ASPECTS OF IMPACT OF INTELLIGENT TRANSPORTATION SYSTEMS ON MODAL SPLIT OF SURFACE FREIGHT CARRIERS

BY

VISHWESHWAR MUMMIDI

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

MASTER OF SCIENCE

Department of Civil and Geological Engineering
University of Manitoba
Winnipeg, Manitoba

0-612-23435-5

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

COPYRIGHT PERMISSION

ASPECTS OF IMPACT OF INTELLIGENT TRANSPORTATION SYSTEMS ON MODAL SPLIT OF SURFACE FREIGHT CARRIERS

BY

VISHWESHWAR MUMMIDI

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

MASTER OF SCIENCE

Abstract

The objectives of the thesis are: (1) to demonstrate the possible capacity gains in terms of passenger cars when advanced vehicle control system is implemented and speculate its probable implications on freight transportation by trucks, (2) to develop mathematical freight demand models for the railway and trucking industry using the most recent data available, and (3) to propose a methodology to modify the demand models to capture the effects of *Intelligent Transportation Systems* (ITS) technologies on the modal split. Accordingly, probable automated highway scenarios are discussed and passenger car capacity gains are estimated for one of the automated highway scenario. The possible effects on freight movement due to this increased capacity is discussed. Statistical modal split models for three commodity groups are developed for the present highway infrastructure. The models developed incorporate the level of service (LOS) characteristics. A methodology is developed from the concepts of fuzzy logic, fuzzy expert systems, and approximate reasoning to capture expert opinions regarding changes in LOS characteristics in crisp terms and incorporate it in the model developed earlier. The methodology proposed may be utilized as a decision support system by the transportation planners, especially, when studying the market potential of new products.

Acknowledgments

I am indebted to my advisor Dr. A.H. Soliman who using determination, motivation and strong foot managed me to get through my Master's Degree. I am especially grateful to the encouragement and freedom he gave me in exploring subject area. Thanks to Mr. Lewis Sabounghi for his valuable guidance from time to time. Thanks to Dr. C. R. Bector and Mr. A. Clayton for their comments. Thanks to my parents for their patience and understanding during my long absence from home. Thanks also to my brother for his encouragement from time to time. Finally, thanks to my friends Ram Kishan and Radha Krishna for their support when I most needed.

> "The reasonable man adapts himself to the world; the unreasonable one persists in trying to adapt the world to himself. Therefore all progress depends on the unreasonable man." – George Bernard Shaw

Table of Contents

List of Tables

List of Figures

Nomenclature

Keywords

ADVANCED TECHNOLOGY

COMMERCIAL VEHICLE OPERATION

COMMODITY GROUPS

DECISION SUPPORT SYSTEMS

EXPERT SYSTEMS

FREIGHT TRANSPORTATION

FUZZY FORECASTING

FUZZY LOGIC

FUZZY EXPERT SYSTEM

MODAL SPLIT

TRUCK AND RAIL TRANSPORTATION

Abbrevations

ATIS	Advanced Traffic Information Systems
ATMS	Advanced Traffic Management Systems
ACS	Automated Clearance Sensing
AVCS	Advanced Vehicle Control Systems
AVI	Advanced Vehicle Identification
AVL	Advanced Vehicle Location
CMI	"Crude Materials Inedible" commodity group
CN	Canadian National Railways
CP	Canadian Pacific Railways
CVO	Commercial Vehicle Operations
CVOO	Commercial Vehicle Operator or Owner
DR	Dead Reckoning
EPI	"End Products Inedible" commodity group
FFB&T	"Food, Feed, Beverages and Tobacco" commodity group
GPS	Global Positioning System
ITS	Intelligent Transportation Systems
IVHS	Intelligent Vehicle Highway Systems
LOS	Level of Service
SAS	Statistical Analysis System
WIM	Weigh in Motion

Chapter 1

Introduction

1.1 Objective

The research objective is to enhance econometric models developed to capture technological changes occurring in transportation industry. The market potential of new technologies and their possible effects on market trends are difficult to quantify. This aspect has been recognized long before and Delphi Research Technique based on the concept of 'think tanks' was invented to predict success of new product introductions. Few drawbacks were recognized in the application of Delphi Research Technique namely: (1) an excessive time requirement for opinion refinement, (2) the lack of bias correction, and (3) lack of flexibility in mathematical representation of the opinions. The author proposes a methodology which works on the concept of utilizing 'think tanks' without the above mentioned drawbacks of Delphi Research Technique specifically targeting Intelligent Transportation Systems technologies.

1.2 Scope of the Research

The study is restricted to studying the freight transportation between provinces of Québec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia. The questionnaire prepared studies the effects of specific ITS technologies, namely: (1) Automated Vehicle Identification (AVI), (2) Automated Vehicle Location (AVL) and (3) Weigh-In-Motion (WIM). The methodology proposed has the flexibility to incorporate and represent in mathematical fashion several shades of expert opinions. However, there is room for fine tuning it further with actual field implementation. Application of the methodology developed was not attempted.

1.3 List of Publications

Major findings during the course of this research have been presented in conferences or submitted for publication. In 1995 a paper entitled "Optimal Highway Capacity with Advanced Vehicle Control Systems" was presented at the technical sessions of the annual conference of the Canadian Society of Civil Engineering (CSCE). This paper was published by CSCE in the conference proceedings.

In 1996, two papers titled "Modifying the Modal Split Model to Capture Technology Impact" and "Determination of Expert Factor for Transportation Professionals Using the Concepts of Fuzzy Logic and Approximate Reasoning" were presented at the first transportation conference of the Canadian Society of Civil Engineering (CSCE). These papers were published by CSCE in the conference proceedings.

Also, in 1996 a paper entitled "Forecasting Using Expert Opinion the Level of Service Improvement with the Implementation of Advanced Technologies" was presented at the Computer Applications in Railways Conference in Berlin, Germany. This paper was published in special edition book of Computer Applications in Railways.

In addition to the above two other papers were completed dealing with other transportation related aspects and were well received in transportation specialty conferences and journals.

1.4 Organization

The thesis is structured as follows,

Chapter 2: *Review*

This chapter reviews the pertinent previous research concerning freight transportation modeling. It describes the basics of Fuzzy Logic, Fuzzy Expert Systems, and related concepts. Also included is a brief review of various ITS technologies, their potential, and, present stage of development.

Chapter 3: *Capacity Gains with Advanced Vehicle Control Systems*

The automated highway capacities are estimated to demonstrate the potential increase in efficiency of present infrastructure with automaton.

Chapter 4: *Data Collection and Analysis*

The data needed for model development and calibration is described. The chapter also presents model development and statistical and pragmatic validation for model aptness.

Chapter 5: *Modeling Expert Opinion Using Approximate Reasoning*

This chapter describes the Fuzzy Expert System technique used to determine improvement seen in LOS by implementing each of the ITS technologies. An enhanced modal split model is also presented in this chapter.

Chapter 6: *Conclusions and Future Work*

Chapter 6 presents the conclusions and recommendations drawn from the research, and suggestions for future research. ■

Chapter 2

Review

This chapter discusses various freight transportation modeling techniques in vogue. A description of each modeling technique with merits and demerits of each technique is presented. An overview of *fuzzy logic* and *expert systems* with emphasis on *fuzzy expert systems* is also presented. Also presented in this chapter is a description of advanced technologies applied in commercial vehicle operations.

2.1 Background Research

Freight transportation modeling has received less attention than passenger transport modeling until recently. Application of demand theory to commodity transport is less extensive than passenger transportation. Extensive data requirements as well as less attention paid to commodity transportation with respect to important policy and planning issues associated with it are the main reasons for limited development of freight transport modeling until few decades ago. This scenario changed rapidly with progresses in data acquisition and amiability of commodity transportation demand for formal analysis. Several studies were conducted in the past three decades on freight transportation modeling, route choice models, and mode choice models. Examples are: Perle (1965), Mathematica (1967-1969), Baumol and Vinod (1970), Rigaux (1971), Sloss (1971), Kullman (1973), Hartwig (1974), Canadian Transport Commission (1976), Boyer (1977), Roberts and Kresge (1977), Turner (1977), Oum (1977-1979), Levin (1978), Freidlaender and Spady (1981), Hashemian (1981), Winston (1981), Hall (1985), Sargious and Tam (1988), Abdelwahab and Sargious (1990) and Gadi and Soliman (1990). ■

2.1.1 Approaches to Demand Analysis

Analysis and modeling of commodity transportation is not a straight forward and easy process. Commodity transport involves many social variables whose exact interaction and influence is difficult to quantify. Commodity transportation is completely controlled by demands of a particular commodity at the point of consumption. This indicates the nature of transportation demand is understood by studying the underlying production and consumption process. The following variables are assumed to exert considerable influence in the commodity demand: economic vitality, surplus and demand for particular commodity, political considerations, modal characteristics, commodity types, social factors. It has to be noted that in commodity transportation the primary motivation is economic optimization of movement of goods. Thus, the goal of demand analysis is to construct a model to include LOS factors. One advantage in understanding commodity movement compared to passenger movement is relatively small fluctuations in demand process, due to possibility of warehousing with respect to commodities.

Kanafani (1983) proposed three approaches to the analysis of commodity transportation demand. The first is Microeconomic approach. In which the assumption is that demand for commodity transportation is derived considering transportation as one of the inputs into the production or the marketing process of the firm. The second approach is that of spatial interaction modeling, which is aggregate in nature. The surpluses and deficits of commodities are located at various points in space, and a process is then postulated whereby flows of commodities will occur from points of excess supply to points of excess demand. The third approach is the macro-economic approach, in which the interrelations between sectors of an economy are analyzed with the help of input-output model.

Winston (1983) classified freight demand models based on the nature of data into aggregate or disaggregate models. Aggregate models are formulated from data collected for a particular mode in a national or regional level and disaggregate models are formulated from data collected from shipper for individual shipment. Disaggregate models appear to be superior to aggregate models in their power to describe the realty more accurately according to Winston (1983). However, disaggregate modeling requires extensive data and can only be applied in a limited manner as opposed to aggregate models. Aggregate models on the other hand are more useful in practice as large-scale analysis of freight flows that are designed for policy analysis or practical prediction according to Anas (1981). ■

2.1.2 Freight Transportation Models

Some of the widely used freight transportation models review is presented in the following sections.

2.1.2.1 Gravity Models

Gravity models are used extensively for predicting commodity flows. The model states that the flow between origin and destination depends on the strength of the attractive forces (production and consumption) and the significance of the frictional factor (such as mode service attributes and/or the distance or cost) between origins and destinations.

The simplest gravity model is,

$$V_{ij}^k = \frac{P_i^k D_j^k F_{ij}^k}{\sum_i D_j^k F_{ij}^k} \tag{2.1}$$

where,

V_{ij}^k = total tons of commodity k produced in region i and shipped to region j

P_i^k = total shipment of commodity k from region i

D_j^k = total demand for commodity k in region j

F_{ij}^k = a friction factor inversely proportional to distance (d_{ij}) between region i and region j.

Gravity models are extensively surveyed and documented in literature by Corrothers (1956) and Olsson (1965). Gravity models have limited value for the microscopic analysis of commodity demands. The models of the type Black proposed are too aggregate to provide more than approximate estimate of total flows between regions. The utility of Gravity models in forecasting or policy analysis is limited. ■

2.1.2.2 Econometric Abstract Mode Models

The Econometric Abstract Mode Model is one type of gravity model based on the hypothesis that the demand for commodity flows between two regions is derived directly from the economic measures of both regions. The origin is the region of excess supply and the destination is the region of excess demand. The name Econometric Abstract Mode model derives from the inclusion of economy measures at origin and destination and the model's capability to include attributes of all modes involved in the transportation system. The econometric abstract mode model was first developed by Quandt and Baumol (1966) to model intercity passenger transportation. As far as freight transportation is considered, Perle (1965) and Mathematica (1967, 1969) proposed models for freight studies analogous to the Quandt and Baumol model. The Perle model was calibrated using data for five commodity groups and nine origin/destination regions in the U.S. The Mathematica model was not calibrated.

Most of the work done utilizing econometric abstract mode models has been intended to study of policy issues and their impacts, and not to generate detailed freight routing predictions. Friedlaender and Spady (1980) applied aggregate econometric models to calculate the competitive equilibrium rate for the purpose of evaluating regulatory reform. They concluded that their model was not accurate in predicting but it was a useful tool in determining competitive equilibrium. This in turn was a useful benchmark for use in policy analysis. Harker (1987) reviewed the econometric approach to freight transportation and remarked *"the major impetus for the development of these models was not to make predictions about freight transportation system, but rather to understand the productions/cost characteristics of the industry."* These models, though not meant for direct use as a predictive tool, are useful in shedding light upon the definition of potential equilibrium industry structures and output vectors.

After careful consideration of the advantages and disadvantages of different models Smith (1974) recommended the use of the abstract mode modeling approach. He wrote that *"in case of poor data, and particularly where the commodity groups are fairly aggregated, the use of one type of gravity model or of an abstract-mode model be the best that can be done [sic]."* ■

2.1.2.3 Optimization Model

The simplest form of optimization in the analysis of commodity flow demands is the classic transportation problem. The origins represents points of excess supply and destination represents points of excess demand. The procedure used to derive the flows is linear programming. The formulation of the model is as follows.

S_i is the excess supply in location i, D_i be the excess demand in the location j. C_{ij} is the transportation cost between i and j per unit of commodity. The linear programming formulation is to find the commodity flow between i and j, X_{ij}, such that the total cost of transportation is minimized.

$$\text{Minimize} \quad C = \sum_i \sum_j c_{ij} X_{ij} \tag{2.2}$$

Subject to:

$$\sum_j X_{ij} \leq S_i \tag{2.3}$$

$$\sum_i X_{ij} \geq D_j \tag{2.4}$$

$$X_{ij} \geq 0 \ \forall \ (i, \ j) \tag{2.5}$$

The linear programming approach to commodity flow analysis has been used extensively in transportation planning, particularly at the macroscopic regional level. However, two major restriction limit the applicability of optimization models. One is that in order to apply the rather simple technique of linear programming, the assumption constant unit transport cost to be made. This could distort the flow estimates. The other limitation of the linear programming technique is the assumption that there is one central decision-making unit that decides on the distribution in the whole system. It is thereby not suitable for small-scale operations who have to adopt ever changing transportation demands. ■

2.1.2.4 Input-Output Models

The ideas of organizing inter-sectoral flows as inputs and outputs dates back to over two centuries, although its formulation as input-output matrices can be credited to Wassily Leontief (1936). The basic structuring of an input-output model begins by identifying the flows of goods and services X_{ij} between sectors of economy, where i is a producing sector and j is a purchasing sector. For a required regional demand, the inputs and outputs of each sector of the economy could be determined. These models in theory could provide information on inter-regional commodity flows and modal split and they have been used for this purpose by Chenery (1953) and (1956), Isard (1951), (1953) and (1960), Leontief and Strout (1963), Polenske (1966) and (1967), Riefter and Tiebout (1970) and Lee (1971).

Specific studies employing Input-Output models indicate their limitations in applying them for long-term prediction. Extensive data requirement and short-term forecasting ability are some of the limitations of this kind of model. ■

2.1.2.5 Market Share Models

This type of modeling technique examines the total imports into a region or countries and the share of that market of different exporting regions or countries. Alternatively, Market Share models are based on examination of a region's exports and share of each of the destinations. These type of models were used by Rigaux (1971) in trying to explain fluctuations in Canadian wheat sales with respect to "distribution", and "competitive" and "smaller-market" effects. These kind of models are not suitable for long term forecasting.

Smith (1974) noted that, *"the Market Share models will provide a practical and convenient approach for short-term forecasting in situations of stable trading patterns. However, these models essentially explain very little and are not capable of coping with fluctuations in commodity flows."* ■

2.1.2.6 Inventory-Theoretic Mode Choice Model

Inventory-Theoretic Mode Choice modeling is based on the principle of profit maximization. A drawback of this model is that an industry may break into the market and experience some losses in the short-run. However, in the longer term the same industry may regain its losses and experience major profit. This drawback of the model is quite evident. Inventory-Theoretic only recognizes short-run profit maximization. The major problem of Inventory-Theoretic mode choice model development is the data requirement. The data requirement problem was mentioned by the authors of Mathematica team who first developed this kind of model. Smith (1973) stated that, *"data collection for calibration is almost impossible for Inventory-Theoretic Mode Choice model for any meaningful utility of these type of models."* ■

2.1.3 Canadian Freight Transportation Studies

2.1.3.1 Canadian Transport Commission Model

In 1976 Canadian Transport Commission (CTC) published its report (No. ESAB-76-16-1) presenting a medium-term forecasting model for the demand for freight transport in Canada.

The model falls within the econometric abstract mode model classification. it is multi-modal in structure, containing three modes, namely: rail, truck, and marine transportation. However, with respect to parameter estimation, this model was only calibrated for rail and marine.

The model considers the demand for commodity g from origin i to destination j for a given mode m at time t and will vary directly with the production of commodity at origin i and the consumption of commodity at destination j. It will vary inversely with the cost of transport between the origin and destination. The formulation of the model is as follows,

$$\begin{aligned} V_{gijmt} &= \alpha_{gijm} + \beta_{gim}\rho_{git} - \bar{\beta}_{gim}C_{git} + \gamma_{gjm}C_{gjm} \\ &\quad -\bar{\gamma}_{gjm}\rho_{gjt} + \delta_{gm}R_{gijmt} + \sum_{\bar{i},\bar{j},\bar{m}} \psi_{gijm}V_{g\bar{i}\bar{j}\bar{m}t} \end{aligned} \tag{2.6}$$

where,

V_{gijmt}	=	demand of transport of commodity g from i to j by mode m at time t
ρ_{git}	=	production of commodity g in zone i during time t
C_{git}	=	consumption of commodity g in zone i during time t
R_{gijmt}	=	cost of transporting commodity g from i to j by mode m at time t
$\sum_{\bar{i},\bar{j},\bar{m}}$	=	$\sum_{g=1}^{G}\sum_{i=1}^{I}\sum_{j=1}^{J} M_{gij}$ = all links that are complementary or competitive.
α,β,$\bar{\beta}$,γ,$\bar{\gamma}$, δ, ψ	=	empirically determined parameters

The collective term $[\beta_{gim}\rho_{git} - \bar{\beta}_{gim}C_{git}]$ represents excess production zone i. Similarly the collective term $[\gamma_{gjm}C_{gjm} - \bar{\gamma}_{gjm}\rho_{gjt}]$ represents excess consumption zone j. The cost component R_{gijmt} is a function of the level of competition between modes. It in turn affects the amount of commodity g moved and the choice of a transport mode.

In terms of model service attributes, the CTC model included only freight rate. Travel time was recommended in this model, but not included in the published model. The CTC model estimated only rail/marine parameters to study modal split. The model was not tested because of large amount of data requirement for the estimation of number of parameters. ■

2.1.3.2 Oum Model

Oum (1979) developed an aggregate freight transportation demand model. This model is an econometric abstract demand-site model. Oum's model assumes that producing firms are profit maximizers and that transportation is a factor in their production processes. Assuming perfect competition in this market, the demand for transportation can be found via *Shepard's Lemma* (derivative property). The demand function in his model relies on the assumed cost function of the producing firm. Oum's general cost function is of the following form,

$$UC_l = C(P_l, Z_l, D_l) \qquad l = 1, 2, 3, ..., L \tag{2.7}$$

where,

UC_l = average freight cost per ton-mile on link l

P_l = $M \times l$ vector of prices of M modes on link l

Z_l = $M \times N$ matrix of quality attributes of service of M modes on link l

D_l = distance of link l in miles.

Data for two freight transportation modes, rail and truck, was obtained from the Canadian Freight Transportation Model (CFTM) data base for the year 1970. Eight different commodity groups representing a wide variety of commodity attributes were used. For each commodity group, the distance of each link, the total tonnage moved by each mode on each link, and the quality of service attributes for each model were obtained. The service attributes employed in this study are the speed and reliability of alternative modes. Average transit time was used to generate "average speed in miles per day" (proportional to the inverse of average transit time) and "reliability" (reliability of transit time determined as the reciprocal of the coefficient of variation in transit time distribution). Rail transit times were obtained from CN and CP for bulk and non-bulk commodities, for actual car movements during October 1970 for CN and March 1971 for CP. For those links with no recorded data, Oum developed regression models to estimate both the average transit time and standard deviation of railway transit time. These models developed have very poor explanatory variables with R^2 values less than 50%.

Oum utilized hypothesis testing to identify which of the three alternative models was best overall. He concluded that speed and reliability do influence the shippers of high-value products, whereas for low-value industrial raw material they do not influence the shippers in making their mode selection. He added for low-value commodities competition between modes is high for short distances, with rail dominating over medium and longer distances. On the other hand, for high-value commodities the competition between the two modes was likely to take place over short and medium distances. ■

2.1.4 Mode Choice

There are many factors that influence users in the process of choosing a freight mode. Some factors weigh more than others, and their relative importance differs from one shipper to another and from one commodity to another. Some of these factors can be quantified and determined while others cannot be done so readily. Knowledge of such factors is necessary because they constitute some of the explanatory variables in the freight model.

Modal level of service attributes are the different characteristics of competing modes which motivate or influence the user to ship his commodity by one mode or another. Cost to the user (rate), door-to-door travel time, distance, service frequency and reliability among other factors are of some relative importance in influencing shippers, receivers and other decision makers. According to study done by Watson *et al.* (1974), in addition to the above factors, such as, weight, accessibility of the shipper and receiver to the mode, packaging requirements, loss and damage for each mode, and special services offered by various carriers also influence modal choice. In examining the factors that influence mode choice decisions of freight shipment in Atlantic Provinces of Canada, Wilson *et al.* (1986) concluded cooperation between shipper and carrier personnel has some influence in the decision to use trucking, and the shipment tracing capability of carriers is one of the important factors influencing the choice of rail. Similar findings were also made in earlier studies by Church (1971) and Turner (1975). A study to identify the effect of different commodity properties and shipping characteristics on modal choice decisions in Canada was conducted by Sargious and Tam (1988). They concluded that travel time and rate affect mode choice, however, the effects of these attributes is very sensitive to the type of commodity and shipping distance. In this research, commodities were grouped under a homogeneous entities for modeling purpose.

Several other studies were conducted on mode choice by shippers over the past two decades. Noteworthy studies were made by, Morton (1972), Rakowski (1973), Breitenbach (1973), Roth (1977) and Hall (1985). It can be concluded from the extensive studies carried out that, cost and travel time are of great importance in determining mode choice and should be included in any freight transportation demand and mode choice modeling process. Shipping distance and commodity type, as discussed in the literature, are also of great important to mode choice selection. The limitation to including other apparently important factors in the modeling development process, as discussed earlier, is principally the requirement for accurate and extensive data. In most cases such data is unavailable. ■

2.2 Fuzzy Systems and Expert Systems

2.2.1 Fuzzy Systems Review

Fuzzy sets are mathematical concept proposed by Prof. L.A. Zadeh in 1965. If there are points of similarity between computers, which are logical machines, and the thinking of people, with their emotions and intuition, there are also differences. If the capabilities of humans and computers could be put together, a superior system would be possible. ■

2.2.1.1 Basics of Fuzzy Theory

Fuzzy theory is a mathematical theory, and what is called *fuzziness* takes in one aspect of uncertainty. Fuzziness is the ambiguity that can be found in the definition of a concept or the meaning of a word. Fuzziness in nature differs from randomness; i.e. they are different aspects of uncertainty. Fuzziness is more of vagueness i.e. clouding of information as opposed to chance of event which typifies probability. An abstract representation of the fuzzy subset of set X is illustrated in Fig. 2.1. The rectangular frame represents set X. The dotted circle is the ambiguous border of what is inside and outside of the circle and is $\tilde{A}$, a fuzzy subset of X. ■

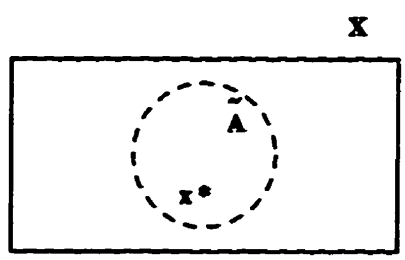

Figure 2.1: Fuzzy Subset $\tilde{A}$

2.2.1.2 Fuzzy Logic

Fuzzy logic is a superset of conventional (Boolean) logic that has been extended to handle the concept of partial truth – truth values between "completely true" and "completely false".

Zadeh says that rather than regarding fuzzy theory as a single theory, we should regard the process of "fuzzification" as a methodology to generalize any specific theory from a crisp (discrete) to a continuous (fuzzy) form. Thus researchers have recently also introduced "fuzzy calculus," "fuzzy differential equations," and so on. ■

2.2.1.3 Fuzzy Sets

Fuzzy set theory defines the degree to which element x of set X is included in a subset. The function that gives the degree to which it is included is called ***membership function***. The degree of inclusion is sometimes called the ***extent*** or ***grade***. The member is the element x. the grade of membership of element x in area $\tilde{A}$ is expressed by,

$$\mu_{\tilde{A}}(x_1) = 1,\ \mu_{\tilde{A}}(x_2) = 0.8$$
$$\mu_{\tilde{A}}(x_3) = 0.3,\ \mu_{\tilde{A}}(x_4) = 0$$

μ is the membership function which gives the membership grade, a value from zero to 1. Fuzzy sets can be utilized to portray linguistic vagueness mathematically. For example, consider a set of heights from 140 cm to 200 cm. A linguistic description like tall, about average, and short can be defined mathematically by membership function. There are two aspects which control fuzzy sets. The first is the horizontal axis, the whole set X. The second is membership function, which illustrates grade. For example, anyone would probably think of the membership function of "about average" as rising in the middle, but the grade of about 150 cm or 170 cm would probably vary subjectively with the person doing the thinking. ■

2.2.1.4 Crisp Sets

The word crisp indicates clearly defined boundaries. Mathematically a ***crisp set*** is defined as a collection of elements or objects $x \in X$ which can be finite, countable, or uncountable. Each element can either belong to or not belong to a set **A**, $\mathbf{A} \subseteq X$. In the above cases, either x can belong to **A**, or not. The differences between crisp and fuzzy sets in terms of membership function can be illustrated as follows.

If E is a crisp subset of X, the function

$$\chi_E(x) = \begin{cases} 1;\ \mathrm{x} \in \mathrm{E} \\ 0;\ \mathrm{x} \notin \mathrm{E} \end{cases} \tag{2.8}$$

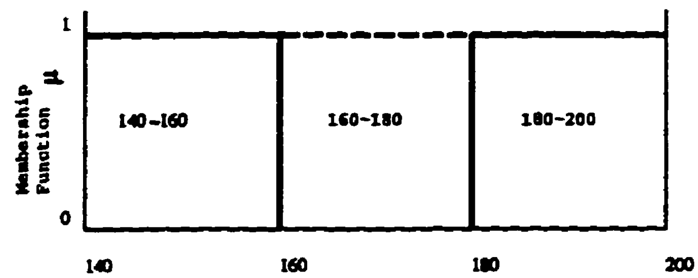

Figure 2.2: Characteristics Functions of Crisp Sets

is called the ***characteristic function*** of E. In other words characteristic function of the crisp set is expressed by

$$\chi_E : X \rightarrow 0, 1$$

and the range of values 0, 1 is one part of the range of values of the membership function of the fuzzy set. In other words, the height from 140 cm to 200 cm are divided into three parts, 140 up to but not including 160, 160 up to but not including 180, and 180 and above. This is clearly illustrated in the Fig. 2.2. ■

2.2.2 Formal Definitions

The following subsection provides formal definitions for operations on fuzzy sets which are referred later in thesis.

Definition 2.1: The **union** of two fuzzy sets $\tilde{A}$ and $\tilde{B}$, $\tilde{A} \cup \tilde{B}$, is a fuzzy set defined by the following membership function,

$$\mu_{\tilde{A} \cup \tilde{B}}(x) = \mu_{\tilde{A}}(x) \vee \mu_{\tilde{B}}(x).$$

Definition 2.2: The **intersection** of two fuzzy sets $\tilde{A}$ and $\tilde{B}$, $\tilde{A} \cap \tilde{B}$, is a fuzzy set defined by the following membership function,

$$\mu_{\tilde{A} \cap \tilde{B}}(x) = \mu_{\tilde{A}}(x) \wedge \mu_{\tilde{B}}(x).$$

Definition 2.3: The **complement** of a fuzzy set $\tilde{A}$, $\tilde{A}^c$, is a fuzzy set defined by the following membership function,

$$\mu_{\tilde{A}^c} = 1 - \mu_{\tilde{A}}(x).$$

Definition 2.4: The **equivalence relation** of two fuzzy sets is defined as,

$$\tilde{A} = \tilde{B} \leftrightarrow \mu_{\tilde{A}}(x) = \mu_{\tilde{B}}(x); \quad \forall x \varepsilon X.$$

Definition 2.5: The **inclusion relation** of two fuzzy sets is defined as,

$$\tilde{A} \subset \tilde{B} \leftrightarrow \mu_{\tilde{A}}(x) \leq \mu_{\tilde{B}}(x); \quad \forall x \varepsilon X.$$

Definition 2.6: The **fuzzy relation** R from set X to set Y (or between X and Y) is a fuzzy set in the direct product X × Y = {(x,y) | x ε X, y ε Y}, and is characterized by a membership function μ_R,

$$\mu_R : X \times Y \rightarrow [0,1].$$

Operations on Fuzzy Relations: If R and S are fuzzy relations in X × Y, the following operations are applicable,

inclusion	$R \subseteq S$	$\leftrightarrow$	$\mu_R(x,y)$	$\leq$	$\mu_S(x,y)$
union	$R \cup S$	$\leftrightarrow$	$\mu_{R \cup S}(x,y)$	$=$	$\mu_R(x,y) \vee \mu_S(x,y)$
intersection	$R \cap S$	$\leftrightarrow$	$\mu_{R \cap S}(x,y)$	$=$	$\mu_R(x,y) \wedge \mu_S(x,y)$
complement set	R^c	$\leftrightarrow$	$\mu_{\bar{R}}(x,y)$	$=$	$1 - \mu_R(x,y)$.

where, $\vee$ = max and $\wedge$ = min.

Definition 2.7: If R is a fuzzy relation in X × Y and S is a fuzzy relation in Y × Z, the **composition** of R and S, R ∘ S, is a fuzzy relation in X × Z as defined below,

$$R \circ S \leftrightarrow \mu_{R \circ S}(x,z) = \bigvee_y \mu_R(x,y) \wedge \mu_s(y,z).$$

This composition* uses max min operations, so it is called a *max-min composition*. ■

*Many other kinds of compositions for fuzzy relations can be considered. For example, there is a *min-max composition* that is dual composition operation, reversing $\vee$ and $\wedge$. Only *max-min composition* is used in the present thesis.

2.2.3 Expert Systems

Expert systems are software systems that mimic the deductive or inductive reasoning of human expert. Expert systems belong to the family of information-intensive machines. For a task to qualify for knowledge engineering, there must be at least one acknowledged human expert. Expert systems requires two things: a collection of facts and rules about a given field and a way of making inferences from those facts and rules. Any rule is a pattern-invoked program. Such a program is not called by other programs in the ordinary way but is instead activated when-ever certain conditions hold in the data. ■

2.2.3.1 Expert Systems as Decision Support Systems

A decision support system can be defined as an interactive computer system that directly helps executives make decisions. Because of its information-processing speed, a decision support system has the potential to be part of an effective man-machine problem solving system. Decision support systems are most effective in solving *semistructured* problems, that is, problems with sufficient structure to make computer and analytical aids valuable, but problems in which human judgement is still essential.

There are two basic types of decision systems: procedural and definitional. In procedural systems, one commands the computer to do each step. Definitional systems or nonprocedural systems are problem-oriented systems. In a procedural system, one uses the machine not as an intelligent being that is trying to help but rather as a tool that adopts a predetermined solution scheme and follows a detached list of instructions very rapidly. Users of nonprocedural systems do not try to figure out how to solve the problem; rather, they rely on the computer to read and in some sense understand the problem as an expert might.

A new development in expert systems is the development of *genetic programming.* In this the program evolves or mutates in several ways before it is able to find best possible solution. All the intermediate program subroutines will die and fittest program combination survives. This technique is still in the development stages, so application of it to solve the transportation problems is ahead in future. ∎

2.2.3.2 Fuzzy Expert System

A fuzzy expert system is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, to reason about data. The rules in a fuzzy expert system are usually of a form similar to the following,

$$\text{if } x \text{ is low and } y \text{ is high then } z = \text{medium}$$

where, x and y are input variables (names for known data values), z is an output variable (a name for a data value to be computed), low is a membership function (fuzzy subset) defined on x, high is a membership function defined on y, and medium is a membership function defined on z. The antecedent (the rule's premise) describes to what degree the rule applies, while the conclusion (the rule's consequent) assigns a membership function to each of one or more output variables. Most tools for working with fuzzy expert systems allow more than one conclusion per rule. The set of rules in a fuzzy expert system is known as the rule-base or knowledge base.

The general inference process proceeds in four steps.

1. Under *fuzzification*, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise.

2. Under *inference*, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Usually only *min* or *product* are used as inference rules. In *min* inferencing, the output membership function is clipped off at a height

corresponding to the rule premise's computed degree of truth (fuzzy logic *and*). In *product* inferencing, the output membership function is scaled by the rule premise's computed degree of truth.

3. Under *composition*, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Again, usually *max* or *sum* are used. In *max* composition, the combined output fuzzy subset is constructed by taking the pointwise maximum over all of the fuzzy subsets assigned to variable by the inference rule (fuzzy logic *or*). In *sum* composition, the combined output fuzzy subset is constructed by taking the pointwise sum over all of the fuzzy subsets assigned to the output variable by the inference rule.

4. Finally is the *defuzzification*, which is used when it is useful to convert the fuzzy output set to a crisp number. Two of the more common techniques are the *centroid* and *maximum* methods. In the *centroid* method, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function for the fuzzy value. In the *maximum* method, one of the variable values at which the fuzzy subset has its maximum truth value is chosen as the crisp value for the output variable.

■

2.3 Advanced Technologies For Commercial Vehicle Operations

Commercial Vehicle Operations(CVO) systems apply various ITS technologies to improve the operating, safety, and efficiency of commercial vehicles. CVO systems can expedite deliveries, improve operational efficiency, improve incident response, and increase safety. While potential benefits from a comprehensive ITS program in CVO are broad-based, the primary goals and the most significant gains are in the areas of safety and productivity. Safety is enhanced for both commercial vehicle operators and others affected by them. Productivity is enhanced by making more effective fleet management techniques available to the private sector and by facilitating efficient traffic management and administration. CVO builds on the functional areas of Advanced Traffic Management Systems (ATMS), Advanced Traffic Information Systems (ATIS), and Advanced Vehicle Control Systems (AVCS). There are also a number of primary or enabling technologies that are prerequisite to many CVO integrated functions. Advances in these technologies will be incorporated into CVO applications as they become available. These enabling technologies are,

- AVI - Automated Vehicle Identification
- AVC - Automated Vehicle Classification
- AVL - Automated Vehicle Location
- ACS - Automated Clearance Sensing
- WIM - Weigh-In-Motion
- OBC - On-Board Computer
- TWC - Two-Way Real-Time Communications (Audio Visual)
- Road side beacons

Commercial Vehicle Operations (CVO) application assists in automating existing manual procedures, electronically capturing and reporting data, and improving the flow of information between carriers and regulatory agencies and between operators and dispatchers.

These efficiencies come from: simplification or elimination of the various regulations, without compromising regulatory oversights; and from overall improvements in fleet management. Electronic systems, if proven to be cost effective, will reduce the expense and effort on a motor carrier to comply with provincial licensing and reporting requirements. The states will likewise benefit through more efficient program administration, better enforcement of provincial requirements, and a higher level of carrier compliance with state regulations.

AVI, AVL and WIM are primary technologies applied to CVO. They are discussed in the following sections. The discussion is limited to system description without going deeply into the actual electronics. Since most of the systems are in early stages of development, and no standardization is attempted as yet. ■

2.3.1 Automated Vehicle Identification

Commercial vehicles are identified either by their physical characteristics (e.g., heavy trucks) or by the type of function they perform. The key objective of CVO in implementing ITS is to create transparent provincial and national borders. This will in part, be achieved by automating the collection of information required by governmental agencies. Enhanced benefits are possible if the information can be shared by several provinces. By expanding the information collected, carriers will gain access to essential information for managing their fleets while governmental agencies obtain information which they can utilize for planning purposes.

Equipment and communication standards are critical to CVO. Large vehicle fleets demand equipment standardization in order to reduce the training and maintenance costs associated with part proliferation. Standards for AVI are crucial given the essential role of AVI in so many CVO applications. Electronic vehicle equipment interface standards are essential if vehicle manufacturers are to be able to integrate add-on devices efficiently – a problem of particular concern to heavy truck manufacturers. Trucks that travel across the provincial borders and national borders need to be able to receive traffic information broadcasts (voice and data) anywhere without having to carry several different kinds of receivers.

AVI will make *electronic permitting* possible, this in turn will enable motor carriers to obtain and pay for all required licenses, registrations, and permits on a just-in-time basis electronically. An electronic record of the credentials will be sent to the motor carrier's headquarters or other desired location. A supporting database will contain information about these transactions for access by appropriate governmental authorities.

The near term AVI applications are vehicle identification and reporting and automatic toll collection at toll booths. The middle term AVI applications are highway speed toll collection. ■

2.3.2 Automated Vehicle Location

Automated Vehicle Location(AVL) systems are useful for a variety of tasks in the CVO (Intelligent Vehicle Highway Systems, A Synopsis, 1992). For instance, safe shipment of hazardous materials is of great concern to society in general, to truck operators, and to those who regulate truck movements. Electronic hazmat tracking technologies are being developed which hold promise as a means to provide enforcement and incident management response teams with timely, accurate information on cargo contents, thus enabling them to react properly in emergency situations. Early detection of cargo problems would allow time for the driver to respond and possibly prevent a serious accident.

The primary *vehicle navigation* and *vehicle location* modules in general have the following subsystems,

- Global Positioning System(GPS)
- Transit Navigation Satellite System (TRANSIT)

- Dead-Reckoning (sensor driven - heading, speed, altitude, etc.)
- Low Power Transceiver Signposts
- Map Matching

The ultimate success of AVL (along with *vehicle navigation*) depends on the the characteristics of navigator. The navigation subsystem consists of an optimal mix of navigation satellite fixes (GPS) and a highly evolved dead-reckoning implementation which features continuous automatic calibration. GPS augmented by dead-reckoning (GPS/DR) will provide continuously available, extremely accurate position estimates. A brief description of GPS and Dead-Reckoning is warranted for understanding their important role in AVL system. ■

2.3.2.1 Global Positioning System

Global Positioning System(GPS) is a global, all weather, 24-hour, satellite based navigation system being deployed by the U.S. Department of Defense. The system provides two classes of accuracy; namely, the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS) for non-military users. Current testing with Block I prototype satellites indicate accuracies of about 15 meters. In order to reduce the accuracy available to users, the SPS accuracy will be intentionally degraded. This degradation, or Selective Availability (SA), will still provide civilian users with an expected 50 m accuracy. By providing a GPS receiver at a known, fixed location (e.g. dispatcher station), and by using differential techniques, the accuracy can be enhanced to under 5 m, even with degraded satellite signals. ■

2.3.2.2 Dead-Reckoning

The new generation navigator will be a GPS multi-channel receiver augmented by Dead-Reckoning (DR). Using *Kalman filtering*, the GPS receiver evaluates and weighs satellite data to produce continuous optimal positioning data (Intelligent Vehicle Highway Systems, A Synopsis, 1992). In the event of a loss of satellite information (due to signal blocking by buildings or tunnels, for example), the system will detect the loss and maintain positioning information by monitoring speed and heading sensors (DR) until the satellites are again available. At that time the GPS data will be used to update the dead-reckoning accuracy.

For DR, the speed sensor consists of a transducer connected between the transmission and the speedometer cable of the vehicle. Heading is obtained via a flux-gate compass either fixed or mounted on a pendulum and installed on the roof of the vehicle. Heading can be improved by use of sensors attached to a vehicle's wheels which monitor the differential movement.

When the system is installed, it will be deemed successful not only if "vehicles are locatable automatically", but the user must accept the concept as one that improves the overall operation. In case of freight transportation the overall operation applies to the driver of the vehicle, the dispatcher, the management, enforcement agency and finally government. ■

2.3.3 Weigh in Motion

WIM is used to find weight information from WIM devices to determine if the vehicle is traveling legally. Exceptions and violations would be brought to the attention of enforcement officials for appropriate action. Potential benefits of WIM are summarized in the following subsections. ■

2.3.3.1 Travel Time Saving

Travel time saving can be defined as the anticipated reduced stopping and idling costs, and potential lost revenue captured for motor carriers associated with automaton of weigh station operations. Cost savings for potential lost revenue captured is based on typical operating margin per unit of time delay. According to studies travel time savings is determined for several operating scenarios of improved operations compared to existing corridor-wide operations (Assessment of benefits for Advantage I-75, 1992). ■

2.3.3.2 Safety Enhancement

Safety enhancement can be defined as the potential cost savings associated with reduction in vehicular accidents (within 1/2 mile in each direction of all weigh stations) caused by improved operations at weigh stations. In safety enhancement studies it has been assumed that automaton of weigh station operations will permit a large degree of station by-passing, significantly reducing the occurrence of truck weaving/conflicts in these areas, and thus minimizing the probability of vehicular accidents (Assessment of benefits for Advantage I-75, 1992). ■

2.3.3.3 Enforcement and Regulation Agencies

The benefits to commercial vehicle enforcement and regulation agencies seem obvious. States would be able to reduce their investments in manpower costs while increasing their revenue. Total automaton, such as that provided by sufficiently advanced AVI and related technologies, could allow unattended weigh stations to operate on a round-the-clock, 24-hour schedule.

The cost of installing and maintaining the new technology could be more than offset by the certainty of collecting revenue from commercial vehicles 24 hours a day, 365 days a year. Additional benefits to enforcement and regulation agencies would result from increased safety and reduced pavement damage achieved by better monitoring of over dimension and overweight vehicles (Assessment of benefits for Advantage I-75, 1992). ■

2.3.3.4 Paperwork Reduction

Paperwork reduction can be defined as the potential cost savings associated with reduced monitoring of paperwork and operating credentials at weigh stations due to the automaton of operations (Assessment of benefits for Advantage I-75, 1992). ■

2.3.3.5 Other Benefits

Other non-direct benefits can be summarized as follows,

- Lower prices to the general public as a result of more efficient movement of goods

- Increased data collection and information sharing for planning, registration, permitting, emergency response, enforcement, and revenue collection
- Improved two-way communications between provinces and truckers
- Real-time travel conditions monitoring to improve trip-making for all motorists in the corridor.

■

2.4 Research Direction

The preceding review demonstrates that there are a variety of freight transportation modeling approaches. The rigorous data requirements for the modeling process and the high cost and time consuming collection, or unavailability and inaccuracy of available data, make most of the reported models of limited use. In the author's opinion models of aggregate nature appear to be useful in studying situations such as impacts of introducing a national policy or reform of a transportation mode on the inter-modal split and on economy as a whole. Also, in the author's view the econometric abstract mode modeling technique is of great use in studying the impacts of newly implemented technologies on the user mode choice and consequently on the regional and national economy.

The freight modeling and mode choice literature also indicates that among the factors that influence the user to choose the freight mode are freight rate (cost to the user), travel time, distance and commodity nature. These factors are found by different studies carried by different researchers, to be the most influential on the user. In this research aggregate models for inter-provincial freight movement in Canada are developed. User cost, door-to-door travel time, origin/destination distance and different commodity groups among other factors will be analyzed and included in model development process. The data applied is the most recent available (1992) and is aggregated under three commodity sections supplied by Statistics Canada. Expert opinion on success and the direction of ITS technologies are collected through a questionnaire. These expert opinions being linguistically fuzzy in nature are subjected to preset rules and output is obtained with the help of computer program. The opinions thus obtained are inputed into the models previously developed to predict and analyze the impacts of Intelligent Transportation Systems on rail/truck modal split across Canada. ■

Chapter 3

Capacity Gains with Advanced Vehicle Control Systems

Advanced Vehicle Control Systems (AVCS) are some of the most revolutionary concepts in the whole array of the Intelligent Transportation Systems (ITS) technologies. The AVCS concept has been explored to gain understanding about its possible implications to freight transportation. It has been observed that there is a possibility of carrying six to eight times passenger car equivalent traffic on an automated highways compared to the present highways at consistently high speeds.

3.1 Background

The growing power of microchips and drop in their costs, large-scale automaton of highways does look feasible. Since AVCS coupled with an automated highway system (AHS) is the ultimate goal of the ITS program, study of its feasibility and potential benefits is of utmost importance. Technologically speaking, AVCS development has a long way to go before widespread implementation of a fully automated highway. With the present level of development of individual vehicle control technologies the probable scenarios of a functional AHS can be imagined with fair degree of accuracy. Mobilizing public support for such a technologically complex and costly endeavor will probably be more difficult than actual AVCS system design. One way of garnering public support for this program would be to quantify the benefits that AVCS can deliver in terms of improved highway capacities, safety, and level of service, without significant investment in building new highways. In the author's opinion automated highway resemble in some way the present day high occupancy vehicle corridors. The following sections discuss some probable automated highway scenarios and attempt to quantify the increased capacity possible with AVCS in place. The automated highway scenarios described are hypothetical and hence the capacities computed are applicable only under those circumstances described. Moreover, the critical parameters influencing highway capacity, such as speed, deceleration rates and vehicular lengths, are assumed to belong to a crisp set of allowable parameter values. In this research longitudinal vehicle spacing in platoon formation is the controlling factor in arriving at the required capacities of the AHS.

ITS technologies are implemented to improve highway capacities, reduce emissions, improve level of service and reduce adverse environmental impact by improving the productivity of the existing infrastructure. Improved information input to drivers will encourage highway users to become better route planners. The initial phase of ITS concentrates on information transfer to the highway users, leaving them to decide how to avoid congested areas. Optimal information input to the user does seem to increase highway efficiency, though to what extent drivers use the information input and modify their routes is still debatable. According to certain estimates, advanced traffic management techniques will improve the present capacity of the highways with recurrent congestion by 15%–20% and by even less in non-recurrent congestion as estimated by Al-Deek and Kanafani (1990). Unfortunately, the rate at which the traffic from suburbs to metropolis is growing means that this increase in capacity will be outstripped in two to three years (Shladover, 1990). This being the case, exploring the possibility of providing a substantial increase in highway capacity leads us to the most sophisticated technologies of the ITS program–Advanced Vehicle Control Systems (AVCS).

AVCS with advanced vehicle-road and vehicle–vehicle communication offers the potential for solving the congestion problem for the better part of the next century. The success of this concept depends heavily on overcoming some very important human factors and technological problems. The safety concerns of the users, product failure liability, and cost factors must be addressed.

The technology required for a fully developed automated highway is quite complex and still needs extensive research in many areas. AVCS can be classified into three main sub–systems: advanced longitudinal guidance system (ALOGS), advanced lateral guidance system (ALAGS) and steering control system (SCS). ALOGS mainly controls the inter-vehicle or intra-platoon spacing (if the vehicles are moving in platoon formation). This system will be an evolution of present–day collision warning devices, with the additional capability of maintaining fixed distances between vehicles traveling at high speeds. Longitudinal guidance can be accomplished by using either infrared laser beam units or millimeter wave retrodirective transponders for sensing the safe distance from the preceding vehicle and providing an alerting on board computer for necessary action (Kornhauser, 1991). Lateral guidance technologies enable vehicles to maintain a predetermined path and also assist lane merging and entry to and egress from the automated highway. Lateral guidance can be accomplished by using vision, passive wire, radar sensors and laser beams for sensing lateral clearance between the vehicles and feeding this data to an on board computer which warns the SCS of any necessary adjustments (Heller, 1993). ■

3.1.1 AHS Design Options for Operating AVCS

Any proposed automated highway design should consider the following operating scenarios: separation of automated traffic from manual traffic, with automated traffic moving in platoon formation, or with free agent vehicles traveling in a segregated road segment; shared highways with dedicated automated lanes with barriers and platooning; shared highways with barriers and free-agent vehicles following; shared highways with barriers under platooning; and shared highways without barriers under free-agent vehicle following as proposed by Tsao and Shladover (1993). Even with vehicle platooning, two types of road trains are envisaged by Saboungbi (1993), one formed of cars with independent power units and the other formed of a commercial vehicle with a high capacity power unit pulling a number of trailers each with remotely controlled braking and steering capabilities. In a segregated automated highway the vehicles equipped with a vehicle control device undergo necessary diagnostic checks and then enter the designated highway segment in the form of a platoon. This pre-platooning can be done on a ramp leading to the automated highway or in a buffer lane between the automated highway and the manual traffic lane. Once manual control is transferred to a centralized computer, various vehicle functions are monitored and adjusted according to the requirements of the situation. It is a moot point whether the vehicles will enter the automated highway under manual control and transfer the command after reaching a particular velocity, or whether control will be assumed by the computer in the buffer zone or on the ramp itself before the vehicle merges with traffic already on the automated highway.

A segregated automated highway with free vehicles moving with variable velocities (controlled by a centralized computer) is another possible scenario. However, it would pose computational challenges for the computer controlling the critical parameters dynamically for each vehicle.

Barricades separating manual control lanes and automatic control lanes would reduce the available lane widths, thereby reducing the number of platoons that can travel with close lateral spacing. Shared highways with no barricades or buffer zones but with designated automated highway lanes pose difficult technological problems. ■

3.1.2 Critical Parameter Ranges for Determination of AHS Capacity

Automated highway capacity is determined keeping in view the automated highway scenarios discussed above. The capacities are computed assuming that the vehicles moving on the automated highway are passenger cars. Automated highway capacity, like any uninterrupted highway capacity, depends on the following critical parameters: speed of the vehicles on the given highway segment, deceleration rates of the vehicle in an emergency situation and spacing. The major difference is reaction time. Additional following distance is needed if vehicles are driven by humans, in case an emergency arises. This is not required in an AHS, even when the vehicles are moving at high speeds in close quarters.

The speed of the individual vehicles is the most important element determining the capacity of a given highway segment. Population growth increases the average number of trips originating from homes. Increasing population and living standards will push up automobile usage, thereby putting pressure on the existing infrastructure in certain urban centers in North America, Europe and Japan (Shladover, 1990). A greater number of automobiles without matching improvements in infrastructure will lead to decreased speeds. Decreased speeds mean more unproductive time spent by highway users. Decreased speeds also lead to wastage of fuel and increased pollution. With AVCS, high constant speeds and cars moving in close platoon formation are proposed. In non-automated highways, high speeds mean a higher possibility of drivers losing control of their vehicles. An automated highway with AVCS permits better control of vehicles moving at high speeds with close following distance. In the analysis carried out in this paper, vehicle velocities are chosen to vary between 60 and 180 km/hr. Higher automobile velocities are possible with the amount of control that would be provided for the vehicle platoons.

Failure mode emergency response are also critical aspects affecting the capacity of an automated highway with operational AVCS. In the author's opinion making an AHS absolutely reliable should be the top priority in designing AVCS subsystems. Thorough inspection of the various subsystems of vehicle and control systems must be carried out before the vehicle enters the designated automated highway. However, the AVCS should be capable of bringing the vehicles to a complete stop on an automated highway if the need arises. Buffer zones for acceleration and deceleration of AVCS equipped vehicles do not obviate the need to be able to bring vehicles or vehicle platoons to a complete halt, because spill over due to an accident will affect these buffer zones. In a failure mode the efficiency of the AVCS lies in bringing the vehicles or vehicle platoons immediately succeeding the vehicle/platoon involved in an incident to a complete stop without the danger of involving multiple vehicles/platoons in a serious accident. The physical limitations of vehicle braking efficiency also constitute a critical parameter controlling the capacity of the automated highway. Current North American braking standards require vehicles to have braking efficiencies greater than or equal to 0.3 times the acceleration due to gravity. Higher braking efficiencies of 0.6 times acceleration due to gravity are currently used for standard computations (Tsao, Hall & Shladover, 1993). Continued research on tire and rubber technologies will result in higher braking efficiencies and ultimately lead to higher standards. Both the above deceleration rates were considered in the determination of the capacities of the automated highway. However, dynamically computer–adjusted deceleration rates for individual vehicles are more efficient than a constant deceleration rate for the whole platoon.

Spacing between the vehicles in a platoon is another critical parameter. The advantage of AVCS is that it eliminates human error when operating at high speeds and at close inter-vehicle distances. Minimal clearance of one to two meters between vehicles moving at high speeds would substantially improve the capacity of the automated highway. Low relative velocities between the vehicles in a platoon ensure that there are no serious accidents even if accidental contact occurs. A dynamic adjustment in inter-vehicle spacing depending on platoon speeds may also be possible. All this depends on critical human reactions to traveling in different vehicles at high speeds with close spacing. Spacing adjustments may be necessary while entering and exiting the automated highway. A typical scenario would be a driver communicating the desire to change from manual drive mode to automatic driving mode. Once this is relayed to the central computer, the vehicle is electronically coupled with the nearest passing platoon with larger spacing to avoid any collision due to differences in the alignment and speed of the vehicle joining the platoon. The longitudinal and lateral spacing of the newly joined vehicle would be adjusted after entry. Similar adjustments would occur as a vehicle leaves a platoon. For the present analysis constant spacing of one meter and two meters was chosen.

Another critical parameter is vehicle length. Longer vehicles increase the total distance required by the platoon to come to a complete stop. Average family sedans in today's market measure about 4.78 m. Compact cars measuring 3.50 m are also available. It can be safely assumed that the passenger cars in platoons will be of different lengths. Therefore any theoretical analysis is bound to have discrepancies when compared to an actual situation. However, variation within a few centimeters will not seriously affect the capacity computed. In the present study, uniform vehicle lengths of 4.78 m and 3.50 m were used to estimate automated highway capacity.

Platoon size also affects the capacity of an automated highway. Large platoons pose maneuvering problems on curves. If pre-platooning of vehicles were done before entering the automated highway, then constant platoon sizes from origin to destination would be possible. However, if platoons are formed dynamically on a shared highway, then variable platoon lengths are more likely to operate on an AHS. Platoon sizes of 6, 8, 10, 12, 14 and 16 vehicles were chosen for the present analysis.

3.1.3 Automated Highway Capacity Estimation

Capacity of a facility is defined as the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic and control conditions (Highway Capacity Manual, 1985). Determination of automated highway capacity with platoons of vehicles moving at high speeds depends on safe inter-platoon spacing. In other words, the deciding factor for highway capacity is failure response of the AVCS system. In an emergency mode the AVCS is expected to localize the incident and to ensure that multiple accidents are avoided. This requires safe following distance for individual platoons. Thus, in case of an incident, the succeeding vehicles are brought to a complete halt until the accident spill over, if any, onto the adjacent lanes is cleared to allow safe passage of the vehicles. The safe stopping distance (S_{sd}) and safe following distance (S_{fd}) can be written as functions of the following terms,

$$S_{sd} = f(V_i, V_f, a) \tag{3.9}$$

$$S_{fd} = f(S_{sd}, P_j, D_{car}, S_{pl}) \tag{3.10}$$

where,

V_i	=	the stable speed that the platoon attains and maintains depending on the design speed at which it is allowed to operate,
V_f	=	is the final velocity the succeeding platoons have to reach once an incident occurs, so as to avoid multiple collisions,
a	=	the maximum deceleration rate that the individual vehicles in the platoon can reach without loss of control of the platoon,
P_j	=	the number of vehicles in the platoon,
D_{car}	=	the length of individual vehicles in the platoon, and
S_{pl}	=	the intra-platoon or inter-vehicle spacing.

In case of an emergency the platoon moving with a speed of V_i comes to a stop traveling a certain distance (S_{sd}) according to the following equation, which is based on vehicle dynamics,

$$S_{sd} = (V_i^2 - V_f^2)/2 \times a \qquad (3.11)$$

According to the Highway Capacity Manual (1985), spacing is defined as, the distance between successive vehicles in a traffic stream, as measured from front bumper to front bumper. In the case of platoons, the vehicle must be replaced by a train of vehicles, each platoon being regarded as a single unit. Thus, if an incident occurs this information is communicated to the following platoons, so as to isolate the damage to a single platoon. Since no human reaction time lag exists, immediate emergency procedures are invoked, so as to protect oncoming vehicle platoons. With this reasoning, the safe following distance can be written as,

$$S_{fd} = S_{sd} + D_{car} \times P_j + (P_j - 1) \times S_{pl} \qquad (3.12)$$

This line of reasoning is sound, in view of the possibility of accidents and resulting hazardous conditions on adjacent lanes. Once the spacing is determined, headway (sec/platoon) and flow rate (platoons per hour) are determined according to the following relations,

$$Headway(sec/platoon) = Spacing(ft/platoon)/Speed(ft/sec) \quad (3.13)$$

$$FlowRate(pph) = 3600sec/hr/Headway(sec/platoon) \quad (3.14)$$

Platoon flow rate thus determined can then be converted into equivalent passenger cars. Capacities of the automated highway with variations in the critical parameters were determined according to above relations. These results have been plotted (see Figures 3.1 to 3.8). ■

3.1.4 Results

As can be seen from the plotted capacity curves, substantial capacity gains can be obtained by implementing AVCS. As can be intuitively concluded, an increase in intra-platoon spacing decreases the overall capacity gains. It can be noted by comparing Figure 3.3 and Figure 3.4 that an approximate decrease of 1000 vph capacity occurs with a one meter increase in intra-platoon spacing. Decreasing car lengths from 4.78 m to 3.50 m leads to a capacity gain of 1000 vph (comparing Figure 3.3 and Figure 3.5). Increased platoon lengths increase the capacity of the automated highway no matter how other critical parameters are varied, as can be noted in Figures 3.3 to 3.10. Comparing the graphs in Figures 3.3 to 3.6 and Figures 3.7 to 3.10 shows that decreased deceleration rates have a profound negative effect on the capacities of the automated highway. This agrees with intuitive conclusions, as improved braking efficiencies will positively affect the capacities of the highways.

One counter-intuitive finding is the decrease in automated highway capacity with increased platoon speeds. This can be explained by the fact that at higher speeds platoons need large following distances to cope with any emergencies that may arise. Maximum capacity for a deceleration rate of 0.6 times acceleration due to gravity is attained in a velocity range of 90 to 110 km/hr (see Figures 3.3 to 3.6). Similarly, for a deceleration rate of 0.3 times acceleration due to gravity the maximum capacity is attained in a velocity range of 75 to 80 km/hr. ■

3.2 Remarks

This chapter highlighted various possible AHS scenarios using AVCS and outlines a method for estimating the capacities of such systems. The scenario best suited for the North American environment is a matter for further study. Pre-platooning of vehicles with the same destination and running diagnostic tests at the pre-platooning stage is logistically and technologically simpler than, for example, having vehicles joining and leaving the platoons at random.

The effects of having platoons moving with close lateral clearance have not been studied. Close lateral spacing between vehicles will effectively increase the number of lanes in which vehicles or platoons can travel. This could be achieved by lateral guidance systems; however, close lateral spacing of vehicles moving at high speeds will create tremendous drag forces and eddy currents, which disrupt alignment of the platoon, thereby causing loss of control of the platoon. Vehicles must be designed to counteract these external forces and maintain proper alignment, so as not to cause serious accidents. Barricading the automated highway lanes and manual traffic lanes has a negative effect on the capacity of the automated highway, as effective lateral clearance for such traffic is reduced by the barriers.

When it becomes possible to have acceleration lanes and deceleration lanes as buffer zones between automated and manual highways and to confine incidents to the automated highway, so that succeeding platoons need not come to a halt, then the capacity curves depicted in the figures would not do not a convex shift with increasing speeds.

AVCS operating on an AHS promises to provide the capacity gains that will be required on highways in coming years, without the need for substantial infrastructure buildup. However, much depends on public acceptance of AVCS. Low-cost and efficient peripheral development will help the public to take a positive view of AVCS.

This study was attempted to understand the implications of automated highways on freight movement and aspects of modal split. The study is incomplete because of limited information available on AVCS. However, some observations can be made regarding AVCS implication on freight movement and possibly on modal split. The capacity gains obtained through AVCS may release certain lanes for exclusive truck and heavy vehicle traffic. This could positively affect the LOS factors for trucks and may lead to higher market share for trucking industry. ■

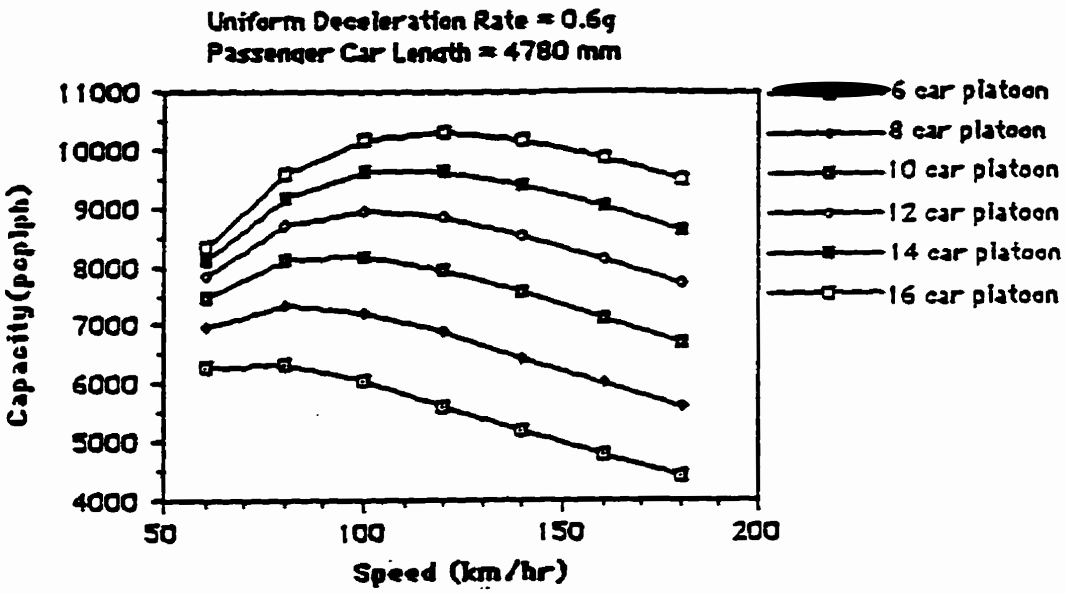

Figure 3.3: Capacities Achieved at 1 m Intraplatoon Spacing

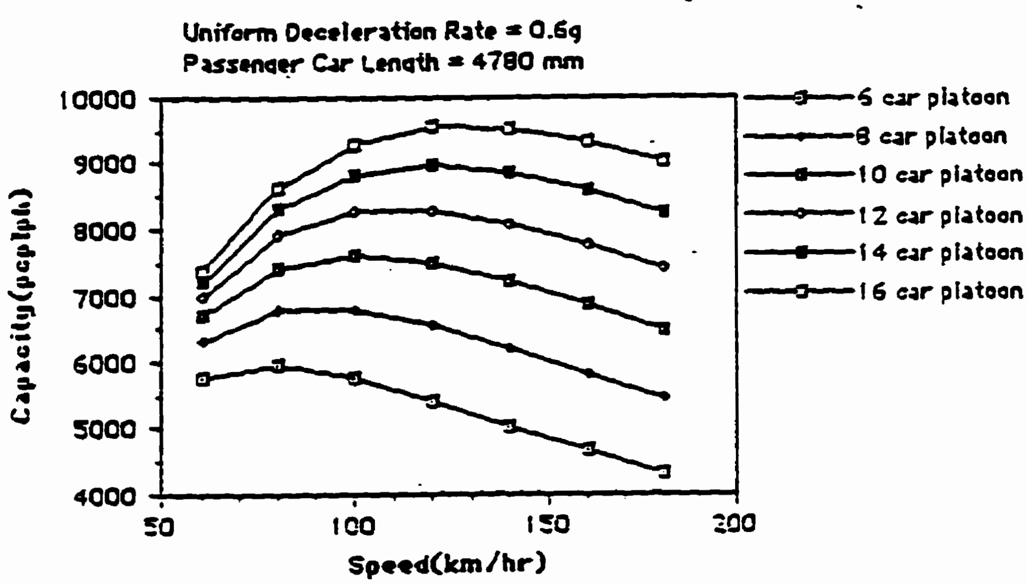

Figure 3.4: Capacities Achieved at 2 m Intraplatoon Spacing

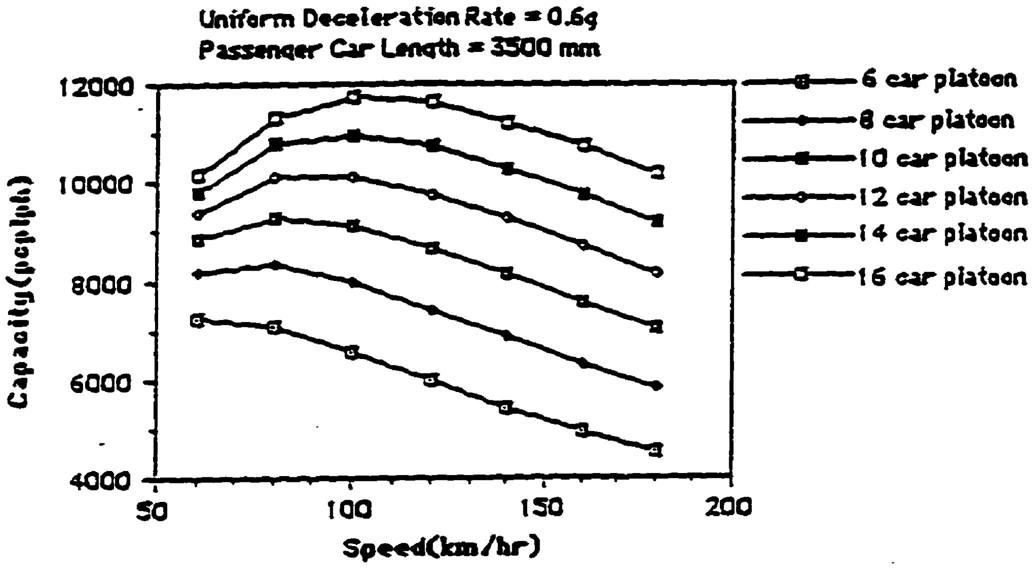

Figure 3.5: Capacities Achieved at 1 m Intraplatoon Spacing

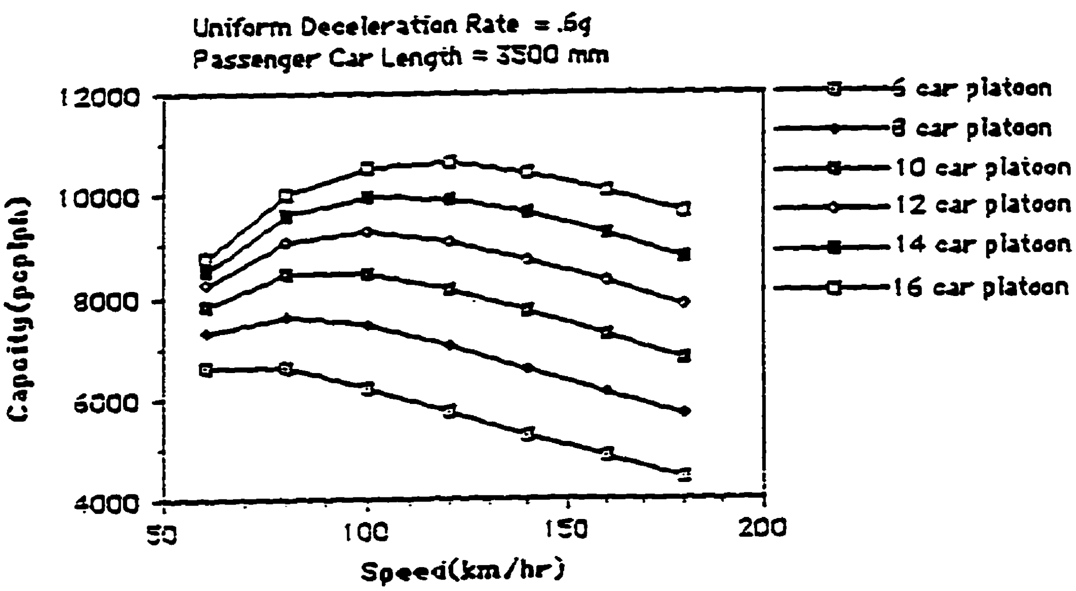

Figure 3.6: Capacities Achieved at 2 m Intraplatoon Spacing

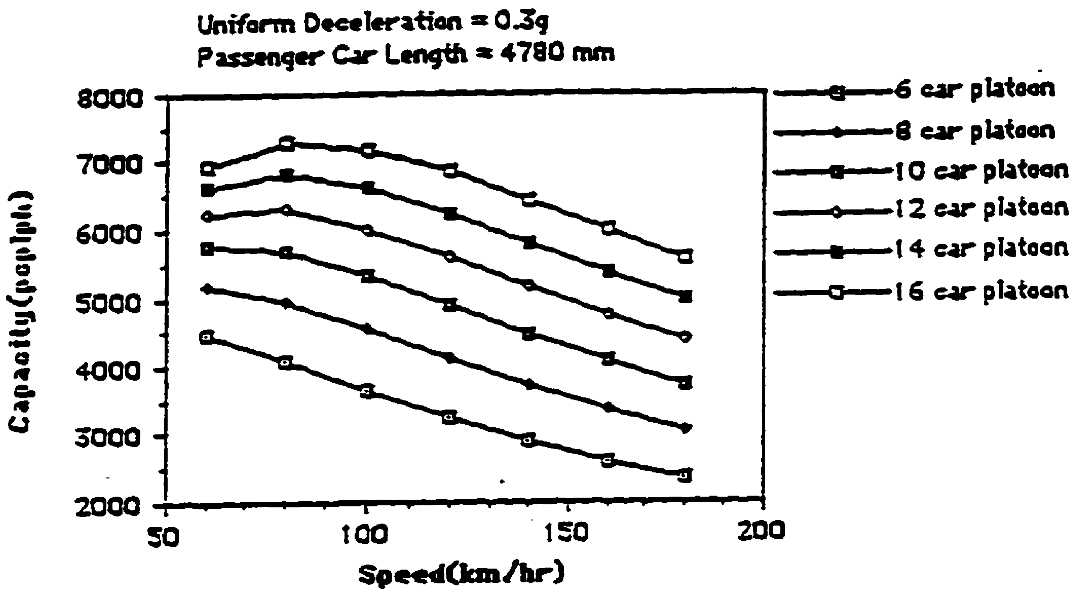

Figure 3.7: Capacities Achieved at 1 m Intraplatoon Spacing

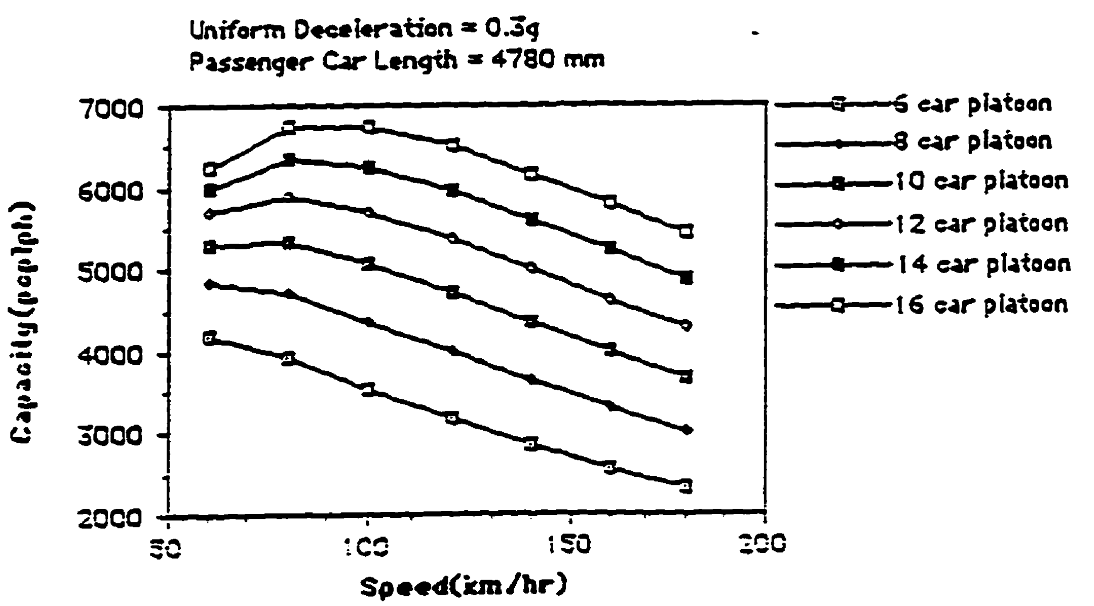

Figure 3.8: Capacities Achieved at 2 m Intraplatoon Spacing

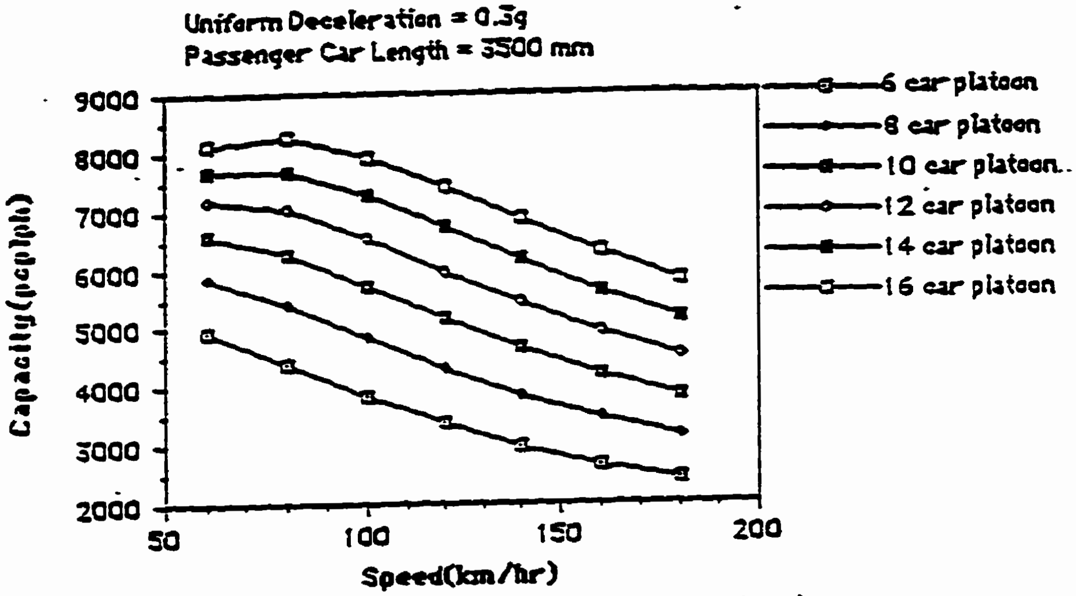

Figure 3.9: Capacities Achieved at 1 m Intraplatoon Spacing

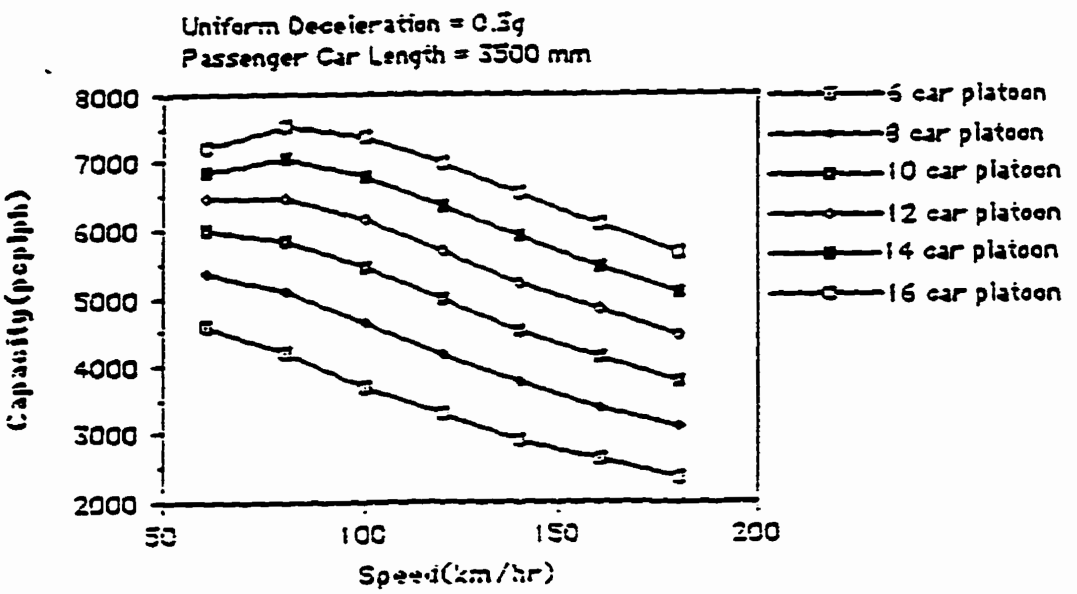

Figure 3.10: Capacities Achieved at 2 m Intraplatoon Spacing

Chapter 4

Data Collection and Analysis

The aggregate models developed in the present research predict truck volume considered apart from origin/destination (O-D) railway and trucking service characteristics those socio-economic factors which affect transportation volume between two regions. Six central and western provinces were considered for the present study namely: Québec, Ontario, Manitoba, Saskatchewan, Alberta and British Columbia. The present research had dealt with technologies which need joint public and private participation on much larger scale than say such technologies like Collision Warning, Adaptive Cruise Control etc., which are solely provided by the operators, needing more micro level study.

The socio-economic factors that influence the generation and attraction of freight trips are: population, per capita, market index and industrial index of origin and destination stations. The LOS characteristics of two modes were represented by travel time and user cost. Transportation is a not a direct phenomena but a derived phenomena depending on demand generated by socio-economic activity in the market served. For the three commodity sections, origin and destination factors selected were measures of market activity, industrial activity, population and mean personal wealth.

4.1 Data Collection

The primary data was obtained from statistics Canada publications 53-222 *Trucking in Canada* for 1992, and *Railway Transport Commodity Origin and Destination Statistics* for the year 1992. O-D socio-economic indicators were obtained from Statistics Canada and respective years the Financial Post's *Canadian Markets*. These include the Financial Post's market index and industrial index statistics. These are defined as follows,

Market Index : "Average retail sales per capita in each area as measured against the national average retail sales per capita. This index gives an indication of relative retail sales of each market."

Industrial Index : "Total value added per capita in each area as measured against the national total value added per capita." This index gives an indication the relative industrial productivity of each province.

The Annual Motor Carriers of Freight (AMCF) survey is carried out using long or short questionnaire survey forms, adapted to each group of carriers. The four levels of carriers defined as follows in the AMCF,

- Level I carriers - Revenues of $ 5 million or more;
- Level II carriers - Revenues of $ 1 million to $ 5 million;
- Level III carriers - Revenues of $ 250, 000 to $ 1 million;
- Level IV carriers - Private carriers with annual operating expenses over $ 1 million.

The *Railway Transport Commodity Origin and Destination Statistics* report tabulates annual tonnage and revenues for each interprovincial link for each of the commodity sections. The surveyed railways are grouped into two classes: Class I (Canadian National and

Canadian Pacific); and Class II (all other railways). In 1992, Class I railways account for 91% of tonne-kilometers; which accounted for 84.1% operating revenues. There is a steady decline in overall railway revenues in the past decade.

This study focuses exclusively on interprovincial freight movement and hence Level III trucking companies (local and intraprovincial trucking companies) and Class II railways (local networks) were excluded. The trucking freight volume considered for model formulation is exclusively for For-Hire trucking companies and does not include data for private carriers. Trucking travel times were obtained through discussion and consultation with representatives two national carriers. Responses received reported door-to-door service including transit time and terminal handling time. Rail transit times were obtained from published Canadian National Railway Schedule. Door-to-door travel times were obtained by estimating the terminal times (one half to three days were used depending on commodity type) and adding it to transit times. Since, major attractions and generators of traffic are major cities located in each province, they were chosen for determining the centroids of each province. When two major cities are present in a single province, the one closer to main CN rail line is chosen. Thus, Edmonton and Saskatoon were chosen in Alberta and Saskatchewan respectively.

Industry pricing depends on factors including preferred customer policies, and various incident specific variations. Thus, for determining the rate-per-tonne is determined from revenue values for each O-D link and corresponding tonnage (data provided by *Statistics Canada*). This method proved reliable for determining the trucking rates but produced a highly dispersed data for railways. In order to harmonize the data a function between cost and distance was derived and used in place of rate data for model formulation.

$$C_{rail} = f(K_{od}) \tag{4.15}$$

C_{rail} = user cost by rail, in \$/tonne

K_{od} = distance between principal cities of origin and destination province, in kilometers

■

4.2 Commodity Groupings

Statistics Canada railway (seven sections) and motor transport(six sections) data is grouped under commodity sections as shown in Table 4.1. "Food, feed, beverages and tobacco" (FFB&T) comprised 16.73% and 13.9% of interprovincial freight volume moved by Class I railways and Class I & II for-hire trucking respectively, "Crude Materials, Inedible" (CMI) comprised 48.43% and 30.4% respectively and "End Products, Inedible", (EPI) comprised 1.38% and 10.1% respectively. In terms of revenues "Food, feed, beverages and tobacco" (FFB&T) comprised 56.9% and 17.3% of interprovincial freight volume moved by Class I railways and Class I and II for-hire trucking respectively, "Crude Materials, Inedible" (CMI) comprised 58.59% and 9.2% respectively and "End Products, Inedible", (EPI) comprised 69.0% and 31.0% respectively. Competitive advantage will increase for trucking industry if ITS is applied for CVO and the modal split is going to shift in favor of trucking industry if no action is taken by railways.

For all three commodity sections, models were calibrated using 1992 data for thirty interprovincial O-D pairs. The overall tonnage moved between these six provinces are more than 85% of the total interprovincial tonnage moved in the entire Canada. Marine transportation is not considered in the analysis.

■

Table 4.1: Commodity Sections

Trucks	Railways
1. Live animals	1. Live animals (car load)
2. Food, feed, beverages and tobacco	2. Food, feed, beverages and tobacco (car load)
3. Crude Materials, inedible	3. Crude Materials, inedible (car load)
4. Fabricated Materials, inedible	4. Fabricated Materials, inedible (car load)
5. End products, inedible	5. End products, inedible (car load)
6. General or unclassified freight	6. Special types of traffic (car load)
	7. Non-carload freight

4.3 Rail/Truck Competition and Modal Split

The commodity sections studied form bulk of the freight traffic in Canada. There is increase in the freight carried by rail and truck in Canada in the past decades but, the growth is slower in railway industry compared to trucking industry. A general observation is that the trucking industry captured bulk of valuable commodity market for short distance haul leaving less valuable and lower revenue bulk commodities over longer distances to the railways. For FFB&T and EPI commodity sections, trucking carries more than rail over the short distance and is competitive over longer distance. In case of CMI the rail set to dominate both over short haul and long haul. Commodity rates increase with the distance for both rail and trucks. However, the slope is much steeper for trucking compared to rail as the distance increases. ■

4.3.1 FFB&T: Commodity Composition and Movement

FFB&T class freight carried by railways differs in some way with trucking mode. A disproportionate amount of wheat, rice, oats, wheat flour barley and soya bean is carried by railways in this commodity group (almost 90%). For trucks the FFB&T is exclusively composed of food preparations, dairy products, fruits, vegetables, meat and fish, beverages, and tobacco. A detailed description of composition of the FFB&T is given in the Table 4.2. Bulk of the commodity transported by rail is from prairies (agriculture belt) to Ontario, Alberta and B.C. Also it appears that trucking volume is more scattered over several links, Ontario to Québec dominating the scenario.

■

Table 4.2: FFB&T Composition for Truck and Rail

Truck	Rail
Misc. food preparations	Wheat
Dairy products	Diary products, eggs and honey
Cereal grains (unmilled)	Rice
Vegetables (fresh or chilled)	Oats
Fermented alcoholic beverages	Wheat flour
Meat (except poultry)	Barley
Non-alcoholic beverages	Soybean
Distilled alcoholic beverages	Food preparation
Sugar, molasses and syrups	Vegetables and preparations
Canned food	Animal feed of vegetable origin
Other bakery products	Malt and malt flour
Cereal grains (milled)	Ground cereals and by-products
Complete feed	Wheat barn, shorts and middlings
Poultry (fresh or frozen)	Hay, forage and straw
Fish (whole or dressed)	Fruit juice concentrates (frozen)
Fruit juice concentrates	-
Fruits (fresh or chilled)	-
Sugar preparations	-
Tobacco products (manufactured)	-
Meat preparations (cooked meat)	-

4.3.2 CMI: Commodity Composition and Movement

The commodity group CMI is dominated by railways both in the amount and range. This is also the largest component of rail tonnage comprising nearly 50% of the whole freight transported by the railways. On the other hand for CMI less than 15% of the total freight is carried by the trucking industry. Also, the short haul split in CMI transportation it appears that there is scope for competition between rail and truck in future. This phenomenon has been observed studying Ontario/Québec, Manitoba/Saskatchewan. However, Alberta and B.C. link appears to be dominated by the railways entirely capturing more than 50% of the inter-provincial tonnage. The nature of commodities classified under CMI for rail and truck are tabulated in Table 4.3. Iron and bituminous coal constitute more than 50% of the rail share of this commodity and is not carried by truck. Likewise sand, gravel and crude stone constitute about 40% of truck freight and are not shipped by the rail. ■

4.3.3 EPI : Commodity Composition and Movement

EPI commodity group composition is same for rail and trucks. The market is more competitive over medium and long range. The freight rate increases for trucking at a much faster rate than rail. It is also noted that a substantial difference exists in east bound and west bound rates. This is attributed to excess capacity available for east bound traffic (westbound traffic is 40% more compared to east bound traffic). The reason primarily is due to concentration of manufacturing bases in the east and raw material abundance in the west.

As in FFB&T the EPI transport is competitive in medium long haul and dominated by the trucking in short haul. In case of Ontario and Québec the truck carries more than 100% of EPI freight compared to rail. In case of east to west extreme (Québec & B.C.) the truck competition is almost negligible. The major types of end products moved by rail and truck are in Table 4.4. Automobiles and motor vehicle parts comprise majority of EPI transported by rail. Trucking on the other hand carries wide variety of commodities. Commodities ranging from passenger automobiles, chassis, motor vehicle engines, and related automotive items (trucks, truck chassis, and tires) collectively account for 35% end products moved by trucks. ■

Table 4.3: CMI Composition for Truck and Rail

Truck	**Rail**
Sand, gravel & crude stone	Iron ore and concentrates
Pulpwood chips	Bituminous coal
Logs and bolts	Gypsum
Other crude non-metals	Liquid sulphur
Crude mineral oil	Bauxite ore and alumina
Other waste & scrap materials	Nickel-copper ores & concentrates
Other metal-bearing ores, concentrates and crap	Limestone crushed or broken
Pulpwood logs	Pulpwood logs
Nursery & green house stock	
Copper ore concentrates & related material	
-	Zinc ore concentrates
-	Iron and steel scrap
-	Rape seed
-	Lignite coal
-	Logs and bolts of wood
-	Common salt, rock salt
-	Phosphate rock
-	Lead ore concentrate
-	Flaxseed
-	Natural abrasive

Table 4.4: EPI Composition for Truck and Rail

Truck	Rail
Passenger automobiles and chassis	Motor vehicle engines accessories, parts assemblies
Motor vehicle engines accessories, parts assemblies	passenger automobiles & chassis
Shipping and distribution containers & closures	Road motor vehicles
Paper and end-products	Toiletries, cleaning preparations & household chemicals
Drilling, excavating,	Railway rolling stock
Mining, oil & gas machinery	Household & personal equipment
Truck, truck chassis and truck tractors	-
Pneumatic tires	-
Other machinery classified by function	-
Other special industrial machinery construction & maintenance equipment	-
Other material handling equipment	-
Household furniture	-
Floor coverings	-
Electric equipment & appliances	-
Other printed matter	-
Cleaning and polishing preparations	-
Stationary and office paper supplies	-
Toilet preparations and cosmetics	-

4.4 Model Formulation & Calibration

The modal split in commodity transport is dependent on level of service of each mode. The commodity transport between two regions heavily depends on the origin-destination socio-economic characteristics. Thus, the commodity modal split can be written as,

$$V_{ijp} = f(O_i, D_j, L_1, L_2, L_3, ..., L_n) \quad (4.16)$$

where,

V_{ijp}	=	total volume of commodity from region i to j by mode p
O_i	=	socio-economic characteristics of origin i
D_j	=	socio-economic characteristics of destination j
$L_1, L_2, ..., L_n$	=	level of service characteristics of each mode
n	=	number of modes.

In the present research Statistical Analysis System (SAS) was used for statistical analysis of FFB&T, CMI & EPI data for the year 1992 (latest comprehensive data available). The selection and validation of the variables chosen is discussed in the following sections. ■

4.4.1 Model Formulation

Models assist in simplifying reality by providing a mathematical representation of it. Selection of appropriate variables is key to any meaningful mathematical representation of the reality. The main criteria to follow for selecting the independent variable are viz, strength of the independent variables in predicting the dependent variable, statistical significance of independent variables, and the ability to minimize the difference between computed model and actual data. In the present research eight significant variables were chosen commodity wise to determine the volume of freight (in tonnes) transported by the trucks. It has been observed that a high degree of multicollinearity existing between four pairs of variables chosen. Thus, at the supply side and demand sides the population and industrial index, and per capita and market index of the regions appeared to be highly correlated. Any results obtained by having highly correlated variables in the model cannot be considered for analysis. However, the effects of high degree of correlation can be reduced by multiplying the two variables which are correlated. This technique however masks the actual contribution of each variable in the model. This however does not hinder the application of modal split model for studying effects of the improvements in LOS characteristics by implementing ITS program.

The resulting statistical model for all three commodity sections is as follows,

$$\begin{aligned} V_{ijp} &= \alpha_0 \cdot (POP_i \times IND_i)^{\alpha_1} \cdot (PC_i \times MI_i)^{\alpha_2} \cdot TT_k^{\alpha_3} \cdot CO_k^{\alpha_4} \\ &\cdot (POP_j \times IND_j)^{\alpha_5} \cdot (PC_j \times MI_j)^{\alpha_6} \cdot TT_r^{\alpha_7} \cdot CO_r^{\alpha_8} \end{aligned} \tag{4.17}$$

V_{ijP} = volume by truck ($\times$ 1000 tonnes)

O_i: Supply available at origin region i

$POP_i \times IND_i$ = product of population (in thousands) and industrial index at origin

$PC_i \times MI_i$ = product of per capita income and market index at origin

D_j: Demand needed at destination region j

$POP_j \times IND_j$ = product of population (in thousands) and industrial index at

$PC_i \times MI_i$ = product of per capita income and market index at origin

L_k: Transportation service characteristics for trucking

TT_k = travel time by truck (days)

CO_k = user cost by truck ($/tonnes)

L_r: Transportation service characteristics for rail

TT_r = travel time by rail (days)

CO_r = user cost by rail ($/tonnes)

$\alpha_0, \alpha_1, ..., \alpha_8$ = coefficients derived by regression analysis.

■

4.4.2 Independent Variables

The underlying reasons for transportation are economic. It was proposed by Soliman and Gadi (1990) that modeling a transportation phenomenon can be done by considering underlying economic factors. Soliman and Gadi (1990) had developed modal split model with population, market index, industrial index, per capita and LOS factors of both rail and truck as independent variables. These same independent variables were used for model development using the 1992 data. Independent variables are discussed in detail by Gadi (1991). The data used in the model development is listed in *Appendix 3.* ■

4.5 Statistical Validity of Models

It is important to evaluate the validity of the models developed to have confidence in their power to describe the reality. It can be noticed from the coefficients of the parameters any increase in travel time or user travel cost of trucking will contribute to the decrease in the volume of that commodity transported by trucks. Also a positive sign for LOS attributes of rail indicates that any increase in them will increase the market share for trucks.

Several tests exist to determine the validity of a given model. Several different aspects of the model have to be checked for the overall strength of the model. For instance, to check the contribution of each variable in the model Mallow's C_p statistic, Mean Squared Error (MSE) and Maximum R^2 improvement tests were carried out. Analysis of Variance (ANOVA) was used to check the overall validity of the model. Statistically the least square procedure is valid only if the residuals are random variables with a mean zero and a constant variance (i.e., it has a *Gaussian or Normal distribution*). A thorough analysis of residuals was performed and the results are summarized below. ■

4.5.1 Analysis of Variance

The ANOVA for each commodity groups are summerized in Tables 4.5, 4.6 and 4.7. The model was validated using the F-test. The F statistic is obtained from the ratio of mean squared model and mean squared error. This calculated value of F exceeded the critical value corresponding to $\alpha = 0.001$ thus giving evidence against the null hypothesis (which is parameters in the model are equal to zero, $H_0 : \beta_i = 0$) at a level of significance of 99.99%. The P-value (significance value) suggests that the models are valid and adequately fit the data.

The R^2 values for the models are 80.67%, 80.43% and 93.10% for FFB&T, CMI and EPI respectively. As indicated before R^2 values measure the percentage of dependent variable explained by the independent variables.

The ANOVA table reveals that MSE value is low indicating the deviation between observed and calculated values is very small.

■

Table 4.5: FFB&T: Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F
Model	8	41.1818	5.14773	10.432	0.0001
Error	20	9.86907	0.49345		
C Total	28	51.0509			
R-square	0.8067				

Table 4.6: CMI: Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	8	110.2726	13.78409	10.27	0.0001
Error	20	26.83775	1.34189		
C Total	28	137.1104			
R-square	0.8043				

Table 4.7: EPI: Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	8	37.6809	4.71012	33.751	0.0001
Error	20	2.79112	0.13956		
C Total	28	40.4721			
R-square	0.9310				

Table 4.8: FFB&T: Parameter Estimates

Variable	Parameter Estimate	Standard Error	T for H_0 Parameter = 0	Prob> $\|T\|$
$ln(\alpha_0)$	-42.6824	36.364978	-1.17	0.0001
$POP_i \times IND_i$	0.240967	0.3108795	0.775	0.0001
$PC_i \times MI_i$	2.058727	1.7754047	1.144	0.0001
TT_k	-1.17682	1.7266228	-0.68	0.0001
CO_k	-1.90956	0.5249281	-3.63	0.0016
$POP_j \times IND_j$	0.392646	0.3150382	1.246	0.0001
$PC_j \times MI_j$	1.033564	1.7631421	0.586	0.0002
TT_r	0.045081	1.3155711	0.034	0.0568
CO_r	1.168671	2.0601977	0.567	0.0768

4.5.2 Parameter Estimates

The validity of each variable in the model was also determined. A T-test (the ratio of each parameter estimate to its standard error gives t-value based on null hypothesis (H_o)) was carried out for each variable for this purpose and as can be noticed from the following tables (Table 4.8 – Table 4.10) the probability of each parameter corresponding to each of the variables being zero is quite low. The probability values ranged from 0.0768 to 0.0001 for FFB&T; 0.0855 to 0.0001 for CMI; and 0.037 to 0.0001 for EPI. High confidence levels were noticed for most of the parameters except for cost and travel time for rail. ■

Table 4.9: CMI: Parameter Estimates

Variable	Parameter Estimate	Standard Error	T for H_0 Parameter = 0	Prob> $\|T\|$
$ln(\alpha_0)$	-116.0888	69.999722	-1.65	0.0001
$POP_i \times IND_i$	0.1724081	0.5811896	0.300	0.0001
$PC_i \times MI_i$	5.9854854	3.4286900	1.746	0.0001
TT_k	-5.131143	2.6183023	-1.96	0.0001
CO_k	-0.661323	0.6243892	-1.059	0.0001
$POP_j \times IND_j$	0.8702309	0.5892700	1.477	0.0001
$PC_j \times MI_j$	1.3927496	3.4463897	0.404	0.0001
TT_r	2.2429643	3.5489607	0.632	0.0534
CO_r	1.0335444	4.3725348	0.236	0.0855

Table 4.10: EPI: Parameter Estimates

Variable	Parameter Estimate	Standard Error	T for H_0 Parameter = 0	Prob> $\|T\|$
$ln(\alpha_0)$	-61.3858	19.8313841	-3.095	0.0001
$POP_i \times IND_i$	0.787455	0.15365180	5.125	0.0001
$PC_i \times MI_i$	0.905873	0.93440424	0.969	0.0001
TT_k	-2.07894	0.83710010	-2.484	0.0001
CO_k	-1.27275	0.42745357	-2.978	0.0001
$POP_j \times IND_j$	0.168827	0.15583945	1.083	0.0001
$PC_j \times MI_j$	3.442794	0.94774516	3.633	0.0017
TT_r	3.302504	0.95945869	3.442	0.0026
CO_r	0.963822	1.05425295	0.914	0.0037

4.5.3 Significance of Variables in the Model

The Figures 4.11, 4.14 and 4.17 depict Mallow's C_p Statistic for models developed for FFB&T, CMI and EPI commodity groups. Mallow's C_p gives a simple criteria for checking the model for overfitting and underfitting. The impact of underfitting a model results in a fixed bias in the important quantities, the regression coefficients, and the estimate of error variance. In case of overfitting the model it produces results involving variances that are larger than those for adequate model. Mallow's C_p Statistic is useful in detecting the unbiased model with just adequate parameters. For this the C_p values for all possible regression equations are plotted against number of parameters (P), and the models with little bias tend to fall near the ($C_p = P$) line. Models with considerable bias will fall away from this line. Noticing the figures the variable subsets with small C_p values also have small MSE values. Also it can be noticed that models having four variables considerably reduce the C_p values. Adding variables brings the C_p values closer to P. The second set of Figures 4.12, 4.15 and 4.18 for FFB&T, CMI and EPI respectively depict MSE which measures the degree of variance or deviation among the model parameters or variables in accurately predicting the dependent variable. The MSE plotted against number of parameters gives the reduction in standard deviation with the addition of variables. It was noticed that at four variable mark there is considerable reduction in MSE values and little reduction after that by the addition of next four variables. However, transportation characteristics like travel time and travel cost for both modes are very significant for further analysis for predicting the shift in model split by introducing ITS technologies. The third set of Figures 4.13, 4.16 and 4.19 for FFB&T, CMI and EPI respectively illustrate the maximum R^2 improvement with the number of parameters in the model. R^2 measures the percentage of dependent variable explained by independent variables. A dramatic improvement in the R^2 value

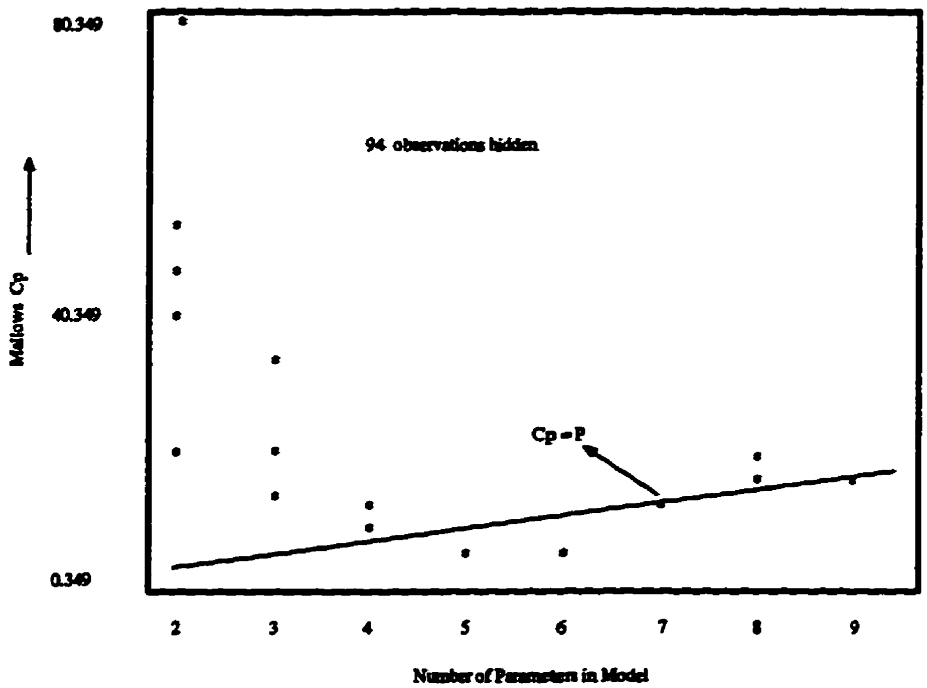

Figure 4.11: FFB&T: C_p Improvement With Number of Parameters in the Model

is noticed after inclusion of four variables and does not show much further improvement including four more variables. These variables specifically are LOS characteristics of truck and rail. However, it has to be noted that these characteristics have impact on modal split from earlier studies by Soliman and Gadi (1990).

A number of statistical tests were carried out to check the validity of the developed models and was found that the models developed are statistically sound (from t tests, F test, Mallow's C_p, R^2, MSE procedures). Also, none of the underlying assumptions of least square regression procedure were violated. Also, the previous studies done by Soliman and Gadi (1988) indicate that the eight independent variables selected in the model development are significant in truck freight volume estimation. The *expert system* refinement with the application of new technologies can be applied to these models for determining any changes in the modal split between trucking and railway industry. ■

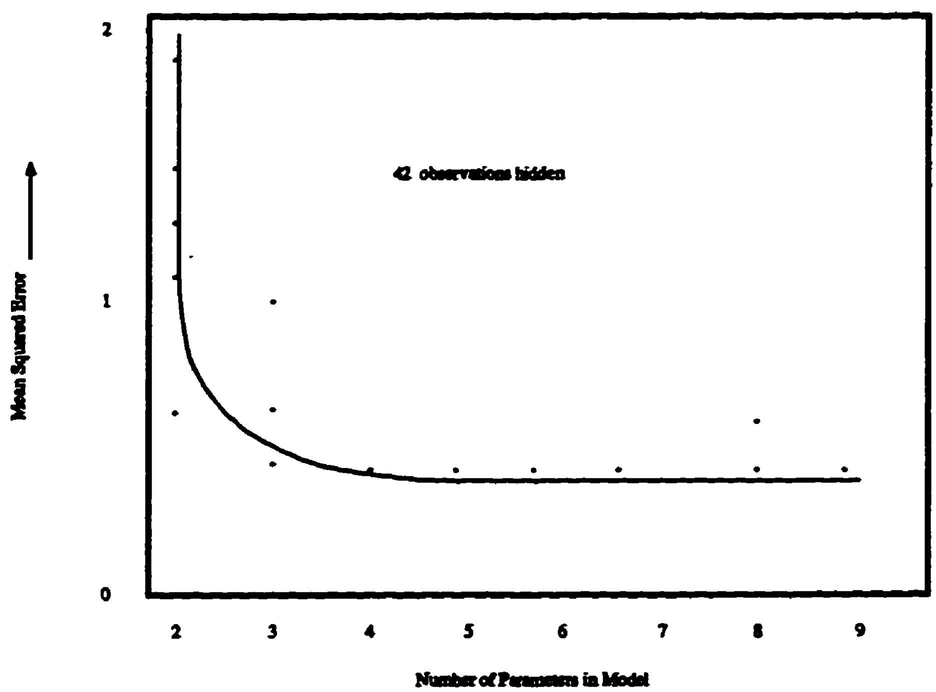

Figure 4.12: FFB&T: Mean Squared Error Improvement With Number of Parameters in the Model

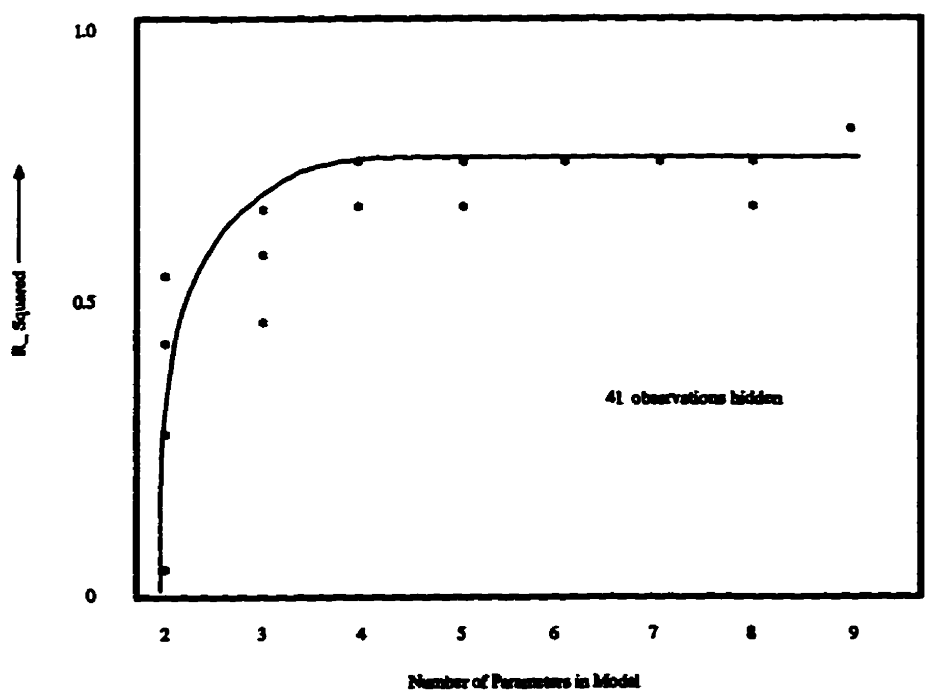

Figure 4.13: FFB&T: Maximum R^2 Improvement With Number of Parameters in the Model

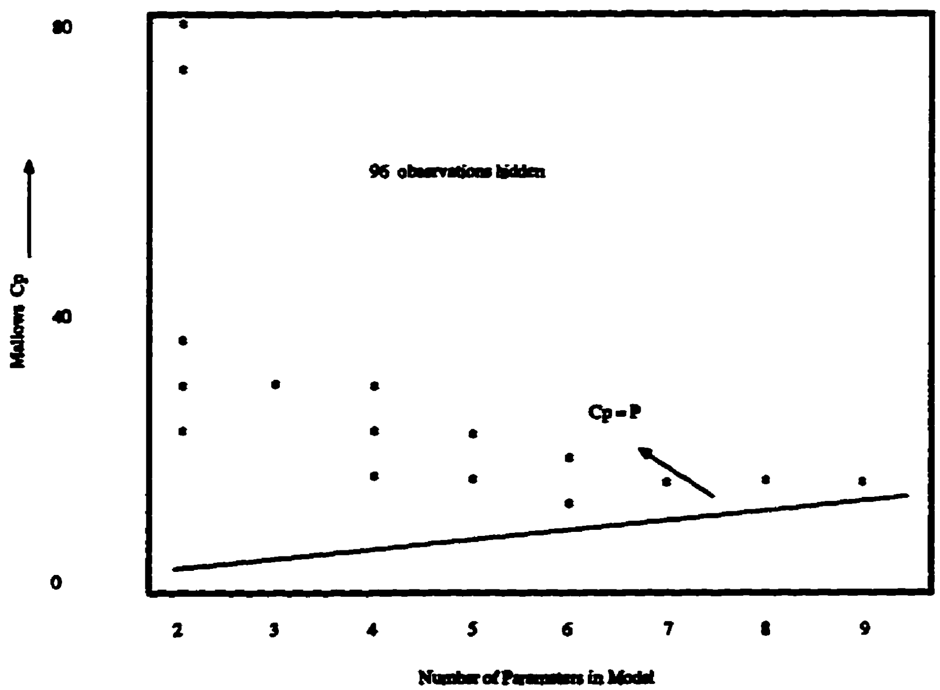

Figure 4.14: CMI: C_p Improvement With Number of Parameters in the Model

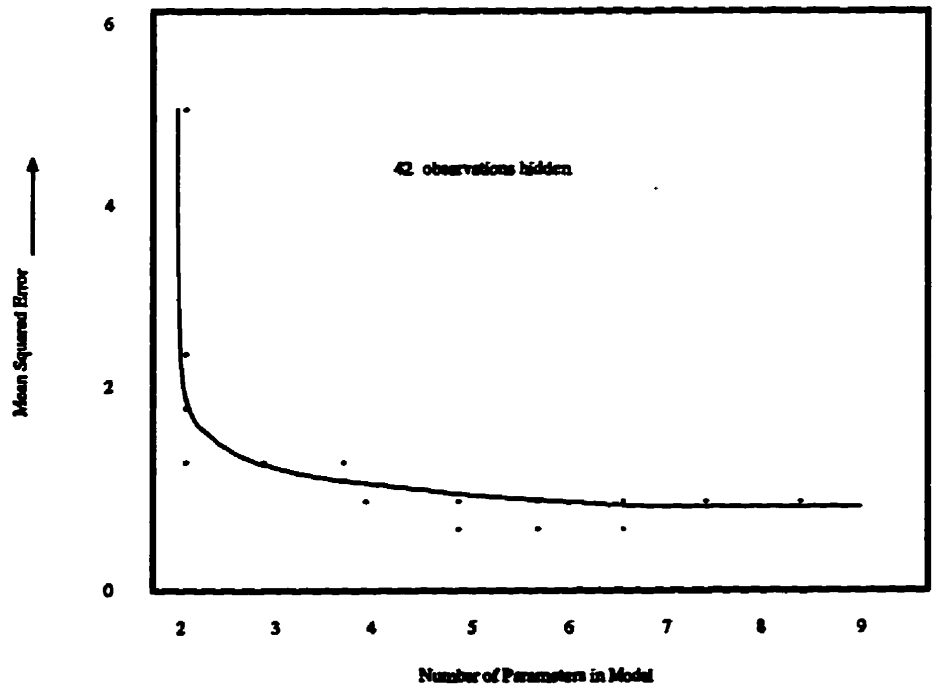

Figure 4.15: CMI: Mean Squared Error Improvement With Number of Parameters in the Model

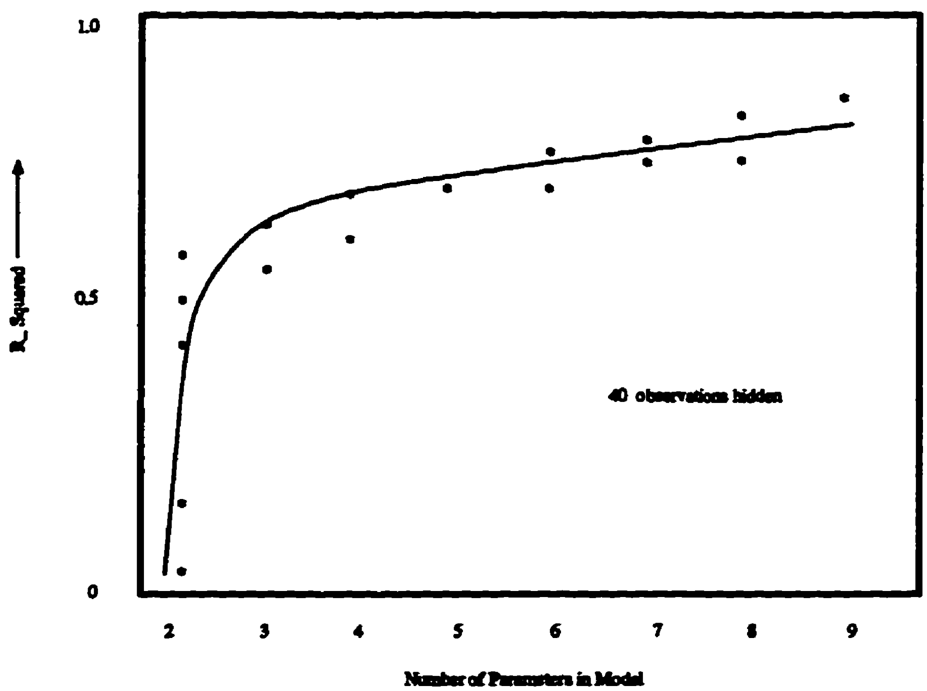

Figure 4.16: CMI: Maximum R^2 Improvement With Number of Parameters in the Model

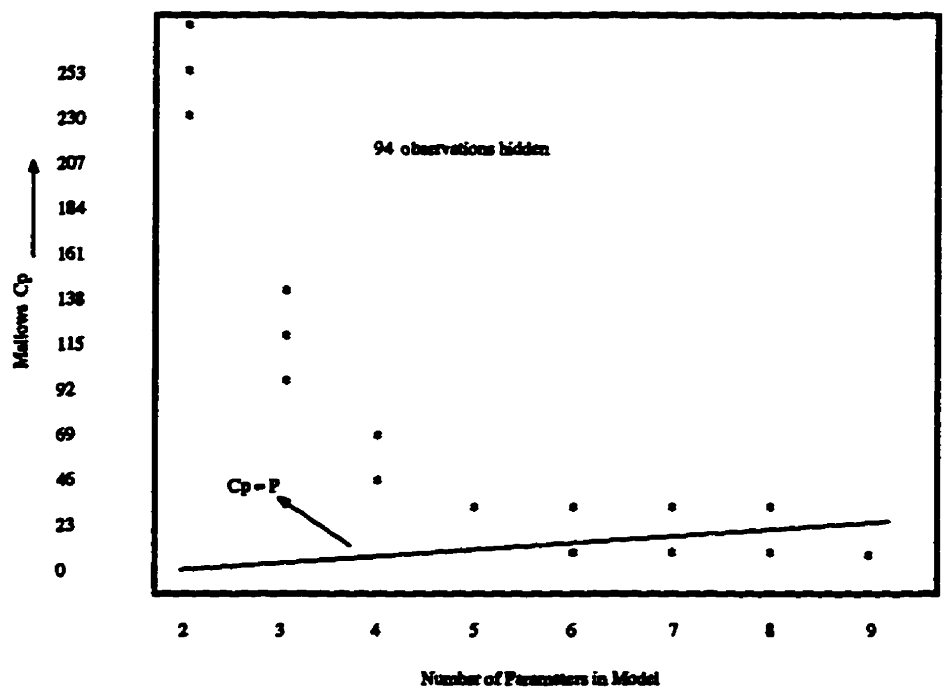

Figure 4.17: EPI:C_p Improvement With Number of Parameters in the Model

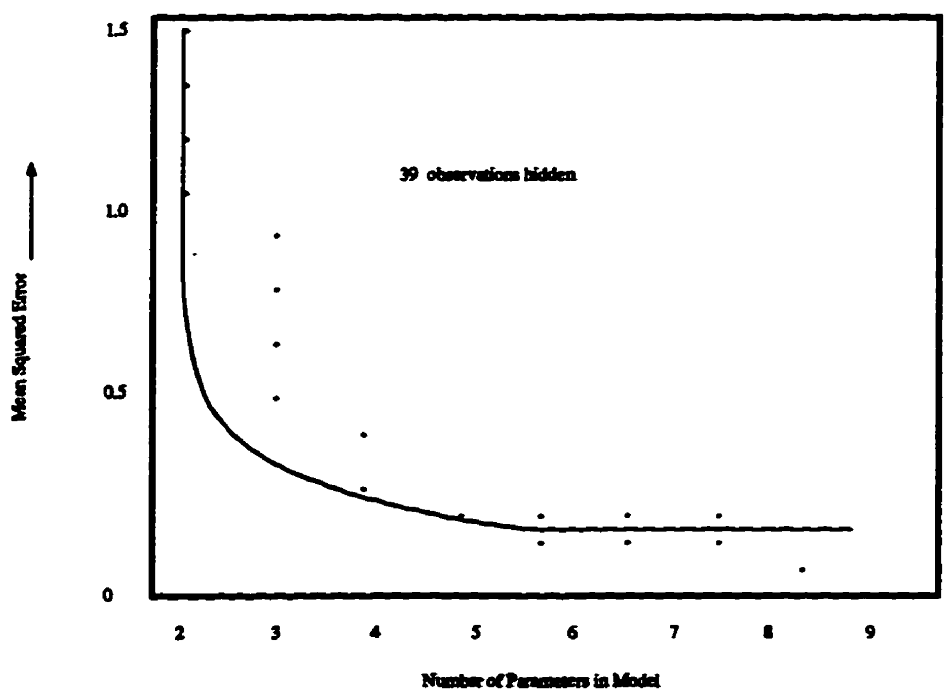

Figure 4.18: EPI: Mean Squared Error Improvement With Number of Parameters in the Model

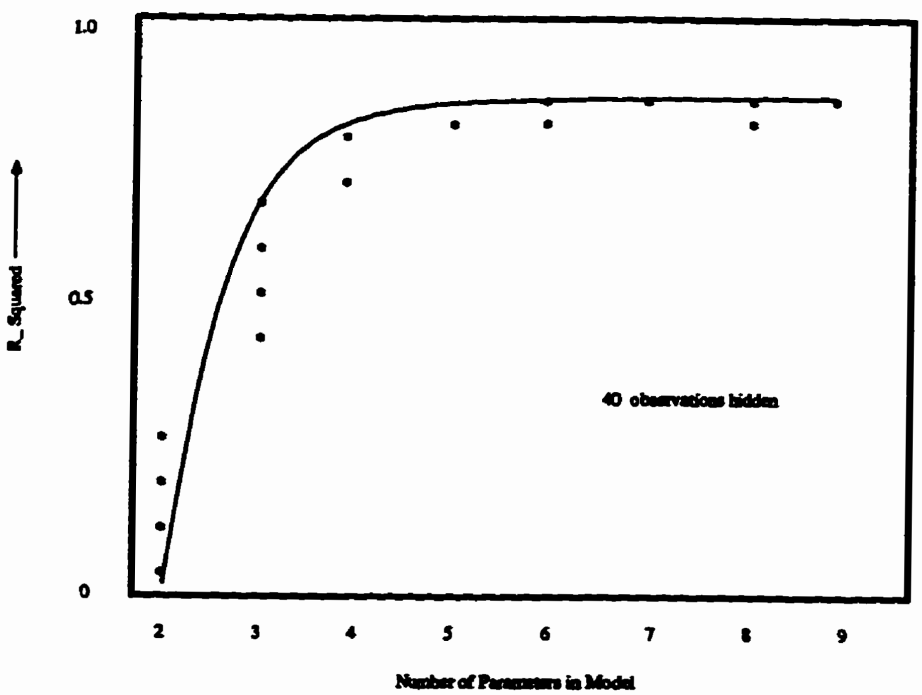

Figure 4.19: EPI: Maximum R^2 Improvement With Number of Parameters in the Model

4.5.4 Residual Analysis

The statistical model developed earlier was checked by testing if any fundamental assumptions underlying the use of least squares method are not violated. The assumptions are: the residuals are random variables; they are normally distributed; have a mean zero; and have constant variance. If the model is appropriate for the data at hand, the observed residuals should reflect these assumptions.

For the three developed models, residual analysis was carried out. First to check the randomness of the residuals (constant variance), the residuals are plotted against predicted values. The results as can be seen from the Figures 4.20, 4.21 and 4.22, show that the residuals are truly random and do not exhibit any pattern.

The *univariate analysis* is carried out (Figures 4.23, 4.24 and 4.25) and is divided into two parts. The output of SAS gives descriptive statistics at the top and graphical depiction at the bottom. The top left hand corner gives the summary of measures of skewness, kurtosis and mean of the residuals. As an illustration the values given in FFB&T are used to describe the residual analysis.

From the table it can be noticed that skewness and kurtosis are -0.013911 and -0.00852 respectively. Also the mean is equal to 0 and median 0.02676. Both of these statistic sets indicate that the residual distribution is close to normal distribution. The right hand side statistics named as quantiles which indicates the spread of the data about the center. Thus $Q1$ gives the 25% of data below the median and $Q3$ gives 25% of data above the median.

The graphical part of the univariate output consists the *stem and leaf plot*, *box-plot* and *normal probability plot*. The stem and leaf plot shows the shape of residual distribution. As can be noticed the plot is quite close to *normal distribution* bell curve. The box-plot depicts the quantiles of the distribution with the line in the middle indicating the median. The + located at the 50^{th} percentile indicates mean. If the mean and median are same, the + falls on the median line across the box indicating a normal distribution. This can be seen in the Figure 4.23. Finally the normality of the distribution can be seen from the normal probability plot, where plus signs indicate the straight line and asterisk signs the residuals. The straight line indicates normality of the residuals. Durbin-Watson autocorrelation procedure was used to check correlation of the residuals and was found that no autocorrelation exists at 95% confidence.

■

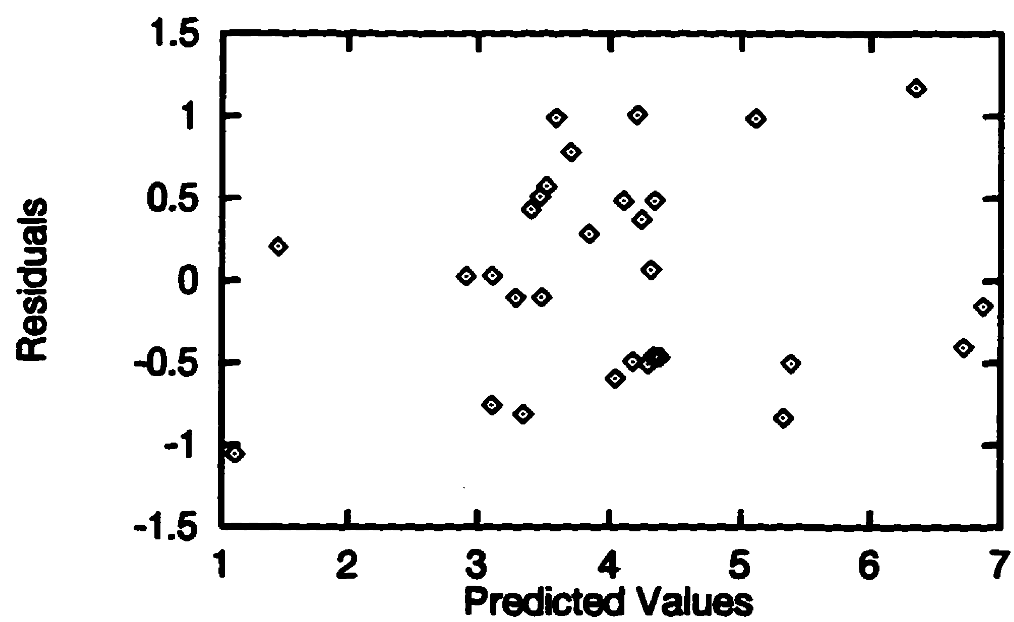

Figure 4.20: FFB&T: Residual Plot

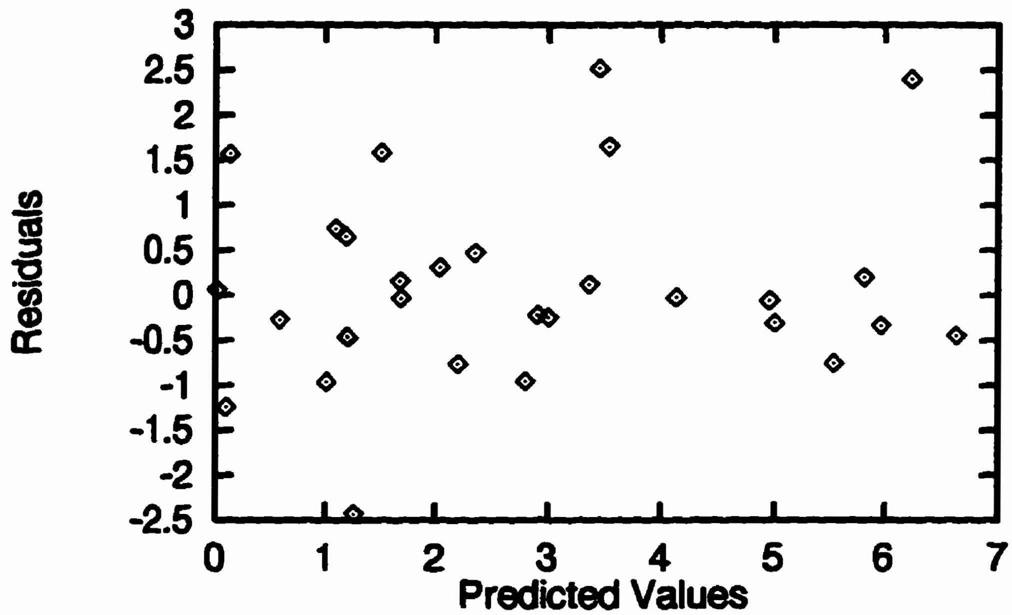

Figure 4.21: CMI: Residual Plot

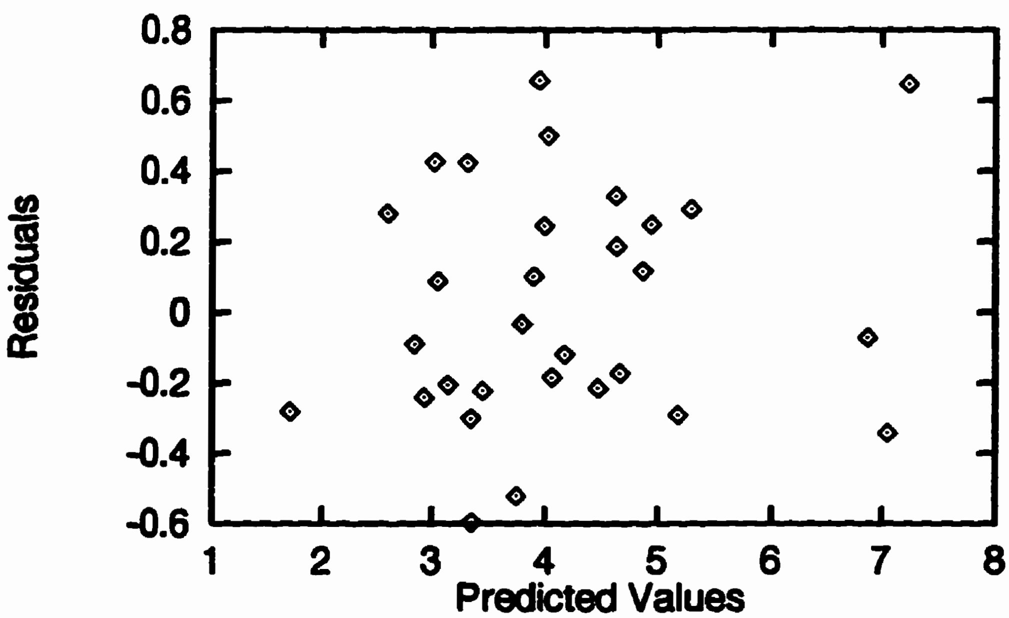

Figure 4.22: EPI: Residual Plot

```
Variable=RESID          Residual

                  Moments                                          Quantiles(Def=5)

N              29   Sum Wgts          29      100% Max  1.006758        99%  1.006758
Mean            0   Sum                0       75% Q3    0.48555        95%  0.992025
Std Dev  0.593689   Variance    0.352467       50% Med  0.026767        90%  0.984913
Skewness 0.013911   Kurtosis    -0.00852       25% Q1   -0.48875        10%  -0.81142
USS      9.869068   CSS         9.869068        0% Min  -1.05532         5%  -0.83471
CV              .   Std Mean    0.110245                                 1%  -1.05532
T:Mean=0        0   Pr>|T|        1.0000      Range     2.062076
Num ^= 0       29   Num > 0           15      Q3-Q1     0.974302
M(Sign)       0.5   Pr>=|M|       1.0000      Mode      -1.05532
Sgn Rank     -4.5   Pr>=|S|       0.9245
W:Normal 0.955042   Pr<W          0.2790

                                  Extremes

                   Lowest    Obs     Highest    Obs
                 -1.05532(     3)  0.573032(     15)
                 -0.83471(    24)  0.780358(      9)
                 -0.81142(    26)  0.984913(     25)
                 -0.75593(    17)  0.992025(     28)
                 -0.59288(     4)  1.006758(     13)

      Stem Leaf                      #             Boxplot
        10 1                         1                |
         8 89                        2                |
         6 8                         1                |
         4 39917                     5             +-----+
         2 187                       3             |     |
         0 337                       3             *--+--*
        -0 600                       3             |     |
        -2                                         |     |
        -4 9109660                   7             +-----+
        -6 6                         1                |
        -8 31                        2                |
       -10 6                         1                |
           ----+----+----+----+
      Multiply Stem.Leaf by 10**-1


                          Normal Probability Plot
   1.1+                                                   ++**
      |                                               *+*
      |                                            *+*
      |                                       **+***
      |                                     *+**
      |                                  *+**
      |                               ***
      |                            *+**
      |                        ****+***
      |                     +**
      |                  *+**
  -1.1+              *+**
       +----+----+----+----+----+----+----+----+----+----+
           -2        -1         0        +1        +2
```

Figure 4.23: FFB&T: Univariate Analysis

```
Variable=RESID          Residual

                    Moments                                        Quantiles(Def=5)

N                29  Sum Wgts        29        100% Max  2.515108        99%   2.515108
Mean              0  Sum              0         75% Q3   0.308985        95%    1.65205
Std Dev    0.979026  Variance  0.958491         50% Med  -0.05713        90%   1.578992
Skewness   0.036072  Kurtosis  0.014055         25% Q1   -0.46548        10%   -0.96583
USS        26.83775  CSS       26.83775          0% Min  -2.42799         5%   -1.24165
CV                .  Std Mean    0.1818                                   1%   -2.42799
T:Mean=0          0  Pr>|T|      1.0000        Range     4.943093
Num ^= 0         29  Num > 0         12        Q3-Q1      0.77447
M(Sign)        -2.5  Pr>=|M|     0.4583        Mode      -2.42799
Sgn Rank      -24.5  Pr>=|S|     0.6050
W:Normal    0.94941  Pr<W        0.2021

                                  Extremes

                      Lowest    Obs     Highest    Obs
                   -2.42799(     15)  0.738557(      8)
                   -1.24165(      5)  1.563223(      4)
                   -0.96583(     16)  1.578992(     28)
                   -0.95773(     29)   1.65205(     23)
                   -0.76716(     27)  2.515108(     12)

        Stem Leaf                     #          Boxplot
           2 5                        1             0
           2
           1 667                      3             0
           1
           0 567                      3             |
           0 11223                    5          +-----+
          -0 433322100                9          *--+--*
          -0 8855                     4          +-----+
          -1 200                      3             |
          -1
          -2 4                        1             0
             ----+----+----+----+
         Multiply Stem.Leaf by 10**-1

                    Normal Probability Plot
  2.75+                                                 *
       |                                              * ++++++
       |                                         **  ++**+
       |                                        +***
       |                                    ++**
  0.25+                               ++++*****  *
       |                         * *********
       |                   ******++
       |                ++****
       |            ***+*
 -2.25+*****+*
        +----+----+----+----+----+----+----+----+----+----+
            -2        -1         0        +1        +2
```

Figure 4.24: CMI: Univariate Analysis

```
Variable=RESID          Residual

                 Moments                                    Quantiles(Def=5)

N                29  Sum Wgts        29        100% Max   0.655681       99%   0.655681
Mean              0  Sum              0         75% Q3    0.247918       95%   0.500561
Std Dev    0.315726  Variance  0.099683         50% Med  -0.07244        90%   0.425789
Skewness   0.031076  Kurtosis  -0.02644         25% Q1   -0.22318        10%  -0.34243
USS        2.791119  CSS       2.791119          0% Min  -0.59623         5%  -0.52161
CV                .  Std Mean  0.058629                                   1%  -0.59623
T:Mean=0          0  Pr>|T|      1.0000        Range      1.251911
Num ^= 0         29  Num > 0         13        Q3-Q1      0.471097
M(Sign)        -1.5  Pr>=|M|     0.7111        Mode      -0.59623
Sgn Rank        0.5  Pr>=|S|     0.9916
W:Normal   0.968879  Pr<W        0.5681

                                   Extremes

                        Lowest    Obs      Highest    Obs
                      -0.59623(     3)  0.32875(      7)
                      -0.52161(    29)  0.424932(     2)
                      -0.34243(     1)  0.425789(    28)
                      -0.30051(    18)  0.500561(    14)
                      -0.29132(    24)  0.655681(    13)

          Stem Leaf                    #             Boxplot
             6 6                       1                |
             5 0                       1                |
             4 23                      2                |
             3 3                       1                |
             2 45                      2             +-----+
             1 029                     3             |     |
             0 945634                  6             |  +  |
            -0 973                     3             *-----*
            -1 872                     3             |     |
            -2 984                     3             +-----+
            -3 40                      2                |
            -4                                          |
            -5 2                       1                |
            -6 0                       1                |
               ----+----+----+----+
          Multiply Stem.Leaf by 10**-1


                      Normal Probability Plot
  0.65+                                                  +++
      |                                               *++++
      |                                            **+++*
      |                                          *+++*
      |                                      **+**
      |                                    **++*
      |                                 **++*
      |                               **+++*
      |                             *+++*
      |                         ***+***
      |                       ***+*
      |                     **+*
      |                   **+*
      |                 **+*
 -0.65+              *++*
       +----+----+----+----+----+----+----+----+----+----+
```

Figure 4.25: EPI: Univariate Analysis

Chapter 5

Modeling Expert Opinion Using Approximate Reasoning

Human decision-making process is a very complex task, involving many faculties of human brain interacting with each other producing a final result. The actual process itself consists of many sub-processes evaluating uncertain data sometimes producing a discrete decision. This uncertainty could be due to randomness in the events involved or lack of information regarding the event under investigation. Expert system building, especially involving forecasting the future trends of new technology in market place, requires special handling. The problem is difficult because of lack of previous studies and real world implementation of new technology.

The research focuses on developing a framework for modeling decision process of an expert using the concepts of fuzzy set theory, approximate reasoning and fuzzy control.

5.1 Decision Making

Each expert differs with other experts in arriving at a solution for freight transportation problem depending on individual expert's background. Different solutions may be offered depending upon whether an expert is a commercial vehicle operator or owner(CVOO) or a government's transportation planner or an academician. Opinions expressed by a CVOO whose geographical area of operation restricted to Québec on time and cost savings of freight operations in B.C. cannot be assigned the same weight as CVOO operating in B.C. Fuzzy set theory and approximate reasoning is utilized to interpret linguistic descriptors used to answer many of the questions. ■

5.1.1 Rules for Approximate Reasoning

As stated before, decision-making is a multi-stage process and is strongly influenced by the professional background of decision maker. In order to bring uniformity in interpretation of the expert responses each expert is assigned a factor (*expert factor*) which will assist in estimating the degree of confidence in his/her estimation of *time* and *cost* savings. The expert factor λ is determined by a set of rules based on the responses given by experts. The rules in the rule base have the general form "IF ... THEN ...", where the left hand side of the rule is some query relating to field of expertise and right hand side corresponding expert factor assigned. As an example, considering the question two in advanced vehicle identification (AVI) technology questionnaire (Appendix 2). If the answer to this question is all the six provinces under consideration, a grade of '*VI*' is assigned. If the person operates in five provinces, a grade of '*V*' is assigned together with a note regarding the province which does not fall under his field of operation. Any decision or recommendation regarding this province by this particular expert will be weighed according to the *expert factor* $\lambda \in \mathbf{X}$ (where, $\mathbf{X}$ is a universal set).

This section gives a sample rule base which assigns grades for each response and some other preliminary tasks for advanced vehicle identification (AVI) technology impact on road transport efficiency. For the rule base for weigh-in-motion (WIM) and advanced vehicle location (AVL) technologies refer to *Appendix 1*. The *Appendix 1* also gives a general *inference engine* that can be used for determining the *expert factor*. The rule base is based on the sample questionnaire on each of the above mentioned technologies. For sample questionnaire please refer to *Appendix 2*.

```
RULE 9999
            IF          QUET(1) IS YES
THEN                    PROCEED TO RULE BASE 0991
         ELSE           PROCEED TO RULE BASE 0992

RULE BASE 09919
SUB RULE 01019
            IF          QUET(2) COUNT IS 6
THEN                    ASSIGN GRADE1 VI TO ESQ#**** AND GREP PROVS
         ELSE IF        QUET(2) COUNT IS 5
THEN                    ASSIGN GRADE1 V TO ESQ#**** AND GREP PROVS
         ELSE IF        QUET(2) COUNT IS 4
THEN                    ASSIGN GRADE1 IV TO ESQ#**** AND GREP PROVS
         ELSE IF        QUET(2) COUNT IS 5
THEN                    ASSIGN GRADE1 III TO ESQ#**** AND GREP PROVS
         ELSE IF        QUET(2) COUNT IS 5
THEN                    ASSIGN GRADE1 II TO ESQ#**** AND GREP PROVS
         ELSE IF        QUET(2) COUNT IS 5
THEN                    ASSIGN GRADE1 I TO ESQ#**** AND GREP PROV

SUB RULE 01029
            IF          QUET(3) RESP IS > 25%
THEN                    ASSIGN GRADE2 V TO ESQ#****
         ELSE IF        QUET(3) RESP IS 15-25%
THEN                    ASSIGN GRADE2 IV TO ESQ#****
         ELSE IF        QUET(3) RESP IS 5-10%
THEN                    ASSIGN GRADE2 III TO ESQ#****
         ELSE IF        QUET(3) RESP IS < 5%
THEN                    ASSIGN GRADE2 II TO ESQ#****
         ELSE IF        QUET(3) RESP IS 0%
THEN                    ASSIGN GRADE2 I TO ESQ#****
```

```
SUB RULE 01039
          IF       QUET(5) IS HM
THEN               ASSIGN NULL TO ESQ#****
       ELSE        GREP THE COMDTY

SUB RULE 01049
          IF       QUET(7) RESP IS VP
THEN               ASSIGN GRADE4 IV TO ESQ#****
       ELSE IF     QUET(7) RESP IS STF
THEN               ASSIGN GRADE4 III TO ESQ#****
       ELSE IF     QUET(7) RESP IS NC
THEN               ASSIGN GRADE4 II TO ESQ#****
       ELSE IF     QUET(7) RESP IS NEG
THEN               ASSIGN GRADE4 I TO ESQ#****

SUB RULE 01059
          IF       QUET(9) RESP IS 1-2 YEARS
THEN               ASSIGN GRADE5 IV TO ESQ#****
       ELSE IF     QUET(9) RESP IS 3 YEARS
THEN               ASSIGN GRADE5 III TO ESQ#****
       ELSE IF     QUET(9) RESP IS 5 YEARS
THEN               ASSIGN GRADE5 II TO ESQ#****
       ELSE IF     QUET(9) RESP IS > 5 YEARS
THEN               ASSIGN GRADE5 I TO ESQ#****

SUB RULE 01069
          IF       QUET(10) RESP IS YES
THEN               NO ACTION
       ELSE        NULLIFY RULE 01039
```

RULE BASE 0992

SUB RULE 02019

	IF	QUET(7) RESP IS VP
THEN		ASSIGN 1GRADE IV TO ESQ#****
	ELSE IF	QUET(7) RESP IS STF
THEN		ASSIGN 1GRADE III TO ESQ#****
	ELSE IF	QUET(7) RESP IS NC
THEN		ASSIGN 1GRADE II TO ESQ#****
	ELSE IF	QUET(7) RESP IS NEG
THEN		ASSIGN 1GRADE I TO ESQ#****

SUB RULE 02029

	IF	QUET(9) RESP IS 1–2 YEARS
THEN		ASSIGN 2GRADE IV TO ESQ#****
	ELSE IF	QUET(9) RESP IS 3 YEARS
THEN		ASSIGN 2GRADE III TO ESQ#****
	ELSE IF	QUET(9) RESP IS 5 YEARS
THEN		ASSIGN 2GRADE II TO ESQ#****
	ELSE IF	QUET(9) RESP IS > 5 YEARS
THEN		ASSIGN 2GRADE I TO ESQ#****

ABBREVIATIONS

QUET(I) ...	QUESTION(1) ... FROM QUESTIONNAIRE
GREP	GRASP
PROV	PROVINCE
RESP	RESPONSE
HM	HAZARDOUS MATERIAL
COMDTY	COMMODITY TYPE
VP	VERY POSITIVE
STF	SATISFACTORY
NC	NO CHANGE
NEG	NEGATIVE

The previous step resulted in a fuzzy descriptor for each response in terms of membership functions. However, these descriptors do not convey much information alone if one has to determine the expertise of individual experts. This can be resolved by creating another set of rules to assign weight to each question in the questionnaire in determining the *expert factor* (λ),

Table 5.11: Fuzzy Reasoning

Premise 1		*if R(1) is A then* Γ_1 is Ω_1
Premise 2		*if R(2) is B then* Γ_2 is Ω_2
...		...
...		...
Premise i		*if R(i) is N then* Γ_i is Ω_k
Conclusion	$\longrightarrow$	*Inference Engine* $\Longrightarrow \lambda$
R(1), R(2),	...,	*R(i)* = *expert response to Quet(1), Quest(2), ...*
A, B, C	...,	*N* = *subjective descriptors*
$\Gamma_1, \Gamma_2, \Gamma_3$	...,	Γ_i = *expert descriptor*
$\Omega_1, \Omega_2, \Omega_3$	...,	Ω_1 = *decision factor to determine expert factor*

The *inference engine* consists of an aggregation process assigning weights to various questions. However, this procedure is bound to encounter trouble because not all of the responses to the questionnaire are crisp. In other words, several questions in the questionnaire are subjective. Subjective responses, though put forth in a limited fashion (i.e. restricted to very good, good, no change, negative etc.). However, there are infinite number of ways for expressing an opinions. These shades of opinions have to be taken into account for effective decision-making. Decision-making (regarding the expertise) is akin to summarization of a story. Here the expert system (computer running expert system) is expected to grasp the overall picture regarding an expert depending upon his responses. These responses not necessarily being crisp the binary logic driven computers fail to infer correctly the *'expertise'* of expert. However, a human expert analyzing the data is able to filter away certain responses, unconsciously assign weights to particular questions and come to a decision regarding the *'expertise'*. The process of inference is to some extent mimicked by something called *approximate reasoning*. The crux of information processing of decision making process lies in the approximate reasoning concept which allows flexible rule interpretation, as well as rule adjustments, and distinguishes itself from traditional exhaustive rule-based expert systems.

Considering the question seven of questionnaire pertaining to AVI technologies, the possible responses are: Exceptional (E), Very Good (VG), Satisfactory (S), No Change (NC), Negative (N). Thus, in this case: $A^j \varepsilon E, VG, S, NC, N$ as demonstrated in Figure 5.26. A response 'Good' falls somewhere in between Very Good and Satisfactory. In other words, the current input of response could be something that does not coincide with any of the categories described above; rather it is likely to overlap with more than one responses given above. Thus, the current input can be considered to belong to a set Ξ. Each of Ξ belongs to different sets with different degrees of membership. Accordingly, there are changes in the premises and necessitate changes in *Inference Engine*. This can be depicted as in Table 5.12.

Approximate reasoning concept was utilized to derive the rules that do not correspond exactly to the rules stipulated. In other words the rule can be used even if the premise is only partially true, and Ω_k * is changed accordingly. The membership function of Ω_k, is *composition* of Ξ^j and the fuzzy relation $A \longrightarrow \Omega_k$ ($\mu_{\Omega_k} = \mu_{\Xi} \cdot \bigcirc \mu_{A \longrightarrow \Omega_k}$). Using correlation product encoding scheme (Kosko, 1992)) the membership function of Ω_k is

*i = Corresponding premise; k = Inference corresponding to premise i; j = Current input to the problem.

Table 5.12: Approximate Reasoning

Premise 1	*if R(1) is* A^1 *then* Γ_1 *is* Ω_1
Premise 2	*if R(2) is* A^2 *then* Γ_2 *is* Ω_2
...	...
...	...
Premise 7	*if R(7) is* A^7 *then* Γ_7 *is* Ω_7
Premise $\acute{7}$	*if R(7) is* Ξ^7
	Γ_7 *is* Ω_7^*
Premise 8	*if R(8) is A then* Γ_8 *is* Ω_8
Premise $\acute{8}$	*if R(8) is* Ξ^8
	Γ_8 *is* Ω_8^*
...	...
...	...
Premise i	*if R(i) is N then* Γ_i *is* Ω_k
Conclusion $\longrightarrow$	*Inference Engine** $\Longrightarrow \lambda$

determined, which is,

$$\mu_{\Omega_k}(\gamma) = \beta \cdot \mu_{\Omega_k}(\gamma) \tag{5.18}$$

where β is the degree with which A and ξ^* overlap given by their max-min composition.

$$\beta = max_{r\epsilon R} min(\mu_{\Xi}(r), \mu_A(r)) \tag{5.19}$$

The new inference thus obtained by input vector is then used to infer the expert factor. The value of λ is determined using *inference engine* rather than *fuzzy reasoning* because of necessity of assigning weights to various responses (the expert factor can be scaled either 1 to 10 scale or 1 to 100 scale). Thus, the expertise supported by different rules is considered in the determination λ for each expert. The weights are used to measure the applicability of a specific premise given the information provided. Weights in this case depend on subjective

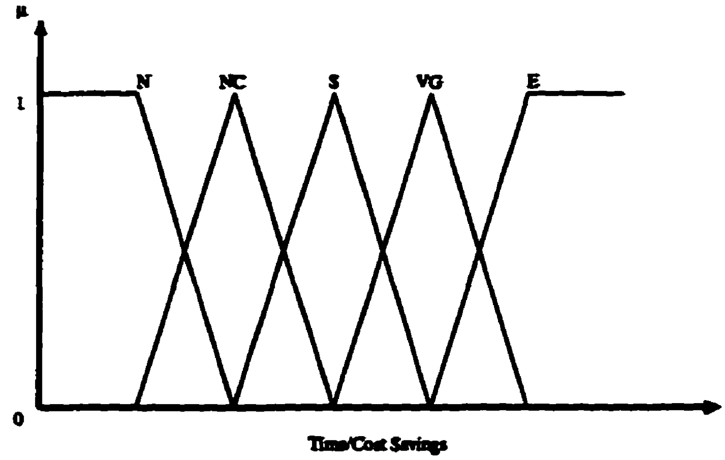

Figure 5.26: Membership Function for Technology Impact

decisions made by expert evaluator (a sample *inference engine* is given in *Appendix 1*). ■

5.2 Reasoning the Expert Opinion

After determining the λ, the next step is quantifying the expert opinion on *level of service* improvement that can be obtained by various technologies. Question number twelve (*Appendix 2*) for AVI technologies queries, "whether a 9.0% savings in travel cost and 6.5% savings in travel time can be expected by implementing AVI technologies in the transport of FFB&T?" The responses to this query can vary from expert to expert. The responses can range from 'benefits far exceeds the percentage quoted' to 'the percentage grossly exaggerates the expected benefits'. Finally expert opinion can be categorized as follows,

. Highly concur with % savings (π_1)

. Estimate is slightly higher % (π_2)

. Estimate is slightly lower % (π_3)

- Estimate is grossly over the % savings (π_4)
- Estimate is grossly under the % savings (π_5)

Fuzzy expert system use a collection of fuzzy membership functions and rules to reason about data. The rules of fuzzy expert system in this case are established as follows,

1. If λ is high and ρ_f is π_1 then τ_n is high
2. If λ is high and ρ_f is π_2 then τ_n is high
3. If λ is high and ρ_f is π_3 then τ_n is high
4. If λ is high and ρ_f is π_4 then τ_n is high
5. If λ is high and ρ_f is π_5 then τ_n is high
6. If λ is satisfactory and ρ_f is π_1 then τ_n is medium high
7. If λ is satisfactory and ρ_f is π_2 then τ_n is medium high
8. If λ is satisfactory and ρ_f is π_3 then τ_n is medium high
9. If λ is satisfactory and ρ_f is π_4 then τ_n is medium high
10. If λ is satisfactory and ρ_f is π_5 then τ_n is medium high
11. If λ is fair and ρ_f is π_1 then τ_n is medium
12. If λ is fair and ρ_f is π_2 then τ_n is medium
13. If λ is fair and ρ_f is π_3 then τ_n is medium
14. If λ is fair and ρ_f is π_4 then τ_n is medium

15. If λ is fair and ρ_f is π_5 then τ_n is medium

16. If λ is poor and ρ_f is π_1 then τ_n is low

17. If λ is poor and ρ_f is π_2 then τ_n is low

18. If λ is poor and ρ_f is π_3 then τ_n is low

19. If λ is poor and ρ_f is π_4 then τ_n is low

20. If λ is poor and ρ_f is π_5 then τ_n is low

where, λ, ρ_f and τ_n[†] are elements of fuzzy sets $\tilde{D}$, $\tilde{E}$ and $\tilde{F}$ respectively. 'High', 'satisfactory', 'fair', 'poor' etc. are expressed by the following fuzzy sets, $\mu_{\tilde{D}}(\lambda)$, $\mu_{\tilde{E}}(\rho_f)$, $\mu_{\tilde{F}}(\tau_n)$.

$$\mu_{\tilde{D}}(\lambda) = \begin{cases} 1, \lambda = 10 \\ \mathcal{Z} \cdot \lambda e^{(\mathcal{M}\lambda + \mathcal{Q})}, 0 \leq \lambda \leq 10 \\ 0, \lambda = 0 \end{cases} \tag{5.20}$$

$$\mu_{\tilde{E}}(\rho_c) = \begin{cases} 1, \rho_c = 10\% \\ \mathcal{O} \cdot \rho_c e^{(\mathcal{W}\rho_c + \mathcal{S})}, 0 \leq \rho_c \leq 10\% \\ 0, \rho_c = 0 \end{cases} \tag{5.21}$$

and

$$\mu_{\tilde{E}}(\rho_t) = \begin{cases} 1, \rho_t = 6.5\% \\ \mathcal{R} \cdot \rho_t e^{(\mathcal{A}\rho_t + \mathcal{B})}, 0 \leq \rho_t \leq 6.5\% \\ 0, \rho_t = 0 \end{cases} \tag{5.22}$$

The limits proposed here are possible ranges of scaled λ and estimated percentage of cost savings (ρ_c) and time savings (ρ_t) by implementing AVI technologies. The shapes of membership functions $\mu_{\tilde{D}}(\lambda)$ and $\mu_{\tilde{E}}(\rho_f)$ can obtained from the above equations[‡] .

[†] λ = expert factor, ρ_f = expert opinion on travel cost (c) or travel time (t) savings, τ_n = weight of expert opinion corresponding to both cost and time; also λ and ρ_f are input variables, τ_n is output variable.

[‡] $\mathcal{Z}$, $\mathcal{M}$, $\mathcal{Q}$; $\mathcal{O}$, $\mathcal{W}$, $\mathcal{S}$; and $\mathcal{R}$, $\mathcal{A}$, $\mathcal{B}$, are constants

The first step in fuzzy reasoning is fuzzification subprocess. The membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule of premise. The degree of truth for a rule's premise is referred here as α_i. If the rule's premise has a non-zero degree of truth the rule is said to *fire*. This can be depicted as follows,

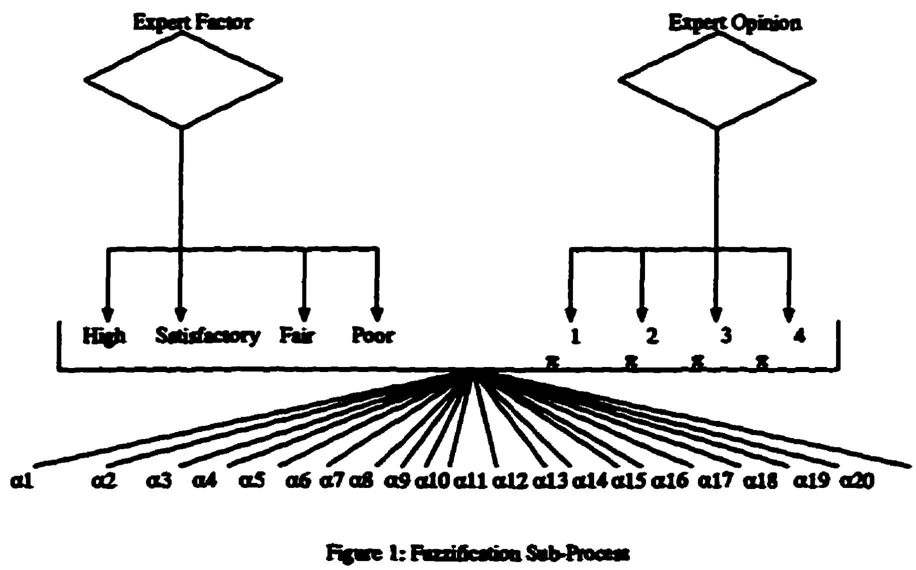

Figure 5.27: Fuzzification Sub-Process

For example, consider $\lambda = 10$, ρ_c (cost saving) $= 9.0\%$ the truth in the following descriptors for λ and ρ_c can be written as depicted in Table 5.13. The first rule of premise is, "if λ is high and ρ_f is π_1 then τ_n is high". According to the fuzzification process it will result in α_1 value of '1.00', α_2 value of '0.90', α_3 value of 0.80, α_4 value of '0' and α_5 value of '0' and so on. In other words, α_i is obtained from intersection of truth or membership values of $\mu_{\tilde{A}}(\lambda)$ and $\mu_{\tilde{B}}(\rho_f)$ $(\mu_{\tilde{A}}(\lambda) \wedge \mu_{\tilde{B}}(\rho_f))$.

The next step is the inference subprocess, in which the truth value for premise of each rule is computed and applied to the conclusion part of each rule. This results in one fuzzy

Table 5.13: Truth Values for Descriptors

λ	ρ_f
High (1.00)	π_1 (1.00)
Satisfactory (0.65)	π_2 (0.90)
Fair (0.36)	π_3 (0.70)
Poor (0.00)	π_4 (0.00)
	π_5 (0.00)

subset to be assigned to each output variable for each rule. *Product* inferencing is utilized for solving the present problem. In *Product* inferencing, the output membership function (α_i) is scaled by premise's computed degree of truth. Thus, considering premise 2 for $\lambda = 10$ and $\rho_c = 9.0\%$ *Product* inferencing will assign τ_n the fuzzy subset defined by the membership functions given in Equations 5.20–5.22. This process is repeated for each and every premise [§] . to obtain a fuzzy set for each inputs of λ and ρ_f.

$$\mathcal{P}_2(\tau_c) = 0.90 * high(\tau_c) \quad or \quad 0.090 * \tau_c \quad (for\ travel\ cost) \tag{5.23}$$

The next step is *Sum* composition subprocess. In this all of the fuzzy subsets assigned to each output variable are combined to form a single fuzzy subset for each output variable. A general form of *Sum* composition can be written as,

$$\mathcal{F}(\tau_n) = \mathcal{J}_n + \mathcal{G}_n * \tau_n \tag{5.24}$$

where, $\mathcal{F}(\tau_n)$ is sum fuzzy subset. The final step in *inference* process is *defuzzification*, which is necessary to convert the $\mathcal{F}(\tau_n)$ to a *crisp* value. *Centroid* method is applied for defuzzification process. In *centroid* method, the crisp value of output variable is computed

[§] $\mathcal{P}_2$ is Premise 2

by finding the variable value of the center of gravity of the membership function for the fuzzy value. The centroid of the function $\mathcal{F}(\tau_n)$ is the ratio of moment of function $\mathcal{F}(\tau_n)$ and area under function $\mathcal{F}(\tau_n)$. The moment of $\mathcal{F}(\tau_n)$ is $\int(\tau_n \cdot \mathcal{F}(\tau_n))d\tau_n$ and area of function $\mathcal{F}(\tau_n)$ is $\int \mathcal{F}(\tau_n))d\tau_n$ with in the limits of 0 to 10 for travel cost saving and 0 to 6.5 for travel time saving. In other words, a realistic time and cost savings that can be obtained from each technology type when applied to each commodity grouping is used as limits. Thus, the centroid for travel cost saving and time savings are given as,

$$\left\{\frac{\int_0^{10}(\mathcal{J}_c + \mathcal{G}_c * \tau_c) * \tau_c d\tau_c}{\int_0^{10}(\mathcal{J}_c + \mathcal{G}_* \tau_c)d\tau_c}\right\} \tag{5.25}$$

$$\left\{\frac{\int_0^{6.5}(\mathcal{J}_t + \mathcal{G}_t * \tau_t) * \tau_t d\tau_t}{\int_0^{6.5}(\mathcal{J}_t + \mathcal{G}_t * \tau_t)d\tau_t}\right\} \tag{5.26}$$

The *crisp* value of τ_n represents the weightiness of opinion of the given expert. Now, the τ_n values are utilized to model the cost and travel time savings as functions of distance to modify the modal split model. This procedure has to be repeated for different commodity groups and different technologies and for each link to obtain the possible savings. The possible savings can be utilized to fine tune the modal split model developed in *Chapter 4* and is described in the following section. ∎

5.3 Modal Split Modeling

The model describing the modal split for the year 1992 had been computed and documented in the *Chapter 4* of the thesis. This model fails to predict the modal split if there are improvements in levels of service. In other words, positive shifts on consumer preference towards trucking cannot be predicted using the models developed in *Chapter 4*. However, as can be noticed from the coefficients of modal split models, any improvement in LOS of trucking industry (i.e. decrease in travel time and decrease in travel cost) will increase the volume shipped by the trucks.

From the above described knowledge engineering procedure estimates of improvements in cost and time savings by experts can be obtained. These estimates form a rich source of information. Based on this information, the modal split model developed earlier can be modified to incorporate changes to LOS factors for trucking industry. The development of analytical tool for informed transportation planning a scattered knowledge base obtained from expert opinions is of little use. Hence, an advanced regression model is developed for scattered knowledge base. The regression model is obtained by plotting the cost/time saving estimates from each expert against the distances between origin and destinations of six provinces chosen for the study for each of the technologies chosen for study.

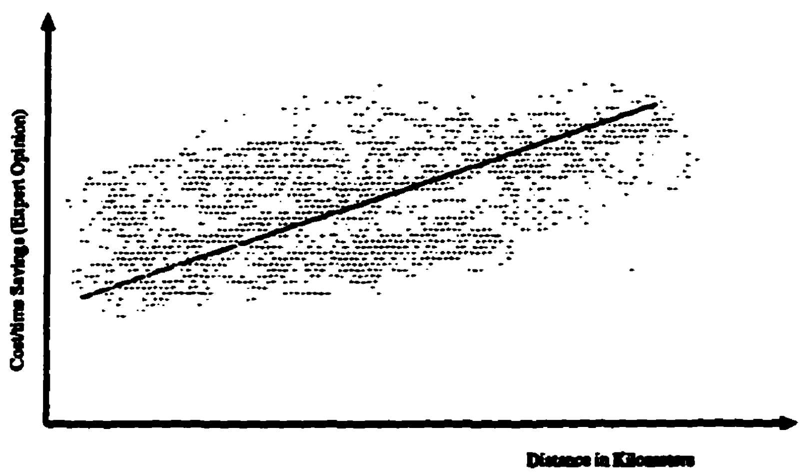

Figure 5.28: Cost or Time Savings with Distance

Variation in cost/time savings for different ITS technologies lead to different equations. For instance, the cost/time savings for AVL, AVI and WIM can be represented in a general form of,

$$\kappa_{n?\Omega} = \eta + \psi \times \mathcal{K} \tag{5.27}$$

where,

κ = savings accrued to trucking industry
n = cost (c) or time (t) component of saving
$\mathcal{H}$ = technology type (AVL, AVI or WIM)
$\mathcal{Y}$ = commodity type (FFB&T, CMI, EPI)
η = regression constant
ψ = regression coefficient
$\mathcal{K}$ = distance in kilometers

The above mentioned equation can be utilized to determine point-to-point savings in cost and travel time and can thereby be utilized to modify the modal split model developed already. Another important variable that has considerable impact on time and cost saving is the extent of market penetration of the above discussed ITS technologies. This aspect and its implications are discussed in the following section. ∎

5.3.0.1 Market Penetration of Technology

Penetration of technology in market place is not easily predictable. Many external factors dictate proliferation of particular technology. Consumer behavior (in this case CVOs) in accepting a particular technology is no different than any consumer product. The decision making regarding implementing new technology can be categorized in to following steps,

- Need recognition — ***the consumer perceives a difference between the desired state of affairs and the actual situation sufficient to arouse and activate the decision process.***
- Search for information — ***the consumer searches for information stored in memory (internal search) or acquires decision-relevant information from the environment (external search).***
- Alternative evaluation — ***the consumer evaluates options in terms of expected benefits and narrows the choice of preferred alternative.***

- Purchase — *the consumer acquires the preferred alternative or an acceptable substitute if necessary.*
- Outcomes — *the consumer evaluates whether or not the chosen alternative meets needs and expectations once it is used.*

Apart from consumer decision making one major influence is of course the federal and provincial governments involvement in establishing the standards. Substantial role is played by government's transportation regulatory agencies. The questionnaire designed during the course of this research has put substantial importance in obtaining the expert input from government regulatory agencies.

In devising the final equation to capture the modal split, a new parameter $\mathcal{MP}$ was introduced. The author postulates that the overall cost or time savings for any given technology is dependent on market penetration of the said technology. Computation of effective cost/time ($\mathcal{ECT}$) savings for a given technology thereby related to $\mathcal{MP}$ in the following fashion,

$$\mathcal{EC} = \mathcal{MP} \times \kappa_{c\mathcal{HO}} \tag{5.28}$$

$$\mathcal{ET} = \mathcal{MP} \times \kappa_{t\mathcal{HO}} \tag{5.29}$$

■

5.4 Enhanced Modal Split Model

Further to the enhancement with market penetration the influence of other technological service attributes have to be incorporated in the modal split model to achieve a comprehensive analytical forecasting tool. It is proposed to introduce an additional variable which captures other technologically significant service attributes. This variable will enhance the already existing cost model proposed above. Thus, the final cost savings (FCS) or final time savings (FTS) can be represented as in following equations,

$$FCS = \mathcal{E}C + OS_c \tag{5.30}$$

$$FTS = \mathcal{E}T + OS_t \tag{5.31}$$

Thus a general equation proposed for modal split can be modified so that it captures changes in LOS according to expert forecast as follows,

$$\begin{aligned} V_{ijp} \;=\;& \alpha_0 \cdot (POP_i \times IND_i)^{\alpha_1} \cdot (PC_i \times MI_i)^{\alpha_2} \cdot (TT_k - FTS)^{\alpha_3} \cdot (CO_k - FCS)^{\alpha_4} \\ & \cdot (POP_j \times IND_j)^{\alpha_5} \cdot (PC_j \times MI_j)^{\alpha_6} \cdot TT_r^{\alpha_7} \cdot CO_r^{\alpha_8} \end{aligned} \tag{5.32}$$

This modified modal split model can be utilized for predicting the impacts of advanced technologies on future trucking industry. It can be noted that from the coefficients α_3 and α_4 of the earlier modal split model any decrease in travel time and travel cost will benefit trucking industry in the freight transportation. ■

Chapter 6

Conclusions and Future Work

The thesis has presented a framework for analyzing and interpreting the expert opinion expressed in subjective terms. This methodology is unique for its attempt to quantify uncertain phenomenon expressed in natural language. The contribution of this thesis to transportation planning and future work necessary for actual field implementation of the methodology is discussed in the following sections.

6.1 Contribution

Given the multidimensional aspect of transportation planning and enormous resource investment required for transportation projects errors in planning phase often result in massive cost overruns (Saboungbi, 1991). It is the opinion of the author that traditional transportation planning relying on *hard* optimization techniques have often failed to deliver results. Transportation field crisp prediction of any aspect, even for short time frame, is difficult.

The thesis starts with probable capacity estimation of an automated highway and explores possible implications to freight transportation. The thesis then develops econometric models based on commodity groups. The developed models are no way different from traditional freight models developed over the past couple of decades by incorporating variables like social factors at origin and destination and service factors of mode of choice to predict volume of particular commodity transported. This model has an obvious drawback of not being useful when the service factors of any of the modes under consideration change. It would prove valuable to transportation planners if it is possible to develop an analytical tool which can determine the shifts in volume based on improvement in service factors and also the actual quantitative improvement in service factors.

Present railway freight rate structure and trucking rate structure have differences. Railway rates, especially for bulk food and crude material transport, have much less steeper slope than trucking rates with increasing distances. This has rendered railways very competitive for long distance freight rates. This changed due to the elimination of subsidies for grain transport from prairie provinces. Trucking industry might become competitive even in the case of bulk commodity transfer over longer distances.

Due to considerable differences in the actual commodities (classified as FFB&T) transferred by rail and truck it is difficult to identify individual commodity shifts. However, it is known that bulk food commodities constitute major part of freight transported by rail. Also, rail is dominant in medium and long distance freight hauling. Trucking with a combined savings from AVL, AVI and WIM ($\approx$ 20%) would dramatically alter the modal split in favor of trucking industry.

CMI is the largest commodity hauled by railways by weight. Railways dominate in long distance hauling of CMI. In short haul, Ontario-Québec and Manitoba-Saskatchewan are highly competitive sectors. Rail dominates Alberta-British Columbia short haul sector. With improved LOS from AVL, AVI and WIM to the trucking industry this balance could be shifted unless there is an comparative efficiency improvement by railways.

EPI is very competitive competitive between rail and trucking industry even in medium and long distance hauling. However, trucking freight rates increase at much faster rate than rail with distance. Increased efficiency brought on by ITS technologies investigated will contribute to increased LOS which when transferred to the customer contributes to competitiveness of trucking industry.

This thesis contributed in developing an analytical tool which can be utilized by transportation planners for predicting the impact of advanced ITS technologies on the future of rail/truck competition. Previous transportation planning studies largely ignored the application of fuzzy logic. Fuzzy logic may provide greater understanding of mechanics of transportation. The first step in this direction was preparing questionnaire. A comprehensive but short questionnaire comprising a maximum of fifteen questions for each of the technologies was prepared. Based on the responses, fuzzy composition and approximate reasoning are applied for proper inference for the question. An inference engine which provides the expert factor is designed. This methodology can be replicated even with an expanded questionnaire and for other technologies as well. The goal of purposing this methodology is to take into consideration of vast differences in expert backgrounds. Consequently, the expert opinion is weighed according to expert factor to ultimately determine the cost and time savings. The predicted cost and time savings are modeled with respect to distance to obtain a linear function which can be easily substituted in the modal split model developed earlier for each commodity group.

The author wishes to propose an alternate approach in interpreting the qualitative expert responses. The method is a multi-criteria evaluation process with each criterion known only vaguely. The method utilizes fuzzy sets and fuzzy measures to represent the vague notions. The degree that a given flow condition belongs to a LOS category is derived using fuzzy integrals. The concept of fuzzy integrals using fuzzy measures was proposed by Sugeno, M.

(1974). Fuzzy integrals are suited to obtain an aggregate performance measure, when the performance of each criterion is determined subjectively, and the existence of dependency among the criteria is not ruled out.

Finally, comparing the Delphi Research Technique (DRT) and methodology proposed by the author all the drawbacks noted earlier have been addressed. The first drawback noted in DRT was excessive time consumed because of several iterations of refining the expert opinion necessary to arrive at the conclusion. This is not particularly needed as the methodology captures shades of opinions effectively. Secondly, in DRT no compensation for bias in expert opinion is applied. On the contrary in the methodology proposed questionnaire is designed to detect bias and compensate it while assigning grades to the expert opinion. Finally, DRT mathematical representation of opinions is not possible. However, in the method proposed opinions can be effectively represented mathematically and can be incorporated with ease in any statistical model. ■

6.2 Recommendations and Future Work

Several expert system softwares were considered. MYCIN and COMMON LISP (Macintosh version) seems to be well suited for the kind of analysis. As a side note, a high impact user interface was developed using Hyper Text Markup Language (HTML) for experts to enter their responses interactively. The developed interface can be easily accessed through internet, thereby eliminating the need to mail questionnaire for the experts who have internet access.

The work presented in this thesis is a first application of fuzzy logic and fuzzy expert system application to freight transport modeling involving ITS technologies. Much work needs to be done in fine tuning the methodology. Also, there is need to minimize certain explicit and implicit simplifying assumptions in the econometric models developed. Additionally, there is a need to develop a test environment to permit implementation of the methodology to empirically determine the effectiveness of it before applying to future technological innovations. ■

Bibliography

♣ Al-Deek, H., and Kanafani, A., 1990. " Some Theoretical Aspects of the Benefits of En-Route Vehicle Guidance (ERVG)," *PATH Research Report UCB-ITS-PRR-89-2*, Institute of Transportation Studies, University of California, Berkeley, California.

♣ Allen, W., 1977. "The Demand for Freight Transportation: A Micro Approach," *Transportation Research*, pp. 9–14.

♣ Amemiya, T., 1981. "Quantal Response Models: A Survey," *Economic Literature*, pp. 1483–1536.

♣ Anas, A., 1981. "The Estimation of Multinominal Logit Models of Joint Location and Travel Mode Choice From Aggregate Data," *Journal of Regional Science*, pp. 223–242.

♣ Assessment of Benefits for Advantage I-75, 1992. *Center for Urban Transportation Research*, University of South Florida-Tampa.

♣ Baumol, W.J. and Vinod, H.D., 1970. " An Inventory Theoretic Model of Freight Transportation Demand," *Management Science*, pp. 413–421.

♣ Birch, S., Yamaguchi, J., Chinworth, M.W., Demmier, A., Jost, K., 1994. "GLOBAL

VIEWPOINTS," *Automotive Engineering*, Vol. 102, No. 7, Brimfield, Ohio.

♣ Bosacchi, B. and Masaki, I., 1993. "Application of Fuzzy Logic Technology (FLT) to the Intelligent Vehicle-Highway System (IVHS)," *Proceedings of the SPIE - The International Society for Optical Engineering Vol: 2061*, pp. 183-196.

♣ Boyer, K., 1977. "Minimum Rate Regulation, Modal Split Sensitivities and the Railroad Problem," *Journal of Political Economy*", pp. 493–512.

♣ Canadian Transport Commission, 1976. *Report on Modeling the Demand for Freight Transport. Research Branch, #ESAB-76-16-1, June. Study Reports.* Toronto: RTAC Publications.

♣ Chadwick, D.J., 1993. "Applications of the Global Positioning System to Intelligent Vehicle Highway Systems," *Conference Proceedings. National Telesystems Conference 1993. Commercial Applications and Dual-Use Technology (Cat. No.93CH3318-3)*, pp. 139-41.

♣ Choy, M., Kwan, M. P. and Hong Va Leong., 1994. "On real-time distributed geographical database systems," *Proceedings of the Twenty-Seventh Hawaii International Conference on System Sciences. Vol.IV: Information Systems: Collaboration Technology Organizational Systems and Technology (Cat. No.94TH0607-2)*, pp. 337–46.

♣ CN Rail. 1992. *Supertrains Schedule.* Montreal: CN Rail.

♣ Cohn, M., 1993. " A Millimeter Wave Retrodirective Transponder for Collision/Obstacle Avoidance and Navigation/Location," *IEEE Vehicle Navigation & Information Systems Conference*, Ottawa.

♣ Cooke, D.F., 1992. "Digital map databases for IVHS," *Proceedings of the 1992 International Congress on Transportation Electronics P-260 (IEEE Cat. No.92CH3231-8)*, pp. 441–4.

♣ Daughety, A., 1979. "Freight Transport Demand Revisited: A Microeconomic View of Multimodal, Multicharacteristic Service Uncertainty and Demand for Freight Transport," *Transportation Research*, pp. 281–288.

♣ Davis, D.B., 1992. "Electronic Toll Collection and Traffic Management Technologies," *Proceedings of the 1992 International Congress on Transportation Electronics P-260 (IEEE Cat. No.92CH3231-8)*, pp. 357-360.

♣ Daganzo, C., 1979. *Multimodal Probit.* New York: Academic Press.

♣ Financial Post. 1989–1992. *Canadian Markets*

♣ Freund, R., and Little, R., 1986. "SAS System for Regression," SAS Institute Inc.

♣ Friedlaender, F., and Richard, S., 1980. "A Derived Demand Function for Freight Transportation," *Review of Economics and Statistics*, pp. 432–441.

♣ Gang-Len Chang, Junchaya, T., 1993. "Simulating Network Traffic Flows with a Massively Parallel Computing Architecture," *1993 Winter Simulation Conference Proceedings (Cat.No.93CH3338-1)*, pp. 762-770.

♣ Gilmour, P., 1976. "Some Policy Implications of Subjective Factors in the Modal Choice for Freight Movement," *The Logistics and Transportation Review*, pp. 39–55.

♣ Hall, R., 1985. "Dependence Between Shipment Size and Mode in Freight Transportation," *Transportation Science*, pp. 436–444.

♣ Harker, P.T., 1987. *Predicting Intercity Freight Flows*, VNU Science Press BV, Utrecht, Netherlands.

♣ Hartwing, J.C. and Linton, W.E., 1974. "Disaggregate Mode Choice Models of Intercity Freight Movement, *Master's Thesis*, Department of Civil Engineering, University of California, Berkeley, California.

♣ Heaver, T.D. and Oum, T.H., 1976. "A Statistical Analysis of the Canadian Railway Rate Structure," *The Logistics and Transportation Review*, pp. 369–387.

♣ Heggie, I.G., 1972. *Transportation Engineering Economics*, McGraw Hill (UK) Ltd.

♣ Heller, M., 1993. "Vehicle Lateral Guidance Using Vision, Passive Wire and Radar Sensors," *IEEE Vehicle Navigation & Information Systems Conference*, Ottawa, Ontario.

♣ Highway Capacity Manual, 1985. "Special Report 209," *Transportation Research Board*, Washington, DC.

♣ Isard, W., 1951. "Interregional and Regional Input-Output Analysis: A Model of a Space Economy," *review of Economics and Statistics*, pp. 318–328.

♣ Isard, W., 1953. "Regional Commodity Balances and Interregional Commodity Flows," *American Economic Review*, pp. 167–180.

♣ Kanafani, A., (1983). *Transportation Demand Analysis*, McGraw-Hill Series in Transportation.

♣ Kelly, M.J., Folds, D.J., 1994. "Intelligent Vehicle-Highway Systems (IVHS): the 'I' in IVHS is Still Mostly Human Intelligence," *1994 IEEE National Telesystems Conference. Conference Proceedings (Cat. No.94CH3419-9)*, pp. 235.

♣ Kennedy, P., 1985. "A Guide to Econometrics," Second Edition, MIT Press.

♣ Khasnabis, S., Arciszewski, T., Hoda, S.K. and Ziarko, W., 1993. "Urban rail corridor control through machine learning: an IVHS approach," *Proceedings of Knowledge Based Systems for Civil and Structural Engineering*, pp. 97–104.

♣ Kornhauser, A.L., 1991. "Neural Network Approaches for Lateral Control of Autonomous Highway Vehicles," *IEEE Vehicle Navigation & Information Systems Conference*, Vol. 2, Dearborn, Michigan.

♣ Kosko, B., 1992. *Neural Networks and Fuzzy Systems*, Prentice Hall.

♣ Kullman, B.C., 1973. "A Model of Rail/Truck Competition in the Intercity Freight Market," *Studies in Railroad Operations and Economics*, MIT Report No. R74-35.

♣ Leontief, W., and Strout, A., 1963. "Multiregional Input-Output Analysis," *Structural Independence and Economic Development"*, pp. 18–45.

♣ Lotan, T. and Koutsopoulos, H.N., 1992. "Models for Route Choice Behavior in the Presence of Information Using Concepts from Fuzzy Set Theory and Approximate Reasoning," *Proceedings of Sixth World Conference on Transport Research*, Lyon, France.

♣ Mahoney, J. 1985. "Intermodal Freight Transportation," *Eno Foundation for Transportation Inc.*

♣ Manheim, M., 1979. *Fundamentals of Transportation Systems Analysis.* Cambridge, MA: MIT Press.

♣ Mathematica. 1967. *Studies of the Demand for Freight Transportation.* Volume I, Princeton.

♣ Mathematica. 1969. *Studies of the Demand for Freight Transportation.* Volume III, Princeton.

♣ McKelvey, D.J., Bothman, R. and Pigman, J., 1992. "Overview of IVHS-CVO Operational Tests," *Proceedings of the 1992 International Congress on Transportation Electronics P-260 (IEEE Cat. No.92CH3231-8)*, pp. 361-369.

♣ Miklius, W. 1969. "Estimating Freight Traffic of Competing Transportation Modes: An Application of the Linear Discriminant Function," *Land Economics*, pp. 267–273.

♣ Morton, A.L., 1972. "Intermodal Competition for Intercity Transport of Manufacturers," Land Economics, pp. 357–366.

♣ Murthy, A.S. and Ashtakala, B., 1987. "Modal Split Analysis Using Logit Models," *Journal of Transportation Engineering*, pp. 502–519.

♣ Niedringhaus, W.P., Opper, J., Rhodes, L. and Hughes, B., 1994. "IVHS traffic modeling using parallel computing: performance results," *Proceedings Eighth International Parallel Processing Symposium (Cat. No.94TH0652-8)*, pp. 688–93.

♣ Ofstead, G., 1992. "Advanced traffic management activities at IVHS America," *Proceedings of the 1992 International Congress on Transportation Electronics P-260 (IEEE Cat. No.92CH3231-8)*, pp. 409–12.

♣ Oum, T.H., 1977. "Derived Demand for Freight Transportation and Intermodal Substitutables in Canada." *Transportation Research Forum Conference Proceedings*, pp. 56–67.

♣ Oum, Tae Hoon, 1979a. " A Warning on the Use of Linear Logit Models in Transportation Mode Choice Studies," *The Bell Journal of Economics*, pp. 374–388.

♣ Oum, Tae Hoon, 1979b. "A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada," *The Bell Journal of Economics*, pp. 463–482.

♣ Oum, T.H., 1979c. "Derived Demand for Freight Transportation and Inter-modal Competition in Canada," *Journal of Transport Economics and Policy*, pp. 149–168.

♣ Oum, T.H., 1980. *Demand for Freight Transportation with a Special Emphasis on Mode Choice in Canada.* Vancouver: Center for Transportation Studies, University of British Columbia.

♣ Parviainen, Jouko A., Ledoux, R. and Carette, C., *National Inventory of IVHS Programs and Related Activities in Canada*, Transport Canada, Canada.

♣ Perle, Eugene, 1964. *The Demand for Transportation: Regional and Community Studies in the United States.* Chicago: Department of Geography, University of Chicago.

♣ Polenske, K.R., 1966. "The study of Transportation Requirements Using National and Multiregional Input-Output Techniques," *Harvard Economic Research Project*, Cambridge.

♣ Quandt, R.E. and Baumol, W., 1966. "the Demand for Abstract Transport Modes: Theory and Measurement," *Journal of Regional Science*, pp. 13–26.

♣ Rakowski, J.P., 1976. "Competition Between Railroads and trucks," *Traffic Quarterly*, pp. 285–301.

♣ Roberts, P.O., 1977. *Development of a Policy Sensitive Model for Forecasing Freight Demand*: Phase 1 Report. Cambridge, MA: MIT.

♣ Roberts, P.O. and Wang, K., 1977. *Predicting Freight Transport Level of Service attributes*, CTS Report No. 79-17. Cambridge, MA:MIT.

♣ Rock, D., Hoskins, D. and Malkoff, D., 1994. "Intelligent Road Transit: the Next Generation," *AI Expert*, pp. 18-24.

♣ Saboungbi, R.L., 1993. "Seminar on Intelligent Vehicle-Highway Systems," *University of Manitoba*, Winnipeg, Manitoba.

♣ Sargious, M.A. and Tam, T.S.L., 1988. "Effects of Commodity Type on Shipper's Mode Choice Behavior," CSCE 1988 Annual Conference Proceedings. Calgary: Canadian Society for Civil Engineering.

♣ Sargious, M.A. and Tam, T.S.L., 1985a. "Data Disaggregation Procedure for Calibrating a logit Model for Intercity Goods movement," *Transportation Planning and Technology*, pp. 165–175.

♣ Sargious, M.A. and Tam, T.S.L., 1985b. "Modeling Rail and Truck Freight Rates in Canada," *Logistics and Transportation Review* pp. 173–184.

♣ Sen, A.S. and Pagitsas, E., 1978. "The Logit Modal Split Model: Some Theoretical Considerations," *Transportation Research*, pp. 321–324.

♣ Shladover, S.E., 1989. " Longitudinal Control of Automotive Vehicles in Close-Formation Platoons," *Advanced Automotive Technologies - 1989, American Society of Mechanical Engineers*, Winter Annual Meeting, San Fransisco, California.

♣ Shladover, S.E., 1991. "Issues in Communications Standardization for Automatic Vehicle Control Systems," *Transportation Research Board*, 70th Annual Meeting, Washington, DC.

♣ Sloss, J., 1971. "The Demand for Intercity Motor Freight Transport: A Microeconomic Analysis," *The Journal of Business*.

♣ Smith, P.L., 1971. "Forecasting Freight Transport Demand—The State of the Art," *The Logistics and Transportation Review*, pp. 311–326.

♣ Soliman, A.H., Wyatt, D.A., Gadi, A.M. and Saboumghi, R.L., 1988. "Mathematical Modeling of End Product Commodity Mode Choice," *CSCE 1988 Annual Conference Proceedings*, Canadian Society of Civil Engineering, Calgary, Alberta.

♣ Soliman, A.H., Gadi, A.M. and Wyatt, D.A., 1990. "Interprovincial Rail/Truck Competition in the 1990's" *Transportation Planning and Technology.*

♣ Soliman, A.H., Gadi, A.M., Wyatt, D.A. and Saboumghi, R.L., 1990. "Modal Shifts in Canadian Freight Transportation," *Transportation Quarterly*, pp. 283–301.

♣ Statistics Canada. 1991 & 1992. *Trucking in Canada*, Statistics Canada Publication, 53-222.

♣ Statistics Canada. 1991 & 1992. *Railway Transport Commodity Origin and Destination Statistics*, Statistics Canada Publication, 52-214.

♣ Stenger, A.J. and Cunningham, W.H., 1978. "Additional Insights Concerning Rail-Truck Freight Competition," *Transportation Journal*, pp. 14–24.

♣ Strategic Plan for Intelligent Vehicle Highway Systems in the United States, 1991. *IVHS America*, Newport Beach, California.

♣ Sugeno, M., 1974. "Theory of Fuzzy Integrals and its Applications,". *Ph.D. Thesis*, Tokyo Institute of Technology, Tokyo, Japan.

♣ Sushko, M.S.K., 1994. "Technical aspects of a IVHS DGPS broadcast service using RBDS," *IEEE 1994 Position Location and Navigation Symposium (Cat. No. 94CH3358-9)*, pp. 520–31.

♣ Terano, T., Asai, K. and Sugeno, M., 1992. *Fuzzy Syatems Theory and its Applications*, Academic Press, INC., Harcourt Brace Jovanovich, San Diego, CA.

♣ Tsao, H.S., Hall, R.W., Shladover, S.E., 1993. "Design Options for Operating Automated Highway Systems," *IEEE Vehicle Navigation & Information Systems Conference*, Ottawa.

♣ Turner, R.E., 1975. *Freight Mode Selection in Canada*, CIGGT Report #75-14, October.

♣ Turner, R.E., 1977. "Rail and Truck Transportation in Canada," *Logistics and Transportation Review*, pp. 419–437.

♣ Tylor, N., 1992. "The Design of High Capacity Bus Systems: The Use of Fuzzy Supports to Represent Expert Opinion," *Proceedings of Sixth World Conference on Transport Research*, Lyon, France.

♣ Watson, P.L., James, C.H. and William, E.L., 1974. "Factors Influencing Shipping Mode Choice for Intercity Freight: A Disaggregate Approach," *Transportation Research Forum Proceedings—Fifteenth Annual Meeting*, pp. 139–144.

♣ Whelan, R., 1995. *Smart Highways and Smart Cars*, Artech House, INC., Norwood, MA.

♣ Wilson, F.R., Bisson, B.G. and Kobia, K.B., 1986. "Freight that Determine Mode Choice in the Transportation of General Freight," *Freight Transportation*, Transportation Research Record. pp. 26–31. Washington: Transportation Research Board, National Research Council.

♣ Winston, C., 1981. "A Disaggregate Model of the Demand for Intercity Freight Transportation," *Econometrica*, pp. 891–1006.

♣ Winston, Clifford., 1983. "The Demand for Freight Transportation; Models and Applications," *Transportation Research*, pp. 419–427.

♣ Young, William, Richardson, A.J. and Kinnear, R.L., 1982. "Modeling Inter-Urban Freight Mode Choice," *Journal of Advanced Transportation*, pp. 303–322.

♣ Young, W., Richardson, A.J., Ogden, K.W. and Rattray, A.L., 1983. "An Inter-Urban Freight Mode Choice Model," *Transportation Planning and Technology*, pp. 61–81.

♣ Zadeh, L.A., 1973. "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," *IEEE Transportation Systems, Man and Cybernetics, Vol SMC-3*, pp. 28–44.

♣ Zadeh, L.A., 1975. "The Concept of Linguistic Variable and its Application to Approximate Reasoning I, II, III," *Information Sciences*, pp. 219– 249.

♣ Zarean, M., Wright, J.L. and Starr, R., 1993. "Genesis: Personal Traveler Information System," *Conference Proceedings. National Telesystems Conference 1993. Commercial Applications and Dual-Use Technology (Cat. No.93CH3318-3)*, pp. 27-30.

♣ Zhang, W., 1993. "Vehicle Monitoring for AVCS Malfunction Management," *IEEE Vehicle Navigation & Information Systems Conference*, Ottawa.

♣ Zimmerman, H.J., 1988. *Fuzzy Set Theory—and its Applications*, Kluwer Academic Publishers, Norwell, MA.

♣ Zimmerman, H.J., Zadeh, L.A. Gaines, B.R., 1984. *Fuzzy Sets and Decision analysis*, Amsterdam, New York, Oxford.

Appendix 1

A rule base for AVL and WIM technologies are included in the following pages. Also included is a general *inference engine* which returns an *expert factor* based on the responses.

RULE BASE FOR ADVANCED VEHICLE LOCATION SYSTEMS

RULE 8888		
	IF	**QUET(1) IS YES**
THEN		**PROCEED TO RULE BASE 0881**
	ELSE	**PROCEED TO RULE BASE 0882**
RULE BASE 0881		
SUB RULE 01018		
	IF	**QUET(2) COUNT IS 6**
THEN		**ASSIGN GRADE1 VI TO ESQ#**** AND GREP PROVS**
	ELSE IF	**QUET(2) COUNT IS 5**
THEN		**ASSIGN GRADE1 V TO ESQ#**** AND GREP PROVS**
	ELSE IF	**QUET(2) COUNT IS 4**
THEN		**ASSIGN GRADE1 IV TO ESQ#**** AND GREP PROVS**
	ELSE IF	**QUET(2) COUNT IS 5**
THEN		**ASSIGN GRADE1 III TO ESQ#**** AND GREP PROVS**
	ELSE IF	**QUET(2) COUNT IS 5**
THEN		**ASSIGN GRADE1 II TO ESQ#**** AND GREP PROVS**
	ELSE IF	**QUET(2) COUNT IS 5**
THEN		**ASSIGN GRADE1 I TO ESQ#**** AND GREP PROV**
SUB RULE 01028		
	IF	**QUET(3) RESP IS > 5**
THEN		**ASSIGN GRADE2 V TO ESQ#******
	ELSE IF	**QUET(3) RESP IS 4**
THEN		**ASSIGN GRADE2 IV TO ESQ#******
	ELSE IF	**QUET(3) RESP IS 3 or less**
THEN		**ASSIGN GRADE2 III TO ESQ#******
	ELSE IF	**QUET(3) RESP IS < None**
THEN		**ASSIGN GRADE2 II TO ESQ#******

Contd...

```
SUB RULE 01038
          IF        QUET(4) IS POSITION
                    -INDICATING BEACONS
THEN                ASSIGN Grade V TO ESQ#****
        ELSE        NO ACTION

SUB RULE 01048
          IF        QUET(6) RESP IS VP
THEN                ASSIGN GRADE4 IV TO ESQ#****
        ELSE IF     QUET(6) RESP IS STF
THEN                ASSIGN GRADE4 III TO ESQ#****
        ELSE IF     QUET(6) RESP IS NC
THEN                ASSIGN GRADE4 II TO ESQ#****
        ELSE IF     QUET(6) RESP IS NEG
THEN                ASSIGN GRADE4 I TO ESQ#****

SUB RULE 01058
          IF        QUET(8) RESP IS 1-2 YEARS
THEN                ASSIGN GRADE5 IV TO ESQ#****
        ELSE IF     QUET(8) RESP IS 3 YEARS
THEN                ASSIGN GRADE5 III TO ESQ#****
        ELSE IF     QUET(8) RESP IS 5 YEARS
THEN                ASSIGN GRADE5 II TO ESQ#****
        ELSE IF     QUET(8) RESP IS > 5 YEARS
THEN                ASSIGN GRADE5 I TO ESQ#****

SUB RULE 01068
          IF        QUET(9) RESP IS YES
THEN                NO ACTION
        ELSE        NULLIFY RULE 01078
SUB RULE 01078
          IF        QUET(10) RESP IS HM
THEN                ASSIGN NULL TO ESQ#****
        ELSE        GREP THE COMDTY
```

RULE BASE 0882

SUB RULE 02018		
	IF	QUET(6) RESP IS VP
THEN		ASSIGN 1GRADE IV TO ESQ#****
	ELSE IF	QUET(6) RESP IS STF
THEN		ASSIGN 1GRADE III TO ESQ#****
	ELSE IF	QUET(6) RESP IS NC
THEN		ASSIGN 1GRADE II TO ESQ#****
	ELSE IF	QUET(6) RESP IS NEG
THEN		ASSIGN 1GRADE I TO ESQ#****
SUB RULE 02028		
	IF	QUET(8) RESP IS 1–2 YEARS
THEN		ASSIGN 2GRADE IV TO ESQ#****
	ELSE IF	QUET(8) RESP IS 3 YEARS
THEN		ASSIGN 2GRADE III TO ESQ#****
	ELSE IF	QUET(8) RESP IS 5 YEARS
THEN		ASSIGN 2GRADE II TO ESQ#****
	ELSE IF	QUET(8) RESP IS > 5 YEARS
THEN		ASSIGN 2GRADE I TO ESQ#****

ABBREVIATIONS

QUET(I) ...	QUESTION(1) ... FROM QUESTIONNAIRE
GREP	GRASP
PROV	PROVINCE
RESP	RESPONSE
HM	HAZARDOUS MATERIAL
COMDTY	COMMODITY TYPE
VP	VERY POSITIVE
STF	SATISFACTORY
NC	NO CHANGE
NEG	NEGATIVE

RULE BASE FOR WEIGH IN MOTION

RULE 7777		
	IF	QUET(1) IS YES
THEN		PROCEED TO RULE BASE 0771
	ELSE	PROCEED TO RULE BASE 0772
RULE BASE 0771		
SUB RULE 01017		
	IF	QUET(2) COUNT IS 6
THEN		ASSIGN GRADE1 VI TO ESQ#**** AND GREP PROVS
	ELSE IF	QUET(2) COUNT IS 5
THEN		ASSIGN GRADE1 V TO ESQ#**** AND GREP PROVS
	ELSE IF	QUET(2) COUNT IS 4
THEN		ASSIGN GRADE1 IV TO ESQ#**** AND GREP PROVS
	ELSE IF	QUET(2) COUNT IS 5
THEN		ASSIGN GRADE1 III TO ESQ#**** AND GREP PROVS
	ELSE IF	QUET(2) COUNT IS 5
THEN		ASSIGN GRADE1 II TO ESQ#**** AND GREP PROVS
	ELSE IF	QUET(2) COUNT IS 5
THEN		ASSIGN GRADE1 I TO ESQ#**** AND GREP PROV
SUB RULE 01027		
	IF	QUET(3) RESP IS > 30%
THEN		ASSIGN GRADE2 V TO ESQ#****
	ELSE IF	QUET(3) RESP IS 20–30%
THEN		ASSIGN GRADE2 IV TO ESQ#****
	ELSE IF	QUET(3) RESP IS 10–20%%
THEN		ASSIGN GRADE2 III TO ESQ#****
	ELSE IF	QUET(3) RESP IS < 10%
THEN		ASSIGN GRADE2 II TO ESQ#****

Contd...

SUB RULE 01037		
	IF	QUET(4) RESP IS > 1 hour
THEN		ASSIGN GRADE4 IV TO ESQ#****
	ELSE IF	QUET(4) RESP IS 30–40 MINUTES
THEN		ASSIGN GRADE4 III TO ESQ#****
	ELSE IF	QUET(4) RESP IS 15–30 MINUTES
THEN		ASSIGN GRADE4 II TO ESQ#****
	ELSE IF	QUET(4) RESP IS < 15 MINUTES
THEN		ASSIGN GRADE4 I TO ESQ#****
SUB RULE 01047		
	IF	QUET(5) IS HM
THEN		ASSIGN NULL TO ESQ#****
	ELSE	GREP THE COMDTY
SUB RULE 01057		
	IF	QUET(7) RESP IS VP
THEN		ASSIGN GRADE4 IV TO ESQ#****
	ELSE IF	QUET(7) RESP IS STF
THEN		ASSIGN GRADE4 III TO ESQ#****
	ELSE IF	QUET(7) RESP IS NC
THEN		ASSIGN GRADE4 II TO ESQ#****
	ELSE IF	QUET(7) RESP IS NEG
THEN		ASSIGN GRADE4 I TO ESQ#****
SUB RULE 01057		
	IF	QUET(9) RESP IS 1–2 YEARS
THEN		ASSIGN GRADE5 IV TO ESQ#****
	ELSE IF	QUET(9) RESP IS 3 YEARS
THEN		ASSIGN GRADE5 III TO ESQ#****
	ELSE IF	QUET(9) RESP IS 5 YEARS
THEN		ASSIGN GRADE5 II TO ESQ#****
	ELSE IF	QUET(9) RESP IS > 5 YEARS
THEN		ASSIGN GRADE5 I TO ESQ#****
SUB RULE 01067		
	IF	QUET(10) RESP IS YES
THEN		NO ACTION
	ELSE	NULLIFY RULE 01047

RULE BASE 0772

SUB RULE 02017

	IF	QUET(7) RESP IS VP
THEN		ASSIGN 1GRADE IV TO ESQ#****
	ELSE IF	QUET(7) RESP IS STF
THEN		ASSIGN 1GRADE III TO ESQ#****
	ELSE IF	QUET(7) RESP IS NC
THEN		ASSIGN 1GRADE II TO ESQ#****
	ELSE IF	QUET(7) RESP IS NEG
THEN		ASSIGN 1GRADE I TO ESQ#****

SUB RULE 02027

	IF	QUET(9) RESP IS 1-2 YEARS
THEN		ASSIGN 2GRADE IV TO ESQ#****
	ELSE IF	QUET(9) RESP IS 3 YEARS
THEN		ASSIGN 2GRADE III TO ESQ#****
	ELSE IF	QUET(9) RESP IS 5 YEARS
THEN		ASSIGN 2GRADE II TO ESQ#****
	ELSE IF	QUET(9) RESP IS > 5 YEARS
THEN		ASSIGN 2GRADE I TO ESQ#****

ABBREVIATIONS

QUET(I) ...	QUESTION(1) ... FROM QUESTIONNAIRE
GREP	GRASP
PROV	PROVINCE
RESP	RESPONSE
HM	HAZARDOUS MATERIAL
COMDTY	COMMODITY TYPE
VP	VERY POSITIVE
STF	SATISFACTORY
NC	NO CHANGE
NEG	NEGATIVE

```
GENERAL INFERENCE ENGINE

        INPUT : grades assigned to each response;
        OUTPUT: expert factor;

        FOREACH type of professional DO
                        basic block;

         /* Weights Assigned Depending on Sphere of Operation (provinces) */

                FOR[ascending grade]
                assign worth Wp corresponding to grade;

                Create memory for Province(s) identity in
                one to one correspondence with ESQ#**** ;

        /* Weight Assigned Depending on Operations Need for Three Technologies */

                FOR[ascending grade]
                assign worth Wn corresponding to grade;

        /* Weight Assigned Depending on Number of Commodity Groups Shipped by CVOO */

                FOR[particular commodity(ies) type shipper]
                Create memory for commodity type in
                one to one correspondence with ESQ#****;

                FOR[varied commodity shipping experience]
                assign worth Wc to the CVOO;

        /* Weight Assigned Based on Attitude of the Shipper or Professional */

                FOR[positive to negitive attitude]
                assign worth factor Wa in decreasing fashion;

        /* Weight Assigned According to Time Estimated for Penetration of Each */
                                        /*Technology*/

                FOR[shorter to longer penetration time]
                assign worth factor Wt in decreasing fashion;

                                /*Expert Factor*/

                Expert Factor* = f[Wp, Wn, Wc, Wa, Wt] [a linear function]


                        * Weights being assigned to each factor by the forecaster
```

Appendix 2

Sample questionnaire for AVI, AVL and WIM are included in the following pages. The questionnaire is written in HTML and hence can be accessed world wide through web. The following are screen shots of the questions when viewed by Netscape.

Advanced Vehicle Identification (AVI) Technologies Impacts on Canadian Trucking Industry --- Questionnaire

---

Expert Opinion Survey

Please type in your full name:

Code number (leave it blank):

1. Do you own or operate commercial vehicle fleet (CVF) in Canada? (If the answer is "No" skip to (6))

◈ *Yes.*

◇ *No.*

2. If the answer for (1) is "Yes", please list the provinces in which you operate:

3. If you own and/or operate CVF, what percentage of your fleet on an average use toll roads ?

1. ◊>25%.
2. ◊15-25%.
3. ◊5-10%.
4. ◊<5%.
5. ◊0%.

4. If your fleet uses toll roads, how much delay on an average do individual truckers experience due to long queues at toll booths?

1. ◊1 hour or more.
2. ◊30-45 min.
3. ◊15-30 min.
4. ◊<15.

5. If you operate or own CVF, which of the following commodities your company ships the most?

1. ◊Food, feed, beverages and tobacco (FFB&T)
2. ◊Crude materials, inedible (CMI)
3. ◊Hazardous materials (HM)
4. ◊Fabricated materials, inedible (FMI)
5. ◊End products, inedible (EPI)

6. If the answer for (1) is "No", please specify your profession: [redacted]

7. How do you view the AVI technology overall in the present and future trucking industry?

1. ◊ Very Positive.
2. ◊ Satisfactory.
3. ◊ No Change.
4. ◊ Negative.

8. Will the increased competition form US operators accelerate the implementation of AVI in Canadian trucking industry?

1. ◊ Definitely yes.
2. ◊ Certain sectors.
3. ◊ No impact.

9. In your opinion how long before we can see widespread use of AVI technologies in Canadian trucking industry?

1. ◊ 1-2 years.
2. ◊ 3 years.
3. ◊ 5 years.
4. ◊ > 5 years.

10. Does type of commodity has any bearing on productivity of AVI technologies to the operators?

◆ *Yes.*

◊ *No.*

11. Please follow this link for a detailed summary of each commodity volume, cost and travel time data for the provinces under investigation.

12. According to your judgement a 9.5% cost and 6.2% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing AVI technologies?

Cost Saving: Time Saving: -Quebec

Cost Saving: Time Saving: -Ontario

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -British Columbia

13. According to your judgement a 8.3% cost and 5.9% time savings (from trip originating province) will be accrued for CMI transportation for each of the links by implementing AVI technologies?

Cost Saving: Time Saving: -Quebec

Cost Saving: Time Saving: -Ontario

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -British Columbia

14. According to your judgement a 7.8% cost and 5.3% time savings (from trip originating province) will be accrued for EPI transportation for each of the links by implementing AVI technologies?

Cost Saving: Time Saving: -Quebec

Cost Saving: Time Saving: -Ontario

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -British Columbia

15. Any other comments?

To submit your answers, press this button: Submit.

To reset the various form elements to their default states, press this button: Reset To Default Values.

Advanced Vehicle Location (AVL) Technologies Impacts on Canadian Trucking Industry --- Questionnaire

Expert Opinion Survey

Please type in your full name: [redacted]

Code number (leave it blank): [redacted]

1. Do you own or operate commercial vehicle fleet (CVF) in Canada? (If the answer is "No" skip to (6))

◆ *Yes.*

◇ *No.*

2. If the answer for (1) is "Yes", please list the provinces in which you operate:

[redacted]

3. If you own and operate CVF, how many accidents have your vehicles been involved in within the last three years?

   1. ◇ 5 or more.
   2. ◇ 4.
   3. ◇ 3 or less.
   4. ◇ None.

4. If you own and/or operate CVF, what is the most frequent manner in which your vehicles communicate with you while they are on their trips?

   1. ☐ Telephone.
   2. ☐ Two-way radio.
   3. ☐ Mobile telephone.
   4. ☐ Position-indicating beacons.
   5. ☐ Other.

5. If the answer for (1) is "No", please specify your profession: [redacted]

6. How do you view the AVL technology overall in the present and future trucking industry?

   1. ✓ Very Positive.
   2. ✓ Satisfactory.
   3. ◇ No Change.
   4. ◇ Negative.

7. Will the increased competition form US operators accelerate the implementation of AVL in Canadian trucking industry?

1. ◇ Definitely yes.
2. ◇ Certain sectors.
3. ◇ No impact.

8. In your opinion how long before we can see widespread use of AVL technologies in Canadian trucking industry?

1. ◇ 1–2 years.
2. ◇ 3 years.
3. ◇ 5 years.
4. ◇ > 5 years.

9. Does type of commodity has bearing any on productivity of AVL technologies to the operators?

◆ *Yes.*

◇ *No.*

10. If the answer to the (9) is "Yes" choose the commodity type whose transportation benefits most by implementing AVL.

1. ◇ Food, feed, beverages and tobacco (FFB&T)
2. ◇ Crude materials, inedible (CMI)
3. ◇ Hazardous materials (HM)
4. ◇ Fabricated materials, inedible (FMI)
5. ◇ End products, inedible (EPI)

11. Please follow this <u>link for a detailed summary of each commodity volume, cost and travel time data</u> for the provinces under investigation.

12. According to your judgement a 5.0% cost and 3.5% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing AVL technologies?

Cost Saving: Time Saving: -Quebec

Cost Saving: Time Saving: -Ontario

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -British Columbia

13. According to your judgement a 4.5% cost and 5.0% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing AVL technologies?

Cost Saving: Time Saving: -Quebec

Cost Saving: Time Saving: -Ontario

Cost Saving: [redacted] Time Saving: [redacted] - Manitoba

Cost Saving: [redacted] Time Saving: [redacted] - Saskatchewan

Cost Saving: [redacted] Time Saving: [redacted] - Alberta

Cost Saving: [redacted] Time Saving: [redacted] - British Columbia

14. According to your judgement a 5.0% cost and 5.0% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing AVL technologies?

Cost Saving: [redacted] Time Saving: [redacted] - Quebec

Cost Saving: [redacted] Time Saving: [redacted] - Ontario

Cost Saving: [redacted] Time Saving: [redacted] - Manitoba

Cost Saving: [redacted] Time Saving: [redacted] - Saskatchewan

Cost Saving: [redacted] Time Saving: [redacted] - Alberta

Cost Saving: ____ Time Saving: ____ -British Columbia

15. What institutional changes you suggest that will accelerate the implementation of AVL technologies (including government support)? Any other comments?

To submit your answers, press this button: Submit.

To reset the various form elements to their default states, press this button: Reset To Default Values.

Weigh in Motion Technology Impacts on Canadian Trucking Industry --- Questionnaire

---

Expert Opinion Survey

Please enter your full name: [redacted]

Code number (leave it blank): [redacted]

1. Do you own or operate commercial vehicle fleet (CVF) in Canada? (If the answer is "No" skip to (6))

◆ *Yes.*

◇ *No.*

2. If the answer for (1) is "Yes", please list the provinces in which you operate:

[redacted]

3. If you own and/or operate CVF, what percentage of your fleet on an average weigh station visits per month per truck?

1. ◇>30.
2. ◇20–30.
3. ◇10–20.
4. ◇<10.

4. How much delay on an average do individual truckers experience due to long queues at weigh stations?

1. ◇1 hour or more.
2. ◇30–45 min.
3. ◇15–30 min.
4. ◇<15.

5. If you operate or own CVF, which of the following commodities your company ships the most?

1. ◇Food, feed, beverages and tobacco (FFB&T)
2. ◇Crude materials, inedible (CMI)
3. ◇Hazardous materials (HM)
4. ◇Fabricated materials, inedible (FMI)
5. ◇End products, inedible (EPI)

6. If the answer for (1) is "No", please specify your profession: [redacted]

7. How do you view the WIM technology overall in the present and future trucking industry?

1. ◊ Very Positive.
2. ◊ Satisfactory.
3. ◊ No Change.
4. ◊ Negative.

8. Will the increased competition form US operators accelerate the implementation of WIM in Canada?

1. ◊ Definitely yes.
2. ◊ Certain sectors.
3. ◊ No impact.

9. In your opinion how long before we can see widespread use of WIM in Canada?

1. ◊ 1–2 years.
2. ◊ 3 years.
3. ◊ 5 years.
4. ◊ > 5 years.

10. Does type of commodity has any bearing on productivity of WIM to the operators?

◆ *Yes.*

◊ *No.*

11. Which of the following do you rate most important benefit from WIM implementation?

1. ◇ Safety enhancement
2. ◇ Increased data collection
3. ◇ Reduction in paper work
4. ◇ Increased monitoring

12. Please follow this <u>link for a detailed summary of each commodity volume, cost and travel time data</u> for the provinces under investigation.

13. According to your judgement a 12.0% cost and 15.0% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing WIM technologies?

Cost Saving: Time Saving: - Quebec

Cost Saving: Time Saving: - Ontario

Cost Saving: Time Saving: - Manitoba

Cost Saving: Time Saving: - Saskatchewan

Cost Saving: Time Saving: - Alberta

Cost Saving: Time Saving: - British Columbia

14. According to your judgement a 13.0% cost and 13.5% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing WIM technologies?

Cost Saving: [redacted] Time Saving: [redacted] -Quebec

Cost Saving: [redacted] Time Saving: [redacted] -Ontario

Cost Saving: [redacted] Time Saving: [redacted] -Manitoba

Cost Saving: [redacted] Time Saving: [redacted] -Saskatchewan

Cost Saving: [redacted] Time Saving: [redacted] -Alberta

Cost Saving: [redacted] Time Saving: [redacted] -British Columbia

15. According to your judgement a 14.5% cost and 16.0% time savings (from trip originating province) will be accrued for FFB&T transportation for each of the links by implementing AVI technologies?

Cost Saving: [redacted] Time Saving: [redacted] -Quebec

Cost Saving: [redacted] Time Saving: [redacted] -Ontario

Cost Saving: Time Saving: -Manitoba

Cost Saving: Time Saving: -Saskatchewan

Cost Saving: Time Saving: -Alberta

Cost Saving: Time Saving: -British Columbia

16. Any concerns regarding WIM technology?

To submit your answers, press this button: Submit.

To reset the various form elements to their default states, press this button: Reset To Default Values.

The previous sections illustrate the information that has to be gathered from an expert panel. This information is subjected to a fuzzy treatment before utilizing the information as a decision support tool.

Table 1: Data Used for Modeling FFB&T (For-Hire Trucking Only)

From	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
QUE	6820,9	97	17700	100	2	47,04	10028,9	151	21900	106	2,5	29,14	550,2	ONT
QUE	6820,9	97	17700	100	3	142,48	1100,9	56	17100	86	3,5	61,83	24,15	MAN
QUE	6820,9	97	17700	100	4	353,10	1005,4	27	16300	95	4,5	70,06	1,05	SAK
QUE	6820,9	97	17700	100	5	109,39	2487,3	51	19400	95	5,5	80,98	31,5	ALB
QUE	6820,9	97	17700	100	6	200,53	3221,6	73	18800	101	6,5	92,68	23,1	B.C.
ONT	10028,9	151	21900	106	2	47,04	6820,9	97	17700	100	2,5	29,14	822,15	QUE
ONT	10028,9	151	21900	106	3	119,95	1100,9	56	17100	86	3,5	58,73	79,8	MAN
ONT	10028,9	151	21900	106	4	198,77	1005,4	27	16300	95	4,5	67,31	18,9	SAK
ONT	10028,9	151	21900	106	5	189,16	2487,3	51	19400	95	5,5	77,44	88,5	ALB
ONT	10028,9	151	21900	106	6	250,66	3221,6	73	18800	101	6,5	89,55	46,2	B.C.
MAN	1100,9	56	17100	86	3	142,48	6820,9	97	17700	100	4,5	61,83	53,55	QUE
MAN	1100,9	56	17100	86	3	119,95	10028,9	151	21900	106	4,5	58,73	124,95	ONT
MAN	1100,9	56	17100	86	1	58,40	1005,4	27	16300	95	2,5	30,16	183,75	SAK
MAN	1100,9	56	17100	86	2	80,08	2487,3	51	19400	95	2,5	47,56	98,7	ALB
MAN	1100,9	56	17100	86	3	119,02	3221,6	73	18800	101	3,5	64,63	59,85	B.C.
[redacted]														

Table 1: Data Used for Modeling FFB&T (For-Hire Trucking Only)

From	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
SAK	1005,4	27	16300	95	4	353,10	6820,9	97	17700	100	4,5	70,06	5,25	QUE
SAK	1005,4	27	16300	95	4	198,77	10028,9	151	21900	106	4,5	67,31	10,5	ONT
SAK	1005,4	27	16300	95	1	58,40	1100,9	56	17100	86	2,5	30,16	50,4	MAN
SAK	1005,4	27	16300	95	1	49,94	2487,3	51	19400	95	2,5	35,24	131,25	ALB
SAK	1005,4	27	16300	95	2	88,66	3221,6	73	18800	101	3,5	55,72	44,1	B.C.
ALB	2487,3	51	19400	95	5	109,39	6820,9	97	17700	100	5,5	80,98	48,3	QUE
ALB	2487,3	51	19400	95	5	189,16	10028,9	151	21900	106	5,5	77,44	61,95	ONT
ALB	2487,3	51	19400	95	2	80,08	1100,9	56	17100	86	3,5	47,56	100,8	MAN
ALB	2487,3	51	19400	95	1	49,94	1005,4	27	16300	95	2,5	35,24	89,25	SAK
ALB	2487,3	51	19400	95	2	75,14	3221,6	73	18800	101	3,5	45,65	442,05	B.C.
B.C.	3221,6	73	18800	101	6	200,53	6820,9	97	17700	100	7,5	92,68	12,6	QUE
B.C.	3221,6	73	18800	101	6	250,66	10028,9	151	21900	106	7,0	89,55	29,4	ONT
B.C.	3221,6	73	18800	101	3	119,02	1100,9	56	17100	86	4,5	64,63	97,65	MAN
B.C.	3221,6	73	18800	101	2	88,66	1005,4	27	16300	95	3,5	55,72	39,9	SAK
B.C.	3221,6	73	18800	101	2	75,14	2487,3	51	19400	95	2,5	41,38	198,45	ALB

Table 2: Data Used for Modeling CMI (For-Hire Trucking Only)

FROM	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
QUE	6820,9	97	17700	100	2	31,05	10028,9	151	21900	106	4	30,51	279,3	ONT
QUE	6820,9	97	17700	100	3	449,58	1100,9	56	17100	86	5	65,38	1,05	MAN
QUE	6820,9	97	17700	100	4	99,51	1005,4	27	16300	95	6	74,21	0,42	SAK
QUE	6820,9	97	17700	100	5	202,63	2487,3	51	19400	95	7	85,95	4,2	ALB
QUE	6820,9	97	17700	100	6	218,54	3221,6	73	18800	101	8	98,55	0,263	B.C.
ONT	10028,9	151	21900	106	2	31,05	6820,9	97	17700	100	4	30,51	487,2	QUE
ONT	10028,9	151	21900	106	3	72,25	1100,9	56	17100	86	5	62,06	14,7	MAN
ONT	10028,9	151	21900	106	4	103,92	1005,4	27	16300	95	6	71,26	6,3	SAK
ONT	10028,9	151	21900	106	5	176,05	2487,3	51	19400	95	7	82,15	6,3	ALB
ONT	10028,9	151	21900	106	6	201,05	3221,6	73	18800	101	8	95,17	5,25	B.C.
MAN	1100,9	56	17100	86	3	449,58	6820,9	97	17700	100	6	65,38	6,30	QUE
MAN	1100,9	56	17100	86	3	72,25	10028,9	151	21900	106	6	62,06	389,55	ONT
MAN	1100,9	56	17100	86	1	23,80	1005,4	27	16300	94	4	31,58	60,9	SAK
MAN	1100,9	56	17100	86	2	29,91	2487,3	51	19400	95	5	50,11	15,75	ALB
MAN	1100,9	56	17100	86	3	127,71	3221,6	73	18800	101	6	68,39	0,315	B.C.

Table 2: Data Used for Modeling CMI (For-Hire Trucking Only)

FROM	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
SAK	1005,4	27	16300	95	4	99,51	6820,9	97	17700	100	6	74,21	1,05	QUE
SAK	1005,4	27	16300	95	4	103,92	10028,9	151	21900	106	6	71,26	10,5	ONT
SAK	1005,4	27	16300	95	1	23,80	1100,9	56	17100	86	4	31,58	134,4	MAN
SAK	1005,4	27	16300	95	1	34,57	2487,3	51	19400	95	4	36,99	410,55	ALB
SAK	1005,4	27	16300	95	2	68,72	3221,6	73	18800	101	5	58,84	32,55	B,C,
ALB	2487,3	51	19400	95	5	202,63	6820,9	97	17700	100	7	85,95	2,1	QUE
ALB	2487,3	51	19400	95	5	176,05	10028,9	151	21900	106	7	82,15	16,8	ONT
ALB	2487,3	51	19400	95	2	29,91	1100,9	56	17100	86	5	50,11	179,55	MAN
ALB	2487,3	51	19400	95	1	34,57	1005,4	27	16300	95	4	36,99	119,7	SAK
ALB	2487,3	51	19400	95	2	30,54	3221,6	73	18800	101	5	48,08	109,2	B,C,
B,C,	3221,6	73	18800	101	6	218,54	6820,9	97	17700	100	9	98,55	2,1	QUE
B,C,	3221,6	73	18800	101	6	201,05	10028,9	151	21900	106	8,5	95,17	4,2	ONT
B,C,	3221,6	73	18800	101	3	127,71	1100,9	56	17100	86	6	68,39	22,05	MAN
B,C,	3221,6	73	18800	101	2	68,72	1005,4	27	16300	95	5	58,84	6,3	SAK
B,C,	3221,6	73	18800	101	2	30,54	2487,3	51	19400	95	4	43,52	418,95	ALB

Table 3: Data Used for Modeling EPI (For-Hire Trucking Only)

FROM	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
QUE	6820.90	97	17700	100	2	127.84	10028.9	151	21900	106	2.5	35.06	817.95	ONT
QUE	6820.90	97	17700	100	3	310.15	1100.9	56	17100	86	3.5	77.51	42.00	MAN
QUE	6820.90	97	17700	100	4	336.49	1005.4	27	16300	95	4.5	88.43	15.75	SAK
QUE	6820.90	97	17700	100	5	360.79	2487.3	51	19400	95	5.5	103.03	57.75	ALB
QUE	6820.90	97	17700	100	6	588.36	3221.6	73	18800	101	6.5	118.79	43.05	B.C.
ONT	10028.9	151	21900	106	2	127.84	6820.9	97	17700	100	2.5	35.06	898.80	QUE
ONT	10028.9	151	21900	106	3	233.26	1100.9	56	17100	86	3.5	73.42	141.75	MAN
ONT	10028.9	151	21900	106	4	402.94	1005.4	27	16300	95	4.5	84.78	48.30	SAK
ONT	10028.9	151	21900	106	5	414.31	2487.3	51	19400	95	5.5	98.30	179.55	ALB
ONT	10028.9	151	21900	106	6	527.62	3221.6	73	18800	101	6.5	114.57	145.95	B.C.
MAN	1100.90	56	17100	86	3	310.15	6820.9	97	17700	100	4.5	77.51	18.90	QUE
MAN	1100.90	56	17100	86	3	233.26	10028.9	151	21900	106	4.5	73.42	123.90	ONT
MAN	1100.90	56	17100	86	1	169.96	1005.4	27	16300	94	2.5	36.35	99.75	SAK
MAN	1100.90	56	17100	86	2	173.29	2487.3	51	19400	95	3.5	58.77	92.40	ALB
MAN	1100.90	56	17100	86	3	399.61	3221.6	73	18800	101	4.5	81.22	15.71	B.C.

Table 3: Data Used for Modeling EPI (For-Hire Trucking Only)

FROM	POPi	INDi	PCi	MIi	TTk	COk	POPj	INDj	PCj	MIj	TTr	COr	Vijp	TO
SAK	1005.40	27	16300	95	4	336,49	6820,9	97	17700	100	4,5	88,43	4,20	QUE
SAK	1005,40	27	16300	95	4	402,94	10028,9	151	21900	106	4,5	84,78	17,85	ONT
SAK	1005,40	27	16300	95	1	169,96	1100,9	56	17100	86	2,5	36,35	21,00	MAN
SAK	1005,40	27	16300	95	1	107,85	2487,3	51	19400	95	2,5	42,85	89,25	ALB
SAK	1005,40	27	16300	95	2	265,31	3221,6	73	18800	101	3,5	69,46	14,70	B.C.
ALB	2487,30	51	19400	95	5	360,79	6820,9	97	17700	100	5,5	103,03	23,10	QUE
ALB	2487,30	51	19400	95	5	414,31	10028,9	151	21900	106	5,5	98,30	69,30	ONT
ALB	2487,30	51	19400	95	2	173,29	1100,9	56	17100	86	3,5	58,77	54,60	MAN
ALB	2487,30	51	19400	95	1	107,85	1005,4	27	16300	95	2,5	42,85	132,30	SAK
ALB	2487,30	51	19400	95	2	142,65	3221,6	73	18800	101	3,5	56,29	266,70	B.C.
B.C.	3221,60	73	18800	101	6	588,36	6820,9	97	17700	100	7,5	118,79	25,20	QUE
B.C.	3221,60	73	18800	101	6	527,62	10028,9	151	21900	106	7,0	114,57	70,35	ONT
B.C.	3221,60	73	18800	101	3	399,61	1100,9	56	17100	86	4,5	81,22	31,50	MAN
B.C.	3221,60	73	18800	101	2	265,31	1005,4	27	16300	95	3,5	69,46	25,20	SAK
B.C.	3221,60	73	18800	101	2	142,65	2487,3	51	19400	95	2,5	50,75	223,65	ALB

[redacted]