ASPECTS OF ENERGY USE AND EMISSIONS BY HEAVY TRUCKS

BY

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

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"Aspects of Energy Use and Emissions By Heavy Trucks"

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

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ABSTRACT

The thesis develops a model to estimate heavy truck energy use and emissions using new knowledge bases and practical scenario-based analysis techniques. The model is designed to analyze 1) contemporary energy use and emissions and 2) efficiency improvements over time by heavy trucks under regulatory change and emission reduction initiatives. Heavy trucks are tractor trailer semi-combination units operating on non-congested rural highways in Western Canada.

New knowledge bases are developed from ten Prairie-based carriers and from industry officials. These knowledge bases are applied to the Manitoba Heavy Truck Energy and Emissions model using a rational methodology comprised of the consecutive determination of four variables: 1) truck kilometres of travel as a description of activity; 2) truck characteristics; 3) fuel consumption rates expressed as a function of gross vehicle weight and season, based on a survey of actual travel containing 272 million miles of travel and 39 million gallons of diesel from the period between May 1999 and September 2004, and 4) emission factors based on analytical assessment of the literature. The developed fuel consumption relationships are:

Metric Units (kilometres per litre and gross vehicle weight in tonnes)

Winter	Fuel Consumption (km / L) =	3.252	- 0.0264	x	GVW
Spring	Fuel Consumption (km / L) =	3.417	- 0.0268	x	GVW

Summer	Fuel Consumption (km / L) =	3.501	- 0.0260	x	GVW
Fall	Fuel Consumption (km / L) =	3.713	- 0.0327	x	GVW
Spring / Fall	Fuel Consumption (km / L) =	3.698	- 0.0343	x	GVW
Annual	Fuel Consumption (km / L) =	3.468	- 0.0278	x	GVW

Comparing the seasonal and annual relationships shows:

- a seasonal differentiation exists, the winter season having the lowest fuel efficiency
- relative to past relationships fuel efficiency has improved by approximately 1 percent per year
- fuel efficiency decreases at a rate of 0.0278 km / L per metric operating tonne

The Manitoba Heavy Truck Energy and Emissions Model is applied to the Manitoba section of the Trans-Canada highway between Winnipeg and Portage La Prairie. The contemporary relationship applies to year 2002 and is compared to a survey developed for year 1982 based on a similar methodology. The results compare fuel use and emissions along the study section for 1982 and 2002 and show that fuel economy is improving by approximately 1 percent per year and that greenhouse gas emissions are reducing as a function of freight movement. Total emissions are increasing due to increases in heavy truck kilometres of travel.

Scenario-based analysis is developed and shows the sensitivity of fuel use and emissions production to both heavy truck size and weight limits and idling. The average recorded heavy truck operating weight is below the GVW limits for 5-axle 3-S2s, 6-axle 3-S3s and 8-axle B-trains on the Manitoba section of the Trans-Canada highway between Winnipeg and Portage La Prairie. Analysis shows that trip reduction from increased payload capabilities related to increased maximum GVW limits is a successful measure to reduce emissions. The impacts of the Royal Transportation Association of Canada Memorandum of Understanding (RTAC MoU) on the introduction of a 6-axle 3-S3 fleet in Manitoba are assessed by increasing the GVW limit shows that CO_2 emissions are reduced by as much as 13 percent for single tractor semi-trailer combination trucks. One carrier has detailed idling data, which is used to estimate a fuel consumption rate during idling operations. This estimate is 0.787 gal / hr.

The knowledge bases obtained in the research are developed and show that 1) diesel tax revenue in the Province of Manitoba estimated along the study section for years 1982 and 2002 is decreasing over time in constant dollars, 2) Prairie-based carriers employ emission reduction initiatives, and 3) the energy content of biodiesel is lower than petroleum diesel and would introduce fuel economy penalties and increase emissions. Greenhouse gas emissions generated from renewable fuels are not accounted for in emission inventories.

Increasing truck kilometres of travel (tkt) in the province of Manitoba is causing increases in fuel use and greenhouse gas emissions, meaning that environmental obligations like the Kyoto Protocol are not being met. Future research and emission modelling can determine the impacts of new regulation options and emission reduction initiatives.

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INTRODUCTION

1.1 THE RESEARCH

The thesis develops a model to estimate heavy truck energy use and emissions using new knowledge bases and practical scenario-based analysis techniques. The model is designed to analyse 1) contemporary energy use and emissions and 2) efficiency improvements over time by heavy trucks under regulatory change and emission reduction initiatives. Heavy trucks are tractor semi-trailer combination units operating on non-congested rural highways in Western Canada.

The model uses a rational methodology comprised of the consecutive determination of four variables: 1) truck kilometres of travel as a description of activity, 2) truck characteristics, 3) fuel consumption rate, expressed as a function of gross vehicle weight and season, and 4) emission factors based on analytical assessment of the literature. New knowledge bases were developed from ten Prairie-based carriers and industry officials based on a survey of actual travel containing 272 million miles of travel and 39 million gallons of diesel over the period between May 1999 and September 2004.

Using a scenario-based approach, the model analyses the base case and the sensitivity of efficiency changes due to variations in truck size and weight, regulatory limits, and idling. Knowledge bases explain the impact of initiatives designed to reduce energy use and emissions. The initiatives are: 1) emission reduction initiatives centred on industry education and demonstration projects, 2) diesel taxation by federal and provincial governments and, 3) biodiesel fuel as an alternative to petroleum diesel. The model is generic and can be applied to simulate other highway networks by calibrating the defining variables.

1.2 RESEARCH NEED AND BACKGROUND

Reducing heavy truck energy consumption is important for many reasons: 1) diesel is finite and non-renewable, 2) carbon dioxide emissions relate directly to fuel consumption, and 3) improved efficiency results in cost savings (Volvo, 2004).

The Government of Canada has made reducing greenhouse gas emissions a national priority (Environment Canada, 2004) and has ratified the Kyoto protocol, agreeing to reduce its anthropogenic greenhouse gas emissions by 6 percent of 1990 levels by 2012 (Climate Change Canada, 2005).

Heavy trucks produce three types of greenhouse gases, namely carbon dioxide, methane and nitrous oxide (Environment Canada, 2004). In Canada, the transportation sector is the largest emitter of greenhouse gases, and of those emissions, commercial trucks are responsible for over 27 percent (Transport Canada, 2004). Recent advances that produce efficiency gains in heavy truck movement in Canada are being surpassed by increases in activity (Natural Resources Canada, 2005).

Modelling energy use and greenhouse gas emission production by heavy trucks is an important tool for forecasting and for isolating efficiency responses relative to emission reduction initiatives. Knowledge bases on actual heavy truck travel are used to determine how Kyoto obligations can be met under the current regulatory environment and increasing freight demands.

1.3 OBJECTIVES AND SCOPE

Specific objectives of the research are to:

- Design and conduct an environmental scan relevant to the research, consisting of a literature assessment and a survey of industry experts.
- Formulate and describe a pragmatic model for estimating fuel use and emissions of heavy truck operations on major highways in western Canada operating under non-congested free-flow conditions.
- Design and conduct a survey of fuel use by western Canadian-based carriers that derives relationships describing heavy truck fuel economy as a function of operating gross vehicle weight and season of operation.
- Develop practical heavy truck fuel economy relationships based on survey results, and compare and contrast the results with other similar relationships. Identify relevant emission factors for use in converting fuel use to emission production.
- Use a scenario-based analysis technique and real data from actual highway operations in Manitoba to apply the model to estimate:
    - changes in energy use and emissions from heavy truck size and weight limits
    - the impact of idling on heavy truck emission production
- Develop knowledge bases to understand:

- energy use and emission sensitivity to emission reduction initiatives centred on driver education
- how diesel tax revenue has changed over time through the combination of efficiency improvements and increases in activity
- the impacts of using biodiesel as an alternative to petroleum diesel on efficiency.

- Discuss research findings in relation to Canadian governmental targets concerning fuel use and emissions.

1.4 RESEARCH CONSIDERATIONS

The research objectives are aided by the author's involvement in activities consisting of the:

- Development of a basic model concept to estimate heavy truck emissions as part of an undergraduate thesis.
- Conduct of research projects with Manitoba Transportation and Government Services on diesel fuel quality and emission modelling tools.
- Development of a fuel consumption survey for the Manitoba Climate Change Action Fund.
- Interviews of, and informal meetings with, carrier fuel managers, general managers and key figures in the trucking industry.
- Attendance at national and international conferences and meetings.
- Preparation and analysis of results of a heavy truck fuel consumption survey for Battelle Memorial Institute.
- Participation as a member of the Manitoba Biodiesel Advisory Council. The council hosted presentations by experts and participated in a two-day site visit to Iowa to understand the existing research and processing technology.

1.5 THESIS ORGANIZATION

The thesis consists of eight Chapters. Chapter 2 examines energy use and emissions by heavy trucks in Canada. It investigates changes in energy demand and details the regulation and emission reduction initiatives relevant to the research objectives.

Chapter 3 defines the model and its variables. The variables are 1) truck kilometres of travel as a measure of activity, 2) gross vehicle weight as a surrogate for truck characteristics, 3) fuel consumption rate as a function of energy use, and 4) emission factors that relate fuel use to emissions by relating truck operations to emissions production.

Chapter 4 describes the knowledge bases and methodology used to develop fuel consumption relationships as a function of gross vehicle weight and season of operation. The relationships are developed and compared and contrasted with other relationships. Analytical assessment of emission factors obtained from leading research agencies determines the factors most appropriate for use in the research.

Chapter 5 applies the model to a Manitoba segment of the Trans-Canada Highway. Emissions and energy use estimates are developed for years 1982 and 2002 and changes are discussed.

Chapter 6 uses a scenario-based analysis technique to isolate the efficiency effects of idling and truck size and weight regulation limits. Knowledge bases are described and used to understand the potential impacts of a family of emission reduction tools, diesel taxation and biodiesel as an alternative to petroleum diesel.

Chapter 7 analyses the potential of how biodiesel blends utilization may lead to a reduction in emissions.

Chapter 8 concludes the research and suggests areas for future research.

CHAPTER 2

HEAVY TRUCK ENERGY USE AND EMISSIONS

This Chapter summarizes the environmental scan based on the literature review and interviews with industry experts. Current heavy truck energy demand and emissions production on Canadian highways is discussed as well as reduction initiatives employed by government and industry to target fuel consumption and emissions.

2.1 HEAVY TRUCK ENERGY USE

In Canada, domestic and cross-border freight moves predominantly by commercial trucking (Nix, 2003). Diesel engines are chosen over gasoline engines in commercial freight movement for their superior fuel economy (Owen and Coley, 1995). The trucking industry utilises approximately 24 percent (The Centre for Sustainable Transportation, 2004) of Canada's annual diesel consumption of 13 trillion litres (Statistics Canada, 2004). Further, the trucking industry, since 1990, has increases its diesel demand at a rate of approximately 4.6 percent per year while the total energy increase in Canada is 1.6 percent (Nix, 2004).

Fuel efficiency by heavy trucks is improving and is anticipated to continue improving (Nix, 2004). The main factor behind increases in heavy truck fuel use is activity growth (Centre for Sustainable Transportation, 2004).

2.2 HEAVY TRUCK EMISSIONS

Greenhouse gas emissions from the heavy trucking industry are increasing over time (Nix, 2004). The heavy trucks considered in the research are tractor semi-trailer combinations having five or more axles. Greenhouse gas emission rates are estimated for various types of transportation. Figure 2.1 shows that emissions for trucks over 14,970 kg, which is the class most relevant to the research, have almost doubled in the period between 1990 and 2002.

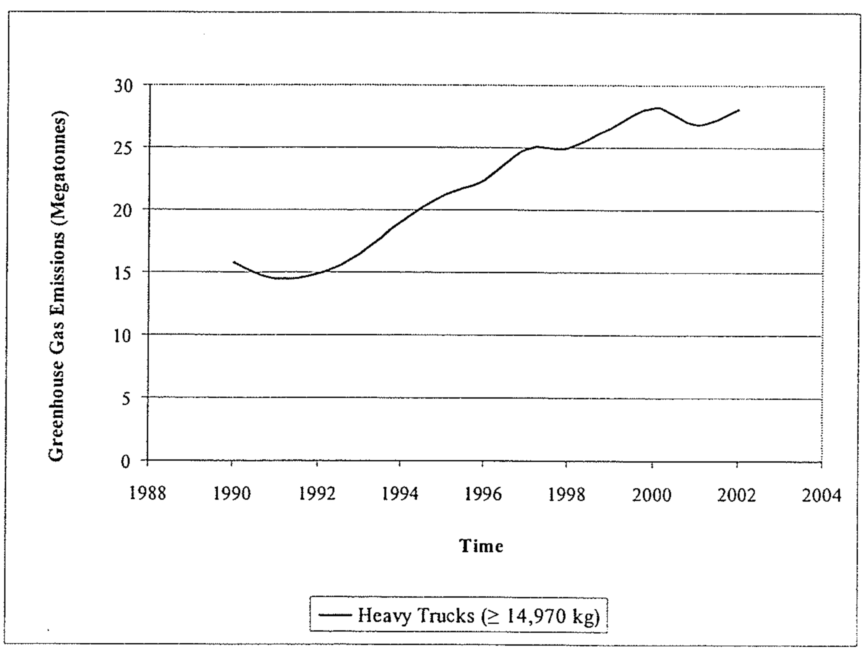

Figure 2.1: Heavy Truck Greenhouse Gas Emissions over Time
Source: Office of Energy Efficiency, 2005

Table 2.1 shows the specific types of pollution produced by heavy diesel trucks, including their production mechanisms, impacts and reduction strategies.

Table 2.1: Pollution from Heavy Duty Diesel Trucks

Pollution	Production	Impact	Reduction Strategy
Hydrocarbons HC	HCs are partially burned fuel – these are also called volatile organic compounds (VOCs). [1]	Form tropospheric (ground level) ozone. [4]	Improve combustion[2] Engine technology: oxidation catalysts. [3]
Carbon Monoxide CO	Carbon monoxide is a product of an incomplete combustion of carbon. [1]	Form smog [9]. Health degradation. [5]	Improve combustion. [2] Engine technology: oxidation catalysts. [3]
Nitrogen Oxides NOx	NOx are the product of high-temperature combustion of nitrogen (present in air). [1]	Forms tropospheric (ground level) ozone. [4]	Engine hardware[7].
Particulate Matter PM	Particulate matter consists of agglomerations of fuel soot and sulphur particulates. [1]	Health damage (particularly smallest particles). [3]	Improve combustion[1] Alter fuel properties, reduce sulphur content[2] After treatment technologies: particulate traps[3]
Carbon Dioxide CO_2	CO_2 represents the complete combustion product of carbon in the fuel. [1]	Linked with climate change. [6]	Improve fuel efficiency[2]
Sulphur Oxides SOx	SOx are created by the combustion of the sulphur contained in fuel (especially diesel fuel). [1]	Health, vegetation damage, water acidification and materials corrosion effects. [3]	Limit sulphur in diesel[7].
Greenhouse Gases GHG	The greenhouse gas emissions produced by heavy diesel trucks include carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). [1]	Linked with climate change[9].	Improve fuel efficiency[2]

Sources:
[1] Environment Canada
[2]Owen and Coley, 1995
[3] Trucks and Air Emissions
[4] Control of Emissions of Air Pollution from Highway Heavy Duty Engines
[5] Environmental Protection Agency (a)
[6] Environmental Protection Agency (b)
[7] Office of Energy Efficiency
[8]Centre for Sustainable Transportation
[9]Nix, 2003

Carbon dioxide is the principal GHG emission by weight produced by heavy trucking, and its production is linked with fuel consumption (Environment Canada, 2003a). Increases in energy consumption are not expected to be equalled by efficiency improvements, meaning Kyoto obligations are not expected to be achieved in the heavy trucking sector (Nix, 2004 TA).

2.3 TRUCKING REGULATIONS

This Section describes specific regulations impacting heavy truck travel. Two specific types of regulation are considered: 1) changes aimed at emissions, and 2) truck size and weight relaxation.

2.3.1 Environmental Regulation

In the early 1960s there were no emission controls for vehicles in Canada (Environment Canada, 2004b). The Federal Government has authority over heavy truck regulation through the Canadian Environmental Protection Act (Environment Canada, 2003a). In February 2001, the Canadian Minister of the Environment announced plans for the development of an official agenda on cleaner vehicles, engines and fuels (Canada Gazette, 2001a). The approach included integrating consideration of fuel and engine regulations and aligning measures with the United States (Canada Gazette, 2001a).

Regulations requiring the introduction of engine hardware were implemented in October 2002. New heavy trucks were mandated to be equipped with exhaust gas recirculation systems or advanced filters. The implementation of these systems is to reduce NOx emissions which contribute to the formation of smog which in turn is harmful to human health (EPA, 1996). The fuel consumption effects of this change were unknown, with some predictions of increases ranging between 2.5 – 4 percent (Pollution Probe). Such a change would correspondingly increase greenhouse gas emissions. Changes are proposed for the heavy duty diesel truck industry for years 2006 and 2007. The changes involve reducing sulphur in fuel paired with further reductions of particulate matter and NOx emissions through additional engine hardware (Transport Canada, 2004).

2.3.2 Truck Size and Weight (TS&W) Relaxation

On February 12, 1988 the Canadian provinces and territories signed the Royal Transportation Association of Canada Memorandum of Understanding (RTAC MoU), creating a designated network of primary highways with standardized truck size and weight regulations. In almost all cases, the network involved the relaxation of truck sizes and weights (Nix, 1988). Federal jurisdiction over highways consists of the national park roadways and involvement in major highway improvements. The basic weight limit on RTAC highways is 62,500 kg.

Truck size and weight regulations are evaluated for their impacts on the environment, pavement costs, safety and operational stability. The relaxation of truck sizes and weights directly impacts the productivity of commercial operations (Montufar, 1999). Truck size and weight impact truck travel patterns; in Manitoba, the Winter Weight Premium (WWP) policies attract truck traffic to the winter months by allowing 3-S2s to operate at higher GVW, and B-train operations at basic RTAC MoU weights on several low-grade highways (Tang, 2003).

US TS&W regulations govern the weight and dimension characteristics for trucks operating between the US and Canada. The principal example is PTH 75, which connects to the I-29 in North Dakota. The US-related truck operations on this route are constrained by US Federal Bridge Formula B, and for trucks operating to/from Minnesota and beyond, the basic maximum GVW limit is 80,000 lbs (Tang, 2003).

The RTAC MoU has resulted in a significant relative decline in 5-axle 3-S2s and 8-axle A-trains, compared with a significant increase in the usage of 6-axle 3-S3s and 8-axle B-trains (Tang, 2003). Truck size and weight relaxation lowers fuel use per unit payload (Nix, 2004).

Additional research relating truck size and weight regulation to the environment is required. Future research should consider 1) the impacts of air resistance of trucks of double-trailer configuration at high speeds, and 2) freight transfer from rail to truck due to reduced unit costs from relaxed TS&W (Battelle, 1995).

2.4 EMISSION REDUCTION INITIATIVES

Research suggests that opportunities exist to reduce greenhouse gas emissions and improve fuel efficiency by developing carrier driving skills and adopting existing technologies (Caceres and Richards, 2005). This Section outlines existing and potential activities by government and the Manitoba trucking industry to improve fuel economy and reduce greenhouse gas emissions. Programs to improve fuel efficiency at the Federal level are led by three main Federal agencies: Natural Resources Canada, Transport Canada and Environment Canada.

2.4.1 Kyoto Protocol

The Kyoto Protocol is a multi-lateral agreement among many nations to reduce anthropogenic impacts on the environment. Canada's specific commitment is to reduce greenhouse gas emissions by 6 percent relative to 1990. Canada ratified the Kyoto Protocol in 2003 and outlines its implementation plan in a *Climate Change Plan for Canada.* Seven key areas are identified in the document to reduce emissions, and transportation is among these. Canada's accountability regarding its Kyoto obligations involves tandem goals of reducing emissions and reporting the reduction. International requirements on emission reporting entail developing modelling approaches to produce detailed emission inventories on an annual basis (Government of Canada, 2004). Public reporting is scheduled to occur bi-annually.

2.4.2 Diesel Pricing

Pricing tools are necessary to promote and achieve fuel economy and reduce emissions (World Energy Council, Nix). Excise tax and provincial diesel taxes are one tool available to Canadian governments to affect the costs of trucking. Provincial taxes paid on diesel purchased in Manitoba increased in 2004 from 10.9 to 11.5 cents / L. The increase is reportedly not associated with efficiency (Manitoba Taxation, 2005).

2.4.3 Government of Canada Programs

The Government of Canada targets heavy trucking and greenhouse gas emission reductions with the following programs:

- FleetSmart is a program run by NRCan which addresses heavy trucking emissions production. This program offers toolkits and workshops on emission-sensitive driving, promotes anti-idling and offers support for anti-idling equipment purchases. Natural Resources Canada also reinforces some of Transport Canada's initiatives. *Fuel Efficiency Benchmarking in Canada's Trucking Industry* was released in March, 2000. This report estimates fuel consumption rates along major trade routes and states that additional fuel consumption data is needed to advance knowledge of heavy truck fuel performance (FleetSmart, 2000).

- Transport Canada addresses climate change and greenhouse gas emissions from the freight and trucking sector through its program called The Freight Efficiency and Technology Initiative. There are three components to this plan:

    1) Freight Sustainability Demonstration Program: provides an opportunity for Canadian carriers to investigate innovative technologies and operational initiatives. The five-year program provides up to $ 4.5 million to reduce emissions from freight modes. Examples of truck-related funded projects include in-cab heaters and other anti-idling approaches.

2) Voluntary Performance Agreements: this program is scheduled to develop voluntary agreements between the Federal Government and various modes of freight movement to lower emission production.
3) Training and Awareness: The aim of this program is to promote efficiency through education. To date this program has not addressed commercial trucking (Transport Canada, 2004).

- Environment Canada operates the National Pollutant Release Inventory and is responsible for much of the greenhouse gas emission modelling at the Federal level. The National Pollutant Release Inventory is a publicly accessible database on air emissions from industry and government (Environment Canada).

2.4.4 Manitoba Programs

Some of the activities in Manitoba targeted towards improving heavy truck fuel efficiency and reducing greenhouse gas emissions are:

- The Manitoba Climate Change Action Fund provides funding for projects and studies in four areas: 1) Education and Outreach; 2) Adaptation Practices; 3) Research, and 4) Alternative energy (Manitoba Climate Change Action Fund, 2004).

- The Manitoba Trucking Association co-hosted a workshop called Fuel Management 101 with FleetSmart in February 2005 (Manitoba Trucking Association, 2005).

- Transportation and government services is researching and developing a modelling tool for greenhouse gas emissions from heavy trucking (Government of Manitoba, 2002).

CHAPTER 3

MANITOBA HEAVY TRUCK ENERGY AND EMISSIONS MODEL

The research develops the Manitoba Heavy Truck Energy and Emissions model based on a basic model concept by Malzer (2001) to estimate emissions by Prairie-based carriers. The model and its four variables are shown in Figure 3.1 within the context of the commercial heavy trucking industry and its environmental outcomes consisting of fuel use and emissions. The specific variables are: 1) truck travel, 2) truck characteristics, 3) fuel consumption rate, and, 4) emission factors.

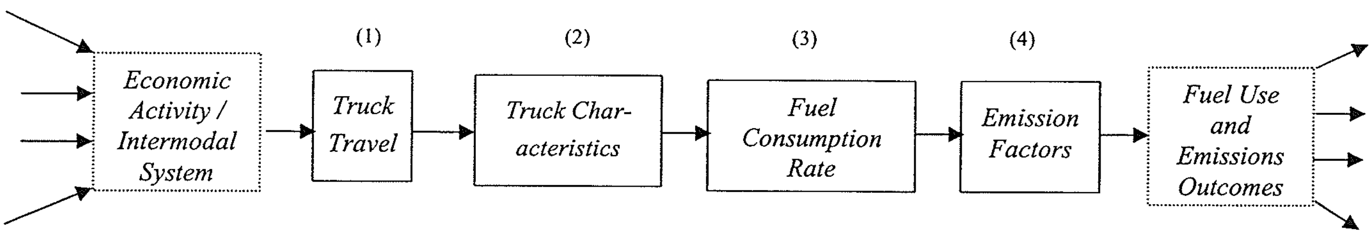

Figure 3.1: Manitoba Heavy Truck Energy and Emissions Model

The meaning of a model in the case of MH-TEEM is a tool that describes a complicated system using parameters that are representative yet obtainable. Parameters may be inaccessible for technological or economic reasons. A model also helps explain the inter-relationships between parameters providing insight into not only the model outcomes but also how those outcomes are defined by the individual parameters.

The input to the model, represented by economic activity and the intermodal system in Figure 3.1, consists of the factors of demand for freight movement and factors that decide mode choice. Some examples are the RTAC MoU, spur-line abandonment in the Prairie-region, and the North American Free Trade Agreement. Freight movement is impacted not only by economic activity but also by urbanization and resource protection laws. The different types of freight, regulation and taxes can impact the mode chosen to transport a certain good. Freight characteristics can also determine the vehicle configuration within the trucking industry. Based on the input, a certain amount of freight is transported by heavy truck involving emission and fuel use outcomes.

The Manitoba Heavy Truck Energy and Emissions model is a pragmatic tool that can be calibrated by modifying the variables to consider:

- highway segments or networks
- current, past or future timeframes
- many or single classes of vehicles
- emissions of interest

Applying the variables develops estimates on two key environmental outcomes: fuel use and emissions. The variables can be applied using carrier data to build inventories on emission by classes of vehicles, and can also be applied to possible scenarios to measure the expected impacts of technological improvements or policy decisions that impact the four variables. This is accomplished with an in-depth understanding of the four variables, their relative importance, and inter-relationship. The four variables are described as:

1) Truck travel is a measure of activity within the study road segment or network. Truck kilometres of travel (tkt) is the particular measure of trucking activity used in this research and is the amount of travel on a highway in a given year. TKT is determined by applying the average annual daily truck traffic (AADTT) to the length of a considered highway segment over a year period. Tkt is shown by equation 3.1:

$$TKT = AADTT \times \text{Highway Segment} \times 365 \qquad (3.1)$$

Truck Kilometres of Travel

Traffic data in the province of Manitoba is generated from 73 permanent count stations, and approximately 2000 coverage count stations. Truck volume estimates are developed using Automatic Vehicle Classifiers and Weigh-in-Motion devices. In 2002 there were 30 Automatic Vehicle Classifier stations, 6-combined Automatic Vehicle Classifier-Weigh-in-Motion stations and 1 Weigh-in-Motion station (UMTIG, 2003). The truck kilometres of travel on the Manitoba highway network in 2002 were 749 million kilometres (Tang, 2003; Malbasa, 2005).

2) Key truck characteristics describe performance regarding freight movement. Some of these characteristics are:

- Number of trailers
- Number and spacing of axles

Truck characteristics also impact the environmental. Fuel use and emissions vary by the environmental technology used in the engine and higher tare weight requires greater power.

The trucks relevant to the thesis are of tractor semi-trailer combination. Three particular classes are considered in applications of the model. These are five-axle (3S-2), six-axle (3S-3) and eight-axle B-train (B-train) configuration trucks. The research uses gross vehicle weight as the surrogate parameter for truck characteristics in analysis. In Manitoba, heavy truck gross vehicle weights and axle weights are estimated using static and dynamic data collection programs. There are three static weigh scales in Manitoba in addition to the Weigh-in-Motion devices (Tan, 2002).

3) The fuel consumption rates used by the model describe the amount of energy required to travel a certain distance. Fuel consumption rates are often expressed in L / 100 km; however, in the research they are expressed in either kilometres per litre (km / L) or miles per gallon (mpg). Fuel consumption estimates used for modelling by Environment Canada are determined by standard laboratory tests and / or are set to recommended values by international agencies. Studies have shown that laboratory estimates may vary by as much as 25 percent from the actual fuel consumption rates (Environment Canada, 2004b).

Contemporary fuel consumption relationships are developed in the research and are applied to the model. These relationships are developed using actual carrier datasets from Prairie-based Sources. The relationships are a function of gross vehicle weight and operating season and are shown in equation 3.2:

$$\text{Fuel Consumption Rate (distance / fuel)} = a - b \times \text{GVW (weight)} \qquad (3.2)$$

Contemporary Fuel Consumption Relationships

Where a is the base fuel consumption rate, and b is the rate at which the basic fuel consumption rate decreases with increasing GVW.

4) Measuring emissions is a recent priority (Environment Canada, 2004). There are currently very few opportunities to directly measure emissions produced by point sources (Environment Canada). Emission factors are a tool to estimate emissions based on either an amount of activity or the energy required to support the particular activity. In the case of heavy trucking, emission factors relate emissions to fuel use or distance travelled. These two emission factors can be expressed as:

- weight of emissions per unit of travel (g / mi)
- weight of emissions per volume of consumed fuel (g / L)

Emission factors are developed using four methodologies. These are summarised for heavy truck operations in Table 3.1 (Environment Canada, 2004).

Table 3.1: Fuel Emission Factor Development Methodologies

Direct Measurement	GHG emission measurements apply to point sources almost exclusively.
Mass Balance	Emissions are determined from the difference between the amount of the component (e.g., carbon) contained in the fuels and that contained in process wastes, or non-emitted residuals.
Technology-Specific Emission Factor Calculations	Company-specific emission factors can be used to estimate the rate at which a pollutant is released into the atmosphere (or captured) as a result of some process activity or unit throughput. Factors may be used to build a bottom-up inventory.
Average or General Emission Factor Calculations	Top-down inventory using general activity and population data to calculate emissions.

Source: Environment Canada

The emissions estimated in the research are greenhouse gas emissions and are:

- carbon dioxide (CO_2),
- nitrous oxide (N_2O), and
- methane (CH_4).

The emission factors for these are developed based on the mass balance methodology, meaning the production of the greenhouse gas emissions is a direct function of fuel use.

CHAPTER 4

FUEL ECONOMY AND EMISSION FACTORS

This Chapter develops contemporary, or 2002, fuel consumption relationships based on analytical tools and actual carrier datasets. Fuel consumption rates are estimated and analysed first by unit, second by carrier and third to develop relationships in a combined database. The relationships are a function of operating gross vehicle weight (GVW) and season, and are developed using SAS computer software. The combined carrier relationships are shown in Appendix C while the individual carrier relationships are in Appendix D. Comparisons are made between the contemporary data findings and past surveys using a similar methodology. Section 4.4 shows the results of an analytical assessment of emission factors. Emission factors relevant to the research are identified and then selected for use in applications of the Manitoba Heavy Truck Energy and Emissions model.

4.1 FUEL CONSUMPTION RELATIONSHIPS: METHODOLOGY

Fuel consumption relationships are developed based on the acquired raw datasets. The data is recorded using any one or a combination of on-board computers, satellite downloads and manual accounts. The steps used in the preparation of carrier data and all subsequent analysis are presented and described. Additional process details and the conversion factors utilised in the analysis are available in Appendix B.

A summary of the necessary data of participating carriers is shown in point 1 below and later described. Additional data of interest provided by some carriers are shown under point 2. The majority of the data shown in point 2 are included to demonstrate the variables that may be part of a future survey.

1) Data from all carriers:

- Trip timeline or season
- Truck configuration (principally 5- and 6-axle; double-trailer, B-trains in particular)
- Miles travelled (principal unit is miles)
- Fuel consumed (principal unit is imperial gallons)
- GVW (actual or estimated)
- Fuel consumption rate (derived from mileage and fuel use estimates)

2) Additional data capabilities:

- Detailed idling characteristics
- Model year
- Fuel use at increasing speeds

Preparation of the data is achieved in five steps. They are listed first and then detailed below:

a) Normalising the data
b) Scanning and filtering of extreme outliers
c) Assigning seasons
d) Developing carrier-specific fuel consumption relationships
e) Combining carrier-specific and seasonal fuel consumption relationships

To combine the datasets and develop sector-wide estimates of fuel consumption, the data from carriers was normalized by miles travelled. Weighting fuel consumption values by miles was accomplished on a per 1000 miles basis. An algorithm was written to produce the fuel economy data in this normalized form, which produced one data point for every thousand miles of travel. Weighted data is used in all evaluations. In limited cases, the data described urban operations, characterized by extremely poor fuel consumption rates and low kilometres. Errors attributed to recording also exist within the datasets, such as fuel consumption rates of over 2000 mpg. Data was deleted from the dataset in cases of extreme outliers. Outliers were deleted based on selection and identification by SAS software which uses the box plot approach. In total, less than 200 points were deleted.

The seasons of analysis were:

- Winter: December - February
- Spring: March - May
- Summer: June - August
- Fall: September - November

Five of the ten carriers provided data in monthly intervals. In the cases where carrier data was not recorded on a monthly basis, the data was assigned to the above seasons. This was performed using two methods:

1) Bi-weekly carrier data was grouped monthly where suitable. Periods that overlapped seasons were grouped under the season with the highest number of days for that specific trip.

2) In cases where the carrier data was reported quarterly, the starting period is January. To fit with the above seasons, the data is lagged by one month to be included in analysis among the other carriers.

Additional steps are required to prepare one of the datasets. This particular Source operates B-train units. A methodology is developed to convert two-way data, representing a combined fuel consumption rate for weighted and unloaded operations. Specifically, conversion factors to predict the forehaul and backhaul fuel consumption rates are developed. The development of forehaul and backhaul conversion factors is based on a tare weight of 42.1 kips (19.1 tonnes) and a maximum weight of 137.8 kips (62.5 tonnes). Theoretical fuel consumption rates for the backhaul and forehaul trips are determined using fuel consumption relationships from the other nine carriers. The conversion factors are estimated by dividing the annual rates by the roundtrip annual rates and are calculated as:

- Backhaul = 1.462
- Forehaul = 0.936

4.2 FUEL CONSUMPTION RELATIONSHIPS: DATA

This Section characterises the individual carrier datasets and the combined database used to develop fuel consumption relationships. In total, more than 30 carriers were contacted to participate in the survey. Twelve carriers were interested in participating but only 10 had the minimum data requirements and sufficient recording capabilities. Outlines of the Sources are shown below.

Source 1 is a western-Canadian based, national and international for-hire carrier that specialises in general freight transport. The fleet is comprised principally of 5 and 6-axle tractor-semi trailer combinations with dry vans and some temperature controlled equipment. Thirteen months of data was received in the period starting from July, 2002 to August, 2003.

Source 2 is a western-Canadian based national and international carrier that specialises in general freight movement using dry vans. The equipment includes 5-axle tractor semi-trailer combinations. Data received from Source 2 was downloaded from satellite tracking systems in approximately bi-weekly intervals. Data was received between June, 2001 and September, 2003.

Source 3 is a large national and international for-hire carrier that transports many different types of freight mainly using flat decks. The equipment consists of 5-, 6- and 8-axle trucks. Data received from Source 3 was downloaded from satellite tracking systems in quarterly intervals. Twelve months of data was provided with the starting period being January, 2002.

Source 4 is principally a western-Canadian carrier with national and international operations that specialises in bulk commodity movement. The equipment consisted of 5, 6 and 8-axle trucks. Data received from Source 4 was downloaded from satellite tracking systems in monthly intervals and was provided between December, 2002 and August, 2003 (not including June, 2003).

Source 5 is principally a western-Canadian carrier with national and international operations specializing in liquid and industrial freight movement. The equipment includes 5 and 8-axle trucks. Data received from Source 5 was obtained from fuel tax receipts in quarterly intervals. Data was provided between July and December, 2002.

Source 6 is a national and international carrier that specialises in general freight movement. The equipment consisted mainly of 5-axle trucks. Data received from Source 6 was downloaded from satellite tracking systems in approximately monthly intervals and was provided between January and September, 2002.

Source 7 is a large, national private carrier. The fleet is principally 5 and 6-axle tractor-semi trailer combinations and most equipment is temperature controlled. Data received from Source 7 was downloaded from on-board computers in monthly intervals. The data was provided between December, 2000 and December 2001 and between August, 2002 and July, 2003.

Source 8 is a western-Canadian based national carrier that specialises in heavy freight movement using 8-axle tractor semi-trailer combinations. Data received from Source 8 was recorded by unit following each delivery, consisting of trip distance and fuel used.

The provided data was recorded consecutively from as early as May 1999 through March 2004 and timelines vary by unit.

Source 9 is a western-Canadian based principally, national carrier that specialises in cube-out and weight-out movement using dry vans. Data was downloaded using satellite technology and organized by survey seasons by the carrier. Equipment used is 5-axle tractor semi-trailer combinations. Twelve months of data was received between June 2003 and May 2004.

Source 10 is a western-Canadian based national and international carrier that specialises in general freight movement using dry vans. The equipment includes 5-axle tractor semi-trailer combinations. Data received from Source 2 was downloaded from satellite tracking systems in approximately bi-weekly intervals. Data includes an advanced breakdown of engine moving time and engine running time. This information is utilised as the basis for a fuel consumption estimate during idling operations. Twelve months of data was received between October, 2003 and September, 2004.

The predominant equipment types used are five- and six-axle tractor semi-trailer combination trucks. Differentiation between these unit types and B-trains is maintained by evaluating fuel consumption as a function of GVW. Table 4.1 shows the participation of the ten Prairie-based carriers for each of the months that data was provided. In total, the Sources provided 14.5 years of operational data between May 1999 and September 2004.

Table 4.1: Source Data by Month and Year

Month	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	S 9	S 10
May-99								√		
Oct-00								√		
Nov-00								√		
Dec-00							√	√		
Jan-01							√	√		
Feb-01							√	√		
Mar-01							√	√		
Apr-01							√	√		
May-01							√	√		
Jun-01		√					√	√		
Jul-01		√					√	√		
Aug-01		√					√	√		
Sep-01		√					√	√		
Oct-01		√					√	√		
Nov-01		√					√	√		
Dec-01		√					√	√		
Jan-02		√	√			√		√		
Feb-02		√	√			√		√		
Mar-02		√	√			√		√		
Apr-02		√	√			√		√		
May-02		√	√			√		√		
Jun-02		√	√			√		√		
Jul-02	√	√	√		√	√		√		
Aug-02	√		√		√	√	√	√		
Sep-02	√	√	√		√	√	√	√		
Oct-02	√	√	√		√		√	√		
Nov-02	√	√	√		√		√	√		
Dec-02	√	√	√	√	√		√	√		
Jan-03	√	√		√			√	√		
Feb-03	√	√		√			√	√		
Mar-03	√	√		√			√	√		
Apr-03	√	√		√			√			
May-03	√	√		√			√			
Jun-03	√	√					√		√	
Jul-03	√	√		√			√		√	
Aug-03	√	√		√					√	
Sep-03		√							√	
Oct-03									√	√
Nov-03									√	√
Dec-03									√	√
Jan-04									√	√
Feb-04									√	√
Mar-04									√	√
Apr-04									√	√
May-04									√	√
Jun-04										√
Jul-04										√
Aug-04										√
Sept-04										√

Tables 4.2 and 4.3 describe the total fuel use and actual kilometres of travel by the ten Sources respectively. Fuel consumption is evaluated by dividing the fuel used in each

trip or time period by the number of kilometres operated. Each fuel consumption record is weighted and combined to develop the fuel consumption relationships.

Table 4.2: Mileage by Source and by Season

Source	Mileage (Total Miles of Travel in million miles)				
	Winter	Spring	Summer	Fall	Total
Source 1	5.1	5.5	8.9	5.6	25.0
Source 2	24.7	26.9	28.0	25.0	104.6
Source 3	0.1	0.1	0.2	0.9	1.3
Source 4	0.9	0.8	0.4	No data	2.1
Source 5	No data	No data	1.0	1.0	2.0
Source 6	4.8	8.0	10.9	3.0	26.8
Source 7	1.0	0.9	1.0	0.9	3.7
Source 8	0.9	0.9	0.9	1.0	3.6
Source 9	11.2	13.0	8.1	10.6	42.9
Source 10	15.5	16.6	16.1	12.7	60.9
Total	63.9	72.9	75.5	60.6	272.9

The greatest mileage contributions are from Source 2 with 104.6 million miles and Source 10 with 60.9 million miles. Similarly the greatest fuel use contributions are from Source 2 and 10 as shown in Table 4.3.

Table 4.3: Fuel Used by Source and by Season

Source	Fuel Used (Imperial gallons in thousands)				
	Winter	Spring	Summer	Fall	Total
Source 1	843.0	848.3	1305.8	861.3	3858.4
Source 2	3515.1	3725.4	3698.6	3341.2	14280.3
Source 3	27.6	25.1	47.9	178.9	279.5
Source 4	187.3	149.8	82.2	No data	419.3
Source 5	No data	No data	146.6	153.1	299.7
Source 6	855.9	1426.5	1788.1	505.1	4575.6
Source 7	180.0	163.5	157.4	148.1	649.0
Source 8	180.4	181.7	152.9	191.1	706.1
Source 9	1627.1	1790.2	1040.5	1401.0	5858.8
Source 10	2250.3	2322.3	2147.9	1722.8	8443.3
Total	9666.7	10632.8	10567.9	8502.6	39370.0

Figure 4.1 shows the contribution of normalised mileage by Source and by season. The Figure shows that the survey database is not evenly distributed by carrier. Five carriers (Sources 1, 2, 6, 9 and 10) represent approximately 95 percent of the entire database mileage.

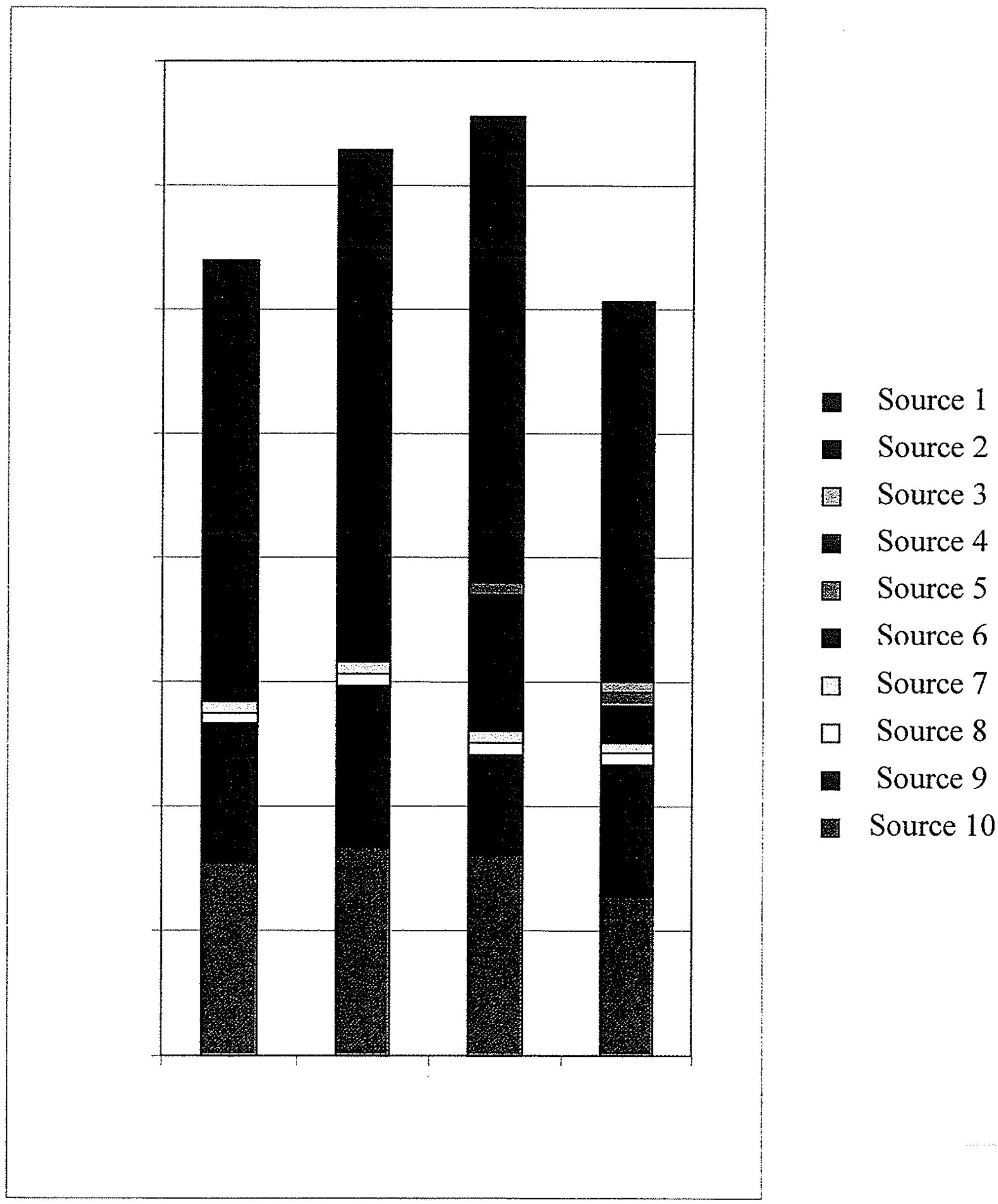

Figure 4.1: Mileage Data by Source and by Season

Figure 4.2 shows database distribution by the number of carrier datasets per month.

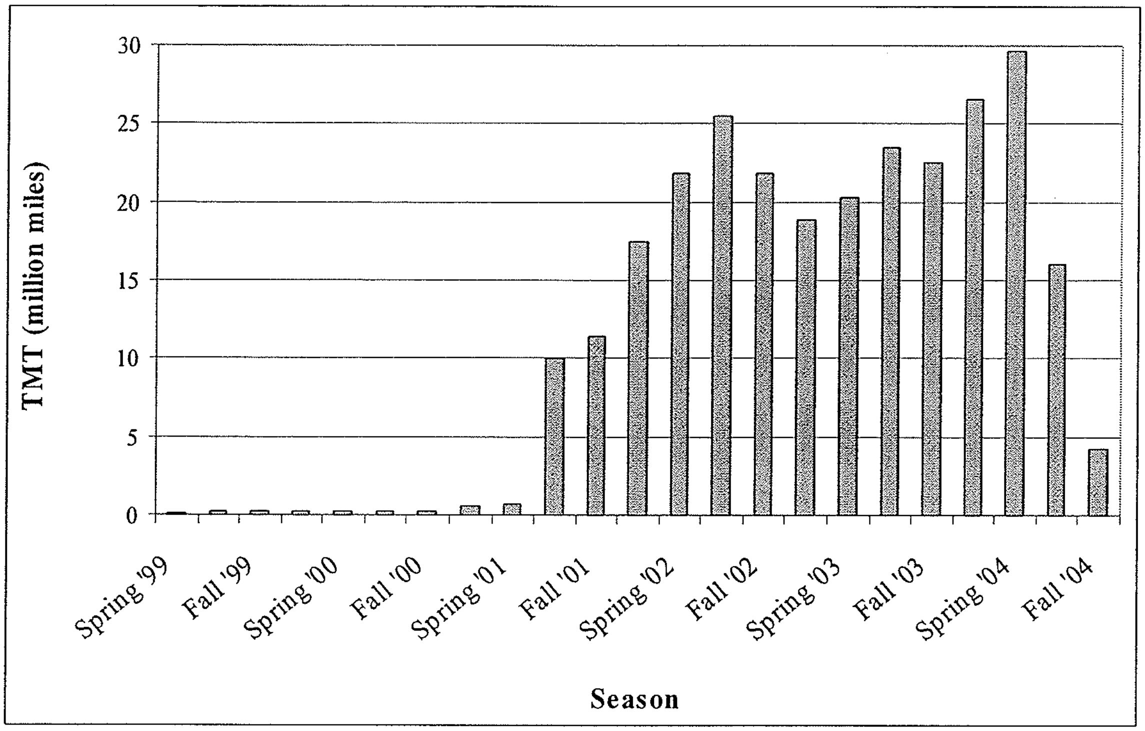

Figure 4.2: TMT by Season (million miles)

Figure 4.2 shows the distribution of the 174 carrier months of data. Analysis of the distribution shows that two-thirds of the Source data was provided for the period between August 2001 and August 2003. Based on the distribution of the database, the fuel consumption research is considered relevant to year 2002.

4.3 FUEL CONSUMPTION RELATIONSHIPS

The combined datasets from the 10 Sources represent over 272 million miles of travel and 39 million gallons of diesel. Using SAS software, the fuel consumption relationships are developed. The carrier-specific fuel consumption relationships are shown in Appendix D and the combined fuel consumption relationships are shown in Appendix C. The relationships are developed by season, and for comparison purposes a Spring / Fall relationship is developed to compare with past surveys. An annual fuel consumption relationship is developed using the aggregate, or entire, database. The fuel consumption relationships are:

Metric Units (km / L and GVW in tonnes)

Winter	Fuel Consumption (km / L) =	3.252	- 0.0264	x	GVW
Spring	Fuel Consumption (km / L) =	3.417	- 0.0268	x	GVW
Summer	Fuel Consumption (km / L) =	3.501	- 0.0260	x	GVW
Fall	Fuel Consumption (km / L) =	3.713	- 0.0327	x	GVW
Spring / Fall	Fuel Consumption (km / L) =	3.698	- 0.0343	x	GVW
Annual	Fuel Consumption (km / L) =	3.468	- 0.0278	x	GVW

Imperial Units (mpg and GVW in kips)

Winter	Fuel Consumption (mpg) =	9.081	- 0.0316	x	GVW
Spring	Fuel Consumption (mpg) =	9.278	- 0.0309	x	GVW
Summer	Fuel Consumption (mpg) =	9.485	- 0.0295	x	GVW
Fall	Fuel Consumption (mpg) =	10.090	- 0.0384	x	GVW
Spring / Fall	Fuel Consumption (mpg) =	9.439	- 0.0324	x	GVW
Annual	Fuel Consumption (mpg) =	9.485	- 0.0324	x	GVW

Figure 4.3 shows fuel consumption relationships for Sources 1 to 10. This Figure shows that fuel consumption by season can differ from the annual relationship by as much as 0.5 mpg.

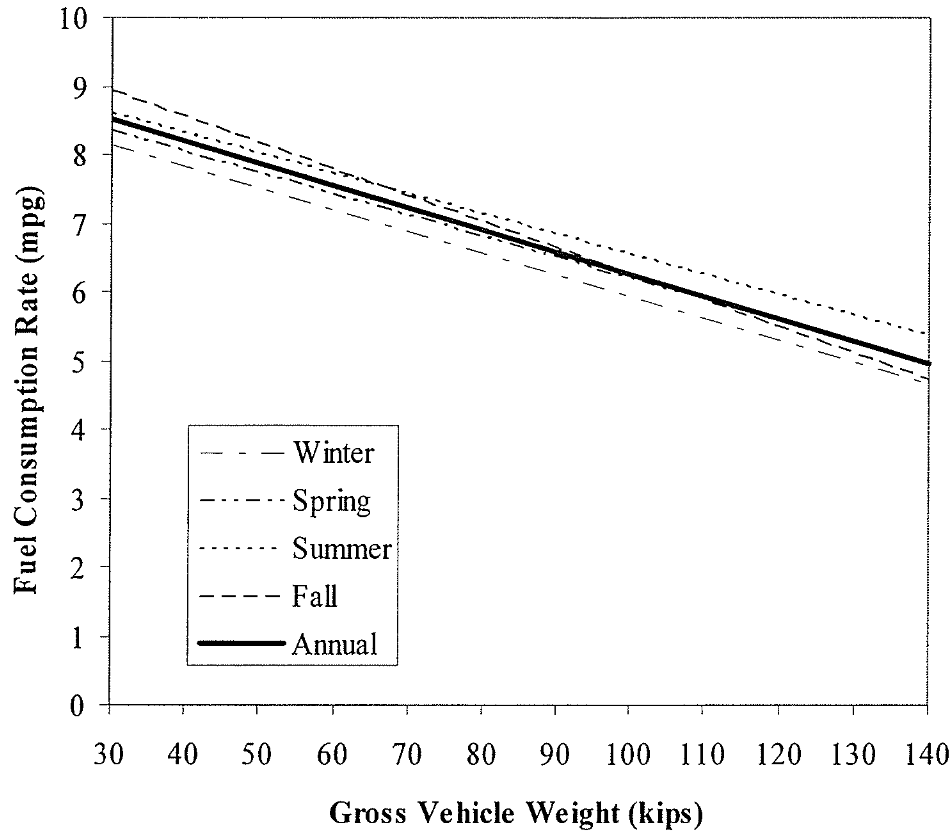

Figure 4.3: Seasonal Fuel Consumption Relationships: Sources 1 - 10

Comparing the seasonal and annual relationships shows:

- a seasonal differentiation exists, the winter season having the lowest fuel efficiency
- fuel efficiency decreases at a rate of 0.0278 km / L per metric operating tonne

Comparison is made between the Source 1 to 10 relationships and past relationships and shown in Figure 4.4. The Pro-Trucker and DriveSave / TruckSave (Nix) relationships were developed in a competition setting. Trips were driven on a specific highway using a carriers best driver and truck to achieve the highest fuel consumption rate possible. The rates are then expressed in a relationship that shows higher efficiency than the Source 1 to 10 relationships. The Pro-Trucker and DriveSave / TruckSave relationships demonstrate that there are still opportunities for the heavy trucking industry to achieve efficiency improvements. Comparison with the Nix 1981 – 1984 relationship shows that fuel efficiency has increased by approximately 1 percent per year. Industry estimates heavy truck fuel consumption has improved by approximately 30 % since 1980 (Volvo, 2004).

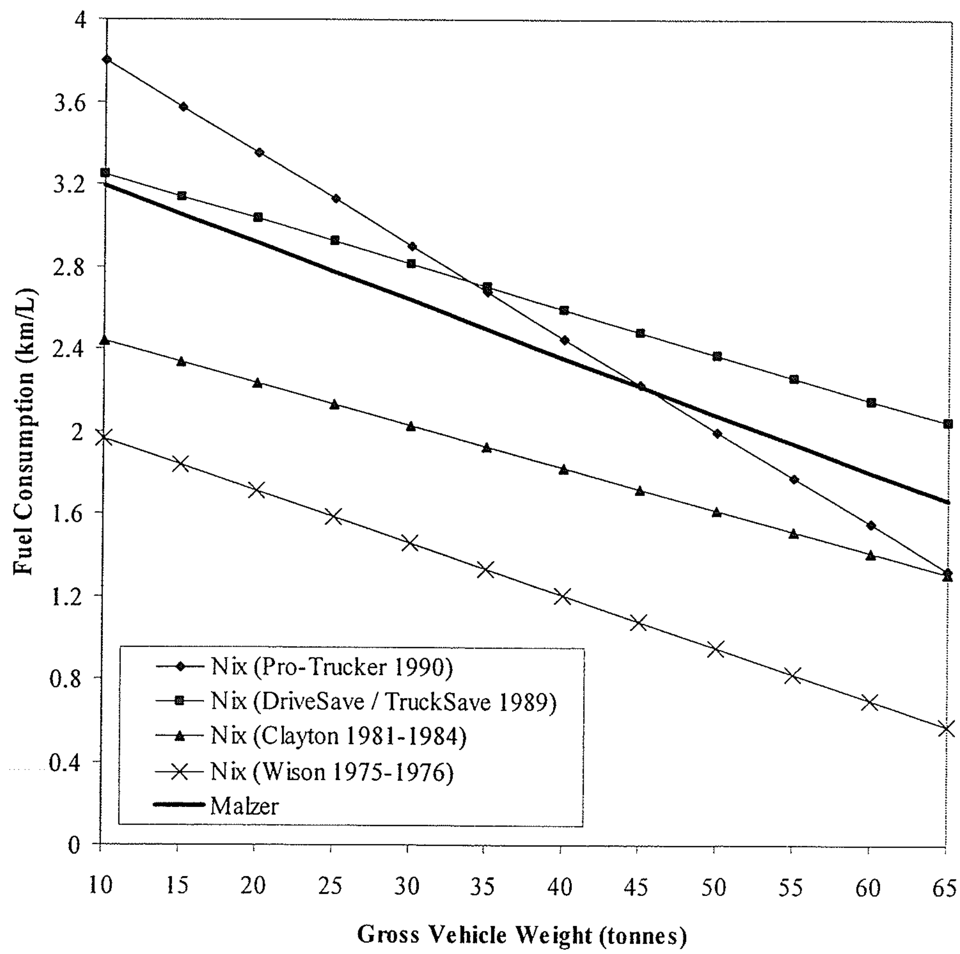

Figure 4.4: Past and Current Fuel Consumption Estimates

4.4 EMISSION FACTORS

This Section shows emission factors from research and governmental agencies and compares the various factor sets in 4.3.2. Analytical assessment of the factors is used to select emission factors applicable for use by the model in the research.

4.4.1 Industry Emission Factors

The research analysed is from Canadian agencies: Environment Canada and Natural Resources Canada, and from US agencies: Environmental Protection Agency (EPA), California Air Resource Board (CARB), and International company: Volvo.

Table 4.4 is from Environment Canada and shows emission factors for CO_2, CH_4, and N_2O, and for different levels of engine-emission control. This Table shows that the production of CO_2 is independent of engine controls. This point is also made in Chapter 3. The Figure also shows that CH_4 is more sensitive to engine control than is N_2O.

Table 4.4: Emission factors by Level of Engine Control

Heavy-Duty Diesel Vehicles (HDDVs)	Greenhouse Gas Emissions (g / L)		
	CO_2	CH_4	N_2O
Advanced Control	2730	0.12	0.08
Moderate Control	2730	0.13	0.08
Uncontrolled	2730	0.15	0.08

Source: Environment Canada, 2004 (c)

Table 4.5 shows emission factors utilised by the California Air Resources Board. These factors provide estimates in g / mi for five types of emissions produced during heavy truck travel. The factors were developed for three classes of heavy trucks. The heaviest category consists of trucks with GVW exceeding 33,000 lbs (15 metric tonnes) and is the class that is most applicable to this research. Table 4.5 shows that all emissions except CO_2 per mile of travel are decreasing over time.

Table 4.5: Federal [USA] Heavy-Heavy Diesel Fuel Emission Rates (g/mi)

Model Year	Hydrocarbon (g / mi)	Carbon Monoxide (g / mi)	Nitrous Oxide (g / mi)	Particulate Matter (g / mi)	Carbon Dioxide (g / mi)
Pre 1974	3.41	17.89	29.72	3.55	2179
1974-78	3.41	17.89	29.72	3.55	2179
1979-83	3.10	16.70	28.32	3.32	2179
1984-87	1.57	10.42	21.04	2.11	2179
1988-90	0.94	6.76	17.76	1.39	2179
1991-93	0.76	4.69	17.57	0.98	2179
1994-97	0.71	3.07	20.42	0.65	2179
1998	0.65	2.24	24.21	0.48	2179
1999-02	0.65	2.24	14.06	0.39	2179
2003	0.32	2.24	7.03	0.39	2179
2004+	0.32	2.24	7.03	0.39	2179

Source: (California) Air Resources Board, 2003

Table 4.6 shows the emission factors (in g / mi) used in GHGenius emission modelling software. The source data for this model was developed and obtained from Natural Resources Canada. The data presented below is a selection of the total emission factors developed in the model. This subset is relevant to heavy trucks operating with diesel containing a maximum of 0.050 percent sulphur, which is the current limit on sulphur in diesel.

Table 4.6: NRCan Emission Factors (g / mi)

Emissions (g / mi)	2000	2001	2002	2003	2004	2005	2006
Total CO_2	1678.21	1677.61	1676.99	1676.36	1675.72	1675.06	1674.62
Total CH_4	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Total N_2O	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Total CO	18.94	18.91	18.87	18.84	18.80	18.77	18.63
Total NOx	28.55	27.40	26.30	25.24	24.22	23.25	22.19
Total VOC, (Ozone-Weighted)	1.78	1.78	1.77	1.77	1.77	1.77	1.76
Total SOx	0.66	0.66	0.66	0.66	0.66	0.66	0.17
Total CFCs+HFCs	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Total PM	1.04	0.97	0.91	0.85	0.80	0.75	0.70

Source: NRCan, GHGenius Model

Table 4.7 shows emission factors from Environment Canada. The emission factors are a function of fuel use and are expressed as g / L. The emission factors used in this table are expressed in grams per litre, meaning that emissions are relative to fuel use.

Table 4.7: Canada's Greenhouse Gas Inventory Emission factors

Heavy Duty Diesel Vehicles:	
Greenhouse Gas Emission	g / L
Carbon Dioxide (CO_2)	2730
Methane (CH_4)	0.13
Nitrous Oxide (N_20)	0.08

Source: Environment Canada, 2003

4.4.2 Comparing Emission Factors

This Section examines the different emission factors shown in Tables 4.4 to 4.9. In particular, the impacts of expressing emission factors using different units are analysed.

Assessment is made of the difference in estimating carbon dioxide emissions using g / mi emission factors versus g / L emission factors. Figure 4.5 shows two relationships estimating emissions by a 36-tonne diesel truck per 100 kilometres between years pre-1974 and post-2004. The first relationship uses the distance-based emission factor of 2179 g CO_2 / mi (1354.3 g / km) from Table 4.4 and the second relationship uses fuel-based emission factor 2730 g CO_2 / L.

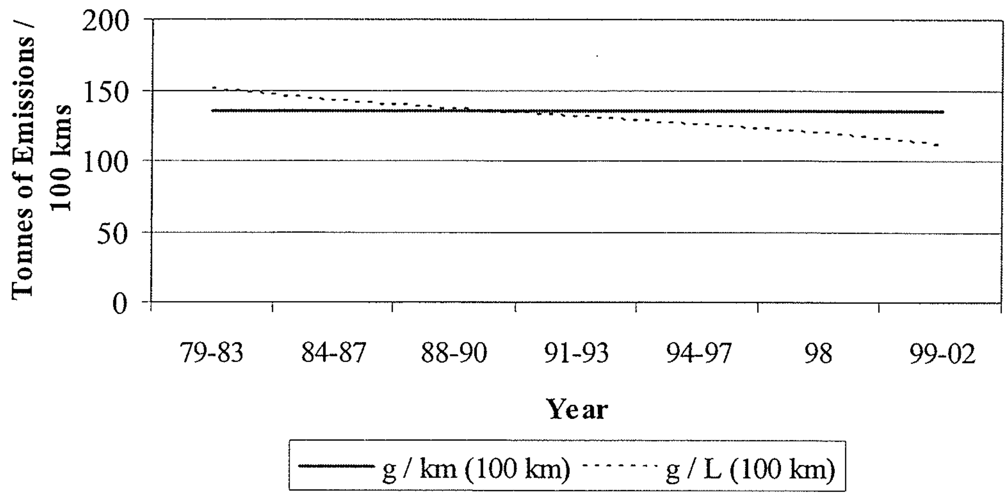

Figure 4.5: Distance-Based vs. Fuel-Based Emission Factors (CO_2)

Comparing the two relationships shows that estimates of emissions over time per 100 kilometres of travel remain constant with distance-based emission factors and diminish with fuel-based emission factors. The rate emissions decrease is proportionate to efficiency improvements, meaning this relationship follows the research in the thesis. Research also shows that CO_2 emissions are directly related to fuel use (Volvo, 2004). Additionally, the research consulted indicates that fuel-based emission factors (expressed in g / L) are considered more accurate since conversions are minimized in their development (Environment Canada). Thus, emission factors used in applications of the MH-TEEM model are those that relate emissions to fuel consumption directly. Emission factors used in MH-TEEM applications in Chapters 5 and 6 are from Table 4.8.

Inspection of the emission factors in Tables 4.5 and 4.6 shows significant differences between the two sets. As an example, the emission factors for CO_2 are 2179 g/mi and 1678.2 g/mi respectively for year 2000. As shown in Figure 4.5, distance-based emission factors need to be adjusted for changes in fuel economy in cases where emissions are related to fuel use. CO_2 is one such emission. Comparing the two sets shows that information regarding fuel economy is needed to use distance-based emission factors. The fleet used to develop the factors must have similar operating weight and efficiency attributes as the research fleet.

CHAPTER 5

ENERGY USE AND EMISSIONS IN MANITOBA: 1982 AND 2002

Chapter 5 applies the Manitoba Heavy Truck Energy and Emissions Model, developed in Chapter 4, to the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie. Estimates of fuel use and emissions are shown along this link for years 1982 and 2002. The changes between the two years are discussed. Detailed calculations are shown in Appendix E.

5.1 STUDY HIGHWAY SEGMENT

Chapter 5 applies the Manitoba Heavy Truck Energy and Emissions model to a particular highway segment to estimate fuel use and emissions over time. The study section is the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie and represents the highest trafficked route in the Province of Manitoba (Tang, 2003). Traffic volumes along the highway are described using data developed by MHTIS. Activity modelling is accomplished by dividing the segment into shorter links having similar counts. The section between Winnipeg and Portage La Prairie is made up of three control segments. Analysis of the three segments is undertaken separately and following, the respective emissions are added. The sum is representative of the total along the full highway section length. Figure 5.1 shows the study section between Winnipeg and Portage La Prairie including length and AADTT for the three segments.

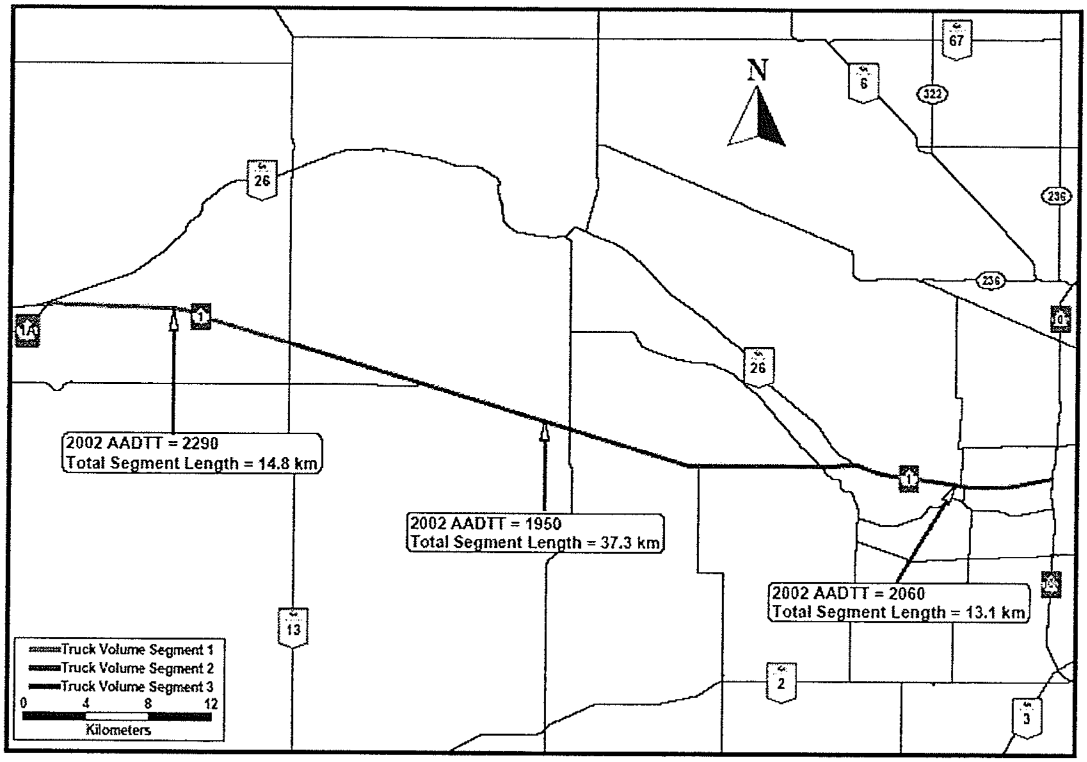

Figure 5.1: Truck Traffic Map (Between Winnipeg and Portage La Prairie)

Source: Malzer and Jacobson, 2003

The lengths of the three control segments are 13.1 km, 37.3 km and 14.8 km from east to west. The entire study section is 65.2 km, and is a four lane divided highway with a 100 km / hr speed limit. Access is limited and the level of service is high, meaning travel is non-stop and free flow.

5.2 SEGMENT ACTIVITY

Heavy truck activity along the study section is measured in truck kilometres of travel (tkt) and is based on AADTT records from the Province of Manitoba. Estimates for 2002 are developed by Tang (2003) and are summarized by segment for 2002 in Table 5.1.

Table 5.1: Segment Activity (2002)

Segment		AADTT	Length (kms)	TKT / day ('000s)
919	PTH 1 Between: PTH 1A – PTH 13	2290	14.8	33.89
920	PTH 1 Between: PTH 13 to PTH 26E	1950	37.3	72.74
921	PTH 1 Between: PTH 26 E to Perimeter Hwy	2060	13.1	26.99

Source: Malzer and Jacobson, 2003

Based on Tang (2003), the directional split of truck traffic on Truck Sequence 919 is 48 percent Eastbound and 52 percent Westbound. Truck Sequences are a naming system used by the Province of Manitoba and the Manitoba Highway Traffic Information System. In this analysis, it is assumed that the directional split of the Annual Average Daily Truck Traffic (AADTT) is equal (50 percent Eastbound and 50 percent Westbound).

AADTT in 1982 on the three truck segments are back-estimated and are summarized by control segment in Table 5.2.

Table 5.2: Segment Activity (1982)

Segment		AADTT	Length (kms)	TKT / day ('000s)
919	PTH 1 Between: PTH 1A – PTH 13	1540	14.8	22.79
920	PTH 1 Between: PTH 13 to PTH 26E	1310	37.3	48.86
921	PTH 1 Between: PTH 26 E to Perimeter Hwy	1385	13.1	18.01

Source: Malzer and Jacobson, 2003

Tables 5.1 and 5.2 show that truck volumes, described by AADTT, are higher on the outside control segments that lead to Winnipeg and Portage La Prairie. Summing tkt / day along the entire study section shows an increase of approximately 49 percent in 20 years from just over 89, 000 tkt / day to over 133,000 tkt / day.

5.3 TRUCK FLEET AND WEIGHT

The research uses truck weights, or GVW, as a surrogate for vehicle characteristics. The fleet mix is determined and fuel consumption rates are developed by configuration using average GVW. The average GVW rates are measured, recorded and averaged by the Province of Manitoba, and fleet mix is also determined on highway segments including the study section. Estimates of the truck fleet mix on this road section are shown below in Table 5.3. While there are some small differences in the fleet mix by direction, for this analysis it is assumed that each direction has the same mix. Table 5.3 also shows the percent fleet mix for 2-, 3-, and 4-axle unit trucks. These particular trucks are not considered part of the research and are not included in fuel use and emission estimates. The units are however estimated by the Province and represent 15 percent of the fleet mix in 2002. The relative proportion of 3-S2s, 3-S3s and double semi-trailer combination trucks in the fleet mix along the study section is determined in applications of the Manitoba Heavy Truck and Emissions model.

Table 5.3: Fleet Mix

Vehicle Type	2002 (percent)	2001 (percent)	1982 (percent)
3-S2s	50	54	77
3-S3s	19	18	1
6-7-8-9 axle double trailer combinations	16	15	12
of which x percent are 8-axle B-trains	(ndm)	12	0
2-3-4 axle units	15	13	10

ndm: not directly measured by AVC

Source: Malzer and Jacobson, 2003

The information in Table 5.3 is developed from records collected at the Headingly weigh scale and shows that the majority of truck travel in the considered configurations is by 3-S2 and that the share of travel using this particular unit diminished between 1982 and 2002. Over the same period use of 3-S3s and double-trailer combination trucks, particularly B-trains, increased from close to zero percent to 19 and 12 percent respectively. Table 5.4 estimates the operating GVW along the study section for 2002 and 1982 for the same truck configurations shown in Table 5.3.

Table 5.4: Truck Operating Weights

Vehicle Type		Average GVW (tonnes)	
		2002	1982
3-S2s	Eastbound	26.9	30.2
	Westbound	26.6	30.2
3-S3s	Eastbound	32.6	30.2
	Westbound	32.3	30.2
8-axle B-trains	Eastbound	52.9	[No]
	Westbound	39.3	[No]
Other 6-7-8-9 axle double trailer combinations	Eastbound	46.4	46.4
	Westbound	46.4	46.4

[No] not operated

Source: Malzer, Jacobson, 2003

Figure 5.4 shows that the average GVW in 3-S2 units is lower in 2002 than 1982 and that higher GVW is being operated using 3-S3 and B-train configuration units. Table 5.5 shows the tare weights for studied truck classes for the study and base years. The 3-S2 units show an increase in tare weight while all larger units operated in both 1982 and 2002 experienced decreases in tare weight.

Table 5.5: Tare Weights

Vehicle Type	Average Tare (tonnes)	
	2002	1982
3-S2s	15.5	14.3
3-S3s	16.5	18.6
8-axle B-trains	19.1	[No]
Other 6-7-8-9 axle double trailer combinations	17.7	18.4

[No] not operated

Source: Malzer and Jacobson, 2003

Payload for the different truck configurations is derived by subtracting average tare weight from the respective GVW. Payload is shown in Table 5.6 for years 1982 and 2002. The table shows a declining payload for 3-S2s and increasing payload for 3-S3s.

Table 5.6: Derived Payload Weights

Vehicle Type		Average Payload (tonnes)	
		2002	1982
3-S2s	Eastbound	11.4	15.9
	Westbound	11.1	15.9
3-S3s	Eastbound	16.1	11.6
	Westbound	15.8	11.6
8-axle B-trains	Eastbound	33.8	No
	Westbound	20.2	No
Other 6-7-8-9 axle double trailer combinations	Eastbound	28.7	28.0
	Westbound	28.7	28.0

5.4 FUEL CONSUMPTION RATE AND EMISSION FACTORS

Fuel consumption rates for years 1982 and 2002 are determined using relationships that estimate fuel consumption rate as a function of GVW. Fuel consumption rates are approximated for each relevant vehicle class based on average operating weights. The fuel consumption relationship used for year 2002 is from Chapter 4 based on Sources 1 – 10. The annual relationship is:

$$\text{Fuel Consumption (km / L)} = 3.47 - 0.0278 \times \text{GVW (tonnes)} \qquad (5.1)$$

The annual fuel consumption relationships used for year 1982 is from Nix, 1984:

$$\text{Fuel Consumption (km / L)} = 2.65 - 0.0207 \times \text{GVW (tonnes)} \qquad (5.2)$$

Table 5.7 shows the emission factors used to estimate greenhouse gas emissions using the Manitoba Heavy Truck Energy and Emissions model. The factors are expressed in g / L and are applied directly to the volume of diesel consumed along the study section for the years 1982 and 2002.

Table 5.7: Emission Factors

Emission	g/L
Carbon Dioxide (CO_2)	2730
Methane (CH_4)	0.13
Nitrous Oxide (N_2O)	0.08

Source: Environment Canada, 2003

5.5 APPLICATION RESULTS AND IMPLICATIONS

The Manitoba Heavy Truck Energy and Emissions model uses four variables to estimate fuel use and emissions. The variables are estimated for the scenario years 2002 and 1982 on the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie and are described in Sections 5.2 to 5.5. Truck activity, truck size and weight, fuel consumption rate and emission factors are applied to develop the results. Total CO_2

emissions increased from over 39 kilotonnes in 1982 to 45 kilotonnes in 2002 (approximately 14 percent). The findings are developed as a function of distance and weight and are shown in Table 5.8. Detailed calculations are presented in Appendix E.

Table 5.8: Manitoba Heavy –Truck Energy and Emissions Model Application Summary

Comparison	1982	2002	Change (percent)
Rolling gross tonne km / L	63.8	81.3	+27.4
Rolling payload tonne km / L	34.5	39.4	+14.2
Payload tonne km / gross tonne km (percent)	54	48	-11.1
Tare tonne km / gross tonne km (percent)	46	52	+13.0
Payload tonne km / tare tonne km	1.173	0.939	-19.9
Grams of CO_2 emissions / thousand rolling payload tonne km	79237	69329	-12.5
Grams of CH_4 / thousand rolling payload tonne km	3.77	3.30	-12.5
Grams of N_2O / thousand payload gross tonne km	2.32	2.03	-12.5

Table 5.8 shows:

- efficiency gains in both rolling gross tonne kilometres and rolling payload tonne kilometres per litre of diesel in 2002 versus 1982
- greater efficiency gains in shipping gross vehicle weight than in moving payload (as a function of rolling tonne kilometres)
- the percent of tare movement relative to gross vehicle weight increased, meaning that payload in 2002 is less dense or that more trucks are travelling partially empty or empty (11 percent change)
- a 12.5 percent decline in the production of greenhouse gas emissions CO_2, CH_4 and N_2O as a function of payload and distance between years 2002 and 1982

The results from Table 5.8 show that efficiency gains in fuel use and emissions along the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie were higher in 2002 than in 1982. This is despite the finding that fuel use and emissions were greater in 2002 than in 1982 along the study segment. A decrease in the average GVW of 3-S2 units would improve the fuel consumption rate estimated by the relationships used in the model. Development of a greater B-train and 3-S3 fleet in 2002 means that freight is being transported more in dedicated vehicles. Recorded GVW varied depending on the direction of travel meaning that payload differed in density or that trucks are travelling empty. Empty trucks would improve efficiency estimated by the model; however, the increased tkt from the additional trips would impact the overall fuel use and emissions levels. Investigation into changes to the value and type of payload from 1982 to 2002 would help answer changes in vehicle characteristics and tkt. The modelling shows that efficiency gains are overtaken by increases in tkt.

5.6 SENSITIVITY ANALYSIS

Emissions modelling using the Manitoba Heavy Truck Energy and Emissions model provides an opportunity for sensitivity analysis by calibrating the variables. This allows the variables to be investigated for their impacts on fuel use and emissions on a specific highway section. The results can later be investigated for their application to other highway sections having similar conditions.

Sensitivity analysis of tkt and GVW is performed on the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie. Changes in fuel use and emissions are recorded following changes to tkt and GVW individually. Two relationships are developed based on the changes to fuel use from varying tkt and GVW. Tkt and GVW are varied by increments of 10 percent and measured between plus and minus 20 percent. The results are shown in Figure 5.2.

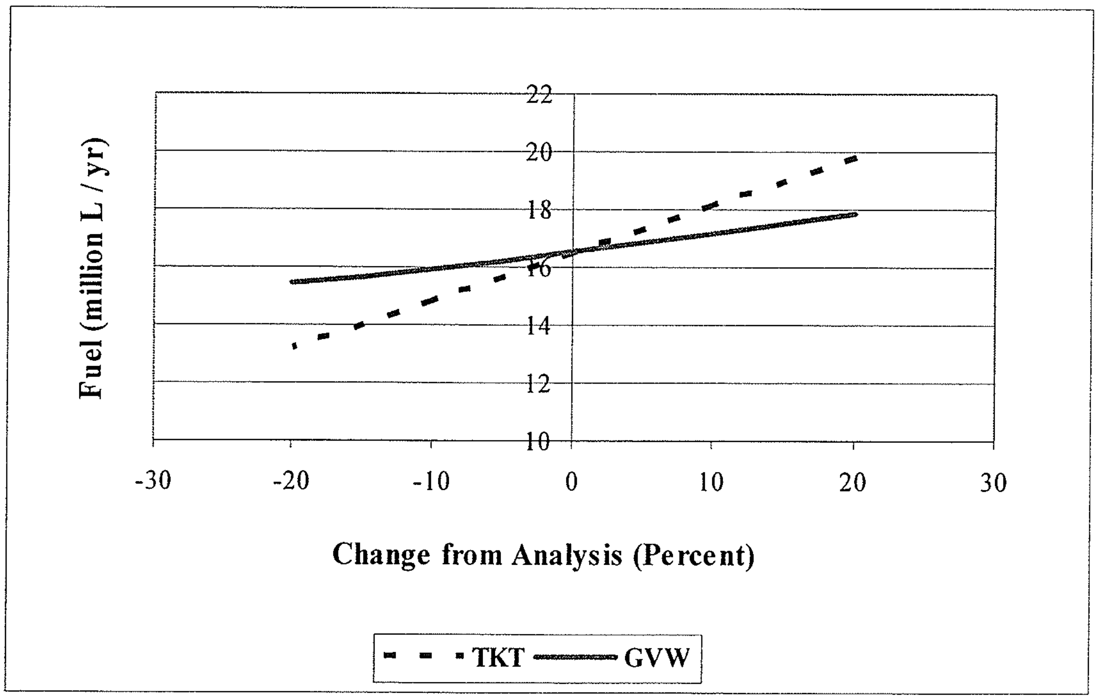

Figure 5.2: Sensitivity of Fuel Use to Changes to TKT and GVW

The relationships in Figure 5.2 show that fuel use is more sensitive to increases in tkt versus GVW. The implication of the relationships is that efforts to improve fuel efficiency and reduce emissions are best directed towards reducing tkt rather than reducing GVW.

CHAPTER 6

SCENARIO-BASED ANALYSIS AND REDUCTION INITIATIVES

Chapter 6 applies developed knowledge bases and fuel consumption relationships to the Manitoba Heavy Truck Energy and Emissions model to determine the impacts of the western Canada environment and the emission reduction strategies on fuel use and emissions. Scenario-based analysis is used to quantify the impacts of idling and truck size and weight limits. The knowledge bases are used to understand the impacts of emission reduction initiatives and changes in diesel taxation revenue over time.

6.1 TRUCK SIZE AND WEIGHT RELAXATION

This Section develops scenarios to test the impacts of truck size and weight limits on emissions from heavy truck operations in Manitoba. The most recent change in truck size and weight regulation occurred following the signing of the RTAC MoU. Adoption of relaxed weight limits in Manitoba occurred in 1988. Nationally this consisted of 1) acceptance of axle-specific weight limits on a national RTAC network, 2) establishment of a 6-axle, 3-S3 configuration truck, and 3) a 9-tonne GVW and payload advantage on 8-axle B-train trucks.

Truck size and weight limits are important in determining the payload-handling capabilities of a truck configuration. The thesis estimates the impacts of RTAC changes on heavy truck fuel use and emissions by developing and applying models to two scenarios. The two scenarios consider the potential fuel use and emission impacts from:

- the creation of a 3-S3 fleet on the principal Manitoba highway network (DT-network)
- B-train operations at varying payloads

The Manitoba Heavy Truck Energy and Emissions model is used to determine the impacts in the two aforementioned scenarios. The model uses four variables to estimate emissions: truck kilometres of travel, truck characteristics, fuel consumption rate and fuel emission factors. The development of the variables for the two scenarios is described below.

Truck kilometres of travel are estimated using volume data from the DT-network for year 2002. The DT-network is a planning network consisting of 14 principal highways representing two-thirds of the total highway network and over 90 percent of the 1999 truck kilometres of travel. This network is segmented into 202 highway links with homogeneous truck travel characteristics (Tang, 2003), and is utilized in the analysis in this Section. Figure 6.1 shows a map of the DT-network.

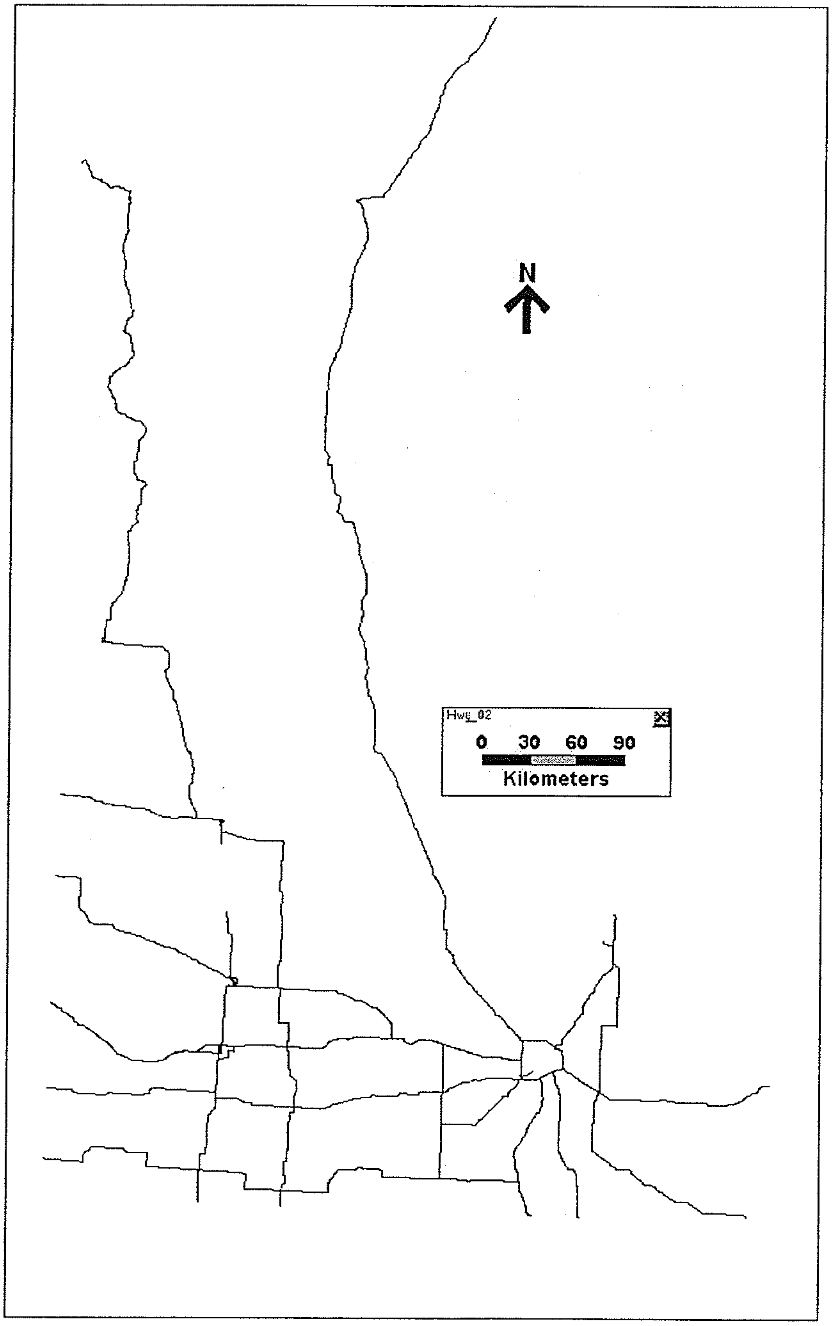

Figure 6.1: DT-Network

Source: Tang, 2003

Appendix F shows the traffic mix and AADTT at Manitoba automatic vehicle stations using the FHWA vehicle classification system. The FHWA classification system is shown in Appendix A. Applying the vehicle mix and the AADTT recorded in the same control sections to the section length in kilometres gives the actual tkt of heavy trucks in 2002.

Gross vehicle weight (GVW) is used as a surrogate for truck characteristics for applications of the Manitoba Heavy Truck Energy and Emissions model. Truck size and weight limits preceding 1987 and following the RTAC MoU are shown by configuration in Table 6.1. Changes in weight limits offered a 9-tonne weight advantage for six-axle trucks over the previous limit and a 7-tonne advantage over the RTAC five-axle 3-S2. B-train configuration trucks following the RTAC MoU were able to operate with an approximate 16.8 percent gain in gross vehicle weight.

Table 6.1: Select Truck Size and Weight Limits in Manitoba

Maximum GVW (tonnes)	Pre-1987	RTAC
5-axle tractor/semi (3-S2)	37.5[1]	39.5[2]
6-axle tractor/semi (3-S3)	37.5[1]	46.5[2]
8-axle B-train (3-S3-2)	53.5[1]	62.5[2]

Source: [1] RTAC, 1987
[2] Motor Truck (2004)

Fuel consumption rates are estimated using the annual relationships developed in Chapter 4. The relationships express heavy truck fuel consumption as a function of gross vehicle weight and season. This Section uses the truck weight limits from Table 6.1 in the analysis. Relationship 1 (Chapter 4) is developed based on the annual datasets from Sources 1 to 10 and is:

$$\text{Fuel Consumption (km / L)} = 3.468\text{-}0.0278 \times \text{GVW (tonnes)} \qquad (1)$$

The scenarios tested in this Section estimate the impacts of changes in truck size and weight limits on energy use and carbon dioxide emissions. The emission factor of 2730 g / L (shown in Chapter 4) is used in the analysis.

6.1.1 3-S3 Operations

Six-axle tractor semi-trailer combination trucks (3-S3) were not regularly operated in Manitoba prior to the RTAC MoU. Relaxation of TS&W limits allowed greater payload by weight on single trailers and led to the development of a 3-S3 fleet. This Section estimates the potential fuel use and CO_2 emission reductions associated with operating 3S-3 trucks following the RTAC agreement in the case where heavy trucks operate at maximum gross vehicle weight only.

The analysis evaluates the fuel use and emissions of the actual 2002 3-S3 travel (Appendix F) at maximum GVW. Comparison is then made to the pre-RTAC case where 3-S2s were the predominant single-trailer truck operated. Developing the pre-RTAC case involves allocating the 3-S3 payload to 3-S2 trucks. The weight limit for pre-RTAC single-trailer combination trucks is 37.5 tonnes.

The scenario employs the Manitoba Heavy Truck Energy and Emissions model. The model parameters are developed as follows:

- GVW data is from Table 6.1.
- Truck kilometres of travel is determined for the RTAC case by applying available AADTT factors, truck mix, and segment length for each of the control sections constituting the DT-network. TKT for the pre-RTAC case is estimated by factoring the RTAC values by the difference in payload. This step adjusts the number of trips required to move the RTAC freight relative to the pre-RTAC payload capabilities.
- Fuel consumption rate is established by applying the 3-S2 and 3-S3 GVW weight limits to the relationship. Both the RTAC and pre-RTAC values are estimated.
- Carbon dioxide (CO_2) emissions are estimated using the emission factor of 2730 g / L (Environment Canada).

Table 6.2 summarises the weight limits, approximated tare weights and derived payload for 3-S3 trucks for both the RTAC and pre-RTAC scenarios. Tare weight estimates are from Chapter 5. Fuel consumption rates are shown for the RTAC and pre-RTAC case based on maximum GVW.

Table 6.2: Summary of RTAC and Pre-RTAC Parameters

	3-S3			
Scenario	Tare (tonnes)	GVW Limit (tonnes)	Derived Payload (tonnes)	Fuel Consumption (km / L)
RTAC	16.5	46.5	30	2.175
Pre-RTAC	15.5	37.5	22	2.426

The information in Table 6.2 describes the performance of RTAC and pre-RTAC vehicles. The four Manitoba Heavy Truck Energy and Emissions model variables are applied to estimate the RTAC and pre-RTAC scenarios. Table 6.3 shows the difference in payload carrying capacity and associated difference in fuel consumption rate between RTAC and pre-RTAC 3-S3 trucks.

Table 6.3: RTAC Scenario Relative to Pre-RTAC Weight Regulations

Reduction in Payload:			Fuel Consumption Difference:
Truck Configuration	Tonnes	Percent	Percent
3-S3	8	36.4	11.502

As shown in Table 6.3, RTAC trucks carry more than 36 percent of additional payload by weight than their respective pre-RTAC trucks. Based on this, pre-RTAC vehicles would need to operate an additional 36 percent trips to transfer the same payload as their counterparts. The pre-RTAC AADTT is developed as follows:

$$AADTT_{pre\text{-}RTAC} = AADTT_{RTAC} / (100 - \%\ Reduction\ Payload)$$

Application of the AADTT estimates along the DT-network for both the RTAC and pre-RTAC scenario shows there is an emissions advantage to allowing greater GVW in weight-out operations. Table 6.4 summarises these results.

Table 6.4: Emissions Results: 3-S3 RTAC & pre-RTAC Weight-out Operations

CO_2 / year (megatonnes):		
RTAC	pre-RTAC	Percent dif
107.46	122.21	-13.73
CO_2 / rolling payload tonne kms (kg)		
RTAC	pre-RTAC	Percent dif
0.042	0.051	-22.43

Table 6.4 shows the carbon dioxide emission benefits associated with the truck weight relaxation for 3-S3 configurations. Specifically, there is a 13 percent reduction in overall emissions and a reduction of over 22 percent by rolling payload tonne kms when weight-out conditions are assumed to be prevalent.

6.1.2 B-train Operations

Chapter 5 showed that the average GVW for 3-S2, 3-S3 and B-train travel along the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie were below the weight limits. Less restrictive GVW limits allow trip reduction by combining payload in a single trip. This Section examines the production of carbon dioxide emissions from B-train trucks as a function of increasing GVW. The analysis is intended to show the relative impact of trip reduction and changes in operating GVW limits on efficiency improvements.

Parameters of the Manitoba Heavy Truck Energy and Emissions Model are developed to show: 1) the percent of generated CO_2 emissions used to move tare weight by increasing GVW, and 2) the CO_2 emissions generated to move one million tkt as a function of increasing GVW using B-trains in the province of Manitoba. The parameters are developed as shown here:

- Emissions are shown as a function of tkt
- The GVW range considered in the analysis is between tare weight and the limit for B-trains. The two weights are 19.1 tonnes and 62.5 tonnes respectively.
- Fuel consumption rate is developed by applying GVW estimates to the annual fuel consumption relationship developed in Chapter 4.
- The emission factor used to convert fuel use to CO_2 emissions is 2730 g / L.

The parameters are applied to estimate CO_2 production associated with increasing GVW. Comparison is made between the emissions at GVW and at tare-only weight. The comparison is used to produce the relationship shown in Figure 6.2. The relationship is non-linear and shows CO_2 production due to tare weight to be less sensitive at greater payload weight. The average B-train GVW from analysis in Chapter 5 is 52.9 for eastbound travel and 39.3 for westbound travel along the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie in 2002. The percent of emissions generated for tare movement for the eastbound and westbound GVW rates are approximately 35 and 50 percent respectively.

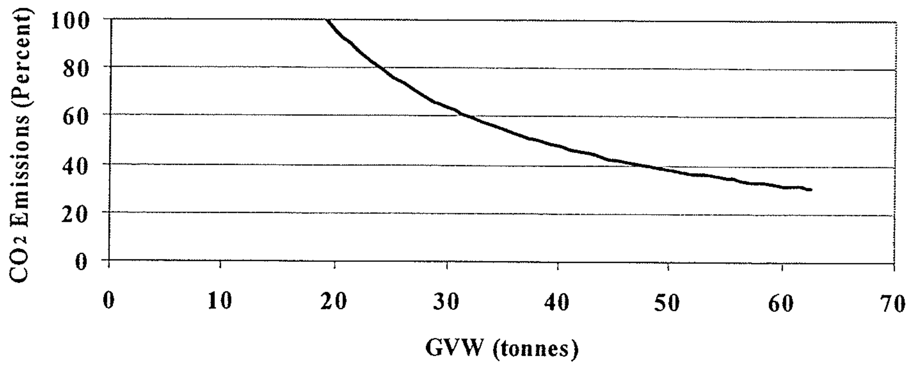

Figure 6.2: Percent CO_2 Production Associated with Tare Weight with Increasing Gross Vehicle Weight (B-trains)

Figure 6.3 shows the CO_2 production for every million truck kilometres of travel by B-trains by increasing payload. This Figure was developed using the Chapter 4 fuel consumption relationships, and shows that the base emissions production level is over 900 tonnes of CO_2 per million tkt. The CO_2 emissions generated by B-trains per one million tkt at the GVW limit are approximately 1600 tonnes.

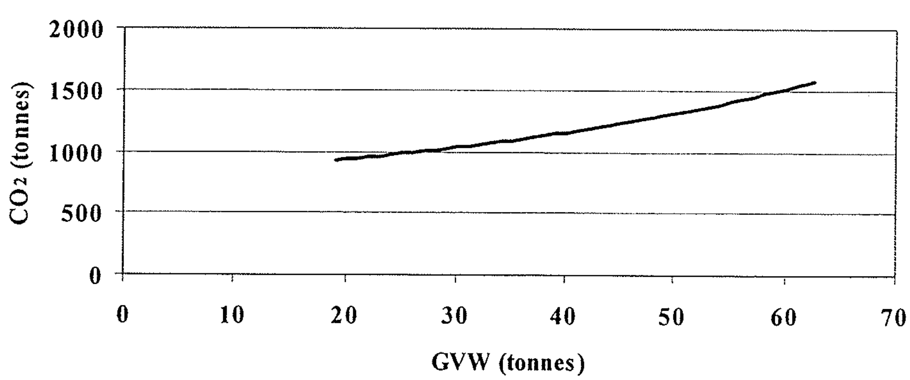

Figure 6.3: CO_2 Production per Million TKT (B-trains)

The relationship in Figure 6.3 shows that emissions produced for two trips at tare weight are higher than the emissions produced by one B-train travelling fully loaded and that decreasing the number of trips made by trucks is a more important reduction initiative than reducing GVW. Comparing travel at maximum GVW to travel at tare weight shows that the emissions generated at tare weight are approximately 56 percent of the emissions generated at the GVW limit.

6.2 EMISSION REDUCTION INITIATIVES

This Section investigates the impacts of operational change on fuel efficiency and emissions production based on the priorities established by Prairie-based carriers surveyed in the research. A two-page survey was distributed to participating carriers and is shown in Appendix G. The practices surveyed in the research are being mirrored in government demonstration programs and educational tool kits, meaning that Federal policies to inform carriers on emission sensitive practices have a definite role to play. Specific measures reported by carriers as contributing most significantly to fuel efficiency are:

- Idling: Carriers indicated that they are beginning to purchase anti-idling technology such as in-cab heaters. The benefit of heaters is that they reduce idling over long periods such as overnight stretches on long-distance trips.
- Driver knowledge / skill: Carriers encourage emission-sensitive driving and provide lessons on skills development. One example of an area where skills are developed is shifting at specific rpm levels. Training by Prairie-based carriers involves in-class sessions on theory, consultation based on on-the-road performance and practice on simulators.
- Driver consultations: In larger fleets, fuel managers evaluate on-the-road fuel performance and meet with drivers. Fuel managers found such sessions to be positive and encouraged drivers to make fuel efficiency a priority.

- Limiting speeding: All of the carriers interviewed restrict travel speeds by minor engine modifications. This practice forces truck travel to be more efficient.
- October 2002 regulations: The introduction of October 2002 regulations included additional engine hardware. Anticipated with this new system were fuel economy penalties of up to ten percent. Manitoba carriers delayed purchasing the new regulation trucks by replacing units in their fleets before the deadline (October, 2002). Similar practices are reported more widely; Today's Trucking detailed that the issue of pre-buying to avoid changes in regulations occurred across North America.

6.3 TAXATION POLICY

The literature referenced in this thesis states that pricing tools are necessary to promote and achieve fuel efficiency, and reduce emissions (World Energy Council, Nix). This Section evaluates the collection of tax on diesel by the Governments of Manitoba and Canada to determine whether carriers are influenced by way of taxes to improve efficiency.

6.3.1 Government of Manitoba

This Section estimates tax collection by the Province of Manitoba from heavy truck diesel consumption for years 1982 and 2002 based on estimated travel on the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie. Tax rates were provided by Manitoba Taxation Division and the 1982 rate is converted to 2002 dollars to compare changes over time. The tax rates are expressed in ¢/L and are applied to energy use estimates on the study highway section for the two study years as shown in Chapter 5. As shown in Chapter 5, the energy use estimates for years 1982 and 2002 along the study section are 14.5 and 16.5 million litres respectively.

The earliest available diesel tax rate for the Province of Manitoba is 1984 and is 8.6 ¢/L (Manitoba Taxation Division, 2003). A 1982 rate is estimated by factoring the 1984 diesel tax for inflation using the Bank of Canada Inflation Calculator. The estimated value for tax on diesel for 1982 is 7.93 ¢/ L. In 2002 dollars this tax rate on diesel is14.26 ¢/L. The actual 2002 diesel tax rate is 10.9 ¢/L.

Total tax revenue for this highway section is determined by applying the tax rate to the total fuel use estimated for years 1982 and 2002. Results of the application are shown in Table 6.7, and the total tax collected on heavy truck diesel use for years 1982 and 2002 on the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie is 2.06 and 1.80 million dollars respectively.

Table 6.5: Heavy Trucking Diesel Taxes Paid to Manitoba for Travel on the Trans-Canada Highway between Winnipeg and Portage La Prairie

Study Year	Benchmark Year 1982	Study Year 2002
Fuel Tax (c/L) (2002 dollars)	14.26	10.9
Litres of Diesel Consumed (millions)	14.5	16.5
Kilometres Travelled (millions)	28.5	42.4
Collected Fuel Taxes (2002 dollars) (million dollars)	2.06	1.80

2002 Dollars determined using Bank of Canada Inflation Calculator

(Average Annual Rate of Inflation Between 1982 and 2002 is 2.98 percent.)

The results of analysis shown in Table 6.7 indicate that despite increases in diesel use and truck kilometres between 1982 and 2002 for travel along the Trans-Canada Highway Winnipeg and Portage La Prairie, tax collection by the Province of Manitoba declined by 13 percent. As a function of distance, taxes paid in 1982 represent approximately 7.2 ¢/km versus 4.25 ¢/km in 2002. As a function of emissions, taxes paid in 1982 represent approximately 5.2 ¢/kg CO_2 versus 2.2 ¢/kg CO_2 in 2002.

6.3.2 Government of Canada

The review of the Canada Transportation Act examines policy options for the Government of Canada in innovative road charging. One recommended strategy is to impose an axle-weight kilometre charge. The purpose of the pricing solutions is to:

- mitigate increases in road use
- direct dollars towards externalities, particularly environmental impacts.

The Federal excise tax rate on diesel fuel has been 4 ¢/L since 1987. In 1986 the tax was 1.80 ¢/L, in 1985 the tax was 1.2 ¢/L and was zero in previous years (including the benchmark year) (Transport Canada, 2003). The results of applying the Federal tax rate to travel in years 1982 and 2002 are shown in Table 6.8.

Table 6.6: Heavy Trucking Diesel Taxes Paid to Canada for Travel on the Trans-Canada Highway between Winnipeg and Portage La Prairie

Study Year	Benchmark Year (1982)	Contemporary Year (2002)
Fuel Tax (c/L) (2002 dollars)	0.0	4.0
Litres of Diesel Consumed (millions)	14.5	16.5
Kilometres Travelled (millions)	28.5	42.4
Collected Fuel Taxes (2002 dollars) (million dollars)	0	0.66

The literature findings in Section 6.3.2 show that the Government of Canada is interested in applying taxes by axle weight. The findings from Section 6.2 show that increasing

GVW can reduce truck activity and correspondingly can reduce fuel use and emissions, meaning that the two have contradictory efficiency effects. The results from Section 6.2 lean more towards increased GVW limits or to increased special permitting for overweight trucks.

Chapter 5 estimated heavy truck greenhouse gas emission as a function of payload movement relative to litres of diesel. The specific units used in analysis (Table 5.8) are rolling payload tonne kilometres per litre. Developing a taxation rate as a function of productivity and fuel use would better address both road use and efficiency in combination.

6.4 IDLING

This Section uses a scenario-based approach to estimate fuel use and emissions production due to periods of extended idling. The analysis uses the Source 10 dataset to 1) estimate fuel consumption rates during periods of idling, and 2) correlate the resources wasted during idling to in-service resource use.

Source 10 data includes idling time and fuel use records among its trip data. Specific fields are:

- Engine time
- Time in motion
- Idling time

- Idling fuel

Figure 6.5 shows, seasonally, the average time spent idling by Source 10. The Figure shows highest use of engine idling in the winter months. Source 10 is a long-distance general freight carrier that operates 3-S2 configuration trucks. The idling characteristics of this carrier are not necessarily representative of other carriers.

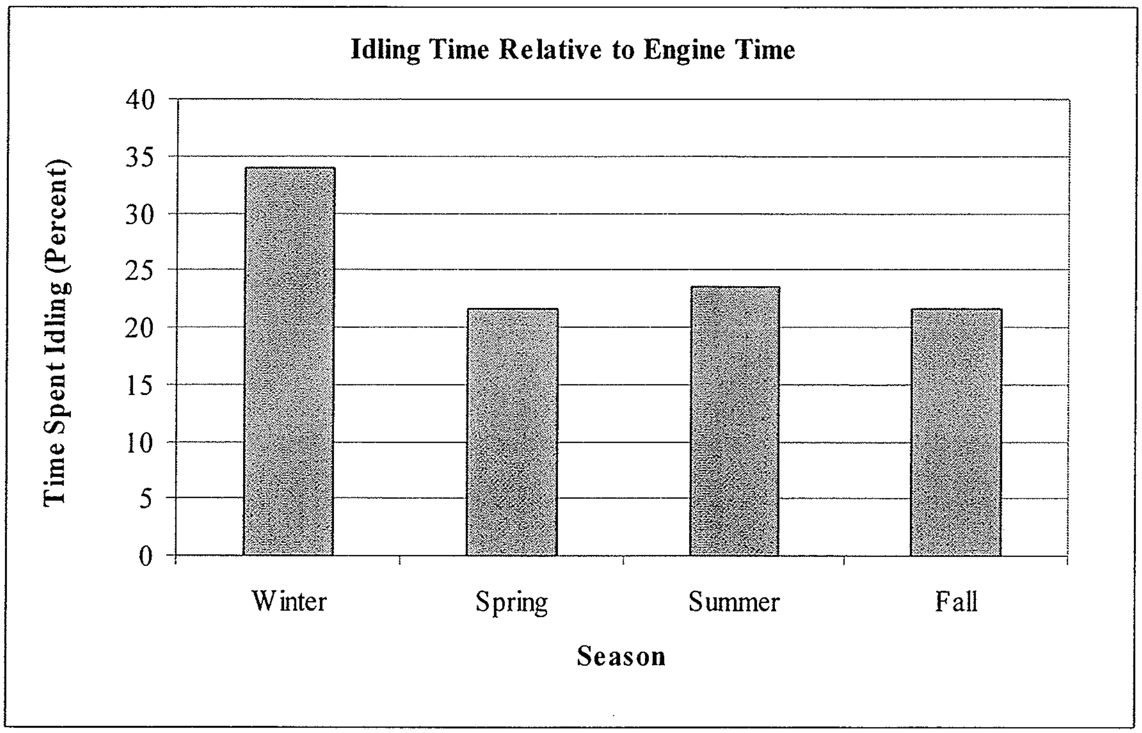

Figure 6.4: Average Time Spent Idling by Season

A fuel consumption rate for idling operations is estimated by dividing the fuel used during idling by the amount of time in hours spent idling. The estimate of the mean fuel consumption rates by season is 0.814 gal / hr. The average idling fuel consumption rate based on the total fuel use during idling and the total time spent idling is 0.787 gal / hour.

The latter rate differs due to the greatest idling hours occurring in the winter relative to spring and fall. The power required to heat an engine and cab than to cool an engine and cab. The latter rate is used in all analysis in the western Canada environment.

Time and fuel resources consumed during periods of idling are correlated to actual travel. Two estimates are developed, specifically 1) average time spent idling as a function of travel, and 2) the additional distance that could be travelled using fuel consumed during idling. The two estimates are based on the Source 10 dataset consisting of a total of 1.86 million gallons of diesel and a total time of 2.36 million hours spent idling. The results of these two estimates are first described and then shown in Table 6.9.

- The average number of hours spent idling as a function of distance travelled is determined by dividing the number of hours spent idling by the distance travelled over the same period.
- To determine an estimate of how many kilometres of travel could be fuelled by reduced idling the following steps are taken:
    - 1) determine the average fuel used during idling per kilometre of travel
    - 2) divide the rate in 1 by the travel fuel consumption rate
- The fuel consumption rates used to develop Table 6.9 are determined from the relationships in Chapter 4. The rates are developed based on the maximum and the average GVW for the study highway section and based on the 3-S2 configuration of the Source 10 truck fleet.

Table 6.7: Evaluation of Idling by Source 10

Resources Used During Idling	
Idling hours / 1000 km	25.25
Potential travel from idling fuel (kms / actual km travelled) (39.5 tonnes)	0.264
Potential travel from idling fuel (kms / actual km travelled) (26.5 tonnes)	0.245

Table 6.6 shows that if the fuel used during idling was instead used for freight movement, Source 10 heavy trucks could travel an additional 0.245 km per km of travel at a GVW of 26.5 tonnes. Applying this rate to the 3-S2 tkt for 2002 throughout the entire DT-network would fuel approximately 60.9 million tkt assuming a 3-S2 tkt of 248.9 million.

CHAPTER 7

BIODIESEL

Alternative fuels are proposed as a means of reducing emissions production and diminishing the demand for non-renewable and foreign petroleum oil resources (United States Department of Energy, Volvo). This Chapter summarizes the literature and interview findings on the use of biodiesel in highway trucking operations and provides discussion on the potential impacts on emissions.

7.1 BIODIESEL BASICS

Biodiesel is a renewable oil product of either animal- or vegetable-based resources. Biodiesel and biodiesel-petroleum diesel blends are used in diesel truck applications. An example of where pure biodiesel (also called B100) is used, is Germany (Western Economic Diversification Canada). Minnesota is planning to mandate that biodiesel will make up two percent of all diesel fuel by the summer of 2005 (New Rules). Blends of up to 20 percent biodiesel and 80 percent diesel (B20) are common in North America (ECD).

Biodiesel is made using a process called transesterification and is regulated under ASTM D6751. Transesterification uses alcohol to separate biomass into vegetable or animal oil and glycerine. Glycerine may be used in the production of soaps and other by-products which may decrease the costs of biodiesel (National Biodiesel Board).

Blends of up to 20% biodiesel (B20) can be used in nearly all diesel equipment and are compatible with most storage and distribution equipment (Biodiesel Canada).

The following is a list of the benefits of biodiesel over conventional petroleum diesel (Biodiesel Canada):

- Easy to use: Biodiesel can be used with fuelling infrastructure and in all diesel vehicles with little or no engine modification.
- Flexible: Biodiesel may be phased in and out of operation and is the only alternative fuel that runs in any conventional, unmodified diesel engine. It can be stored anywhere that petroleum diesel fuel is stored.
- Fuel Properties: Biodiesel has a relatively high cetane number and flash point, and increases lubricity enhancing engine performance, safety, and fuel economy.
- Health impacts: Biodiesel is the only alternative fuel in the U.S. to complete EPA Tier I Health Effects Testing under section 211(b) of the Clean Air Act. Biodiesel is 11% oxygen by weight and contains no sulphur.
- Economic growth: Biodiesel can be made from domestically produced, renewable oilseed crops such as hemp and canola.
- Tested: Biodiesel is a proven fuel with over 30 million successful U.S. road miles, and over 20 years of use in Europe.

7.2 DISADVANTAGES OF BIODIESEL

This section summarizes the disadvantages of using biodiesel, with particular consideration to operations in cold climate areas, based on available resources. General findings relate 1) costliness, 2) biodiesel has a lower energy content than conventional diesel, and, 3) cold weather operations pose problems.

1. NRCAN (2004):

Before biodiesel can become commercially viable in Canada, more research and development must be done to find cost-effective ways to produce it and to make sure it works in cold weather.

2. EPA (2001):

- The database employed to estimate emission contained no engines equipped with exhaust gas recirculation (EGR), NOx adsorbers, or PM traps. In addition, approximately 98% of the data was collected on 1997 or earlier model year engines. The implication is predictions of biodiesel impacts may be less accurate for future fleets.
- Biodiesel is also predicted to reduce fuel economy by 1-2 percent for a 20 volume percent biodiesel blend.
- Table 7.1 shows the energy content of biodiesel blends and of conventional diesel.

Table 7.1: Energy Content: Diesel and Biodiesel Blends

Biodiesel Blend	Average Energy Content 100 % Biodiesel (Btu / US gal)
Animal-based	115,720
Rapeseed/canola-based	119,208
Soybean-based	119,224
Conventional Diesel	138,000

Source: EPA (b)

3. Environment Canada (2004):

- Biodiesel has a lower energy content than does conventional diesel fuel. Use of biodiesel without alteration of the fuel injection system would result in a loss of power. Research by Schumacher (1994) shows that energy penalties are low at or below B50 blends.
- Use of biodiesel may result in filter plugging which can lead to decreased operating power. High quality biodiesel should not produce this effect.

4. National Biodiesel Board (2005):

- Biodiesel, particularly in higher blends, gels faster than conventional diesel. Particular cold flow properties are cold filter plugging point, cloud point and pour point.
- Precautions employed for petroleum diesel are: utilize lower blends, fuel heaters, cold flow improvement additives and storage of the vehicle in or near a building.

7.3 ENERGY AND EMISSIONS IMPLICATIONS

Table 7.1 shows that the energy of biodiesel is lower than conventional diesel. The implication is that fuel economy would decrease and greenhouse gas emission production would increase according to the change in energy content. Biodiesel, however, is a renewable energy source, meaning that under the current accounting system, the use of biodiesel would help Canada meet its Kyoto commitment. Biodiesel also improves the lubricity - the ability of distillate fuels to lubricate (Owen and Coley, 1995), even at low blends like 1 percent (National Biodiesel Board). High lubricity benefits of biodiesel could be used to improve the transition towards ultra-low sulphur diesel in 2006.

Figure 7.1 shows estimates of the impacts of biodiesel blends on particulate matter, NOx, carbon monoxide and hydrocarbons from heavy truck highway operations. The figure shows that production of all emission types except NOx is decreased by higher biodiesel blends.

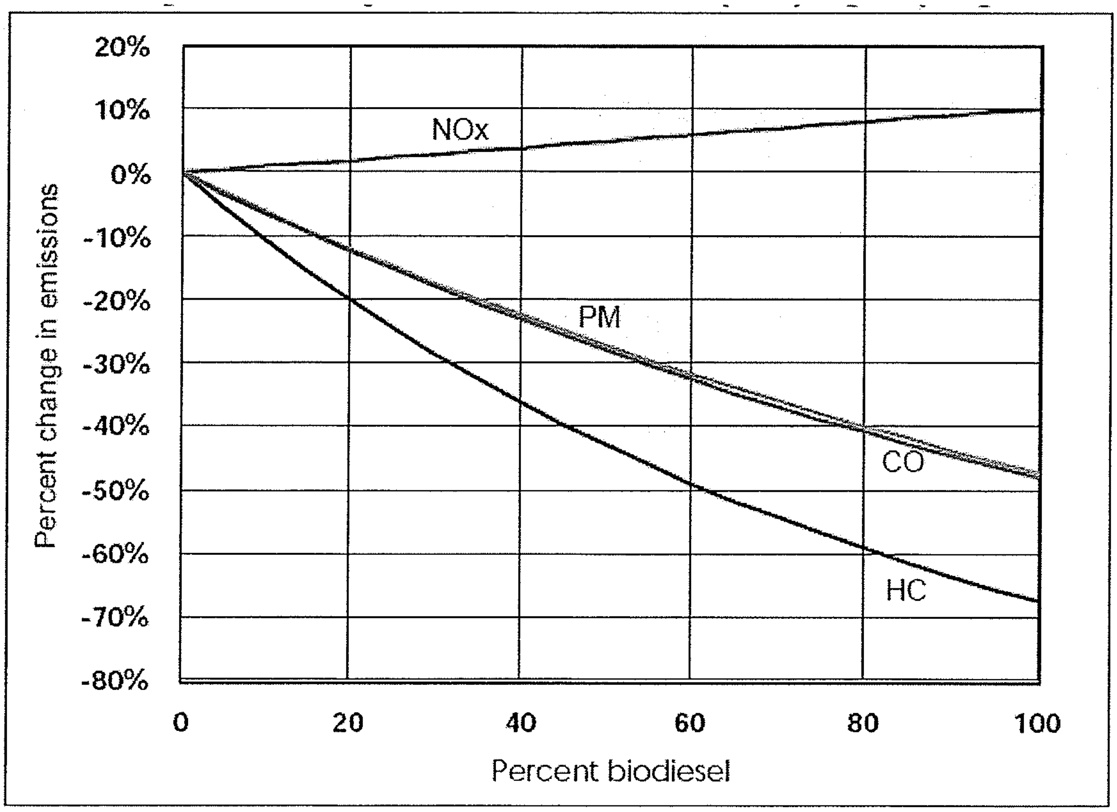

Figure 7.1: Emission Production by Biodiesel Concentration

Source: EPA

7.4 BIODIESEL IN MANITOBA

The author's experience researching the production and utilization of biodiesel by participation as a member on the Manitoba Biodiesel Advisory Council (MBAC) has provided a unique opportunity to the Thesis. This Section details the relevant findings observed during the year 2004. The findings were later published in 2005 in a report to the Government of Manitoba titled Biodiesel: Made in Manitoba.

7.4.1 MBAC Results

Increasing the use of biodiesel by heavy trucks in the province of Manitoba could occur either by voluntary methods or by mandate using regulation. Increased production of biodiesel would likely involve production of grain-based fuels as well as tallow, or animal-based oils. Discussion with members of the Manitoba Biodiesel Advisory has helped develop the following list of benefits to Manitoba and Canada from greater use and development of biodiesel:

- Increased demand for Manitoba-produced canola
- Funding for cattle dead-stock following BSE and decreased sales from border closures.
- Assures proper disposal of dead-stock, in particular that the contamination of ground-water is avoided.
- Offsetting the pollution associated with the production of petroleum diesel, in particular the use of fresh water from tar sand sources.
- Decreases dependence on foreign oil reserves.

The use of biodiesel considered by the Manitoba Biodiesel Advisory Council is the highway trucking industry. The following are concerns related to the development of a biodiesel industry that could meet the demands of a B2 – B20 blend:

- Subsidization is necessary considering 1) funding from the agriculture sector is unlikely, and 2) the costs threshold for alternative diesel purchasing by carriers is very small.
- The industry should be economically sustainable and should not operate on a grant system.
- The provinces of BC, Ontario and Quebec have created a tax incentive for biodiesel over petroleum diesel.
- Cold weather operations and the lowered cloud point caused by the addition of biodiesel to diesel is of greatest concern regarding operating characteristics.
- The impacts of biodiesel production on crop prices are difficult to predict.
- It is possible carriers would avoid purchasing diesel in Manitoba
- Concern exists that funding for biodiesel would be diverted from road expenditures.
- Testing the impacts of biodiesel blends in trucking applications following the introduction of 2006 & 2007 regulations should occur before production of biodiesel.
- A more detailed cost-benefit investigation of biodiesel is needed, including the costs of implementing other environmental initiatives.

CHAPTER 8

DISCUSSION AND CONCLUSIONS

The thesis develops a model to estimate heavy truck energy use and emissions using new knowledge bases and practical scenario-based analysis techniques. The model is designed to analyze 1) 2002 energy use and emissions and 2) efficiency improvements over time by heavy trucks under regulatory changes and emission reduction initiatives. Heavy trucks are tractor semi-trailer combination units operating on non-congested rural highways in Western Canada.

8.1 MODEL DEVELOPMENT

Knowledge bases are developed from carrier operational practices and analysis of actual datasets. Understanding the knowledge bases is accomplished using a rational methodology to estimate energy use and emissions. The Manitoba Heavy Truck Energy and Emissions model contains four variables and is shown in Figure 8.1. The encompassing variables are truck travel, truck characteristics, fuel consumption rate, and emission factors within the context of the heavy truck operating environment defined by freight demand, intermodal competition, regulations, and energy and emission outcomes.

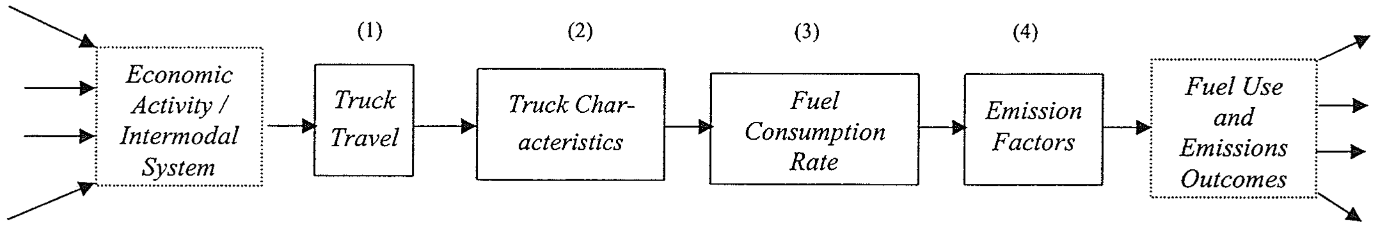

Figure 8.1: Manitoba Heavy Truck Energy and Emissions Model

After: Malzer, 2001

The four model parameters are defined to represent the study highway, fleet and environment, and are subsequently applied to estimate fuel use and emissions. The Manitoba Heavy Truck Energy and Emissions model is generic and can be calibrated to estimate heavy truck travel operating on other highway networks.

8.2 FUEL CONSUMPTION RELATIONSHIPS AND EMISSION FACTORS

The research involved designing and conducting a survey of fuel use by western Canadian-based carriers. Carriers were contacted regarding their participation, which included providing fuel use and travel datasets as well as describing their best practices regarding efficiency. In total, ten datasets were obtained containing fuel use and distance travelled data. Fuel consumption rates were derived from fuel use and distance travelled. The data was normalized by weighting the records for every 1000 miles of travel, meaning a tractor semi-trailer combination truck would be represented once for every

1000 miles of travel in the data. Seasons were defined and linear relationships for each season of operation were developed as a function of gross vehicle weight. A combined annual relationship was also developed. The datasets behind the fuel consumption relationships represent more than 272 million miles of travel and 39 million gallons of diesel consumed by heavy trucks operating on non-congested rural highways from Prairie-based carriers. Comparing the seasonal and annual relationships shows:

- a seasonal differentiation exists, the winter season having the lowest fuel efficiency
- that compared to past relationships fuel efficiency has improved by approximately 1 percent per year
- fuel efficiency decreases at a rate of 0.0278 km / L per metric operating tonne

The research assessed emission factors used in North America and selected factors to be used in the model. The principal finding is to use emission factors that link emissions to fuel use versus distance travelled. Fuel-based emission factors are expressed in grams per litre and the selected factors are from Environment Canada. The emission factor for carbon dioxide (CO_2) is 2730 g / L.

8.3 SCENARIO-BASED ANALYSIS

The model was applied using scenario-based analysis techniques and real volume data from actual highway operations in Manitoba. The model variables were adjusted to consider the impacts of the introduction of certain policies or operational changes. Specifically, the analysis shows 1) changes in energy use and emissions from changes in heavy truck size and weight limits, and 2) the significance of idling in heavy truck emission production.

The data describing truck travel on the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie show that trucks on average do not travel at maximum gross vehicle weight. Scenario-based study of trucks operating on a larger Manitoba highway network, specifically the DT-network, is used to test the full range of emission reductions possible due to truck size and weight limit relaxation associated with the 1987 RTAC MoU. Particular consideration was made of the introduction of 3-S3 travel and of the emissions used to move tare weight at different gross vehicle weight scenarios for B-trains. Relaxation of truck size and weight limits has the potential to reduce truck trips, which reduces emissions far more greatly than the additional emissions to move heavier loads.

The research studied the significance of idling operations on fuel use and emissions. Idling varies by season and by carrier operations. The Source 10 dataset has detailed idling data. The estimated fuel consumption rate for idling operations based on this Source is approximately 0.787 gallons / hour.

8.4 EMISSION REDUCTION INITIATIVES

Knowledge bases are developed using a survey approach and are based on the operational experience of participating carriers. The knowledge bases explain the use of emission reduction initiatives and their effectiveness. Emission reduction initiatives are employed by all participating carriers. Some of the most important initiatives identified are:

- reducing idling
- limiting speed
- educating drivers on emission sensitive driving techniques

Tax collected by the Province of Manitoba on diesel consumed by heavy trucks was estimated based on the projected energy use along the Manitoba section of the Trans-Canada Highway between Winnipeg and Portage La Prairie for the years 1982 and 2002. Taxation rates were determined from Taxation Manitoba and rates for year 1982 are adjusted for inflation. The analysis is conducted in 2002 dollars. The results show that tax collected for travel by 3-S2s, 3-S3s, and B-trains along the study section decreased in constant dollars by 13 percent despite increases in truck kilometres of travel of 49 percent. Tax collected on diesel fuel by the Government of Canada has remained constant at 4 c / L since 1987.

Biodiesel utilization as an alternative to petroleum diesel is considered in the research for its potential impacts on energy use and emissions. Literature and interview findings indicate that biodiesel contains less energy per unit than does petroleum diesel. Emissions relating directly to fuel use would correspondingly be slightly increased. The emissions accounting system used in Kyoto inventory development does not include emissions from renewable fuels, meaning the use of biodiesel can help in achieving Canada's environmental commitments.

8.5 EMISSION TARGETS

Changes in fuel efficiency over time are tested by applying the model to the Manitoba segment of the Trans-Canada Highway between Winnipeg and Portage La Prairie for the years 1982 and 2002. The application shows an annual improvement in fuel economy of approximately 1 percent since 1982. The contemporary fuel consumption relationship are compared against similar relationships developed in an idealized, competition setting. In particular the results from the DriveSave / TruckSave relationships are approximately 11.7 percent more efficient in the 36 tonne range. This result suggests that fuel efficiency will continue to improve.

The research estimates heavy truck emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) by applying emission factors directly to the quantity of fuel consumed. Contemporary (2002) emissions were determined for the Manitoba segment of the Trans-Canada Highway between Winnipeg and Portage La Prairie and were compared to emission estimates for year 1982 using the same model. Over the 20-year period, gross CO_2 emissions increased by approximately 14 percent and grams of CO_2 emissions per thousand rolling payload tonne-kilometres decreased by 12.5 percent.

The Thesis introduces new questions for research, some of these are:

- Intermodal effects: Battelle proposes that the relaxation of truck size and weight regulations prompt increases in freight movement by truck to the disadvantage of the train industry (Environment and Truck Size and Weight Regulations). This pattern is aided by falling unit costs that are passed on to consumers as a result of the fewer shipments being required.
- The model concept used to estimate emissions in this thesis employs fuel emission factors that are based on fuel consumption. Such factors are not available for estimating all emissions. The development of this tool would advance the research in the Thesis.
- Lowered speed limits: this thesis considered fuel consumption rates for heavy trucks operating under free flow, high speed conditions. Discussions with participating carriers conveyed the importance of operating at specific rpm levels to maintain fuel efficiency. Capping travel speed is an important tool used by carriers and could be supported by government agencies with increased enforcement.
- Economic tools: according to Nix (Truck Activity in Canada) fuel efficiency is unlikely to improve substantially because diesel prices and taxes are not expected to rise. Similarly, improvements in fuel economy were realized after the Middle East energy crisis in the 1970s (Automotive Fuels Reference Book). The implication is that raising diesel prices is a tool that would help reduce greenhouse gas emissions.
- Environmental zones: Sweden has established 'environmental zones' in the downtown cores of three principal cities (Trucks and Air Emissions). The zones limit the types of trucks that may enter the urban areas according to environmental impacts. Another initiative is the SmartWay Transport Partnership between carriers and shippers, which is a voluntary effort to take on projects that reduce emissions. The carriers or shippers benefit by attracting contracts with environmentally-minded companies. Such programs invite competition among carriers based on their environmental record, stimulating improvements in fuel economy and emission reductions.

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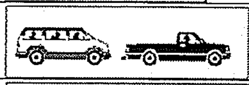
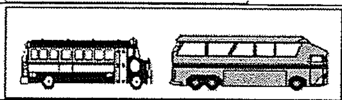
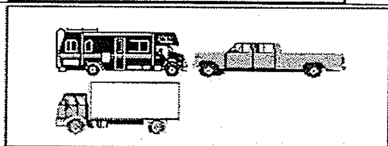
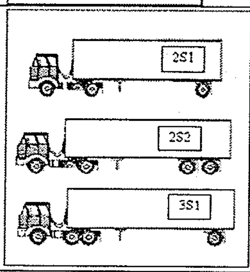
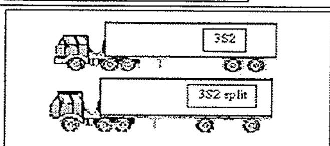
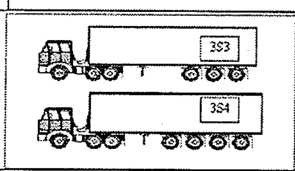
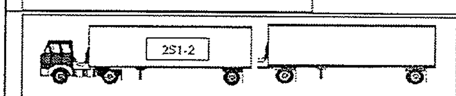
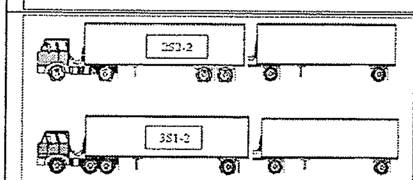
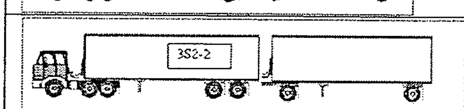
APPENDIX A

FHWA Vehicle Classification System

	**FHWA Class 1 – Motorcycles**
	**FHWA Class 2 – Passenger Cars (With 1- or 2-Axle Trailers)**
	**FHWA Class 3 – 2 Axles, 4-Tire Single Units, Pickup or Van (With 1- or 2-Axle Trailers)**
	**FHWA Class 4 – Buses**
	**FHWA Class 5 – 2D - 2 Axles, 6-Tire Single Units (Includes Handicapped-Equipped Bus and Mini School Bus)**
	**FHWA Class 6 – 3 Axles, Single Unit**
	**FHWA Class 7 – 4 or More Axles, Single Unit**
	**FHWA Class 8 – 3 to 4 Axles, Single Trailer**
	**FHWA Class 9 – 5 Axles, Single Trailer**
	**FHWA Class 10 – 6 or More Axles, Single Trailer**
	**FHWA Class 11 – 5 or Less Axles, Multi-Trailers**
	**FHWA Class 12 – 6 Axles, Multi-Trailers**
	**FHWA Class 13 – 7 or More Axles, Multi-Trailers**

Source: http://manuals.dot.state.tx.us/dynaweb/coltrsys/tda/@Generic_BookTextView/20168

APPENDIX B

The following steps were taken to normalize data between carriers. The data fields of concern were distance travelled, fuel consumed, gross vehicle weight, and fuel consumption rates.

Metric/imperial normalization of these data fields was accomplished by applying the following conversion factors:

Miles to Kilometres:	1.609
Imperial Gallons to Litres:	4.5461
Kips to Tonnes:	0.4536

Generally data was given in miles travelled and imperial gallons consumed; when given in kilometres and litres the inverse factors are applied. Mile per gallon (MPG) values were calculated from mile and gallon values from the dataset; kilometre per litre (km/l) values were likewise calculated from kilometre and litre values.

Data fields were rounded to the following accuracies:

Distance:	0 decimals
Fuel Volume Used:	2 decimals
Weight:	3 decimals
Fuel Consumption rates:	4 decimals

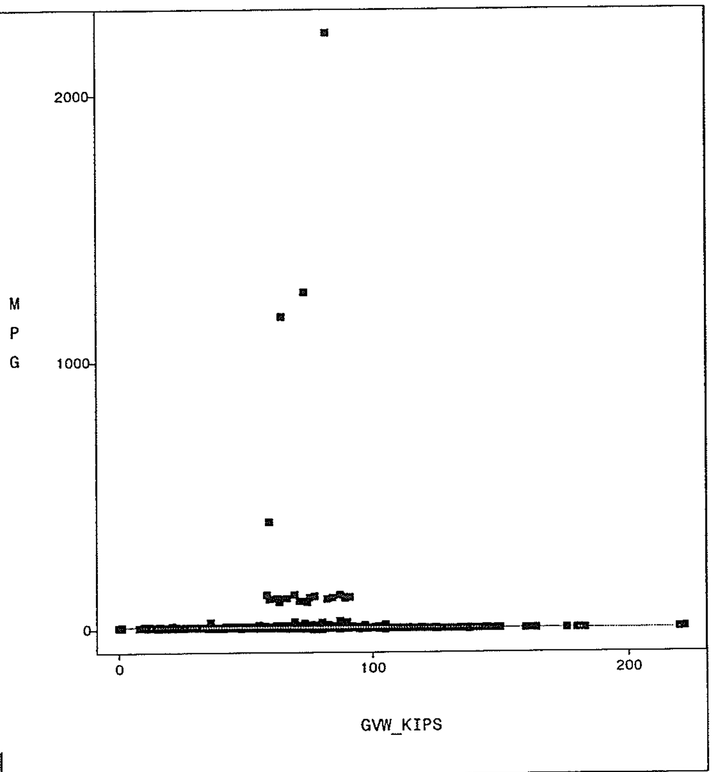
Seasonal regressions by source were calculated from MPG vs. kip values. Combined source regressions (by season and annually) were calculated twice, from MPG vs. kips and from km/l vs. tonnes.

APPENDIX C

Sources 1 - 10: Imperial Annual

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Model Equation					
MPG	=	9.3948	-	0.0303	GVW_KIPS



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
———	1	1	33631.7860	3.E+05	126.4650	0.0010	265.94	<.0001

Summary of Fit

Mean of Response	7.2009	R-Square	0.0010
Root MSE	11.2457	Adj R-Sq	0.0010

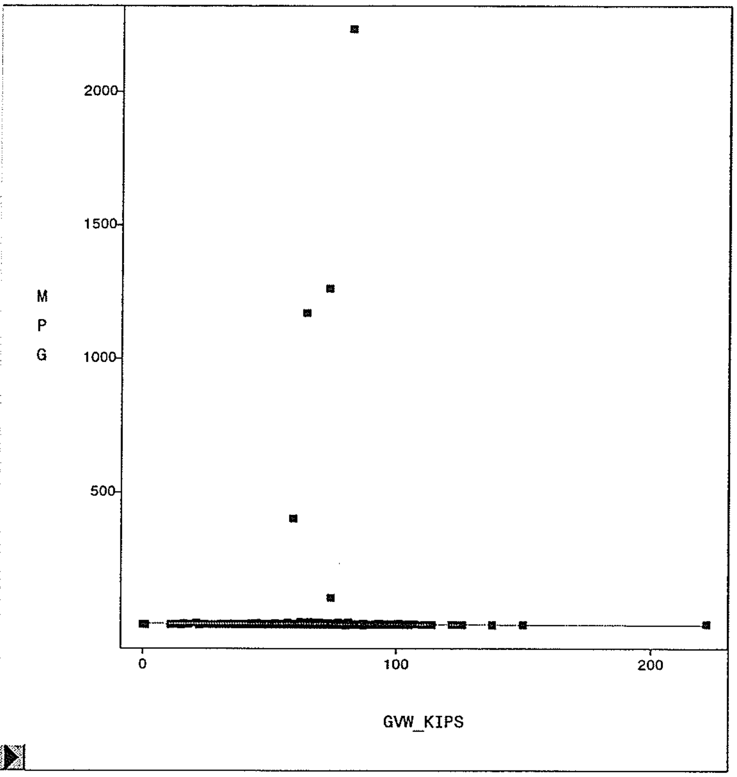
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	33631.7860	33631.7860	265.94	<.0001
Error	3.E+05	34542009.8	126.4650		
C Total	3.E+05	34575641.6			

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Imperial Fall

Model Equation					
MPG	=	10.0446	-	0.0340	GVW_KIPS



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
————	1	1	9600.1332	60495	544.9668	0.0003	17.62	<.0001

Summary of Fit

Mean of Response	7.6161	R-Square	0.0003
Root MSE	23.3445	Adj R-Sq	0.0003

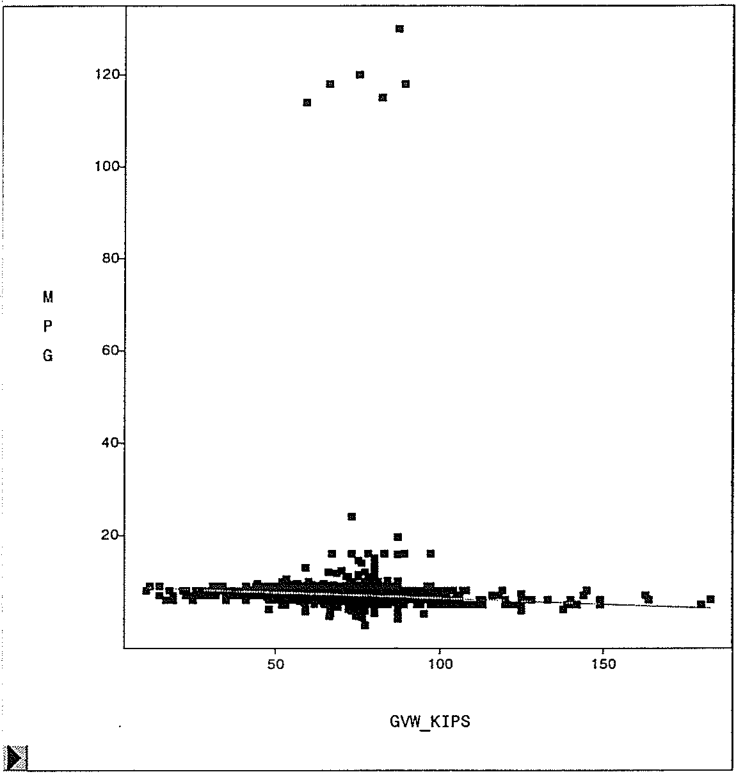
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	9600.1332	9600.1332	17.62	<.0001
Error	60495	32967764.1	544.9668		
C Total	60496	32977364.3			

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Imperial Spring

Model Equation				
MPG	=	8.9143	-	0.0260 GVW_KIPS



Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
————	1	1	6195.7281	72913	7.2255	0.0116	857.48	<.0001

Summary of Fit			
Mean of Response	7.0424	R-Square	0.0116
Root MSE	2.6880	Adj R-Sq	0.0116

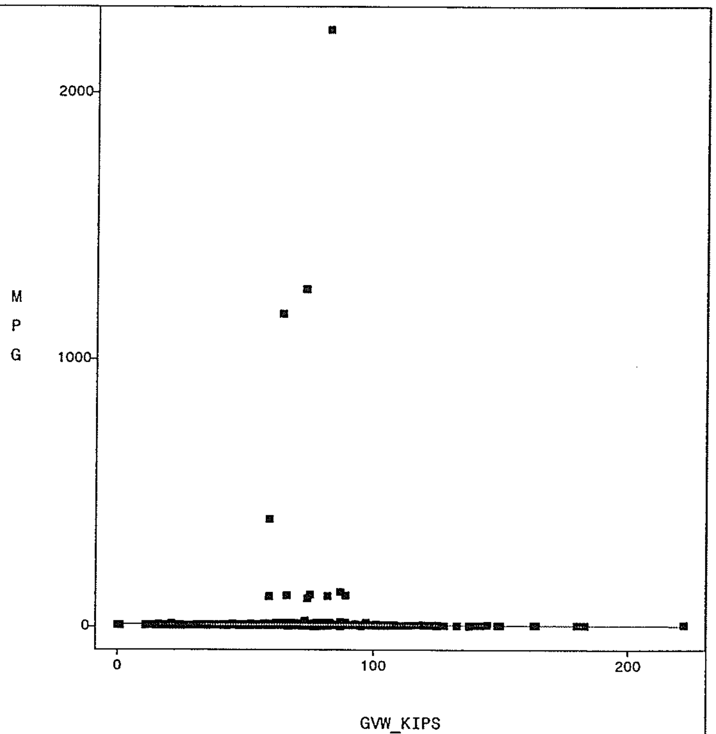
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	6195.7281	6195.7281	857.48	<.0001
Error	72913	526831.980	7.2255		
C Total	72914	533027.708			

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Imperial Springfall

Model Equation					
MPG	=	9.5486	-	0.0312	GVW_KIPS



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	17026.4374	1.E+05	251.1551	0.0005	67.79	<.0001

Summary of Fit

Mean of Response	7.3099	R-Square	0.0005
Root MSE	15.8479	Adj R-Sq	0.0005

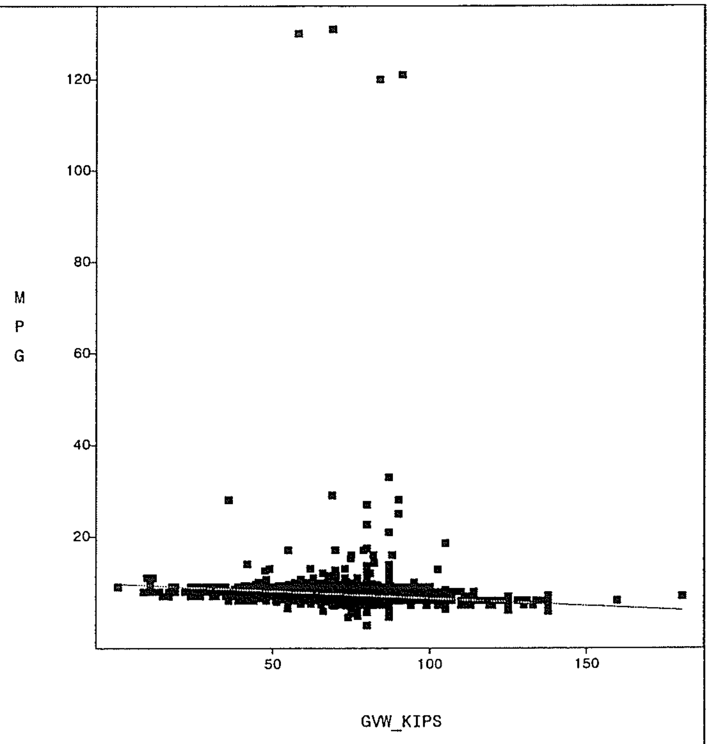
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	17026.4374	17026.4374	67.79	<.0001
Error	1.E+05	33506608.1	251.1551		
C Total	1.E+05	33523634.5			

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Imperial Summer

Model Equation					
MPG	=	9.6574	-	0.0316	GVW_KIPS



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
------	1	1	10069.9802	75666	7.1456	0.0183	1409.25	<.0001

Summary of Fit

Mean of Response	7.3355	R-Square	0.0183
Root MSE	2.6731	Adj R-Sq	0.0183

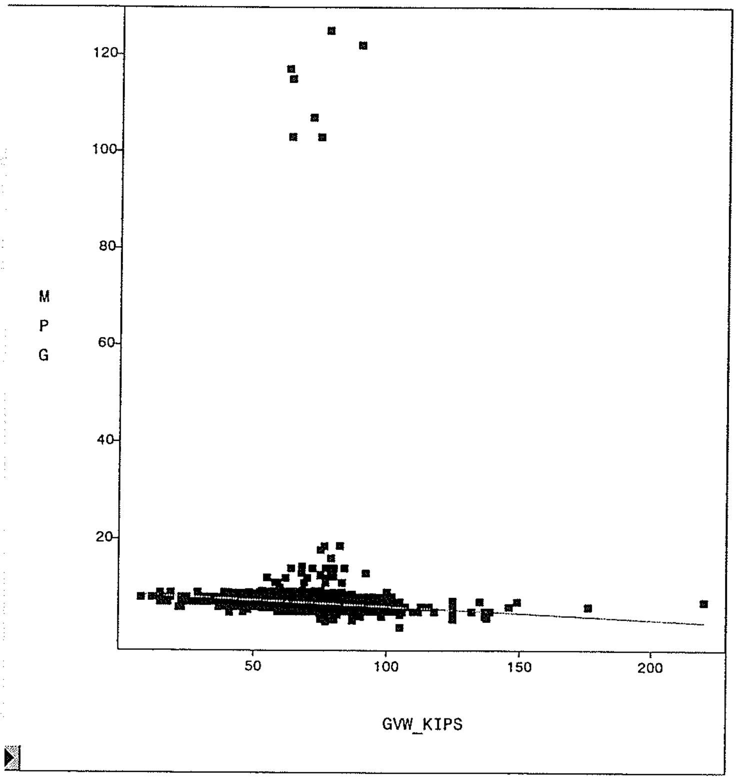
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	10069.9802	10069.9802	1409.25	<.0001
Error	75666	540682.494	7.1456		
C Total	75667	550752.474			

MPG	=	GVW_KIPS
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Imperial Winter

Model Equation					
MPG	=	8.7779	-	0.0275	GVW_KIPS



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
———	1	1	6645.0950	64055	7.4854	0.0137	887.74	<.0001

Summary of Fit

ɫean of Response	6.7998	R-Square	0.0137
Root MSE	2.7359	Adj R-Sq	0.0137

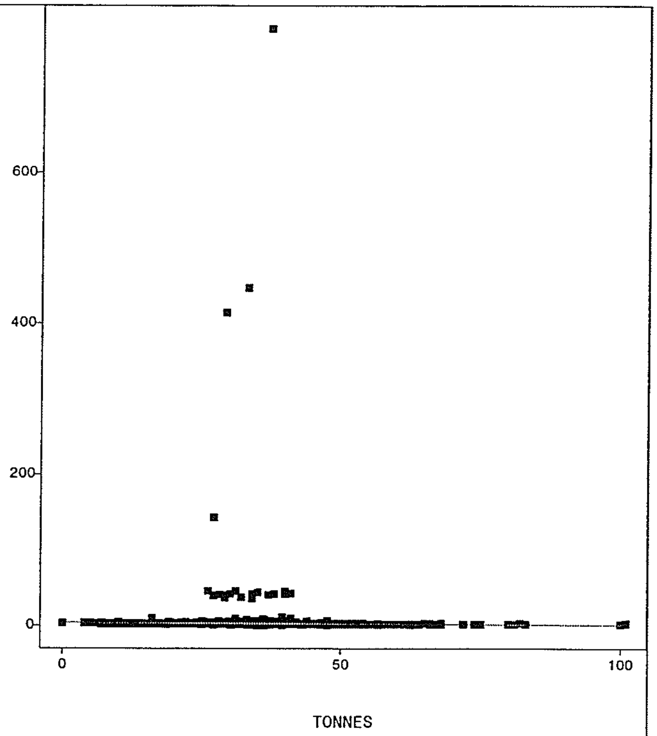
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
ɫodel	1	6645.0950	6645.0950	887.74	<.0001
Error	64055	479476.598	7.4854		
: Total	64056	486121.693			

Sources 1 - 10: Metric Annual

KM_PER_L	=	TONNES
Response Distribution:		Normal
Link Function:		Identity

Model Equation					
KM_PER_L	=	3.4978	-	0.0282	TONNES



Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	5869.4925	3.E+05	15.8803	0.0014	369.61	<.0001

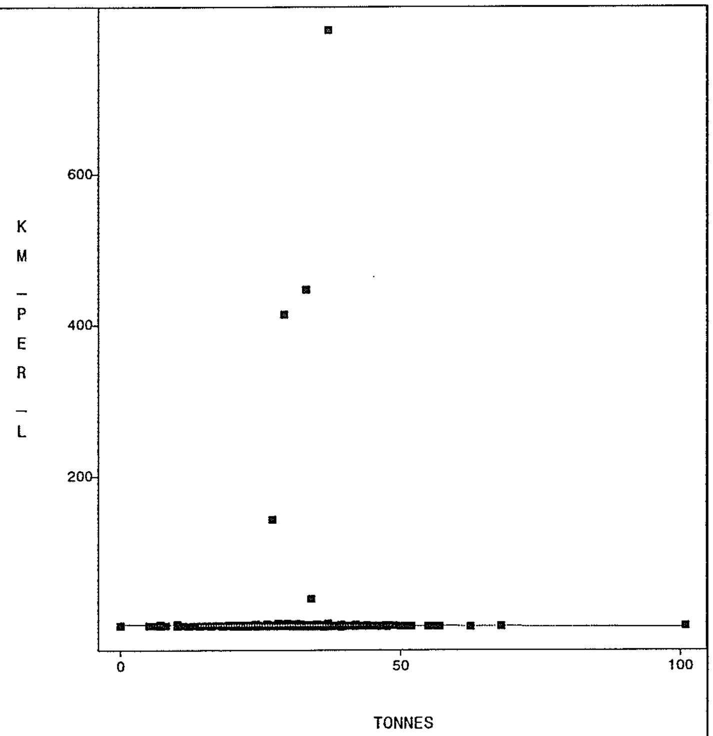
Summary of Fit			
Mean of Response	2.5732	R-Square	0.0014
Root MSE	3.9850	Adj R-Sq	0.0013

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	5869.4925	5869.4925	369.61	<.0001
Error	3.E+05	4337477.59	15.8803		
C Total	3.E+05	4343347.09			

KM_PER_L	=	TONNES
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Metric Fall

Model Equation					
KM_PER_L	=	3.8483	-	0.0341	TONNES



Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	1955.3128	60495	68.2186	0.0005	28.66	<.0001

Summary of Fit			
Mean of Response	2.7427	R-Square	0.0005
Root MSE	8.2595	Adj R-Sq	0.0005

Analysis of Variance

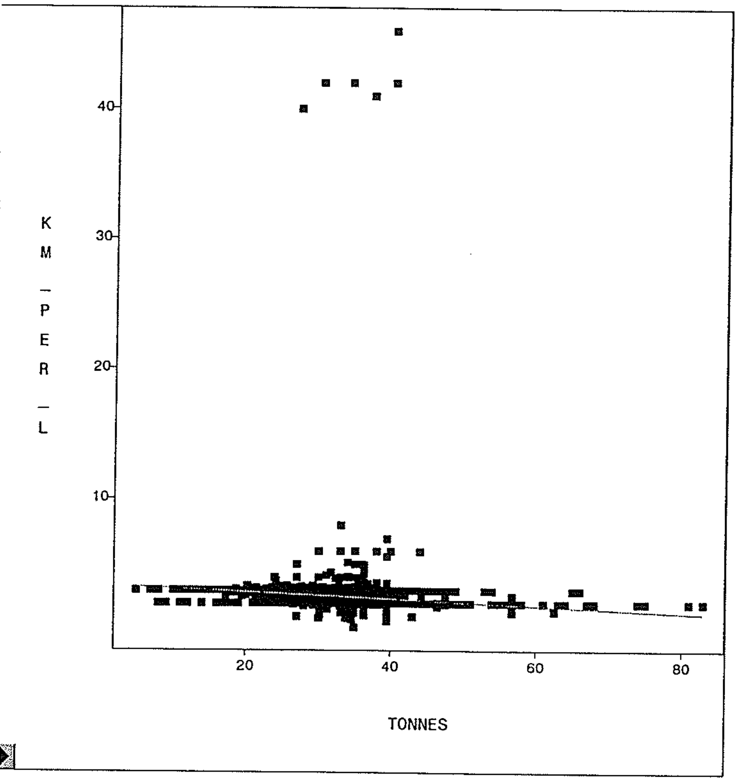
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	1955.3128	1955.3128	28.66	<.0001
Error	60495	4126881.38	68.2186		
C Total	60496	4128836.69			

KM_PER_L = TONNES

Response Distribution:	Normal
Link Function:	Identity

Sources 1 - 10: Metric Spring

Model Equation				
KM_PER_L	=	3.3936	-	0.0263 TONNES



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
———	1	1	1283.9485	72913	0.9771	0.0177	1314.09	<.0001

Summary of Fit

Mean of Response	2.5322	R-Square	0.0177
Root MSE	0.9885	Adj R-Sq	0.0177

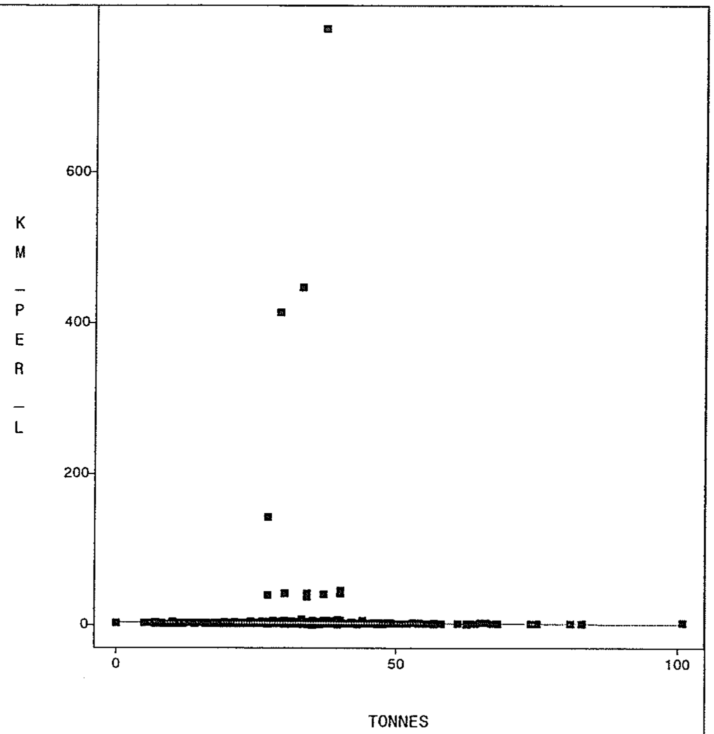
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	1283.9485	1283.9485	1314.09	<.0001
Error	72913	71240.4133	0.9771		
C Total	72914	72524.3619			

KM_PER_L	=	TONNES
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Metric Springfall

Model Equation					
KM_PER_L	=	3.6275	-	0.0307	TONNES



Parametric Regression Fit

		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	3338.8891	1.E+05	31.4794	0.0008	106.07	<.0001

Summary of Fit

Mean of Response	2.6264	R-Square	0.0008
Root MSE	5.6106	Adj R-Sq	0.0008

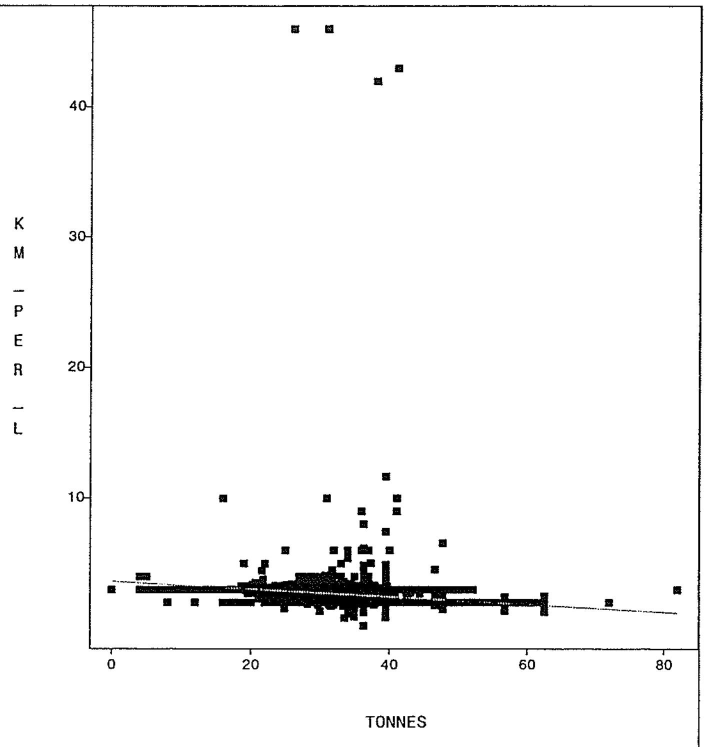
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
Model	1	3338.8891	3338.8891	106.07	<.0001
Error	1.E+05	4199661.31	31.4794		
C Total	1.E+05	4203000.20			

KM_PER_L	=	TONNES
Response Distribution:		Normal
Link Function:		Identity

Sources 1 - 10: Metric Summer

Model Equation					
KM_PER_L	=	3.6276	-	0.0296	TONNES



Parametric Regression Fit								
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	1797.9128	75666	0.9172	0.0253	1960.29	<.0001

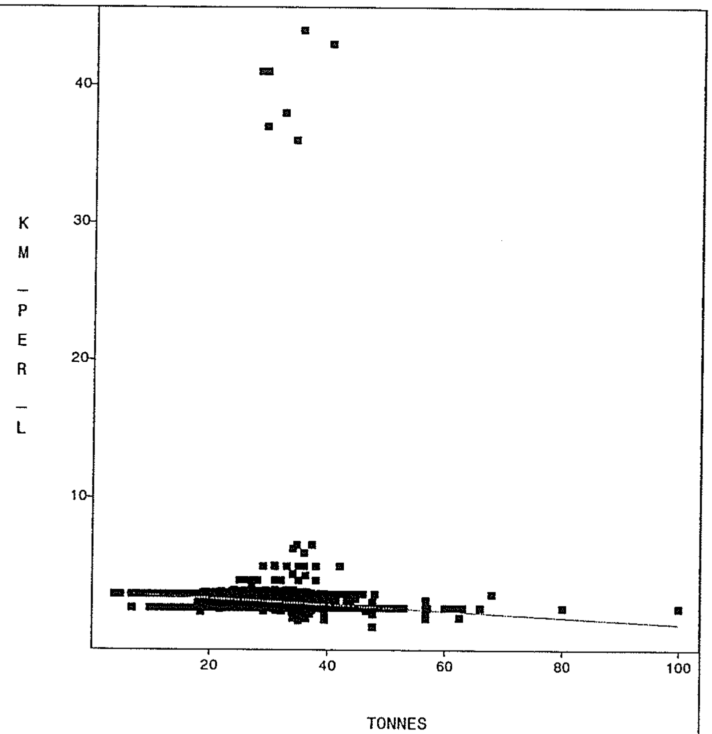
Summary of Fit			
lean of Response	2.6400	R-Square	0.0253
;oot MSE	0.9577	Adj R-Sq	0.0252

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
odel	1	1797.9128	1797.9128	1960.29	<.0001
rror	75666	69398.2676	0.9172		
Total	75667	71196.1804			

Sources 1 - 10: Metric Winter

KM_PER_L	=	TONNES
Response Distribution:		Normal
Link Function:		Identity

Model Equation					
KM_PER_L	=	3.1423	-	0.0231	TONNES



Parametric Regression Fit

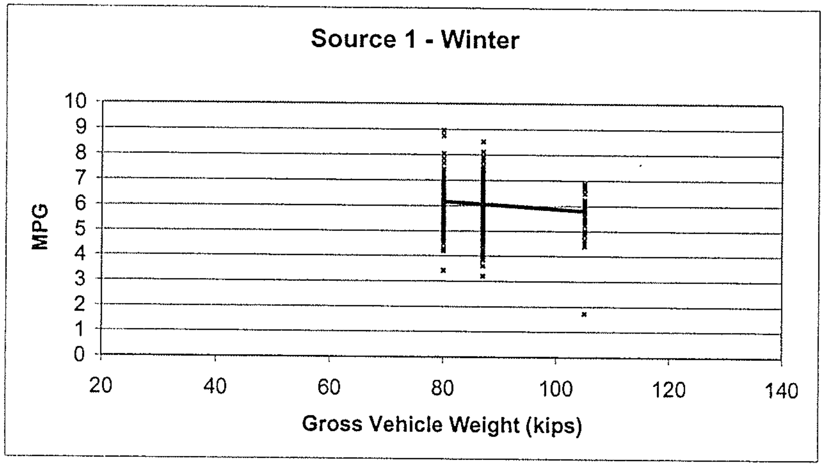
		Model		Error				
Curve	Degree(Polynomial)	DF	Mean Square	DF	Mean Square	R-Square	F Stat	Pr > F
	1	1	953.2781	64055	1.0158	0.0144	938.45	<.0001

Summary of Fit			
ean of Response	2.3864	R-Square	0.0144
oot MSE	1.0079	Adj R-Sq	0.0144

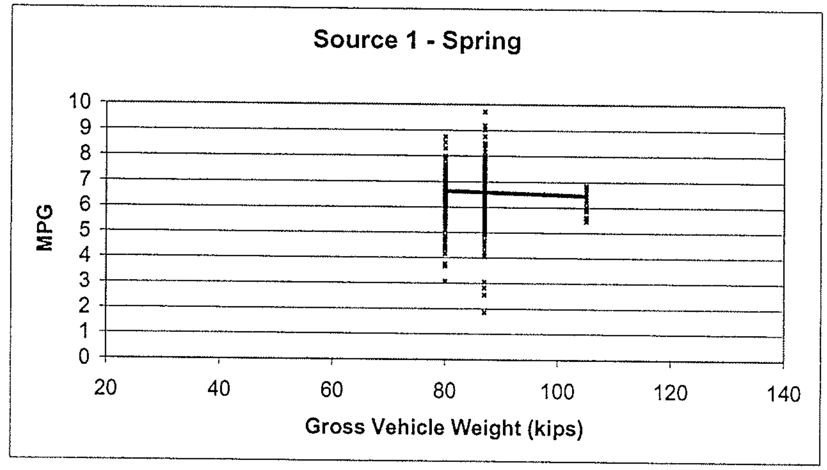
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Stat	Pr > F
lodel	1	953.2781	953.2781	938.45	<.0001
rror	64055	65066.9849	1.0158		
Total	64056	66020.2630			

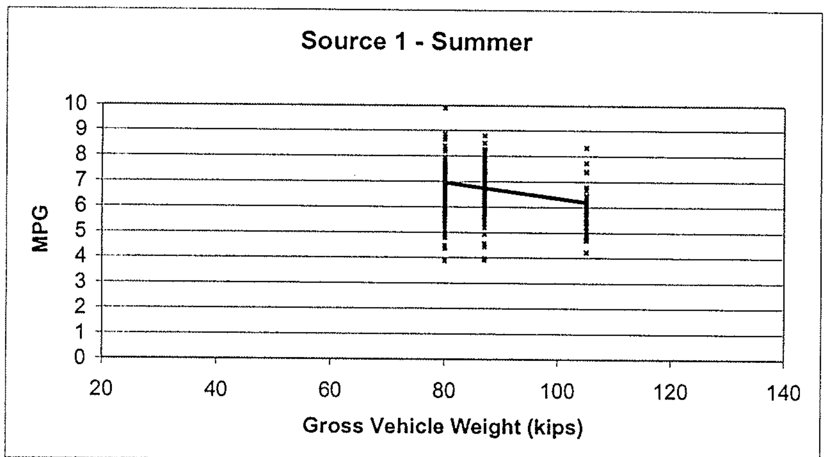
APPENDIX D



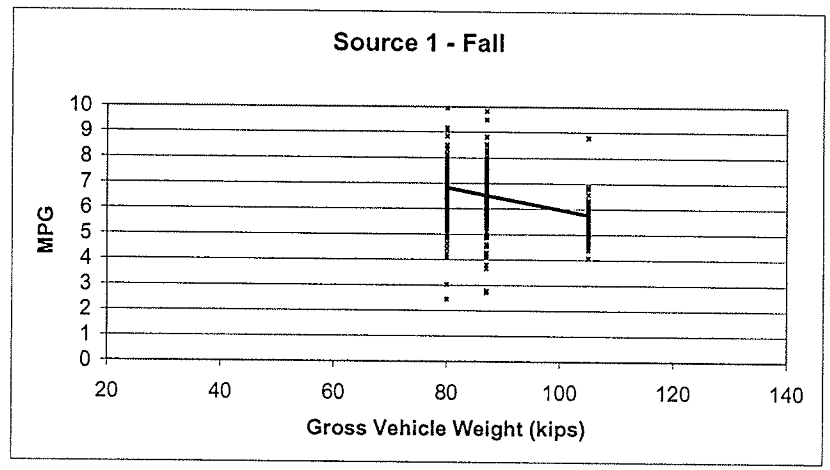
Fuel Consumption (MPG) = 7.3363 - 0.0146GVW (kips)
TMT (000,000's) = 5.050
ImpGallons (000's) = 843.0 5.99



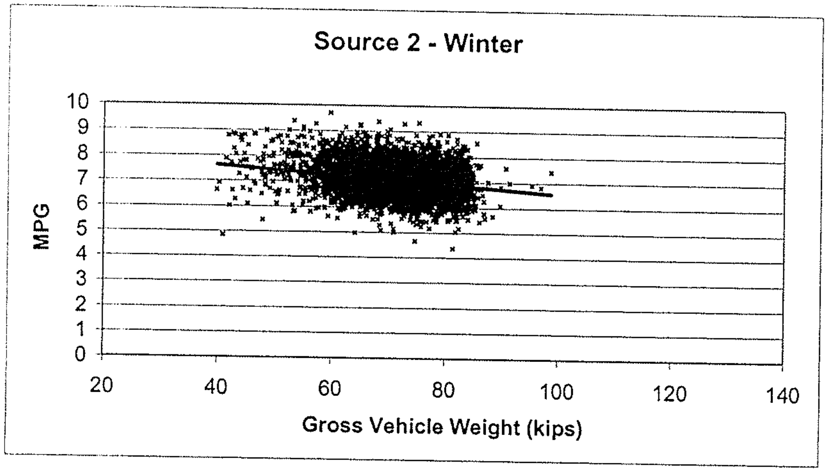
Fuel Consumption (MPG) = 7.2411 - 0.0074GVW (kips)
TMT (000,000's) = 5.508
ImpGallons (000's) = 848.3 6.49



Fuel Consumption (MPG) = 9.4002 - 0.0305GVW (kips)
TMT (000,000's) = 8.920
ImpGallons (000's) = 1305.8 6.83

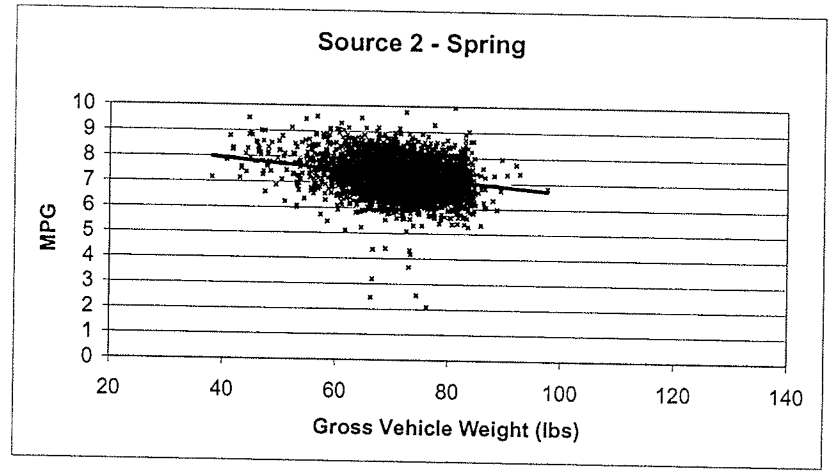


Fuel Consumption (MPG) = 10.2583 - 0.0429GVW (kips)
TMT (000,000's) = 5.566
ImpGallons (000's) = 861.3 6.46



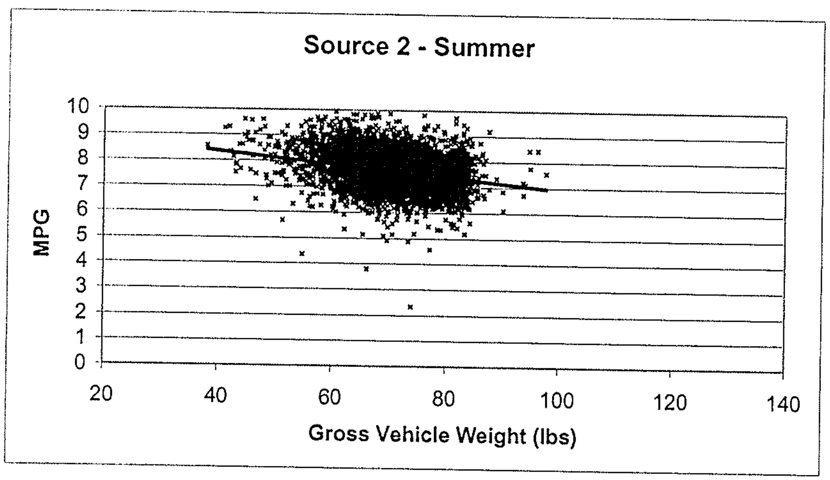
Fuel Consumption (MPG) = 8.3364 - 0.0177GVW (kips)
TMT (000,000's) = 24.670
ImpGallons (000's) = 3515.1

7.02



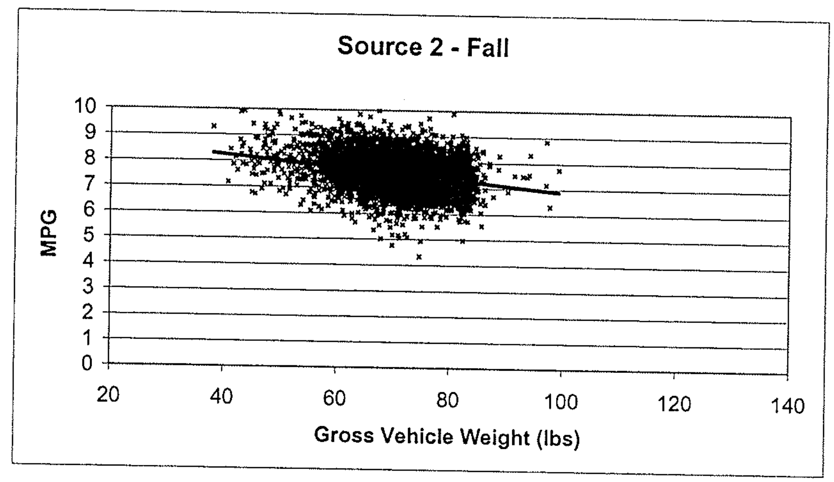
Fuel Consumption (MPG) = 8.7929 - 0.0212GVW (kips)
TMT (000,000's) = 26.917
ImpGallons (000's) = 3725.4

7.23



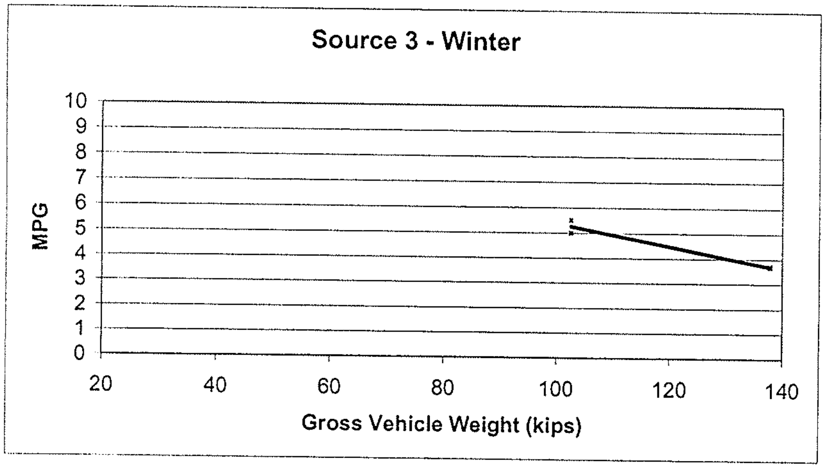
Fuel Consumption (MPG) = 9.3327 - 0.0242GVW (kips)
TMT (000,000's) = 27.968
ImpGallons (000's) = 3698.6

7.56

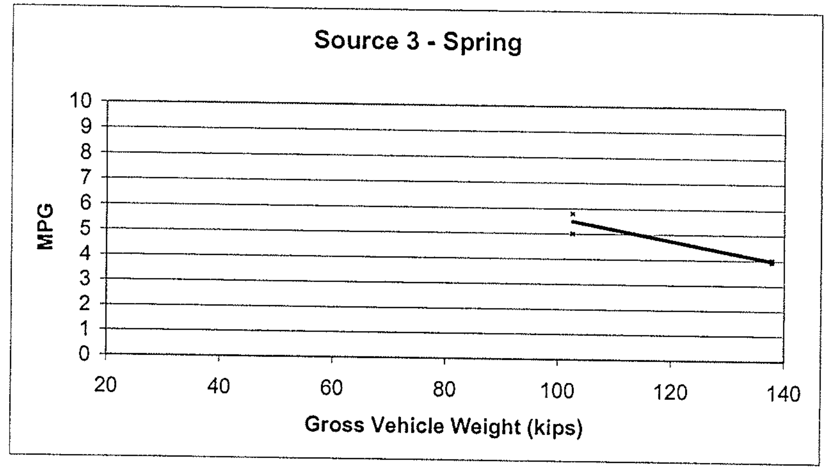


Fuel Consumption (MPG) = 9.1697 - 0.0229GVW (kips)
TMT (000,000's) = 25.023
ImpGallons (000's) = 3341.2

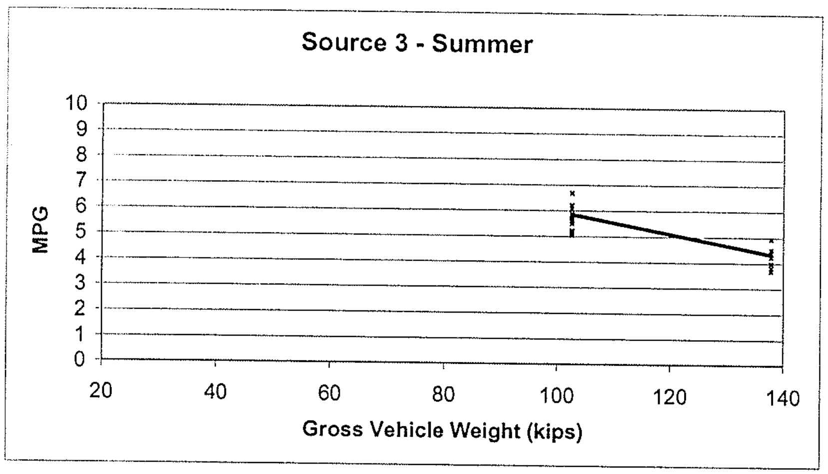
7.49



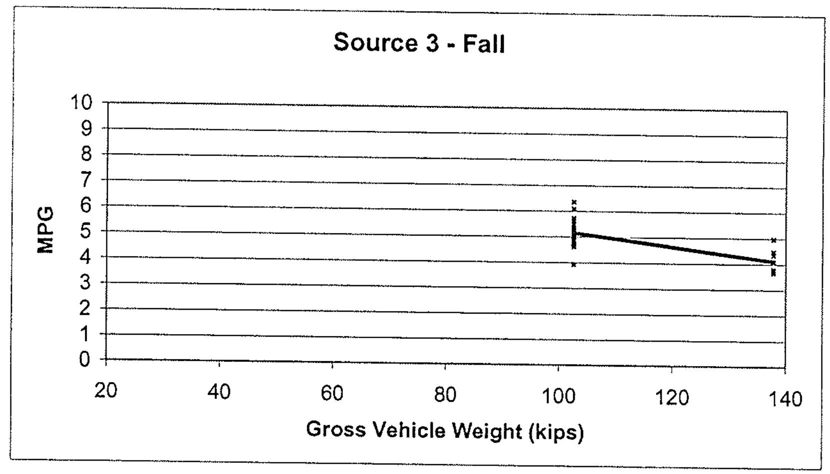
Fuel Consumption (MPG) = 9.7876 - 0.0441GVW (kips)
TMT (000,000's) = 0.120
ImpGallons (000's) = 27.6 4.34



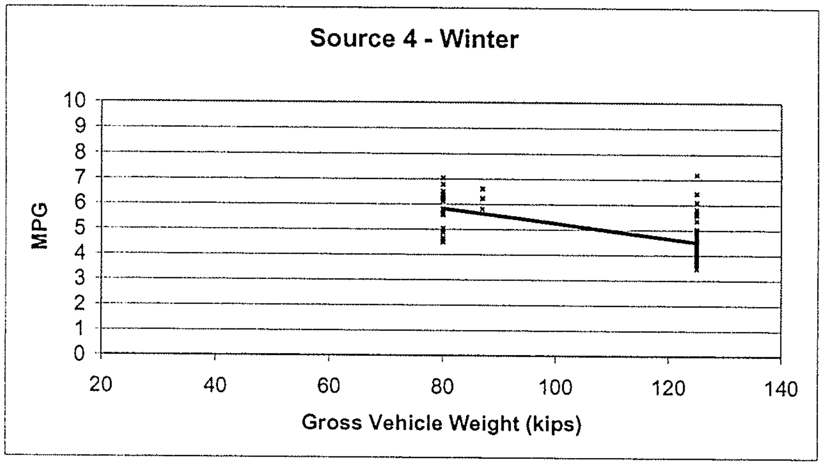
Fuel Consumption (MPG) = 9.9317 - 0.0431GVW (kips)
TMT (000,000's) = 0.115
ImpGallons (000's) = 25.1 4.58



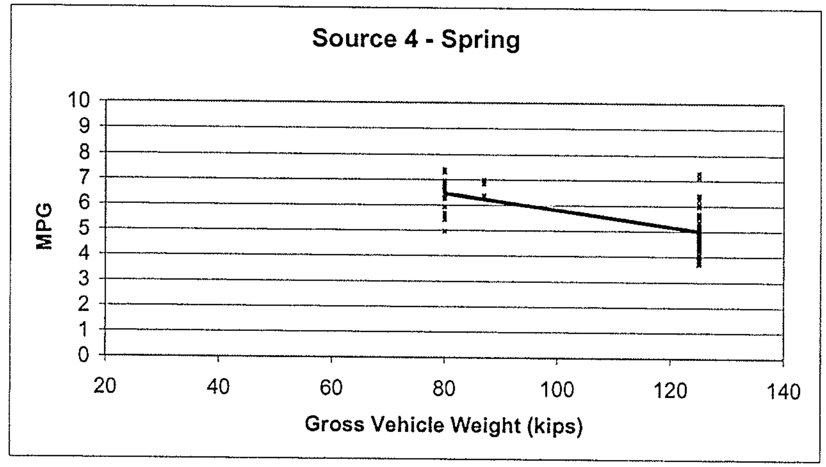
Fuel Consumption (MPG) = 10.2602 - 0.0430GVW (kips)
TMT (000,000's) = 0.240
ImpGallons (000's) = 47.9 5.01



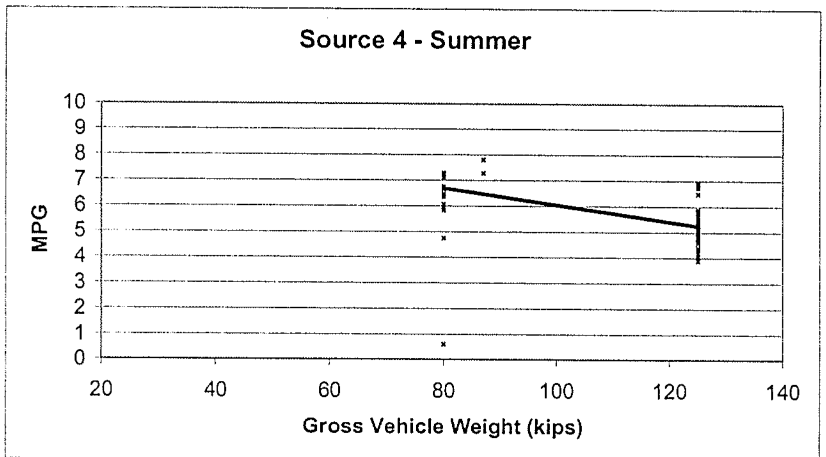
Fuel Consumption (MPG) = 8.1663 - 0.0293GVW (kips)
TMT (000,000's) = 0.867
ImpGallons (000's) = 178.9 4.85



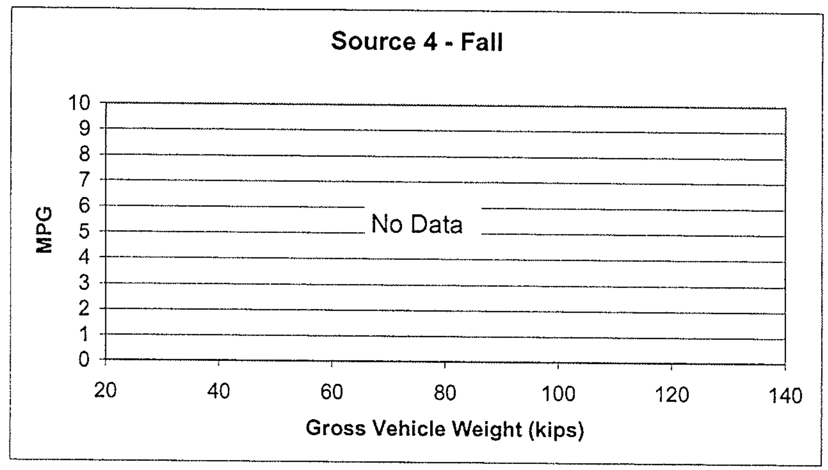
Fuel Consumption (MPG) = 8.1483 - 0.0290GVW (kips)
TMT (000,000's) = 0.889
ImpGallons (000's) = 187.3 4.75

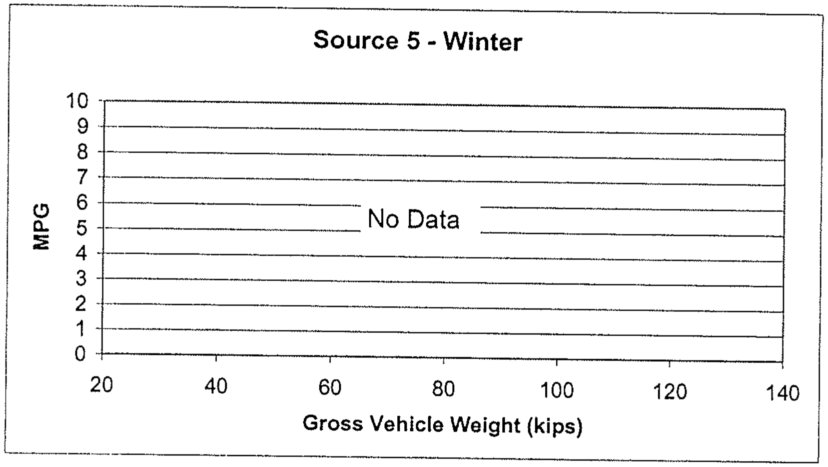


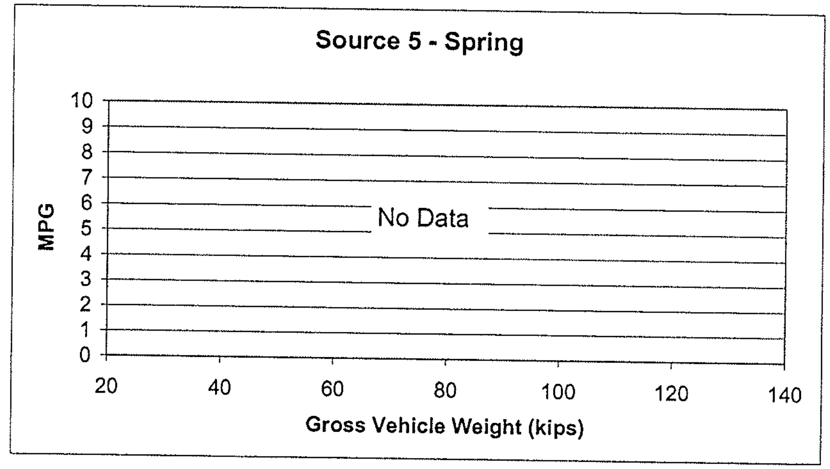
Fuel Consumption (MPG) = 8.9891 - 0.0317GVW (kips)
TMT (000,000's) = 0.779
ImpGallons (000's) = 149.8 5.20

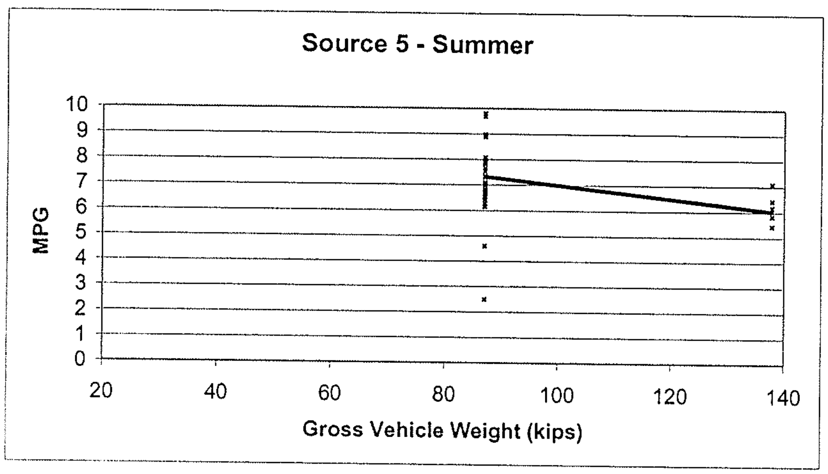


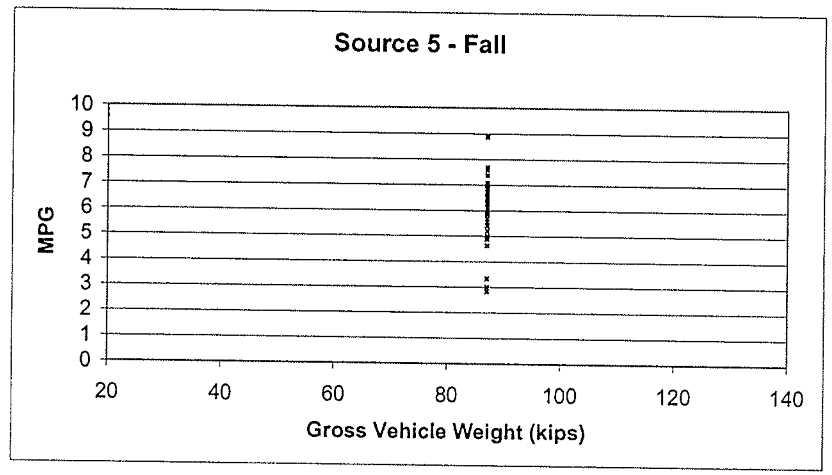
Fuel Consumption (MPG) = 9.2583 - 0.0321GVW (kips)
TMT (000,000's) = 0.442
ImpGallons (000's) = 82.2 5.38





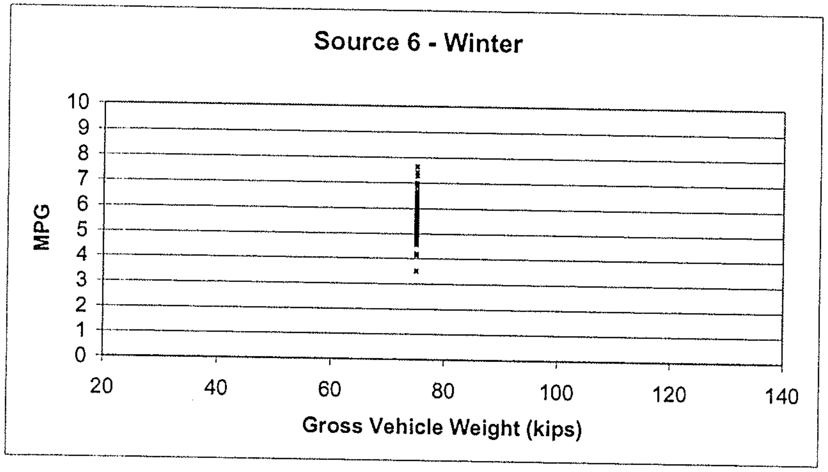




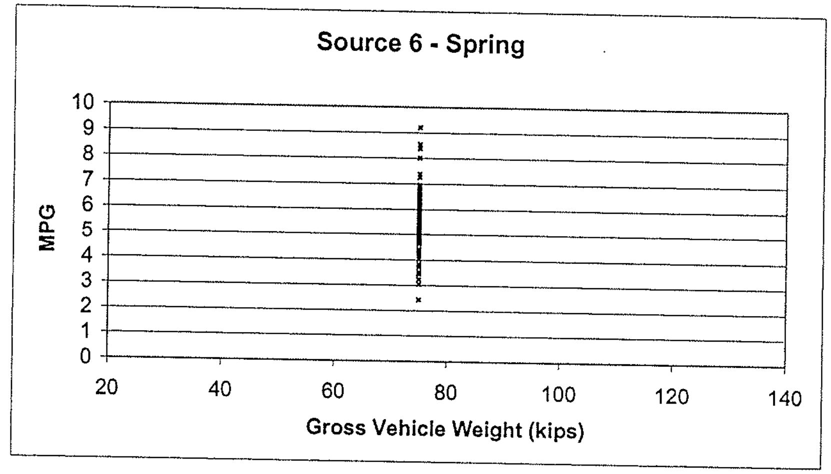


Fuel Consumption (MPG) = 9.5515 - 0.0255GVW (kips)
TMT (000,000's) = 1.030
ImpGallons (000's) = 146.6 7.03

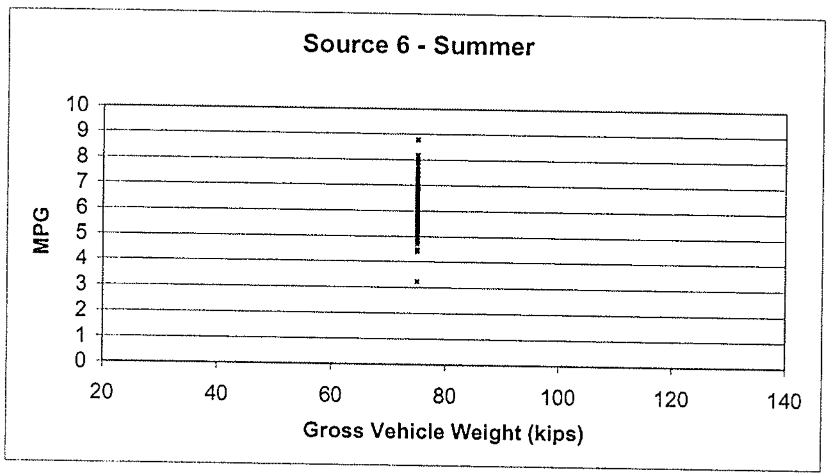
TMT (000,000's) = 0.983
ImpGallons (000's) = 153.1 6.42



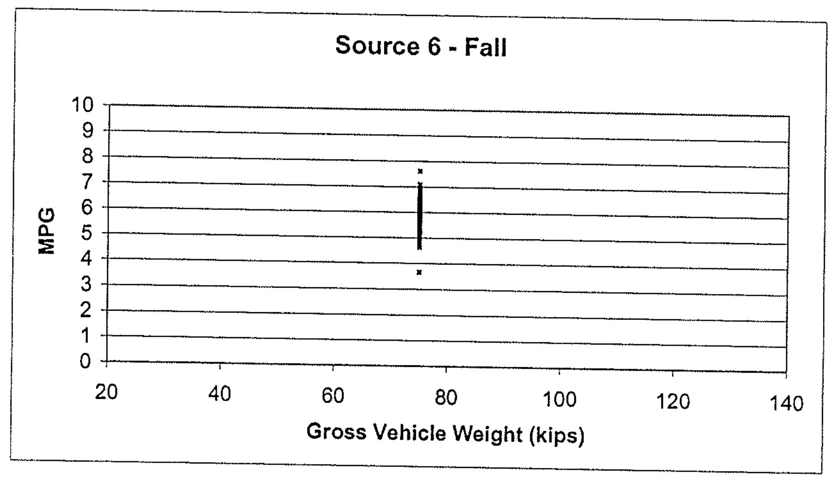
TMT (000,000's) = 4.759
ImpGallons (000's) = 855.9
5.56



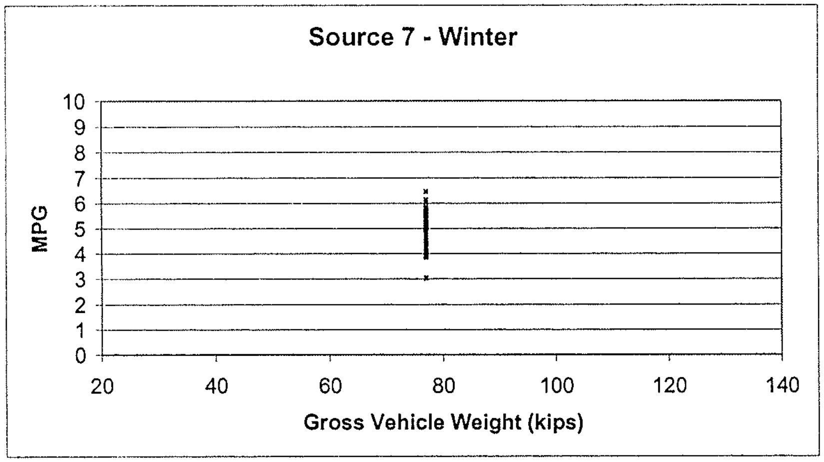
TMT (000,000's) = 8.034
ImpGallons (000's) = 1426.5
5.63



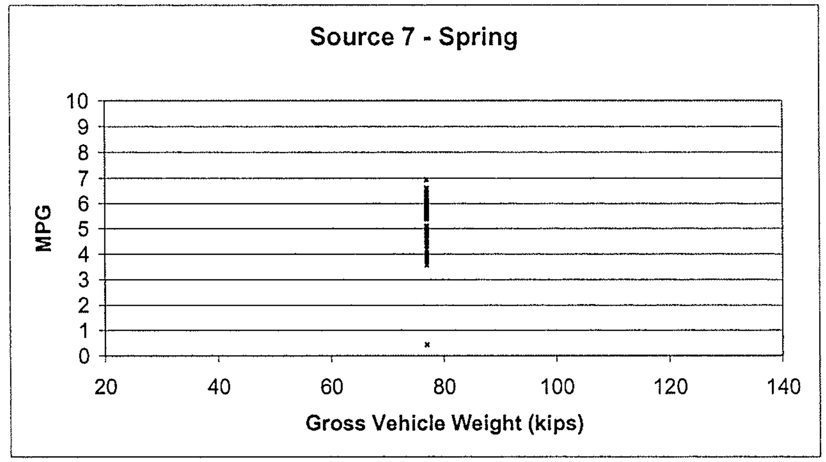
TMT (000,000's) = 10.932
ImpGallons (000's) = 1788.1
6.11



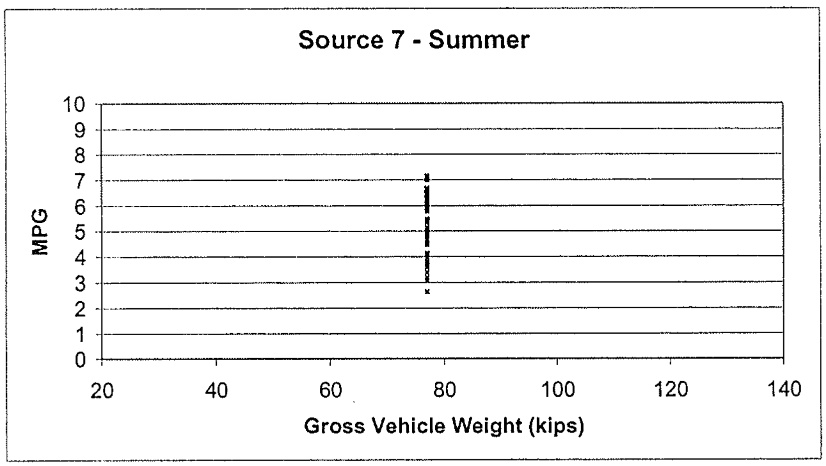
TMT (000,000's) = 3.026
ImpGallons (000's) = 505.1
5.99



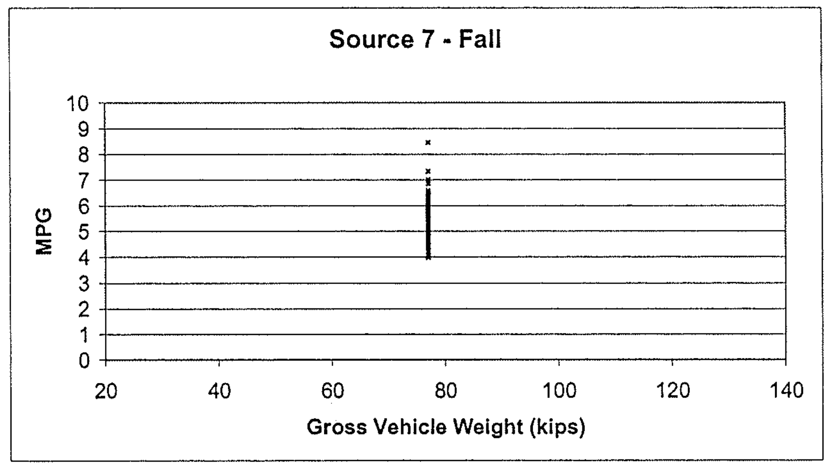
TMT (000,000's) = 0.951
ImpGallons (000's) = 180.0 5.28



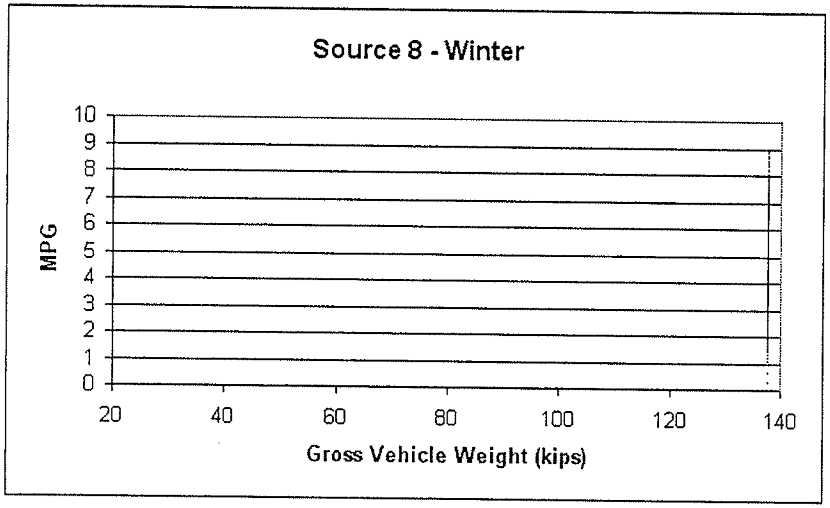
TMT (000,000's) = 0.923
ImpGallons (000's) = 163.5 5.64



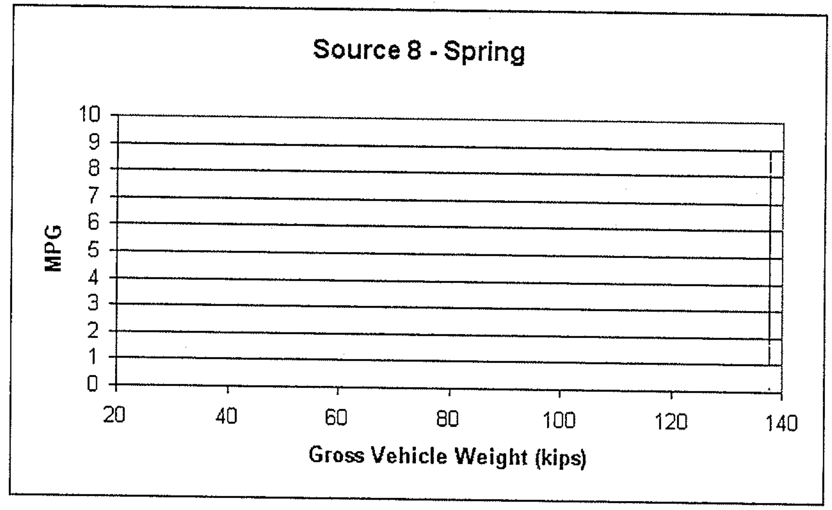
TMT (000,000's) = 0.964
ImpGallons (000's) = 157.4 6.12



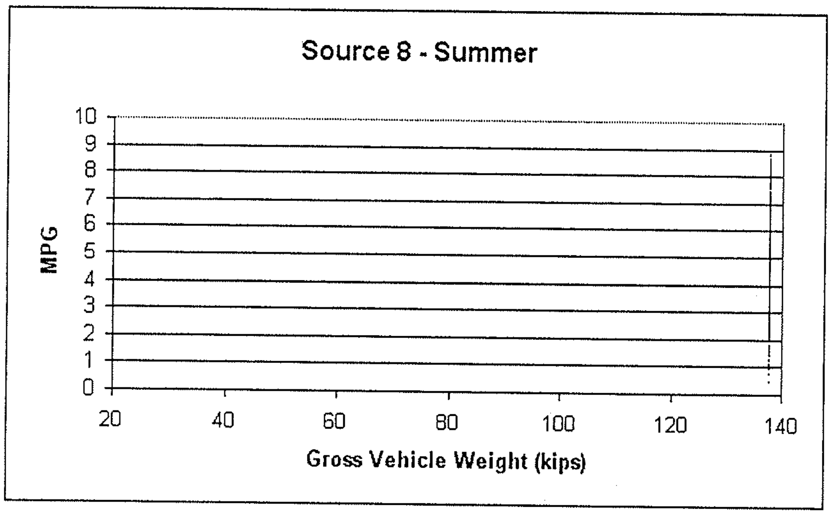
TMT (000,000's) = 0.866
ImpGallons (000's) = 148.1 5.85



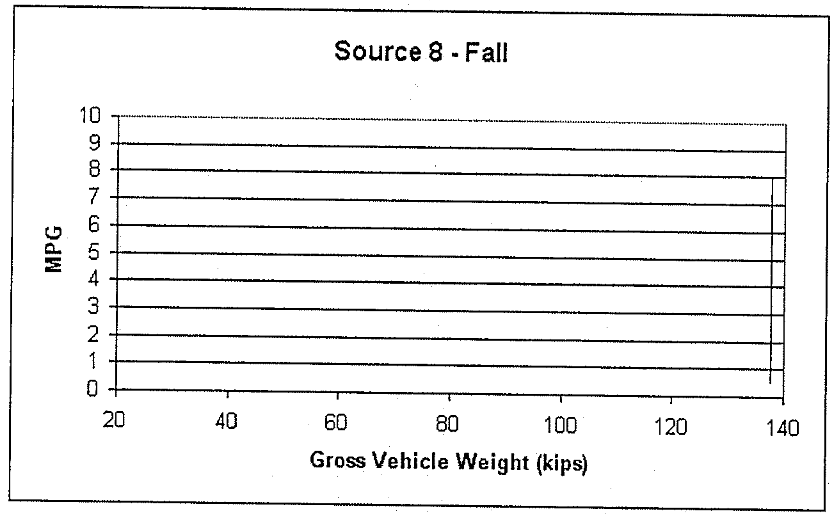
TMT (000,000's) = 0.402
ImpGallons (000's) = 88.1 4.56



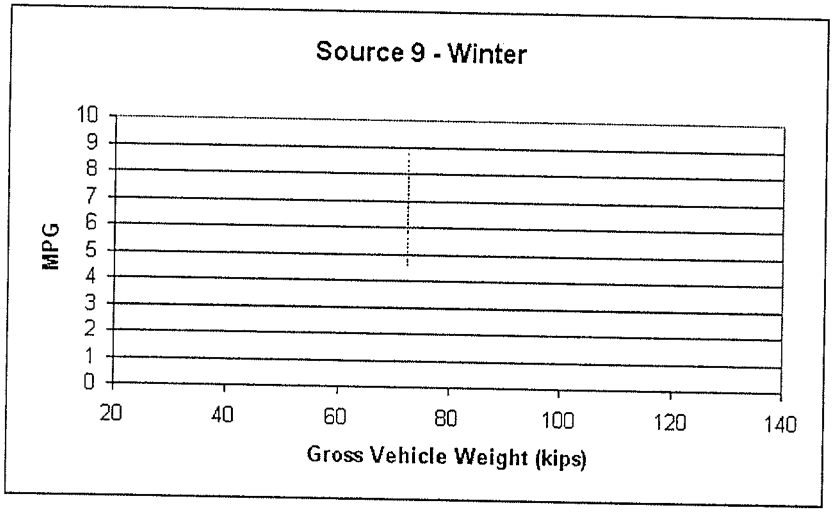
TMT (000,000's) = 0.423
ImpGallons (000's) = 86.9 4.87



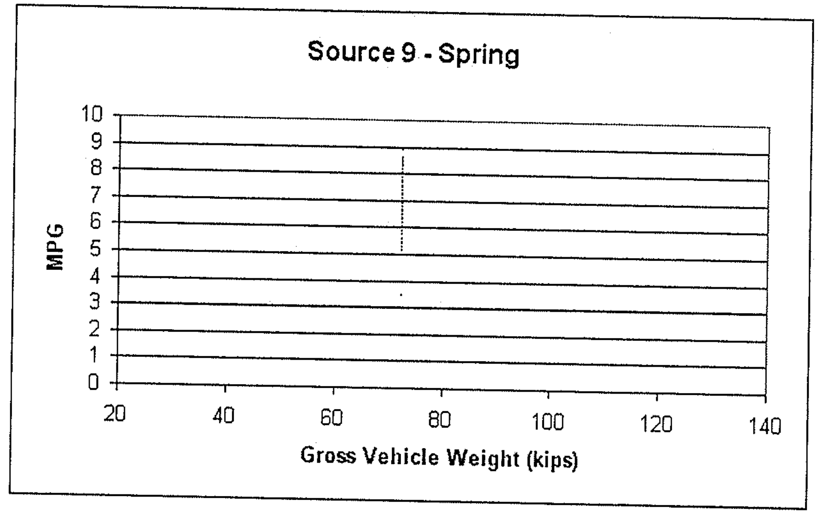
TMT (000,000's) = 0.587
ImpGallons (000's) = 71.5 8.21



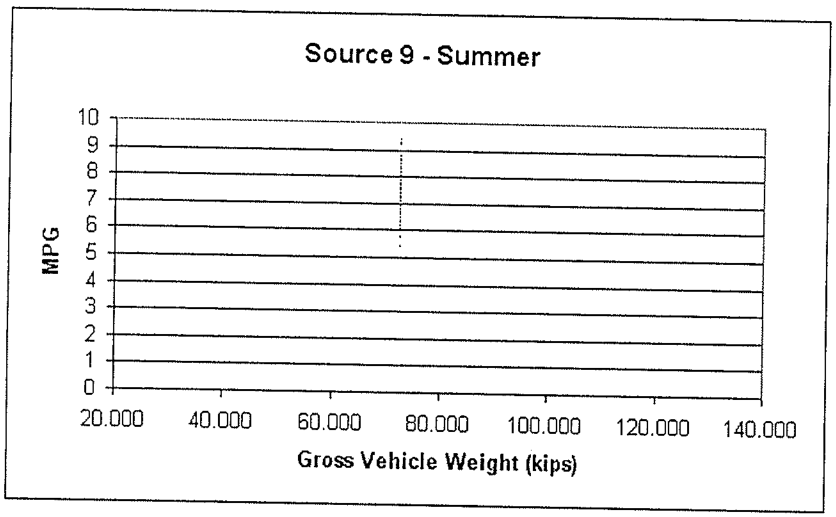
TMT (000,000's) = 0.429
ImpGallons (000's) = 89.1 4.82



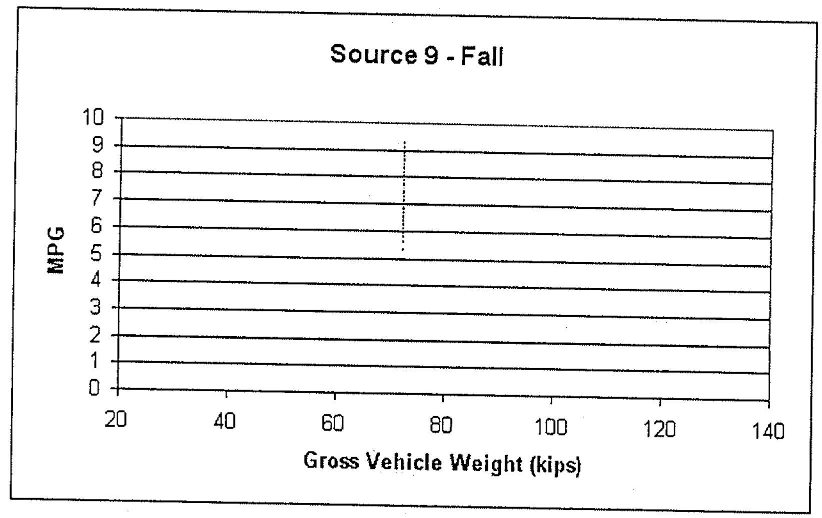
TMT (000,000's) = 410.173
ImpGallons (000's) = 59636.6
6.88



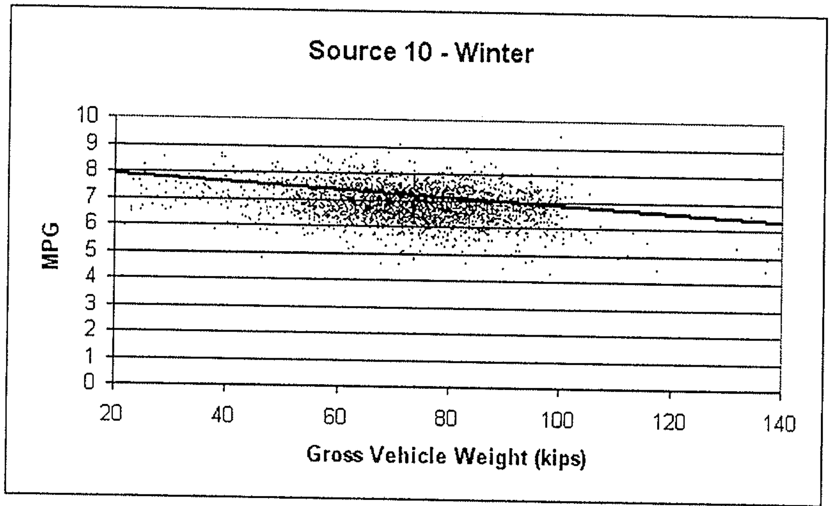
TMT (000,000's) = 531.305
ImpGallons (000's) = 73106.6
7.27



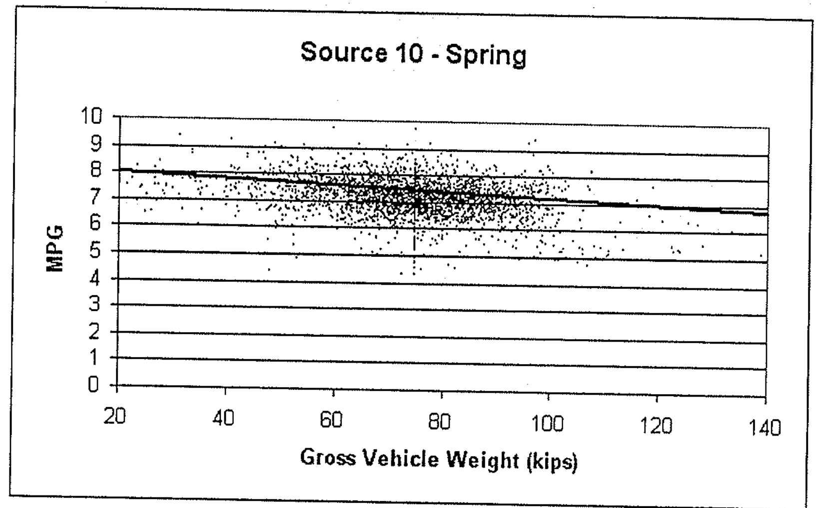
TMT (000,000's) = 271.907
ImpGallons (000's) = 35022.2
7.76



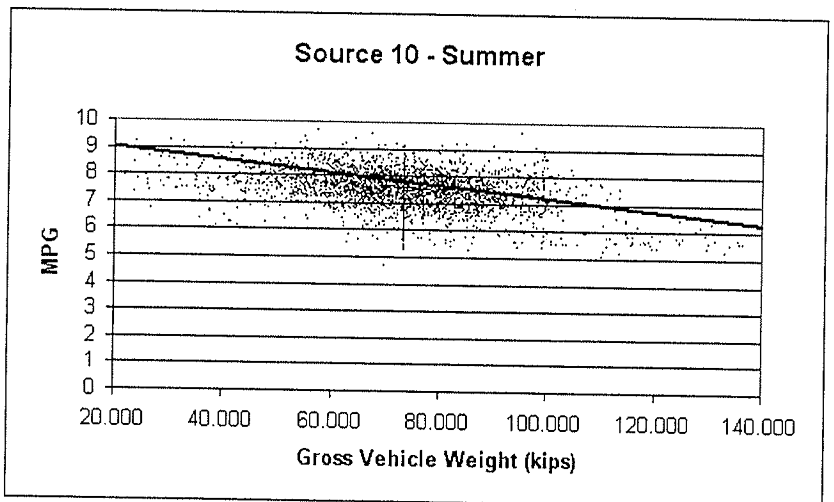
TMT (000,000's) = 405.265
ImpGallons (000's) = 53766.4
7.54



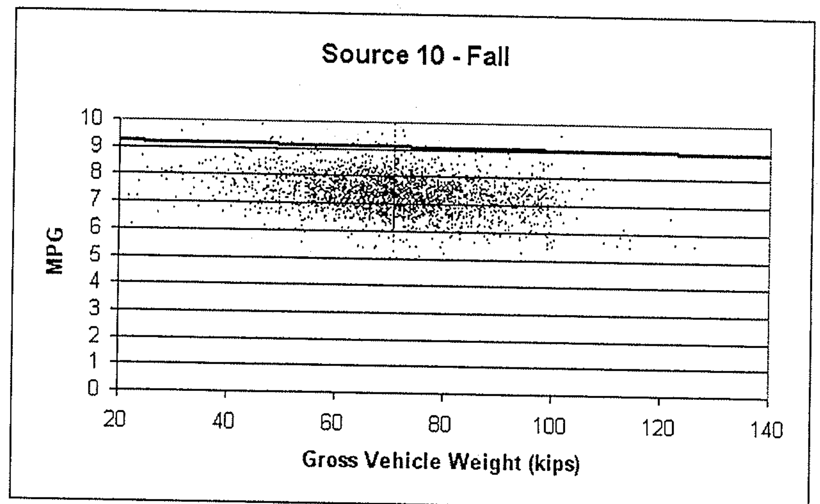
Fuel Consumption (MPG) = 8.149 - 0.0132GVW (kips)
TMT (000,000's) = 15.503
ImpGallons (000's) = 2250.3 6.89



Fuel Consumption (MPG) = 8.277 - 0.0107GVW (kips)
TMT (000,000's) = 16.676
ImpGallons (000's) = 2322.3 7.18



Fuel Consumption (MPG) = 9.457 - 0.0225GVW (kips)
TMT (000,000's) = 16.108
ImpGallons (000's) = 2147.9 7.50



Fuel Consumption (MPG) = 9.273 - 0.0024GVW (kips)
TMT (000,000's) = 12.733
ImpGallons (000's) = 1722.8 7.39

APPENDIX E

AADTT is determined for those truck configurations considered in the research by multiplying each segment AADTT by the percentage of tractor trailerse in the entire fleet.

Truck Sequence	Segment Length (km)	AADTT	AADTT Tractor Trailers	AADTT 3S-2	AADTT 3S-3	8-Bs	Other doubles
				Percent	Percent	Percent	Percent
919.00	14.80						
Two-way		2290.00	1946.50	58.82	22.35	14.12	4.71
EB							
WB							
920.00	37.30						
Two-way		1950.00	1657.50	58.82	22.35	14.12	4.71
EB							
WB							
921.00	13.10						
Two-way		2060.00	1751.00	58.82	22.35	14.12	4.71
EB							
WB							

AADTT by truck configuration is determined by multiplying the relative fleet mix and the AADTT for each truck sequence.

Truck Sequence	AADTT 3S-2	AADTT 3S-3	8-Bs	Other doubles	Sum AADTT
	Actual	Actual	Actual	Actual	
919.00					
Two-way	1145.00	435.10	274.80	91.60	1946.50
EB					
WB					
920.00					
Two-way	975.00	370.50	234.00	78.00	1657.50
EB					
WB					
921.00					
	1030.00	391.40	247.20	82.40	1751.00

TKT per day is determined by multiplying each segment length with the AADTT for each considered truck configuration.

Truck Sequence	TKT per Day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	8473.00	3219.74	2033.52	677.84
WB	8473.00	3219.74	2033.52	677.84
920.00				
Two-way				
EB	18183.75	6909.83	4364.10	1454.70
WB	18183.75	6909.83	4364.10	1454.70
921.00				
Two-way				
EB	6746.50	2563.67	1619.16	539.72
WB	6746.50	2563.67	1619.16	539.72

Gross vehicle weight, GVW, is determined using data collected at the Headingly weigh scale.

Truck Sequence	Operating GVW			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	26.90	32.60	52.90	46.40
WB	26.60	32.30	39.30	46.40
920.00				
Two-way				
EB	26.90	32.60	52.90	46.40
WB	26.60	32.30	39.30	46.40
921.00				
Two-way				
EB	26.90	32.60	52.90	46.40
WB	26.60	32.30	39.30	46.40

Rolling gross tonne kilometres per day is determined by multiplying GVW and tkt.

Truck Sequence	Rolling Gross Tonne Kilometres / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	227923.70	104963.52	107573.21	31451.78
WB	225381.80	103997.60	79917.34	31451.78
920.00				
Two-way				
EB	489142.88	225260.30	230860.89	67498.08
WB	483687.75	223187.35	171509.13	67498.08
921.00				
Two-way				
EB	181480.85	83575.64	85653.56	25043.01
WB	179456.90	82806.54	63632.99	25043.01

Tare weight is determined from data collected at the Headingly weight scale.

Truck Sequence	Tare Weight			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	15.50	16.50	19.10	17.70
WB	15.50	16.50	19.10	17.70
920.00				
Two-way				
EB	15.50	16.50	19.10	17.70
WB	15.50	16.50	19.10	17.70
921.00				
Two-way				
EB	15.50	16.50	19.10	17.70
WB	15.50	16.50	19.10	17.70

Rolling tare tonne km per day is determined by multiplying tkt and tare weight.

Truck Sequence	Rolling Tare Tonne Km / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	131331.50	53125.71	38840.23	11997.77
WB	131331.50	53125.71	38840.23	11997.77
920.00				
Two-way				
EB	281848.13	114012.11	83354.31	25748.19
WB	281848.13	114012.11	83354.31	25748.19
921.00				
Two-way				
EB	104570.75	42300.56	30925.96	9553.04
WB	104570.75	42300.56	30925.96	9553.04

Payload (measured by weight) is derived by subtracting tare weight from GVW.

Truck Sequence	Payload (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	11.40	16.10	33.80	28.70
WB	11.10	15.80	20.20	28.70
920.00				
Two-way				
EB	11.40	16.10	33.80	28.70
WB	11.10	15.80	20.20	28.70
921.00				
Two-way				
EB	11.40	16.10	33.80	28.70
WB	11.10	15.80	20.20	28.70

Rolling payload tonne km per day is determined by multiplying payload and tkt.

Truck Sequence	Rolling Payload Tonne Km / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	96592.20	51837.81	68732.98	19454.01
WB	94050.30	50871.89	41077.10	19454.01
920.00				
Two-way				
EB	207294.75	111248.18	147506.58	41749.89
WB	201839.63	109175.24	88154.82	41749.89
921.00				
Two-way				
EB	76910.10	41275.09	54727.61	15489.96
WB	74886.15	40505.99	32707.03	15489.96

Fuel consumption rate is derived from the fuel consumption relationships developed in Chapter 4

Truck Sequence	Fuel Consumption Rate (Annual) (in km/L)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	2.72	2.56	2.00	2.18
WB	2.73	2.57	2.38	2.18
920.00				
Two-way				
EB	2.72	2.56	2.00	2.18
WB	2.73	2.57	2.38	2.18
921.00				
Two-way				
EB	2.72	2.56	2.00	2.18
WB	2.73	2.57	2.38	2.18

Fuel use per day is determined by dividing tkt by the fuel consumption rate.

Truck Sequence	Fuel Used (L / day)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	3114.87	1256.87	1018.09	311.21
WB	3105.35	1252.79	856.05	311.21
920.00				
Two-way				
EB	6684.76	2697.34	2184.91	667.88
WB	6664.33	2688.59	1837.16	667.88
921.00				
Two-way				
EB	2480.17	1000.76	810.64	247.80
WB	2472.59	997.51	681.62	247.80

Fuel use per year is determined by multiplying the daily fuel use value by 365 days per year.

Truck Sequence	Fuel Used (L / year)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	1136926.60	458756.27	371604.20	113591.60
WB	1133451.47	457267.57	312459.40	113591.60
920.00				
Two-way				
EB	2439937.34	984528.41	797492.97	243776.86
WB	2432479.42	981333.56	670563.39	243776.86
921.00				
Two-way				
EB	905260.87	365277.84	295884.31	90445.62
WB	902493.84	364092.49	248791.14	90445.62

This table represents the emission factors used to estimate the greenhouse gas emission production.

Emission Factors	
Emission	g/L
CO2	2730
CH4	0.13
N2O	0.08

Carbon dioxide emissions are estimated by multiplying the fuel use per year by the emission factor for carbon dioxide in diesel.

Truck Sequence	CO2 Emissions / year (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	3103.81	1252.40	1014.48	310.11
WB	3094.32	1248.34	853.01	310.11
920.00				
Two-way				
EB	6661.03	2687.76	2177.16	665.51
WB	6640.67	2679.04	1830.64	665.51
921.00				
Two-way				
EB	2471.36	997.21	807.76	246.92
WB	2463.81	993.97	679.20	246.92

Methane emissions are estimated by multiplying the fuel use per year by the emission factor for methane in diesel.

Truck Sequence	CH4 Emissions / year (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	0.148	0.060	0.048	0.015
WB	0.147	0.059	0.041	0.015
920.00				
Two-way				
EB	0.317	0.128	0.104	0.032
WB	0.316	0.128	0.087	0.032
921.00				
Two-way				
EB	0.118	0.047	0.038	0.012
WB	0.117	0.047	0.032	0.012

Nitrous oxide emissions are estimated by multiplying the fuel use per year by the emission factor for nitrous oxide in diesel.

Truck Sequence	N2O Emissions / year (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	0.091	0.037	0.030	0.009
WB	0.091	0.037	0.025	0.009
920.00				
Two-way				
EB	0.195	0.079	0.064	0.020
WB	0.195	0.079	0.054	0.020
921.00				
Two-way				
EB	0.072	0.029	0.024	0.007
WB	0.072	0.029	0.020	0.007

AADTT is determined for those truck configurations considered in the research by multiplying each segment AADTT by the percentage of tractor trailerse in the entire fleet.

Truck Sequence	Segment Length (km)	AADTT	AADTT Tractor Trailers	AADTT 3S-2	AADTT 3S-3	8-Bs	Other doubles
				Percent	Percent	Percent	Percent
919.00	14.80						
Two-way		1540.00	1386.00	85.56	1.11	0.00	13.33
EB							
WB							
920.00	37.30						
Two-way		1310.00	1179.00	85.56	1.11	0.00	13.33
EB							
WB							
921.00	13.10						
Two-way		1385.00	1246.50	85.56	1.11	0.00	13.33
EB							
WB							

AADTT by truck configuration is determined by multiplying the relative fleet mix and the AADTT for each truck sequence.

Truck Sequence	AADTT 3S-2	AADTT 3S	8-Bs	Other doubles	Sum AADTT
	Actual	Actual	Actual	Actual	
919.00					
Two-way	1185.80	15.40		184.80	1386.00
EB					
WB					
920.00					
Two-way	1008.70	13.10		157.20	1179.00
EB					
WB					
921.00					
Two-way	1066.45	13.85		166.20	1246.50
EB					
WB					

TKT per day is determined by multiplying each segment length with the AADTT for each considered truck configuration.

Truck Sequence	TKT per Day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	8774.92	113.96		1367.52
WB	8774.92	113.96		1367.52
920.00				
Two-way				
EB	18812.26	244.32		2931.78
WB	18812.26	244.32		2931.78
921.00				
Two-way				
EB	6985.25	90.72		1088.61
WB	6985.25	90.72		1088.61

Gross vehicle weight, GVW, is determined using data collected at the Headingly weigh scale.

Truck Sequence	Operating GVW			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	30.20	30.20		46.40
WB	30.20	30.20		46.40
920.00				
Two-way				
EB	30.20	30.20		46.40
WB	30.20	30.20		46.40
921.00				
Two-way				
EB	30.20	30.20		46.40
WB	30.20	30.20		46.40

Rolling gross tonne kilometres per day is determined by multiplying GVW and tkt.

Truck Sequence	Rolling Gross Tonne Km / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	265002.58	3441.59		63452.93
WB	265002.58	3441.59		63452.93
920.00				
Two-way				
EB	568130.10	7378.31		136034.59
WB	568130.10	7378.31		136034.59
921.00				
Two-way				
EB	210954.47	2739.67		50511.50
WB	210954.47	2739.67		50511.50

Tare weight is determined from data collected at the Headingly weight scale.

Truck Sequence	Tare Weight (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	14.30	18.60		18.40
WB	14.30	18.60		18.40
920.00				
Two-way				
EB	14.30	18.60		18.40
WB	14.30	18.60		18.40
921.00				
Two-way				
EB	14.30	18.60		18.40
WB	14.30	18.60		18.40

Rolling tare tonne km per day is determined by multiplying tkt and tare weight.

Truck Sequence	Rolling Tare Tonne Km / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	125481.36	2119.66		25162.37
WB	125481.36	2119.66		25162.37
920.00				
Two-way				
EB	269015.25	4544.26		53944.75
WB	269015.25	4544.26		53944.75
921.00				
Two-way				
EB	99889.04	1687.35		20030.42
WB	99889.04	1687.35		20030.42

Payload (measured by weight) is derived by subtracting tare weight from GVW.

Truck Sequence	Payload (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	15.90	11.60		28.00
WB	15.90	11.60		28.00
920.00				
Two-way				
EB	15.90	11.60		28.00
WB	15.90	11.60		28.00
921.00				
Two-way				
EB	15.90	11.60		28.00
WB	15.90	11.60		28.00

Rolling payload tonne km per day is determined by multiplying payload and tkt.

Truck Sequence	Rolling Payload Tonne Km / day			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	139521.23	1321.94		38290.56
WB	139521.23	1321.94		38290.56
920.00				
Two-way				
EB	299114.85	2834.05		82089.84
WB	299114.85	2834.05		82089.84
921.00				
Two-way				
EB	111065.44	1052.32		30481.08
WB	111065.44	1052.32		30481.08

Fuel consumption rate is derived from the fuel consumption relationships developed by Nix and shown in Chapter 4

Truck Sequence	Fuel Consumption Rate (Annual) (in km/L)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	2.02	2.02		1.69
WB	2.02	2.02		1.69
920.00				
Two-way				
EB	2.02	2.02		1.69
WB	2.02	2.02		1.69
921.00				
Two-way				
EB	2.02	2.02		1.69
WB	2.02	2.02		1.69

Fuel use per day is determined by dividing tkt by the fuel consumption rate.

Truck Sequence	Fuel Used (L / day)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	4333.59	56.28		809.41
WB	4333.59	56.28		809.41
920.00				
Two-way				
EB	9290.64	120.66		1735.27
WB	9290.64	120.66		1735.27
921.00				
Two-way				
EB	3449.74	44.80		644.33
WB	3449.74	44.80		644.33

Fuel use per year is determined by multiplying the daily fuel use value by 365 days per year.

Truck Sequence	Fuel Used (L / year)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	1581761.60	20542.36		295435.86
WB	1581761.60	20542.36		295435.86
920.00				
Two-way				
EB	3391085.35	44040.07		633374.98
WB	3391085.35	44040.07		633374.98
921.00				
Two-way				
EB	1259156.36	16352.68		235180.79
WB	1259156.36	16352.68		235180.79

This table represents the emission factors used to estimate the greenhouse gas emission production.

Emission Factors	
Emission	g/L
CO2	2730
CH4	0.13
N2O	0.08

Carbon dioxide emissions are estimated by multiplying the fuel use per year by the emission factor for carbon dioxide in diesel.

Truck Sequence	CO_2 Emissions (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	4318.21	56.08		806.54
WB	4318.21	56.08		806.54
920.00				
Two-way				
EB	9257.66	120.23		1729.11
WB	9257.66	120.23		1729.11
921.00				
Two-way				
EB	3437.50	44.64		642.04
WB	3437.50	44.64		642.04

Methane emissions are estimated by multiplying the fuel use per year by the emission factor for methane in diesel.

Truck Sequence	CH_4 Emissions (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	0.206	0.003		0.038
WB	0.206	0.003		0.038
920.00				
Two-way				
EB	0.441	0.006		0.082
WB	0.441	0.006		0.082
921.00				
Two-way				
EB	0.164	0.002		0.031
WB	0.164	0.002		0.031

Nitrous oxide emissions are estimated by multiplying the fuel use per year by the emission factor for nitrous oxide in diesel.

Truck Sequence	N2O Emissions (tonnes)			
	3S-2	3S-3	B-train	Other Doubles
919.00				
Two-way				
EB	0.127	0.002		0.024
WB	0.127	0.002		0.024
920.00				
Two-way				
EB	0.271	0.004		0.051
WB	0.271	0.004		0.051
921.00				
Two-way				
EB	0.101	0.001		0.019
WB	0.101	0.001		0.019

APPENDIX F

Table B.2: 2002 Monthly Distribution Factors (MADTT/AADTT) for Trucks (Classes 5-13) at the 33 AVC Stations

Hwy No.	Station No.	AADTT	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	55	2,060	0.80	0.92	0.94	1.03	1.11	1.11	1.10	1.08	1.12	1.07	0.90	0.83
	61*	920	0.84	0.90	0.97	0.94	1.04	1.21	1.18	1.07	1.06	1.03	0.99	0.79
	62*	1,280	0.89	0.93	0.93	1.04	1.10	1.05	1.08	1.07	1.02	1.04	1.02	0.84
	65*	1,580	0.86	0.90	0.91	1.01	1.11	1.03	1.04	1.03	1.08	1.11	1.04	0.87
2	11	220	0.83	0.92	0.88	0.96	1.04	1.12	1.01	1.06	1.31	1.15	0.99	0.75
	66	160	0.80	0.82	0.76	0.95	1.34	1.01	0.98	1.11	1.10	1.48	1.00	0.69
	92	140	0.80	0.88	0.78	0.85	1.71	1.01	0.94	1.01	1.11	1.14	1.09	0.70
3	15	160	0.74	0.89	0.85	1.16	1.15	1.29	1.05	0.91	1.06	1.10	1.06	0.79
	51	280	0.78	0.80	0.84	1.02	1.03	1.15	1.13	1.07	1.22	1.22	1.03	0.82
5	49	200	0.83	0.88	0.87	0.86	1.21	1.13	1.10	1.01	1.04	1.20	1.07	0.83
	54	200	0.70	0.77	0.80	1.04	1.48	1.10	0.81	0.87	1.39	1.59	0.90	0.67
6	82	100	0.84	1.02	1.16	0.78	0.85	1.25	1.23	1.12	1.13	0.98	0.98	0.87
	88	260	0.85	0.91	0.94	0.69	0.84	1.28	1.14	1.11	1.17	1.20	1.07	0.83
10	21	160	0.96	0.76	0.77	0.97	1.49	1.12	0.89	0.99	1.11	1.12	1.05	0.87
	24	310	0.65	0.66	0.84	1.02	1.50	1.08	0.99	1.09	1.12	1.34	1.03	0.73
	50	140	1.19	1.40	1.07	0.64	0.91	0.81	0.88	0.89	0.97	1.07	1.35	0.92
	52	180	1.21	1.41	1.16	0.58	0.81	0.67	1.07	0.95	1.20	1.14	1.14	0.75
	84	100	0.77	0.94	0.89	0.97	1.28	1.07	1.10	1.04	1.04	1.08	1.06	0.81
	90	140	1.26	1.41	1.12	0.38	0.44	1.39	1.26	1.11	1.03	1.11	0.89	0.76
	98	110	0.68	0.97	0.80	0.74	0.82	1.45	1.26	0.98	1.34	1.33	1.05	0.72
12	10	140	0.87	0.97	0.93	0.85	1.05	1.16	1.07	1.07	1.22	1.04	1.00	0.83
13	81	360	0.84	0.82	0.79	1.04	1.45	1.03	0.98	0.95	1.18	1.17	1.00	0.79
14	87	360	0.80	0.90	0.94	1.12	1.16	1.12	1.07	1.09	1.13	1.15	0.87	0.67
16	43	490	0.91	0.94	0.94	1.00	1.16	1.10	1.06	1.04	1.04	1.02	1.01	0.81
	46	600	0.79	0.94	0.95	1.05	1.20	1.15	1.09	1.09	1.14	0.94	0.95	0.73
50	83	60	0.78	0.79	0.74	0.76	1.20	1.45	1.47	1.03	1.27	1.17	0.87	0.53
59	89	320	0.81	0.87	0.79	0.92	1.14	1.09	1.08	1.00	1.15	1.19	1.10	0.87
75	63*	940	0.91	0.93	0.95	1.09	1.08	1.10	1.01	1.05	1.11	1.00	1.00	0.78
83	53	140	1.10	1.26	0.91	0.70	1.16	0.88	0.92	0.95	1.12	1.19	1.05	0.78
	91	110	0.86	0.89	0.82	0.95	1.18	1.02	0.93	0.98	1.27	1.25	1.02	0.91
100	64	1,070	0.74	0.77	0.78	0.90	1.06	1.13	1.19	1.12	1.36	1.35	0.92	0.72
101	86	870	0.79	0.85	0.88	0.91	0.99	1.04	1.16	1.13	1.31	1.23	0.96	0.77
110	85	450	0.75	0.76	0.72	0.85	1.46	0.96	0.99	1.09	1.20	1.46	1.04	0.75

AADTT and factors are calculated based on AVC data only

Source: Tang, D.

Table 6.2: 2002 Classification Mix at AVC Stations

Hwy No.	Station	Mix of Total Traffic (Percentage)												
		Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13
1	55	0.2	64.2	19.2	0.3	0.9	0.8	0.0	0.9	8.1	3.0	0.2	0.2	2.2
	61	0.2	60.8	19.0	0.3	0.7	0.2	0.6	1.1	10.2	3.9	0.1	0.2	2.8
	62	0.2	51.9	16.9	0.3	0.8	0.7	0.0	1.6	15.6	6.4	0.2	0.4	5.0
	65	0.0	59.7	15.9	0.3	1.0	0.9	0.0	0.6	12.8	5.0	0.0	0.2	3.5
	S1	0.2	43.6	14.6	0.3	0.8	0.9	0.1	1.2	21.6	8.9	0.6	0.6	6.7
	S17^	2.9	55.3	18.6	0.3	1.3	2.6	0.1	2.4	8.9	3.9	0.3	0.3	3.2
2	11	0.1	66.5	20.9	0.1	1.0	1.4	0.0	1.0	4.1	2.1	0.0	0.1	2.7
	66	0.1	63.7	25.7	0.1	0.8	0.8	0.0	0.9	3.9	1.4	0.0	0.0	2.4
	92	0.3	59.9	27.4	0.1	1.0	1.2	0.0	1.2	4.0	1.4	0.0	0.0	3.4
3	15	0.2	63.8	27.0	0.1	0.8	1.6	0.0	0.7	3.4	1.3	0.0	0.0	1.0
	51	0.1	72.4	20.6	0.1	1.1	1.1	0.0	0.3	2.4	1.1	0.0	0.0	0.7
5	49	0.1	60.1	29.3	0.2	0.8	1.0	0.0	0.5	3.2	1.4	0.1	0.0	3.3
	54	0.1	60.8	30.2	0.1	0.8	1.2	0.0	0.5	2.8	1.5	0.1	0.0	1.9
6	82	0.1	43.5	41.8	1.0	1.2	1.1	0.1	0.9	4.8	1.5	0.1	0.0	4.1
	88	0.1	64.0	25.3	0.3	0.8	0.6	0.0	1.4	3.4	1.4	0.1	0.1	2.5
10	21	0.3	61.5	24.6	0.1	0.8	1.5	0.1	0.9	5.3	2.1	0.1	0.0	2.6
	24	0.2	67.5	24.8	0.6	0.8	0.9	0.0	0.7	1.9	1.0	0.0	0.0	1.5
	50	0.1	48.9	34.2	0.4	1.2	1.3	0.0	1.1	2.8	2.7	0.0	0.0	7.2
	52	0.1	46.9	37.3	0.2	1.2	1.2	0.0	0.5	2.3	1.9	0.1	0.0	8.3
	84	0.1	54.2	31.4	0.3	1.0	1.4	0.0	1.1	3.2	1.3	0.1	0.0	5.7
	90	0.1	58.0	34.6	0.2	1.0	0.6	0.0	1.1	1.1	0.5	0.0	0.0	2.7
	95	0.1	66.1	27.0	0.1	0.7	0.6	0.0	0.6	2.5	0.9	0.0	0.0	1.4
	98	0.1	49.5	38.2	0.4	1.1	0.6	0.0	1.5	2.9	1.2	0.0	0.0	4.4
12	10	0.1	58.1	25.7	0.6	0.8	1.2	0.0	1.4	10.7	1.1	0.1	0.0	0.2
13	81	0.2	45.3	22.0	0.0	1.2	1.5	0.1	1.6	16.6	5.6	0.1	0.0	5.8
14	87	0.3	60.3	18.8	0.4	1.3	1.7	0.1	1.9	10.0	2.3	0.1	0.1	2.8
16	43	0.2	54.1	19.0	0.2	1.1	1.1	0.1	1.2	12.4	4.6	0.2	0.3	5.4
	46	0.2	58.6	23.1	0.2	0.9	0.9	0.0	1.1	8.5	2.7	0.1	0.2	3.5
	S16	0.1	44.8	19.5	0.2	0.8	1.2	0.3	4.4	12.2	6.2	1.3	0.7	8.2
50	83	0.1	62.2	32.1	0.0	0.9	1.1	0.0	0.3	1.0	0.5	0.0	0.0	1.8
59	78	0.1	76.4	19.7	0.0	0.5	0.7	0.0	0.5	1.3	0.4	0.0	0.0	0.5
	89	0.1	71.4	20.8	0.1	1.0	1.4	0.0	0.5	3.2	1.1	0.0	0.0	0.4
75	63	0.2	62.7	18.5	0.3	0.8	0.8	0.1	1.0	12.2	1.6	0.4	0.1	1.2
83	53	0.1	54.5	36.2	0.0	0.9	1.1	0.0	0.5	1.2	1.1	0.1	0.0	4.3
	91	0.1	49.6	32.5	0.0	0.9	1.6	0.0	2.0	6.4	3.5	0.1	0.1	3.2
100	64	0.1	64.2	18.9	0.0	0.7	1.7	0.1	0.7	8.3	3.2	0.1	0.1	1.9
101	86	0.2	60.5	19.7	0.0	0.9	2.4	0.0	0.7	10.6	2.9	0.3	0.1	1.8
110	85	0.2	62.0	22.3	0.0	1.1	2.4	0.0	0.4	4.6	3.0	0.0	0.0	3.9

^ *classification mix is calculated based on 2-week data in 2001*

Source: Tang, D.

APPENDIX G

Confidential Survey: Fuel Usage and Driver Training
UMTIG – University of Manitoba Transport Information Group

To better understand fuel consumption as it relates to Manitoba trucking practices, isolating all possible relationships is essential. This survey is designed to capture the priority areas of Manitoba trucking companies and act as the backbone of the fuel consumption data as has been provided.
Your time spent completing this form is greatly appreciated.

Does your company provide the following:

1. Driver training related to fuel consumption?

____

2. Driver training to reduce idling?

____

3. Driver consultations related to fuel consumed?

____

4. Driver consultations related to time spent idling?

____

5. Access to 'fuel efficiency' educational resources, such as FleetSmart?

____

6. Encourage drivers to limit speed, (what speed)?

____

7. Cap driver speed (what speed)?

____

8. What kind of winter grade fuel is typically used?

____

9. What types of emission reduction technology do you use on most trucks?

____

10. What types of emission reduction technology do you use on your best-equipped trucks?

____

11. Does your company own any tractors that are compliant to October 2002 EGR regulations? Does their fuel consumption match pre-October 2002 trucks?

____

____

12. On average, how many years' experience do your truck drivers have?

____

Which of the previous 12 elements do you feel contributes the most significantly to fuel consumption levels?

____

____

Further comments,

____

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