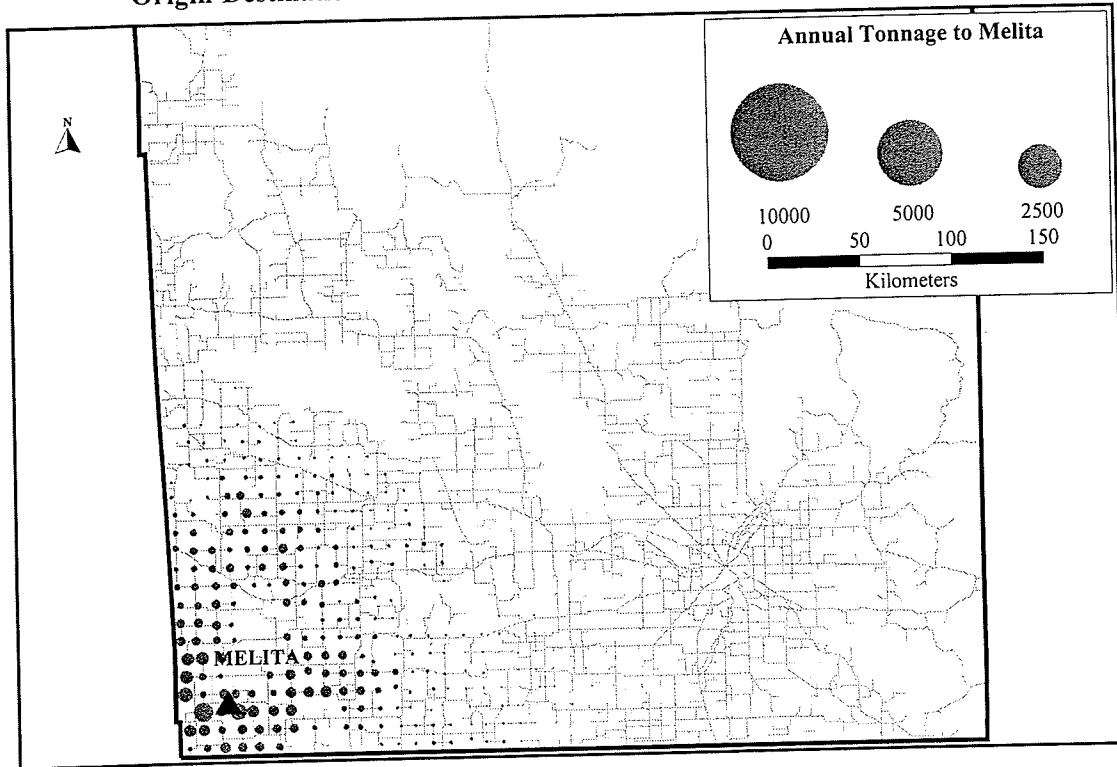


Figure F.4: Minnedosa Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

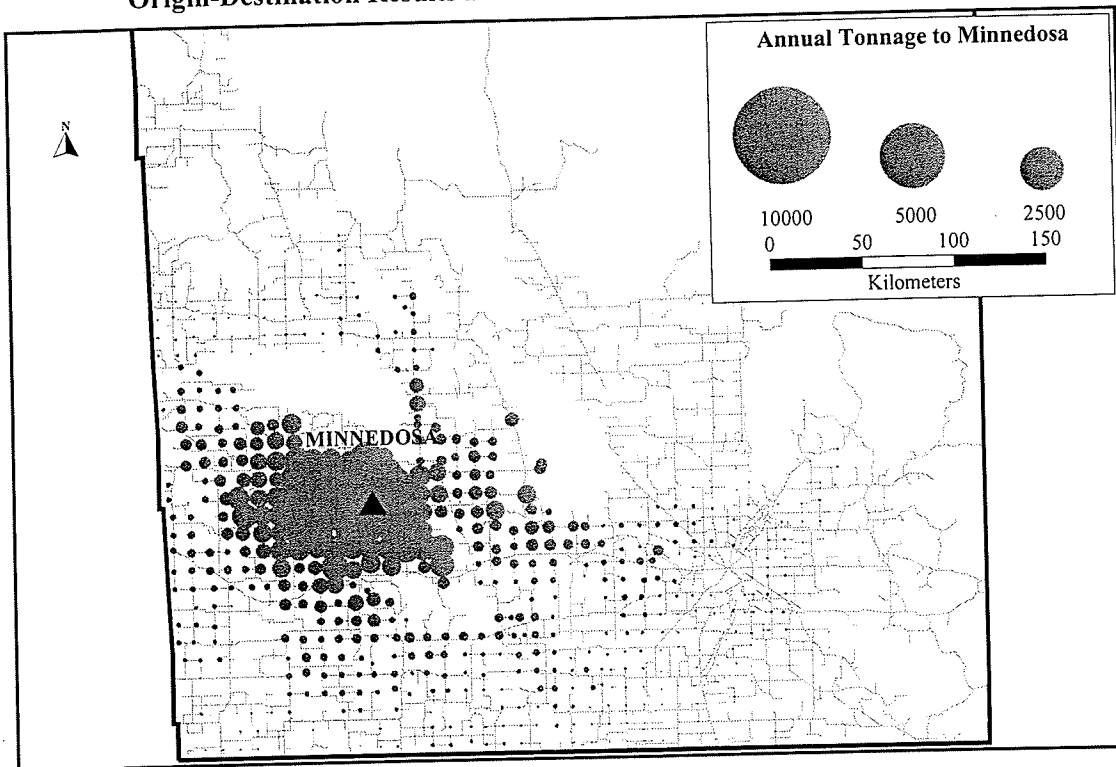


Figure F.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

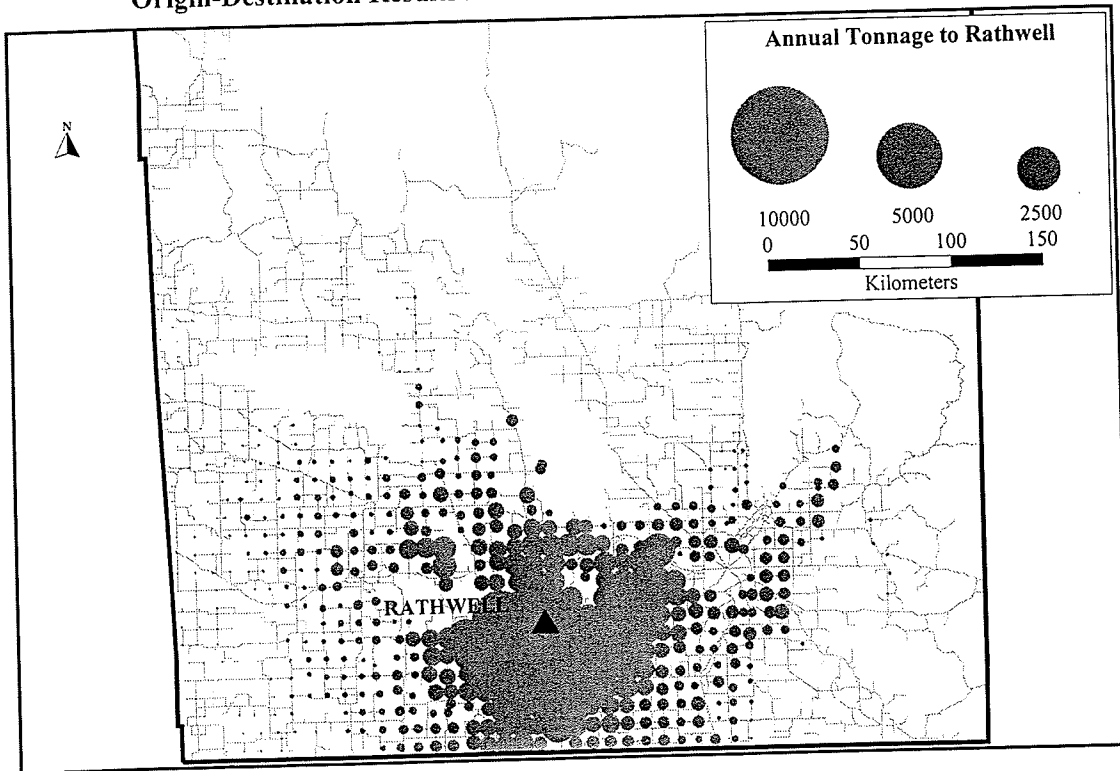


Figure F.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

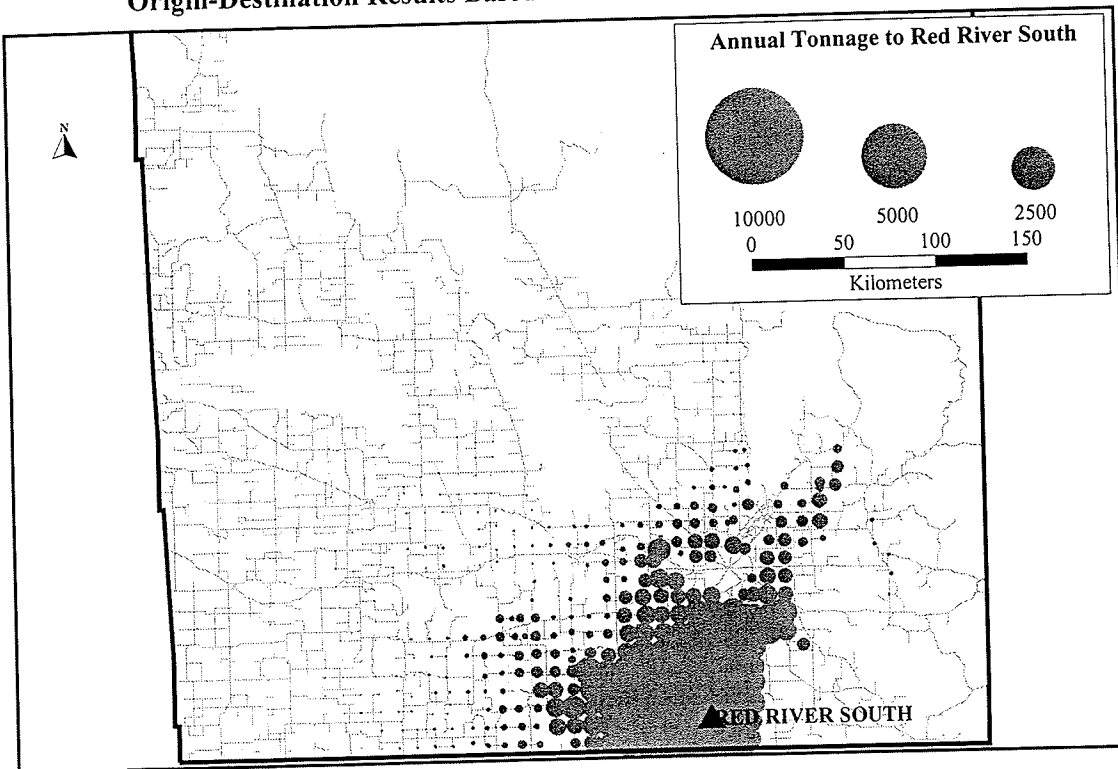


Figure F.7: Swan River Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #2

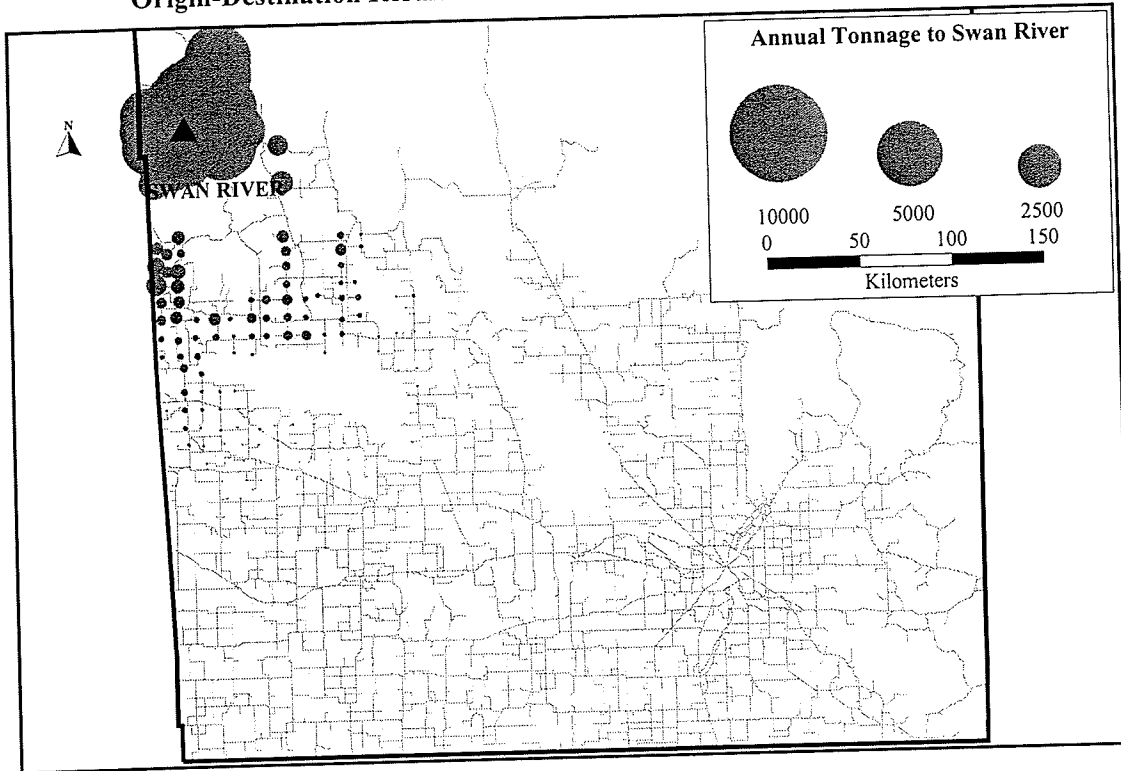


Figure F.8: Virden Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #2

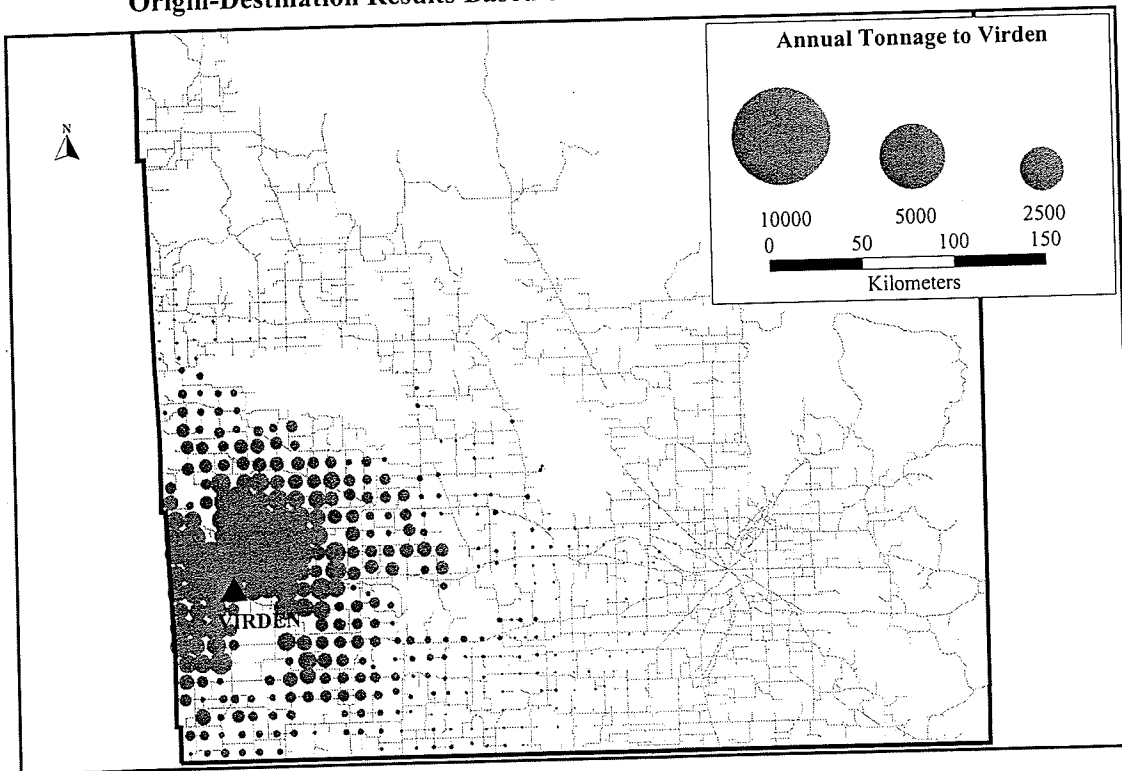


Figure F.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #2

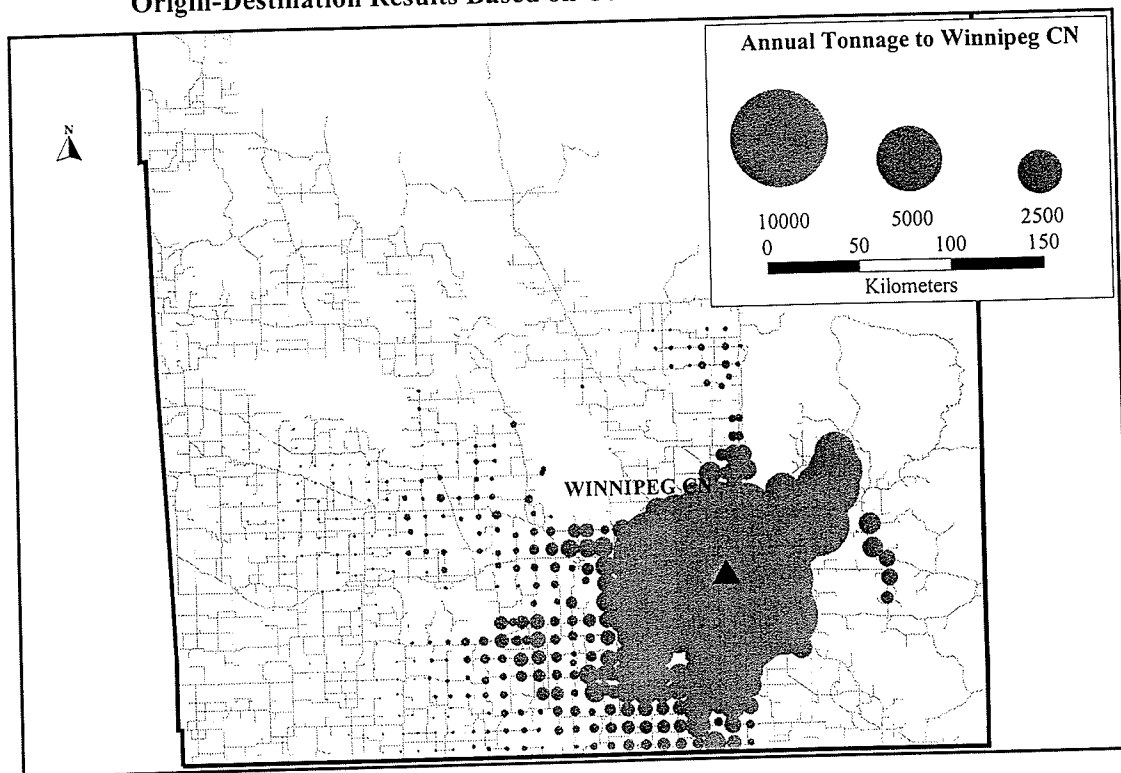


Figure F.10: Township 05-23-W

Origin-Destination Results Based on Cost and Distance Calibration #2

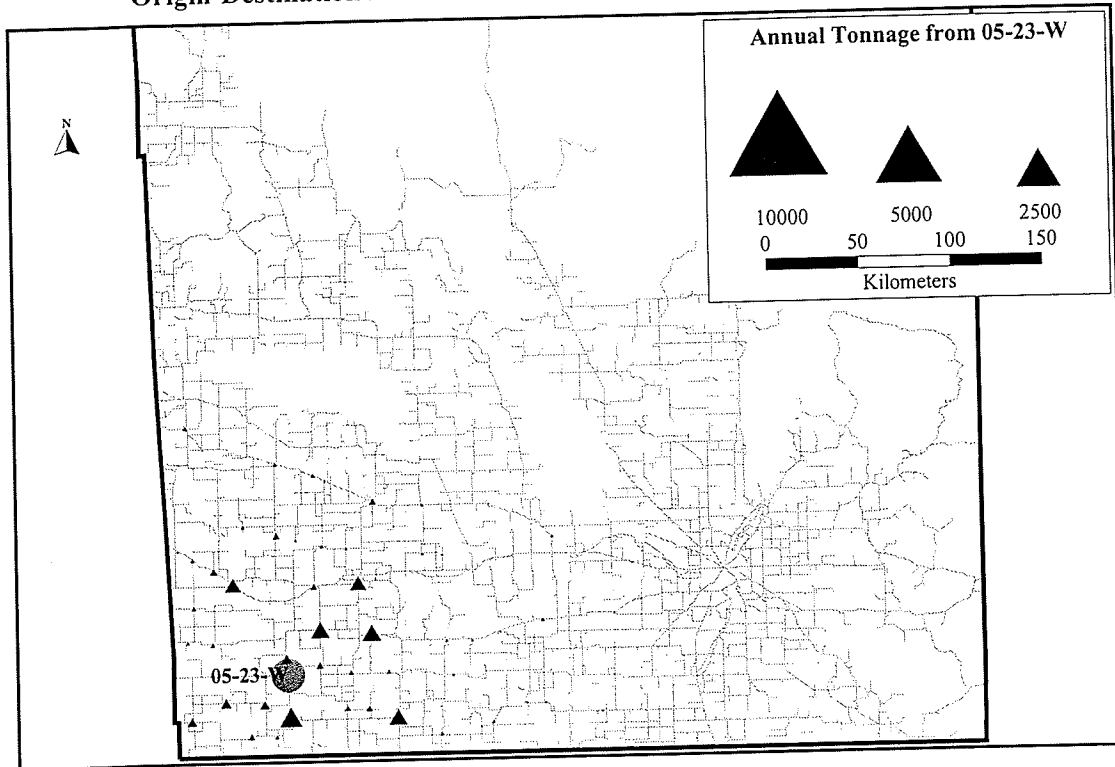


Figure F.11: Township 12-09-W

Origin-Destination Results Based on Cost and Distance Calibration #2

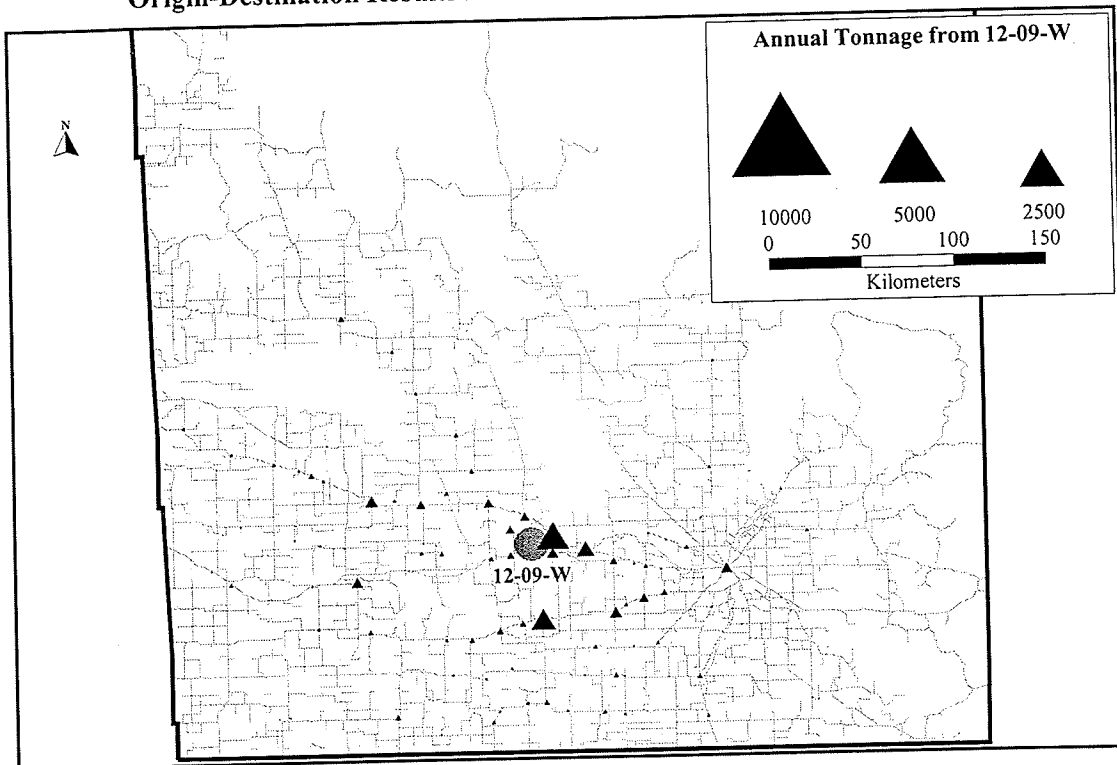


Figure F.12: Township 16-24-W

Origin-Destination Results Based on Cost and Distance Calibration #2

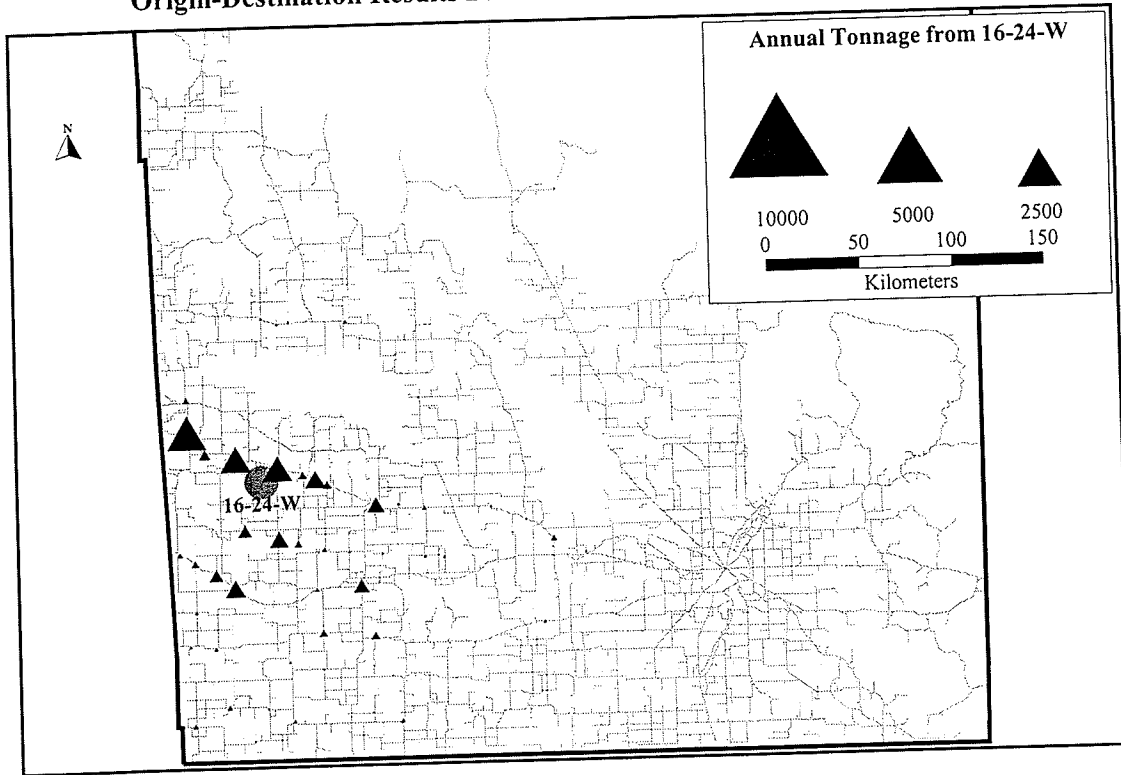


Figure F.13: Township 21-02-E

Origin-Destination Results Based on Cost and Distance Calibration #2

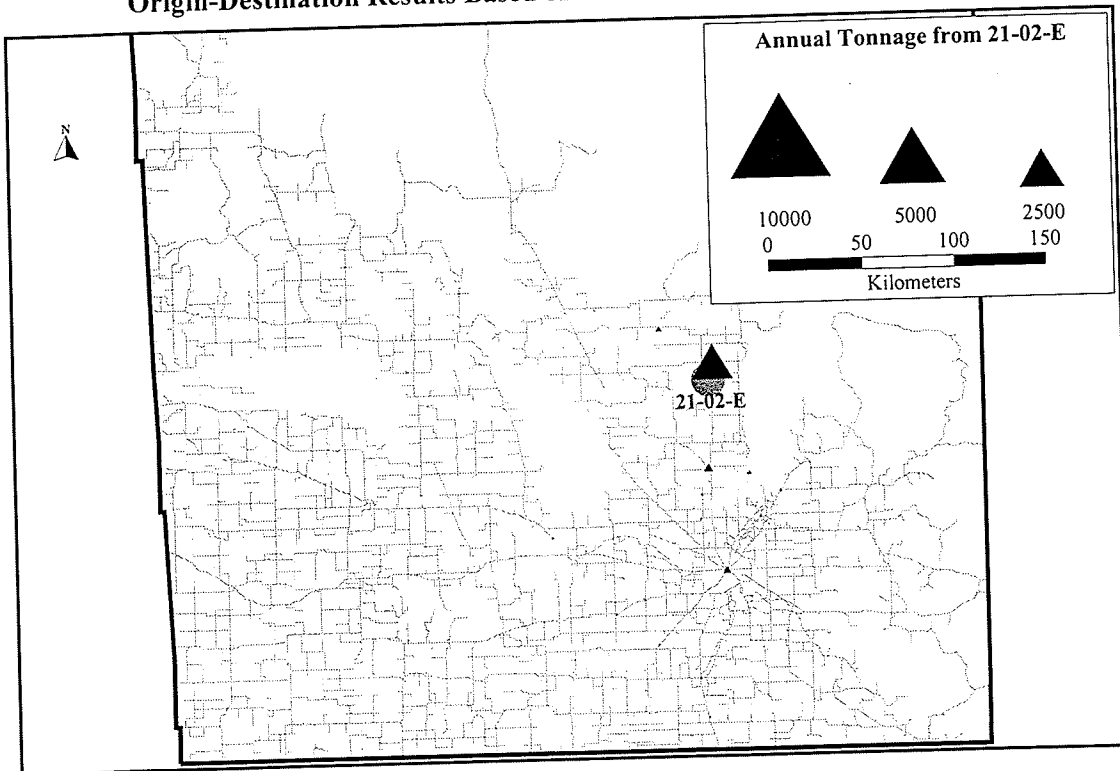
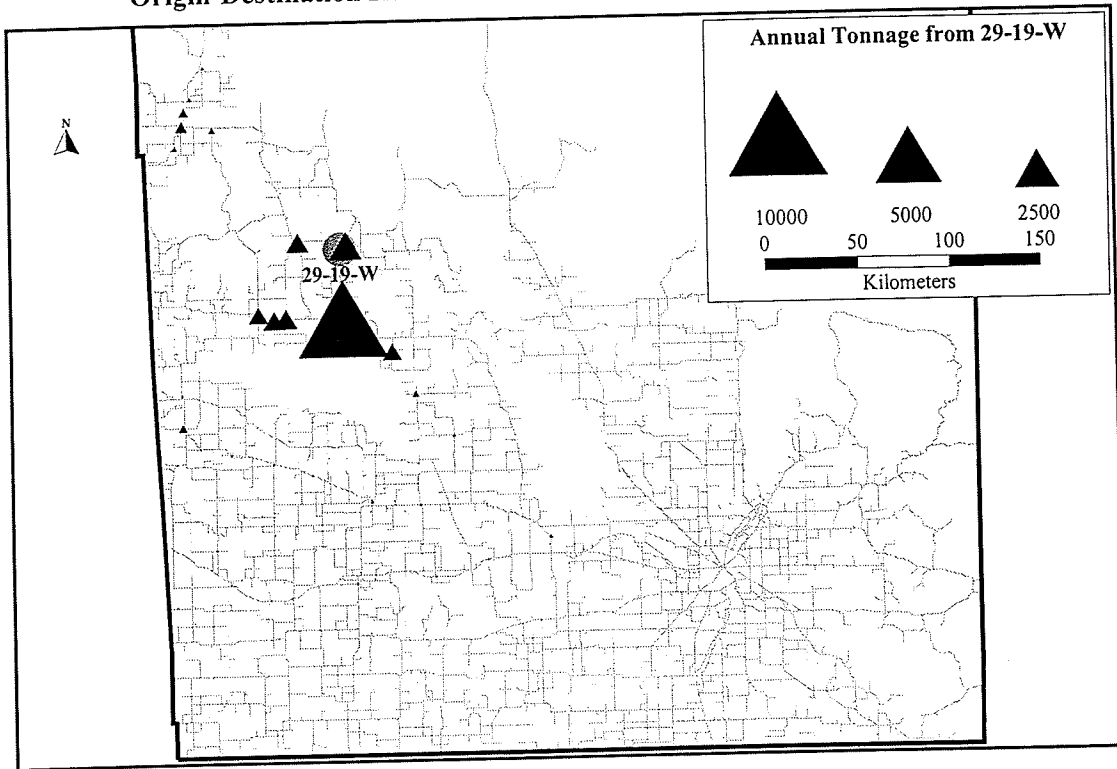


Figure F.14: Township 29-19-W

Origin-Destination Results Based on Cost and Distance Calibration #2



APPENDIX G

*Origin-Destination Results Based on Cost and Distance
Calibration #3*

Figure G.1: Dauphin Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

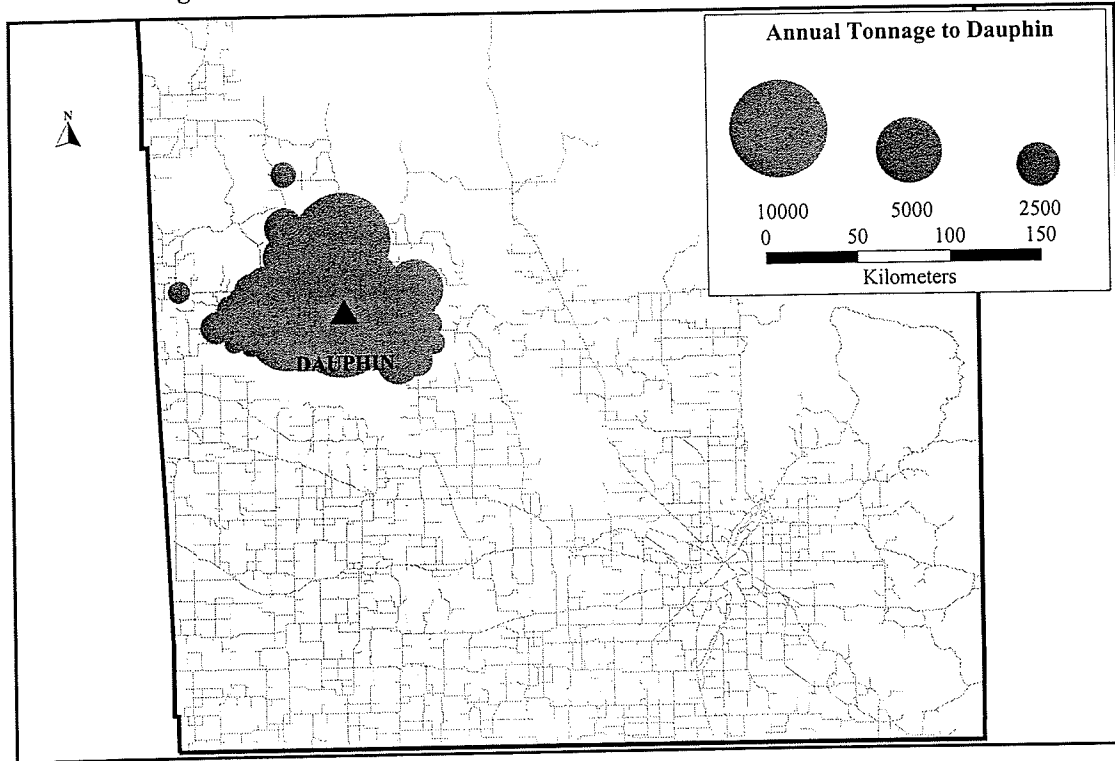


Figure G.2: Killarney Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

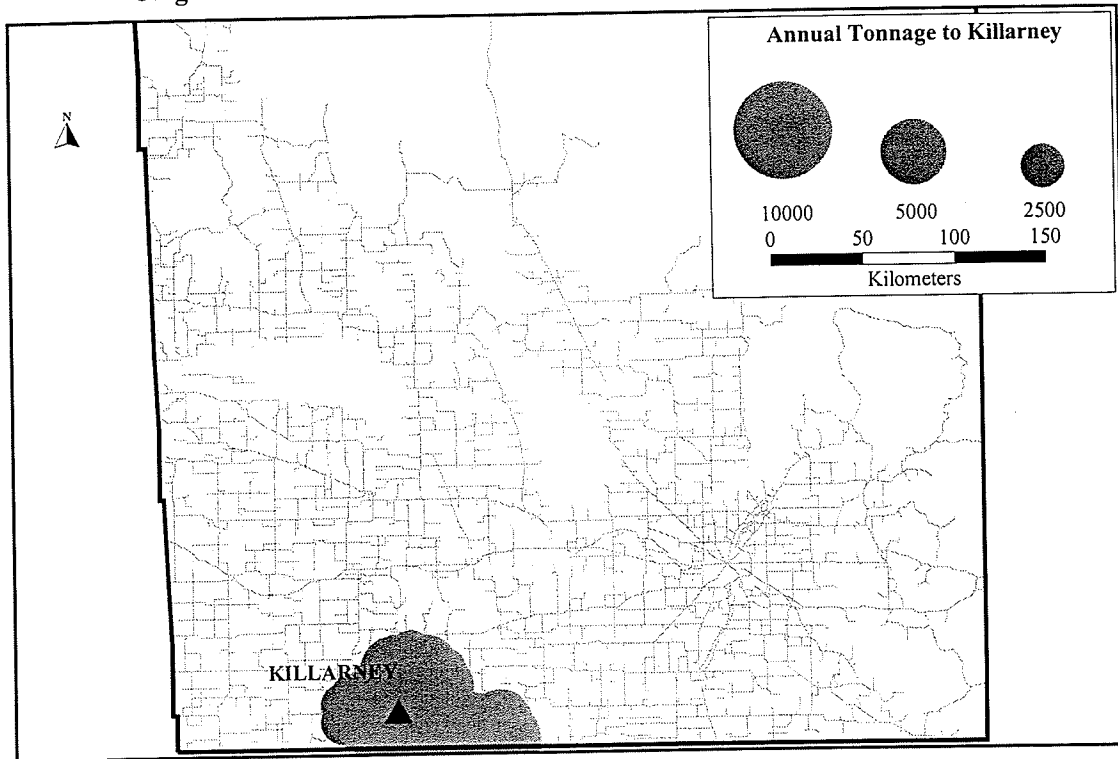


Figure G.3: Melita Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #3

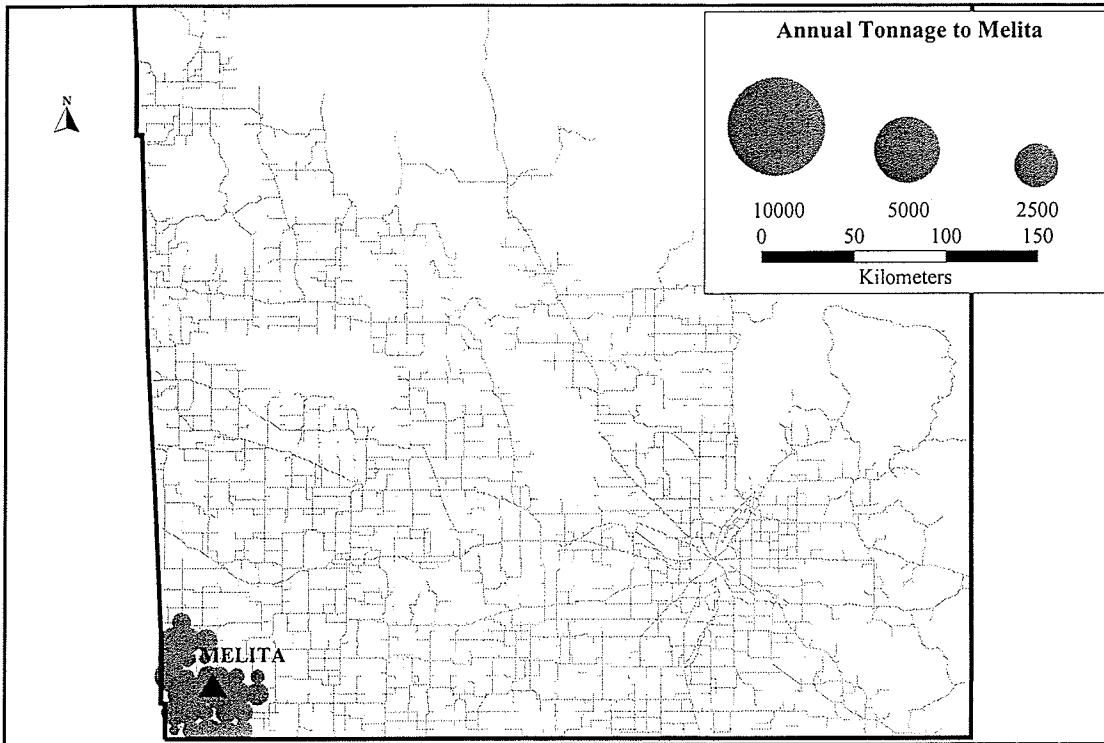


Figure G.4: Minnedosa Grain Delivery Point

Origin-Destination Results Based on Cost and Distance Calibration #3

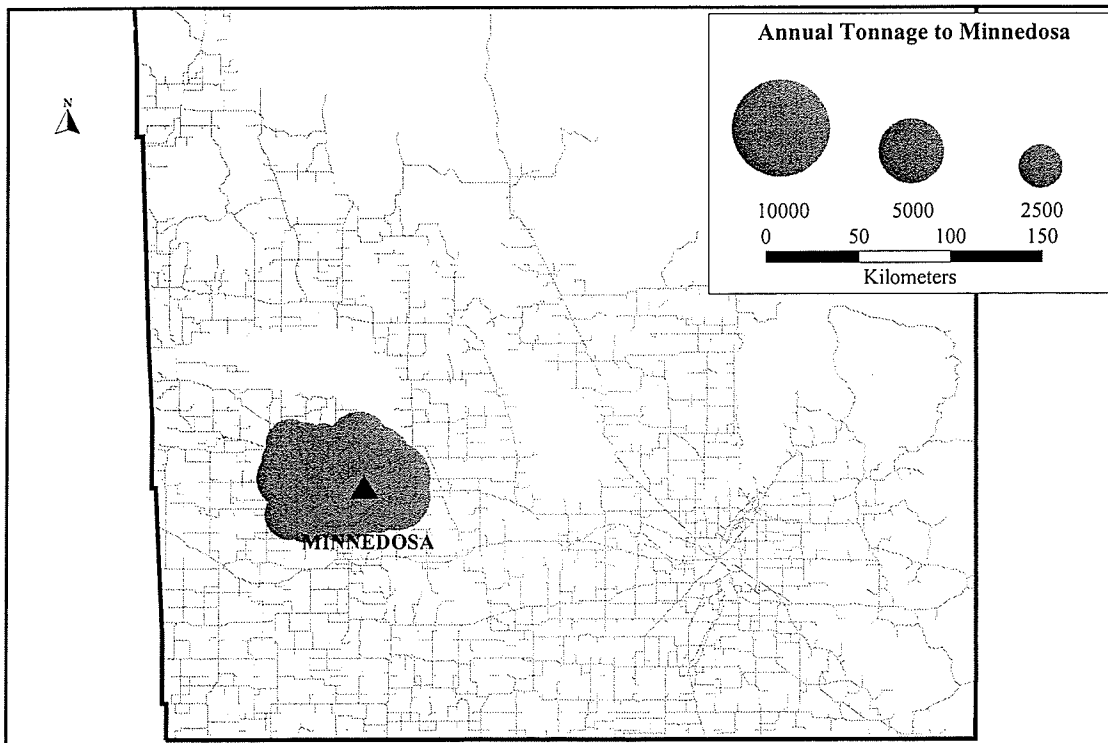


Figure G.5: Rathwell Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

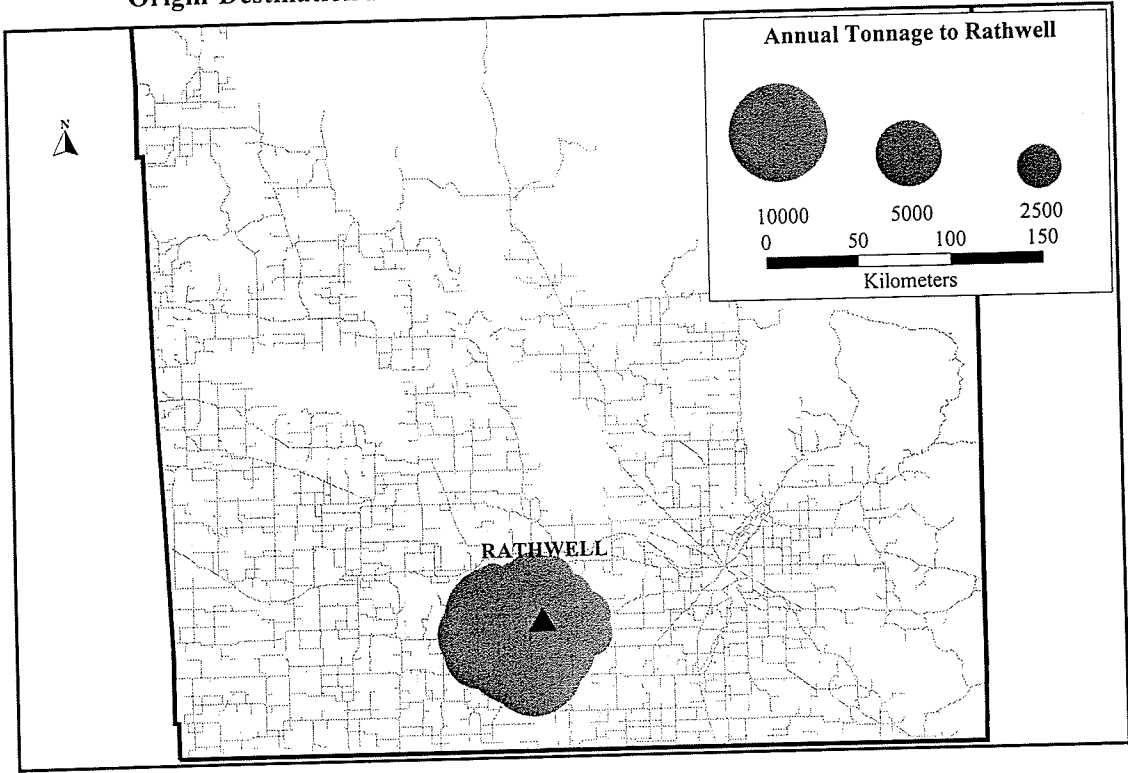


Figure G.6: Red River South Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

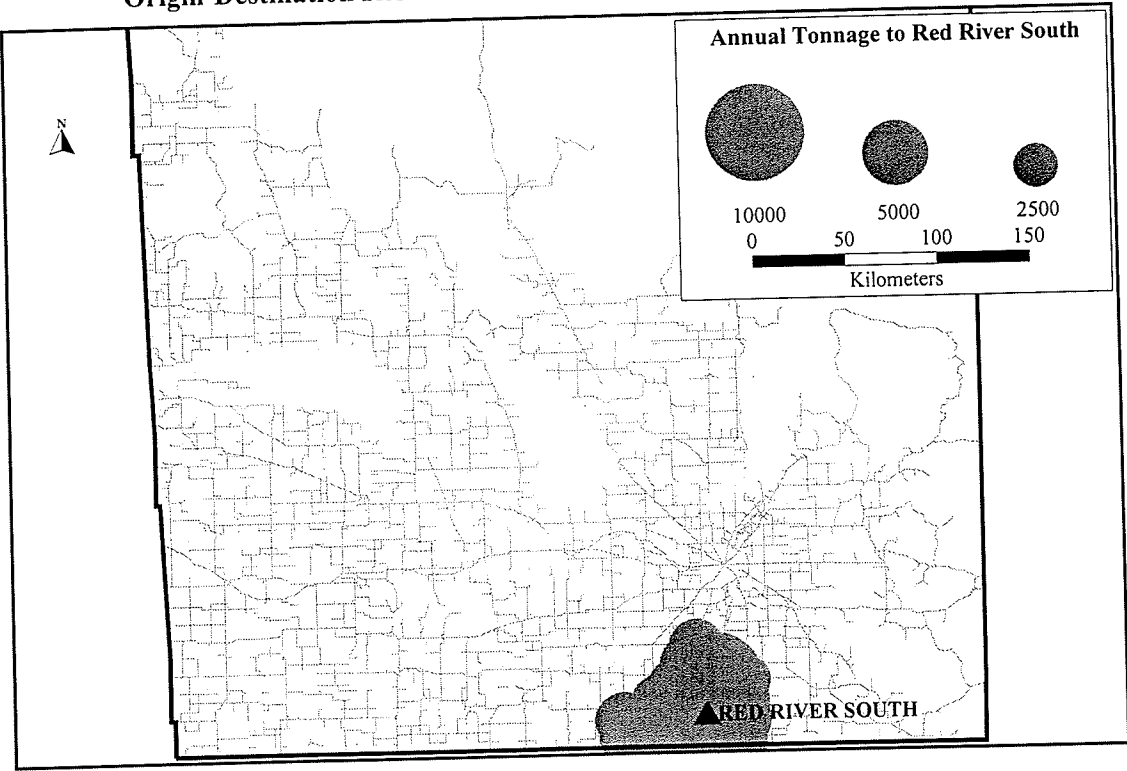


Figure G.7: Swan River Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

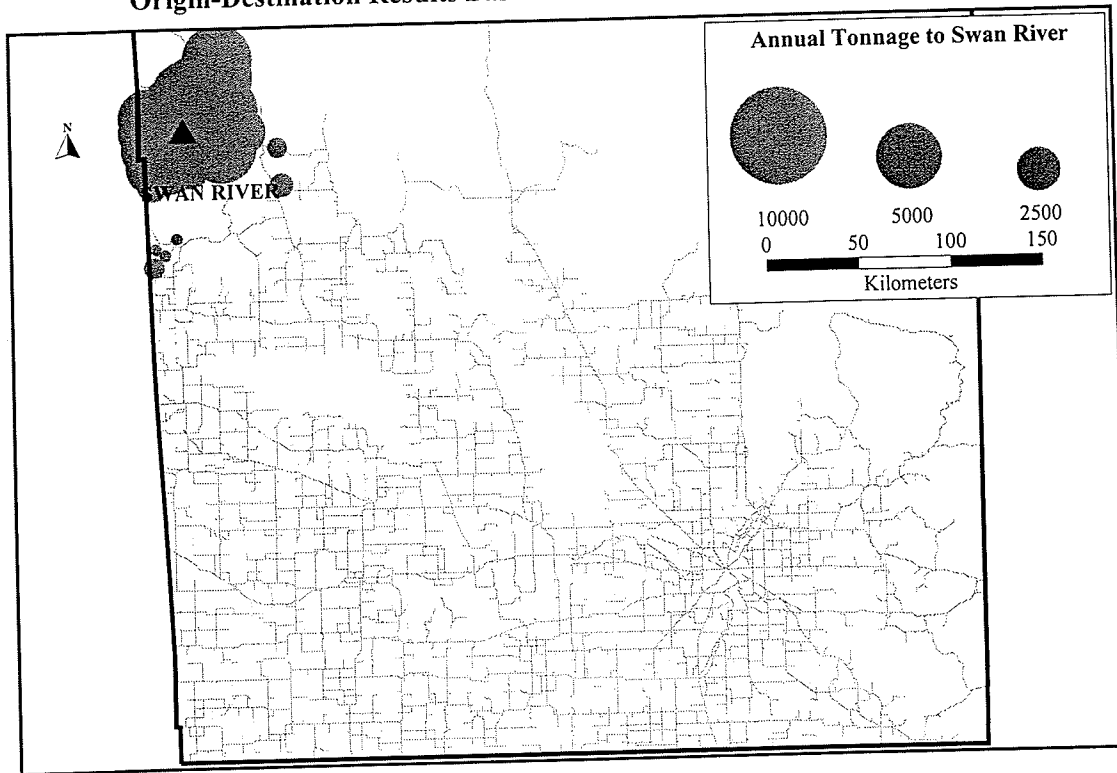


Figure G.8: Virden Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

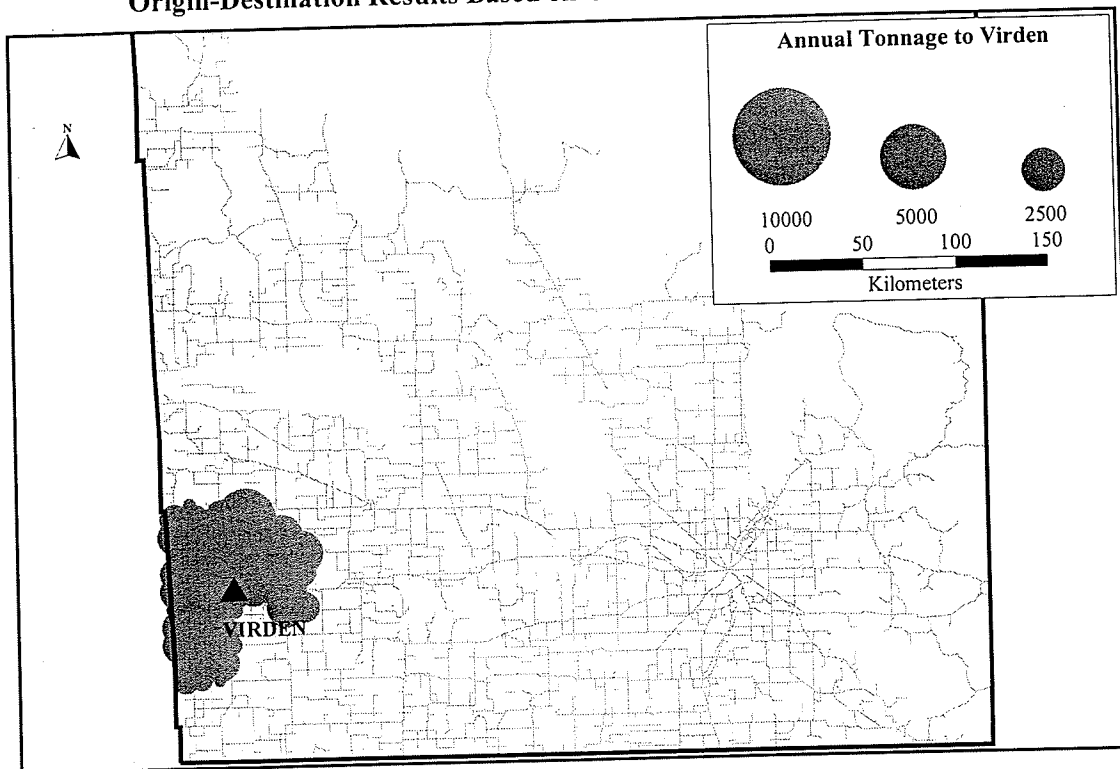


Figure G.9: Winnipeg CN Grain Delivery Point
Origin-Destination Results Based on Cost and Distance Calibration #3

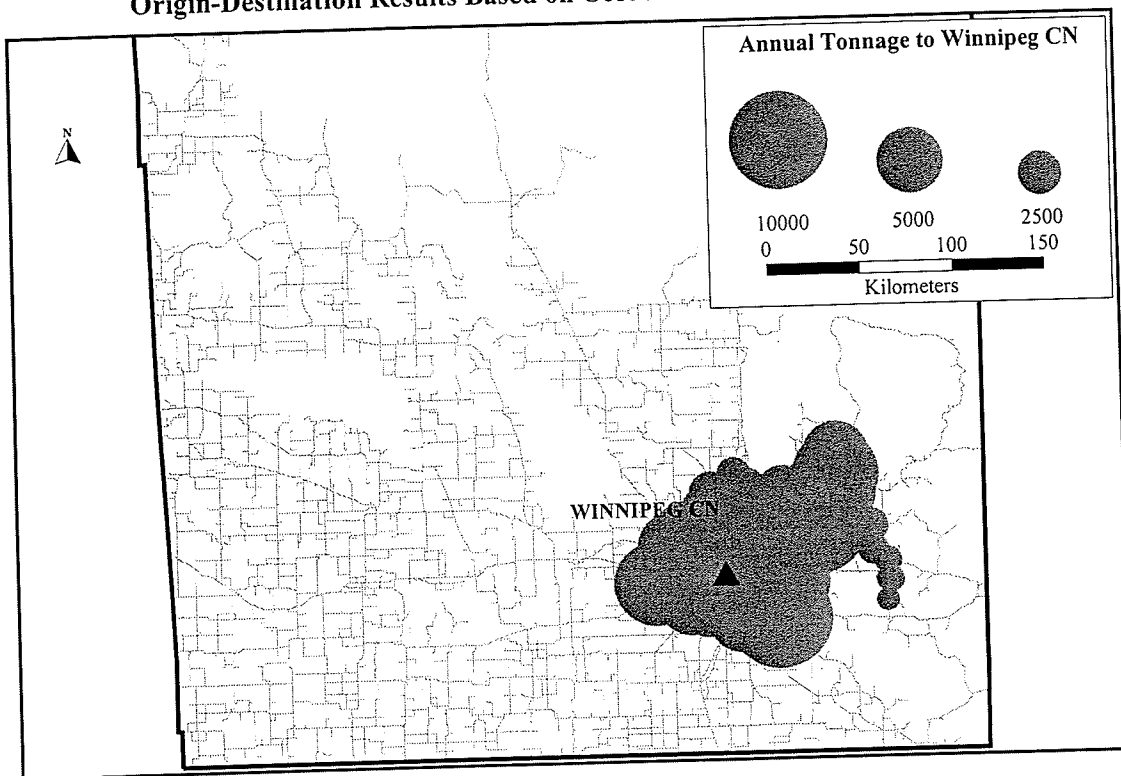


Figure G.10: Township 05-23-W
Origin-Destination Results Based on Cost and Distance Calibration #3

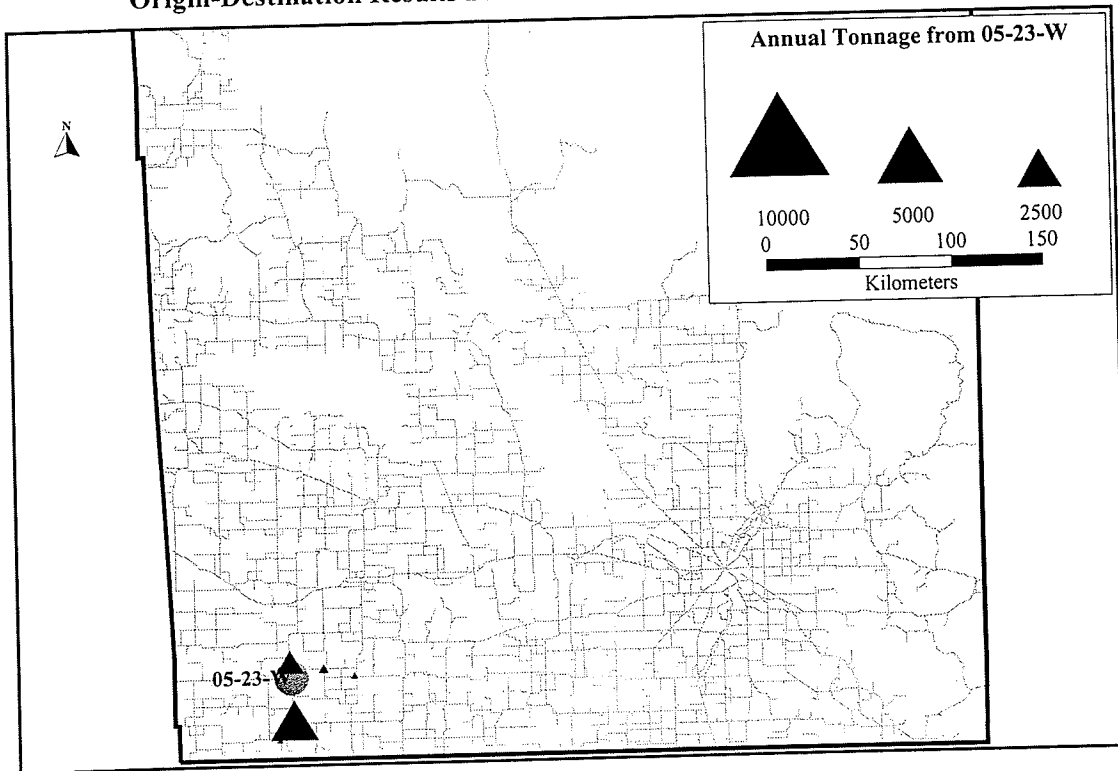


Figure G.11: Township 12-09-W
Origin-Destination Results Based on Cost and Distance Calibration #3

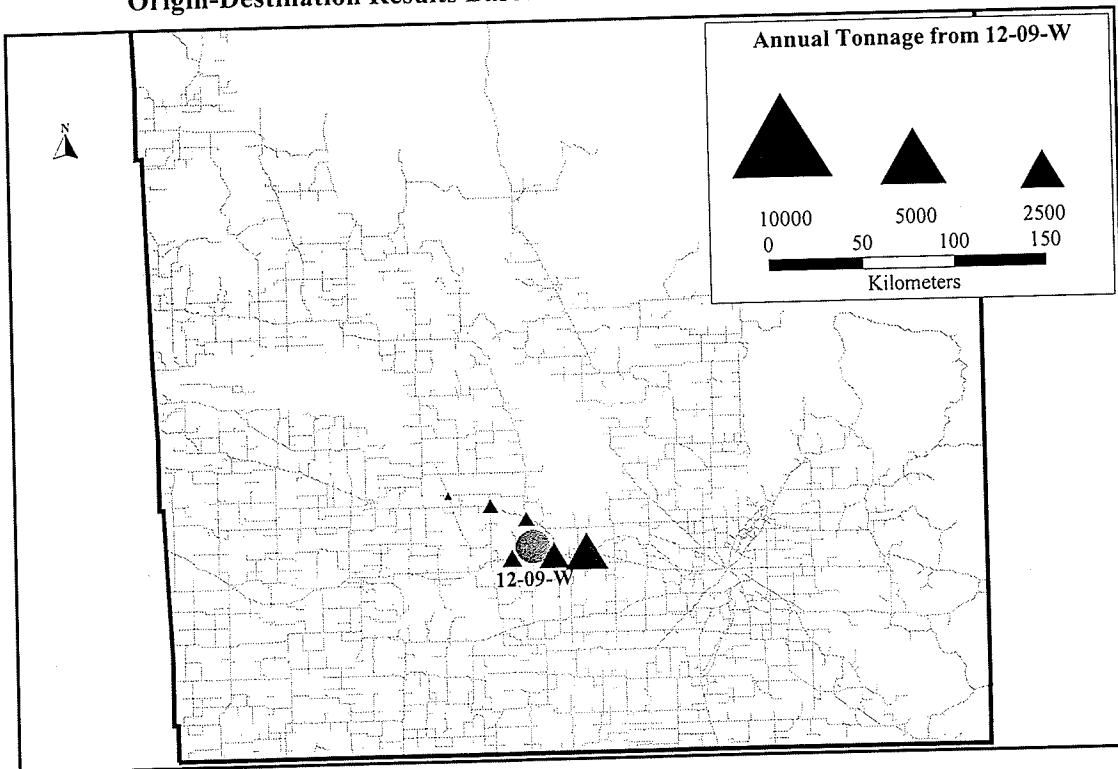


Figure G.12: Township 16-24-W

Origin-Destination Results Based on Cost and Distance Calibration #3

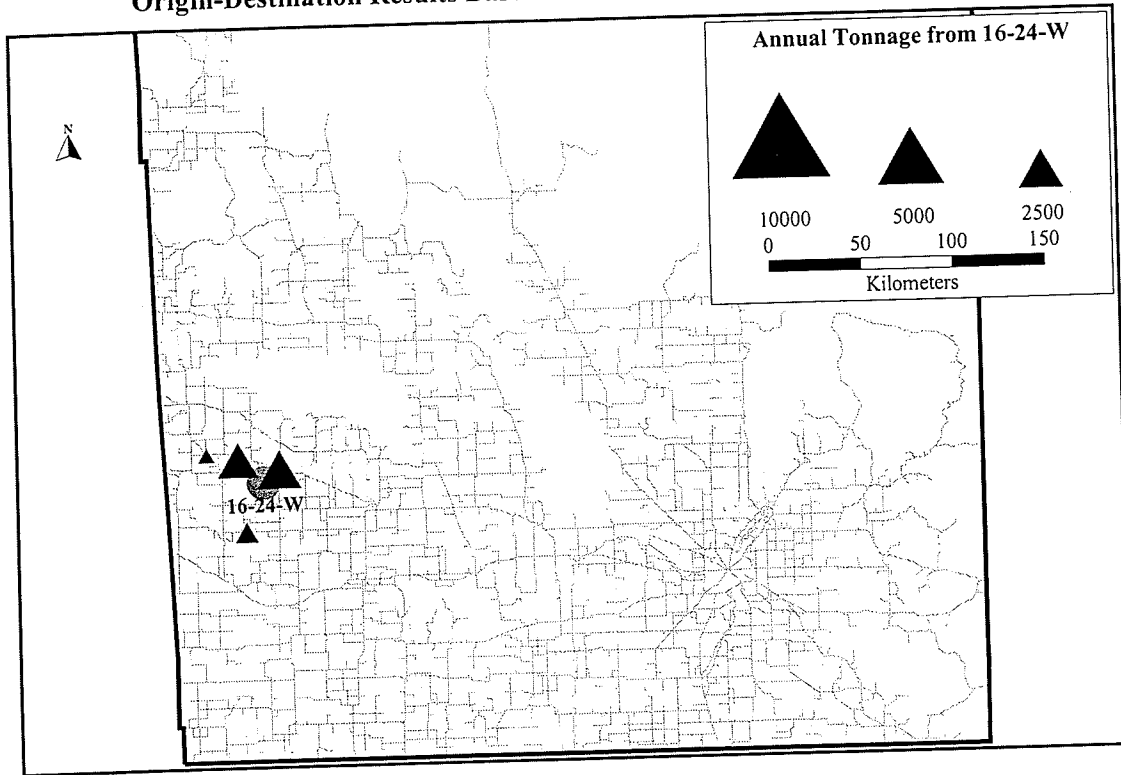


Figure G.13: Township 21-02-E

Origin-Destination Results Based on Cost and Distance Calibration #3

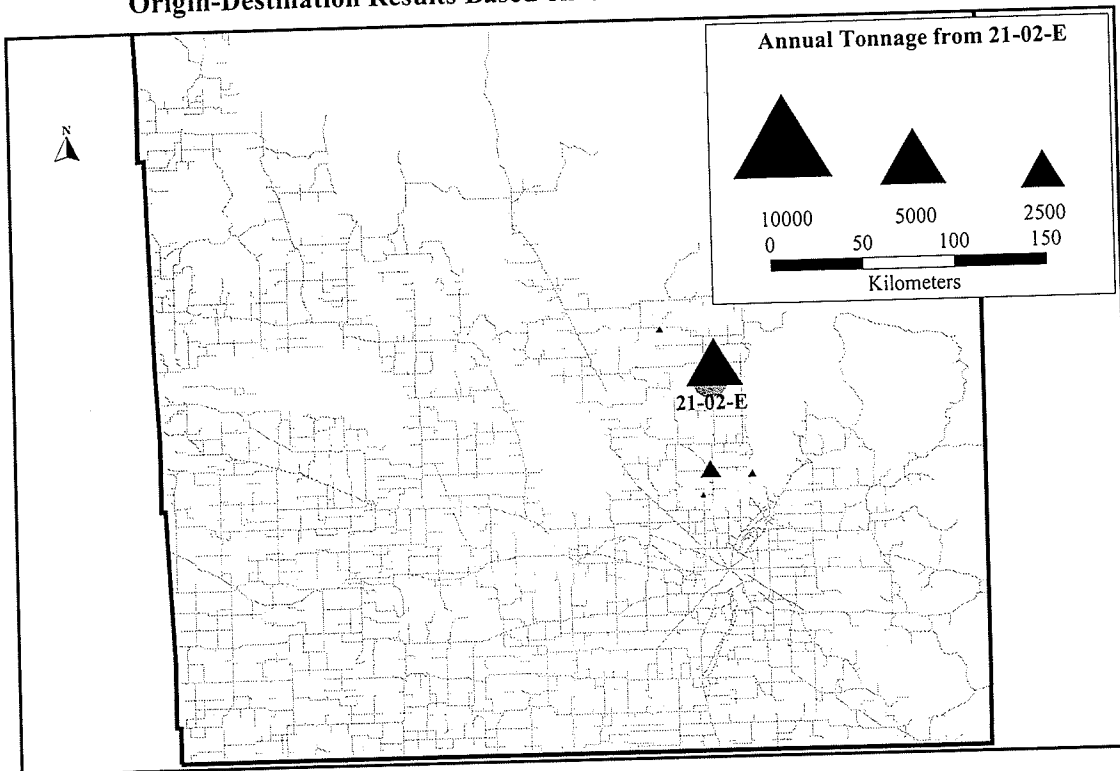


Figure G.14: Township 29-19-W

Origin-Destination Results Based on Cost and Distance Calibration #3

