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**THE TRAVEL TIME PREDICTABILITY PERSPECTIVE
- A BASIS FOR THE USE OF
DRIVER QUALITY OF SERVICE IN TRAFFIC MANAGEMENT**

by

DENNIS G. DAVIS, P.ENG.

B.ENG. (Lakehead University)

M.ENG. (Carleton University)

**A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy***

Carleton University

Ottawa, Ontario

September, 1992

*** The Doctor of Philosophy Program is a joint program
with the University of Ottawa, administered by the
Ottawa-Carleton Institute for Civil Engineering**

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The undersigned hereby recommend to
the Faculty of Graduate Studies and Research
the acceptance of the thesis,

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- A Basis For The Use Of
Driver Quality Of Service In Traffic Management"

submitted by

Dennis G. Davis, B.ENG., M.ENG.

in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

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Abstract

Increasingly restrained public funding will require more comprehensive traffic performance evaluations to aid the rationalization of roadway infrastructure supply. Traffic management should pursue a service balance between the traditional orientation of vehicular movement effectiveness, and driver serviceability. The effect would be the achievement of the most efficient use of existing facilities, in terms of both traffic movement and the drivers' perception of the experienced service.

Traditional traffic performance evaluations are deficient in realistically addressing driver quality of service perceptions of the trip experience. This deficiency was addressed through the modelling of driver serviceability based upon the travel time predictability perspective.

Driver perception of the quality of service experienced for an entire trip can be consistently modelled through the travel time predictability perspective. The primary model relationship relates the trip experience description of travel time predictability to the perceived quality of service. This relationship gauges service quality relative to the extent to which trip travel time predictions are achieved. Drivers have the ability to make both knowledgeable travel time predictions, and rational quality of service descriptions and valuations.

Driver serviceability can also be described through a less direct, secondary description of the trip experience through the combined relationships between travel time predictability, the primary driver stress correlate, and the subjective valuation of service quality. It is possible to consistently record and evaluate relative physiological baseline changes associated with the trip experience.

Preliminary driver serviceability guidelines were derived from the modelling results for both the rural two lane highway and urban arterial settings. It is notable that although the key serviceability relationships are consistent between the settings, that different quality of service travel time predictability ranges were observed. This may be attributable to different travel characteristics associated with the different settings.

Driver serviceability guidelines provide a basis for the maintenance or enhancement of drivers' perceived quality of service, within the bounds of the surveyed conditions. An informed driver has the potential for higher service quality perceptions of the trip experience. The traditional level of service theory and criteria continue to provide the necessary basis for describing and evaluating traffic movement effectiveness.

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Chapter 1

Introduction

1.1 Overview

The performance of roadway traffic depends not only upon the effectiveness of vehicular movement, but equally or perhaps more importantly the drivers' perceptions of the experienced quality of service. Both approaches should be integral elements in comprehensive traffic evaluations.

Comprehensive traffic evaluations are of particular importance in the prevailing economic climate, which will be increasingly characterized by major capital funding restraints. A comprehensive understanding of how a transportation facility's operation affects the users, as well as higher level societal benefit and cost considerations, is necessary to make the most effective application of the limited funding available.

Consequently, traffic performance evaluations should reflect not only the traditional vehicular movement effectiveness approaches, but also the driver serviceability* approach. This research addresses the latter through modelling driver trip experience perceptions. The driver serviceability approach refers to the drivers' gauging of the relative acceptability of the trip experience, as

* See Glossary for definitions of unusual terminology.

described by quality of service valuations. The trip experience encompasses all events that the driver encounters, through direct observation and participation.

1.2 A Major Need In Current Traffic Performance Evaluations

Traffic performance evaluations are fundamental to the rationalization of roadway infrastructure management and supply. The increasing need for comprehensive traffic evaluations can largely be attributed to the problems of unprecedented traffic growth, being compounded through restrained public funding.

However, a notable impediment to achieving comprehensive traffic performance evaluations is the absence of a well founded driver serviceability approach. Traffic performance evaluations without due consideration of automobile drivers' perceptions of quality of service are misleading, and could result in inappropriate facilities.

Mobility is the cornerstone of a region's economy as well as an indication of the quality of life it offers. However, the supporting transportation infrastructure to provide this mobility function is generally by nature and scope, an expensive draw upon public resources. Governments are increasingly faced with difficult choices in the balancing of limited funding against competing public service needs. Consequently transportation engineers will be pressured to arrive at innovative solutions to the grow-

ing dilemma of budget shortfalls while providing tolerable levels of service for the driving public. In view of a general trend towards decreasing roadway funding from all levels of government (1,2)*, the solution increasingly focuses upon concerns of just what tolerable levels of service are.

The increasing traffic congestion associated with the growing urbanization throughout the industrialized world, has been recognized as one of the central issues of the next decade (1,3,4). In 1983 55 percent of urban freeway travel and 40 percent of urban arterial travel occurred under congested conditions in the United States (5). The Transportation Research Board (4) has pointed out that improvements are necessary in the quality of service experienced by users, as well as the provision of additional facility capacity to address the congestion issue properly. Metropolitan and suburban congestion have been identified as one of the critical transportation problems facing users, the public, policy makers, transportation professionals, and safety organizations (1,6,7).

Urban traffic growth has been attributed to a combination of the rate of suburban development, increased automobile ownership and roadway construction (2). An example of urban traffic growth can be found in Vancouver, British

* See the listed references at the end of the thesis.

Columbia which has experienced annual average growth in inbound vehicular traffic of four percent per year between 1971 and 1990, despite current central business district transit usage of approximately 40 percent (8). Through the 1970s and 1980s the number of registered automobiles and licensed drivers doubled in Canada (2). The effect of increased automobile usage also impacts service on the rural primary highway network. For example, in British Columbia the main routes of this network experienced typical average annual traffic growth rates of three to seven percent between 1981 and 1989 (9,10) prompting public demands for roadway capacity modifications.

An informed roadway management decision requires the evaluation of roadway performance. Currently these evaluations include the traditional level of service (LOS)* criteria for vehicular traffic movement effectiveness (11), and pavement ride serviceability (12) through the gauging of the respective service provided. Roadway performance evaluations could be enhanced through the additional comprehension provided through the drivers' perspective of service quality.

Generalized roadway management relationships are presented in Figure 1-1. This figure illustrates the

* See Abbreviations listing for explanation.

Figure 1-1: Roadway Management Relationships

distinction in roles between the traditional traffic movement models and the currently lacking driver serviceability approach. The supply of roadway infrastructure should generally be based upon the comprehensive evaluation of three considerations. These considerations include economic and vehicular traffic movement effectiveness, and driver serviceability. The application of economic assessments, and the evaluation of traditional traffic movement effectiveness are both well developed in theory and routinely applied in practice. However, the driver serviceability approach although acknowledged as an important element of roadway performance, is neither well understood or realistically applied in practice.

The role of economic evaluations must continue to feature prominently in major facility expenditure decisions. These evaluations generally take the form of a social benefit - cost assessment of the economic effectiveness of a facility. These assessments would include not only directly associated construction, driver delay, and vehicle operating costs, but the extent to which the facility addresses social and economic requirements. An ineffective facility has the potential of becoming both a large and continual drain on public resources. This drain could include initial capital, ongoing life cycle maintenance and rehabilitation costs, and indirect incremental user costs.

Traffic management practice should also reflect the driver serviceability approach through the maintenance or enhancement of drivers' perceived quality of experienced service. This approach is consistent with the traditional roadway management objective of optimizing the roadway investment, through rehabilitation and maintenance programs. Traffic management should pursue a service balance between the traditional orientation of vehicular movement effectiveness, and the driver serviceability approach. The effect could be the achievement of the most efficient use of existing facilities, in terms of both traffic movement and the drivers' perception of the experienced service. This view fits within the Transportation System Management (TSM) philosophy. The potential practice would not be dissimilar to other TSM approaches to the management and maintenance of the existing system infrastructure through such activities as traffic management, demand management, or enhanced transit.

Transportation engineers now have a relatively thorough understanding of traffic movement level of service, through the ongoing evolution of the science of traffic movement (13). The traditional level of service approaches emphasize roadway and operational characteristics, such as speed, volume to capacity ratio, or delay (11). There is however a notable deficiency in current evaluations of traffic per-

formance through the lack of an objective description of the traffic effects on drivers. Quality of service criteria are generally nonexistent or only inferred through vague maneuverability or delay descriptions associated with traditional LOS criteria (11). Although these descriptions describe the traffic conditions that drivers may encounter, they do not reflect the driver's perception of the quality of the experienced service.

There is an acknowledged requirement for driver oriented quality of service measures to describe both traffic performance and tolerance to driving stress (14). Croft and Clark (15) note that "Research and traffic engineers have long recognized the need for methods of comparing the effects of various design options and traffic controls on the quality of traffic flow and levels of service in a qualitative manner." The American Association of State Highway and Transportation Officials (AASHTO) (16) in 1973 discussed establishing acceptable levels of congestion. These included an objective that operating conditions should provide a degree of freedom from driver tension. Driver tension was felt to be induced by driving task demands ranging from the frustration of slower moving traffic through the fear of high speed and high volume traffic.

1.3 Need For Modelling Driver Serviceability

In view of the missing driver serviceability approach it was recognized that the modelling of driver perceptions of the experienced quality of service was necessary.

The modelling of driver serviceability including the development of the underlying philosophy, rationale and approach, and the consequent serviceability guidelines have the potential of effectively enhancing roadway performance evaluations. The application of this approach will provide transportation engineers with the additional understanding of the quality of service experienced by drivers.

Although distinct, driver serviceability and traffic movement effectiveness approaches are complementary elements of effective roadway performance evaluations and management. Consequently the role of this driver serviceability modelling is to complement the traditional level of service approaches and criteria, not to replace them.

1.4 Problem Statement

1.4.1 Overview

The overall development and implementation of the driver serviceability approach will necessarily be both a long and involved program. The role of this research within that overall program is illustrated in Figure 1-2. This research covers the block titled "Modelling The Driver

**Figure 1-2: Driver Serviceability Approach
Developmental Overview**

Serviceability Approach". The future research would build upon the foundations herein, and lead to the implementation of the driver serviceability approach.

The modelling was developed and extended to a functional level to verify the existence and potential of the driver serviceability approach. The development of a consistent modelling methodology enables the standardized description of the serviceability processes underlying the trip experience.

The future verification and confirmation of the findings of this research would enable practical implementation of driver serviceability modelling and serviceability guidelines. The future research would both broaden and extend the underlying relationships between trip experience and quality of service. Those extensions should include other roadway classifications and background conditions, and potential facility management applications.

1.4.2 Goal

The goal of this research was to facilitate the enhancement of traffic performance evaluations and roadway management applications, through the modelling of the driver serviceability approach.

The thesis of this research is that the driver serviceability approach can be consistently modelled through descriptions of the quality of service relationships underlying trip experience. Further that serviceability effec-

tiveness ranges associated with these relationships can be developed on the basis of the modelling.

1.4.3 Objectives

The primary objectives of this research were to:

- i. Develop a modelling approach to realistically and consistently describe the drivers' perception of trip experience service quality.
- ii. Develop and demonstrate a practical basis for setting driver serviceability guidelines to complement current vehicular traffic movement effectiveness measures. This includes the development of driver serviceability descriptions that are both meaningful and usable by transportation engineers, and nontechnical people.

The supporting secondary objectives were to:

- i. Systematically identify and measure corresponding model input considerations including the drivers' description of the trip experience through their quality of service valuations and physiological correlates of stress; within the background context of the driver, roadway, environmental, and traffic characteristics.
- ii. Develop appropriate survey procedures for monitoring and evaluating drivers' physiological measures.
- iii. Develop interpretation and analysis procedures to enable the development of a functional model, and subsequent identification of preliminary serviceability ranges.

1.4.4 Scope

Driver serviceability was initially modelled on the basis of research on a rural two lane highway setting, and further extended through an urban arterial setting. Although the rationale and approach apply to driver serviceability generally, the particular findings are most relevant to automobile drivers and roadway settings similar to those used in the modelling.

The intent of this research is to develop and demonstrate the modelling of driver serviceability. The research is of sufficient depth to provide preliminary driver serviceability guidelines for both the rural two lane highway and urban arterial settings. However, the original and theoretical nature of this research requires that any further application of the driver serviceability fundamentals, or wide scale implementation of the driver serviceability guidelines, be a consequence of further developmental research.

1.5 Development Of The Thesis

There are two parallel streams of research in this thesis, as illustrated in Figure 1-3. The parallel streams include the initial research concept of linking physiological measures to quality of service perceptions, and the final research development stream describing driver quality of service through a relationship between travel time pre-

Figure 1-3: Thesis Development - Two Parallel Streams of Research

dictability and the subjective valuation of the trip experience.

The final research development stream was added as theoretical and practical problems became evident for the initial physiological concept. This final development stream was a consequence of a refocusing of trip experience relationships and the determination that travel time predictability was a more direct and practical basis for describing driver quality of service. Although the initial research concept was taken to a logical conclusion as a possible basis for further research, the reader is cautioned that the theoretical background and previous research applications for evaluating physiological baseline change are very limited.

1.6 Organization Of The Thesis

Chapter 2 presents a literature review of the pertinent background used as a foundation for this research. The review includes research and practice in vehicular level of service and driver stress.

Chapter 3 presents the formulation of the research problem. This includes a discussion of the driver serviceability philosophy, the preliminary identification of serviceability parameters, and a conceptual driver serviceability model. A review of the input requirements is also presented.

Chapter 4 presents the data collection process including the field survey protocol and a review of the subject base and survey locations.

Chapter 5 presents the development of the driver serviceability modelling process. The presentation includes the evaluation of serviceability parameters, the development and analyses of survey data, and the linkages underlying driver serviceability. Preliminary serviceability guidelines for a rural two lane highways are developed and presented.

Chapter 6 extends the driver serviceability modelling to an urban arterial setting. Preliminary serviceability guidelines for urban arterial streets are developed and presented.

Chapter 7 presents a discussion of the driver serviceability modelling. This includes a general review of the limitations, and the presentation of conceptual applications.

Chapter 8 presents a summary of results, conclusions and recommendations for future research on the modelling of driver serviceability.

The references, lists of abbreviations and nomenclature, and a glossary of unusual terminology are presented. Appendices covering supporting material are also presented for further reference.

Chapter 2

Background

2.1 Overview

Roadway facilities should be designed and evaluated with consideration of the impacts users will experience (14). Conceptually traffic level of service (LOS) is defined as a qualitative measure describing both operational conditions within a traffic stream, and their perception by motorists (11). The two elements of traffic performance should therefore include both descriptions of vehicular movement effectiveness, and that related to the drivers' perception of the quality of experienced service.

The traffic movement effectiveness element has received and continues to receive the attention it warrants. The drivers' perception of the trip experience has however been limited to generalizations that the less effective the movement of traffic, the lower will be the drivers' perception of service quality. The trip experience encompasses all events that the driver encounters that contribute to their awareness and knowledge. These events may be experienced through both direct observation and participation. The focus of this research is the redress of this limitation, through the development of a fundamental understanding of the driver serviceability approach.

This chapter presents a review of the pertinent background in roadway level of service and driver stress as a foundation for this research. Further related information is presented in the Appendix A and B overviews of the general fundamentals of traffic level of service and human stress, respectively.

2.2 Rural Two Lane Highway Level Of Service

The initial modelling of driver serviceability was based upon a rural two lane highway setting. Therefore a review of the traditional basis of level of service is necessary.

The three basic LOS criteria generally accepted for evaluating rural two lane highways are the average travel speed, percent time delay, and a measure of capacity utilization (11). The average travel speed is calculated through dividing the section length by the average vehicle travel time. A field measure of percent time delay is the percent of vehicles travelling at less than five second headways. Capacity utilization is calculated as the ratio of traffic flow demand to the capacity of the facility.

The capacity of rural two lane highways is difficult to determine due to the variety of local geometric characteristics. Further, Polus, Craus and Livneh (17) note that "this measurement is so sensitive that it may vary on the basis of traffic demand fluctuations, short variations in

speeds and traffic compositions and other random phenomena, such as weather. An hourly capacity is meaningful only if average conditions exist for an extended period during the peak hour".

The 1985 Highway Capacity Manual (11) level of service criteria are summarized in Table 2-1. The empirical relationships observed between two way traffic volume, speed and delay are presented in Figure 2-1.

The related rural two lane highway two-way service flows can be determined though the general equation:

$$SF_i = (2800)((v/c)_i)(f_d)(f_w)(f_g)(f_{HV}) \quad (2.1)$$

where:

SF_i = total service flow rate in both directions, for prevailing roadway and traffic conditions, for LOS i, in vph

$(v/c)_i$ = ratio of flow rate to ideal capacity for LOS i

f_d = adjustment factor for directional distribution

f_w = adjustment factor for restricted lane and shoulder widths

f_g = adjustment factor grade effects

f_{HV} = adjustment factor for heavy vehicles* (11).

The Transportation Association of Canada (TAC) (18) evaluated the applicability of the Highway Capacity Manual

* See Nomenclature listing for explanation summary.

**Table 2-1: Rural Two Lane Highway Level
Of Service Criteria (11)**

TABLE 8-1 LEVEL-OF-SERVICE CRITERIA FOR GENERAL TWO-LANE HIGHWAY SEGMENTS

V/C RATIO ^a																						
		LEVEL TERRAIN					ROLLING TERRAIN					MOUNTAINOUS TERRAIN										
PERCENT TIME DELAY	AVG ^b SPEED	PERCENT NO PASSING ZONES					AVG ^b SPEED	PERCENT NO PASSING ZONES					AVG ^b SPEED	PERCENT NO PASSING ZONES								
		0	20	40	60	80		100	0	20	40	60		80	100	0	20	40	60	80	100	
10%																						
A	≥ 30	≥ 48	0.15	0.12	0.09	0.07	0.05	0.04	≥ 57	0.15	0.10	0.07	0.05	0.04	0.03	≥ 56	0.14	0.09	0.07	0.04	0.02	0.01
B	≥ 45	≥ 55	0.27	0.24	0.21	0.19	0.17	0.16	≥ 54	0.26	0.23	0.19	0.17	0.15	0.13	≥ 54	0.25	0.20	0.16	0.13	0.12	0.10
C	≥ 60	≥ 62	0.43	0.39	0.36	0.34	0.33	0.32	≥ 51	0.42	0.39	0.35	0.32	0.30	0.28	≥ 49	0.39	0.33	0.28	0.23	0.20	0.16
D	≥ 75	≥ 80	0.64	0.62	0.60	0.59	0.58	0.57	≥ 49	0.62	0.57	0.52	0.48	0.46	0.43	≥ 45	0.58	0.50	0.45	0.40	0.37	0.33
E	≥ 90	≥ 95	1.00	1.00	1.00	1.00	1.00	1.00	≥ 40	0.97	0.94	0.92	0.91	0.90	0.90	≥ 35	0.91	0.87	0.84	0.82	0.80	0.78
F	≥ 100	≥ 100	—	—	—	—	—	—	≥ 40	—	—	—	—	—	—	≥ 35	—	—	—	—	—	—

^a Ratio of flow rate to an ideal capacity of 2,800 pcph in both directions

^b Average travel speed of all vehicles (in mph) for highways with design speed > 60 mph; for highways with lower design speeds, reduce speed by 4 mph for each 10-mph reduction in design speed below 60 mph; assumes that speed is not restricted to lower values by regulation

Figure 2-1: Rural Two Lane Highway LOS
Criteria Relationships (11)

(HCM) (11) LOS methodology and criteria to Canadian two lane highways. It was determined that the HCM model was "generally conservative in its platooning, speed and level of service predictions" (18). Consequently, TAC (18) recommends that the terrain (i.e. grade) adjustment factors not be used in computations (Equation 2.1) for use in delay and speed predictions (Figure 2-1) (18).

Traditionally the quality of service on roadways has been inferred from the quantitative LOS traffic movement effectiveness criteria. Research has indicated that drivers perception of serviceability is linked to their relative ability to pass slower moving vehicles, and thereby maintain the uninterrupted flow characterization of rural highway travel (16). In 1973 AASHTO recommended further research to determine whether it may be appropriate to relate percent time delayed to frustration level (16).

The 1985 Highway Capacity Manual (11) introduced percent time delay as a primary measure of effectiveness for rural two lane highways. Percent time delay is defined as "the average percent of time that all vehicles are delayed while traveling in platoons due to their inability to pass " (11). As percent time delay is difficult to measure directly, a surrogate field measure is the percent of vehicles travelling at headways less than five seconds (11). Yagar and Van Aerde (19) point out that percent time delay was

selected on the basis of it "being more sensitive to variation in flow rate than other candidate measures, such as vehicle speeds".

If passing opportunities are limited, drivers will perceive a lower quality of service than when an ample passing supply is available. Morrall and Werner (20) observed that "platoon travel, even at high speeds, results in a build up of driver frustration culminating in some cases with drivers making risky passes." They go on to note that "drivers perceive level of service as one's ability or inability to pass slower moving vehicles, and that ability to overtake is dependent upon the supply of sufficient gaps for passing in the opposing stream, provided sufficient sight distance is available or permitted as dictated by road geometry".(20) Consequently, the ratio of achieved to desired overtakings has been suggested as an additional measure of effectiveness (21,22). It has been observed that passing opportunities limited to 33 percent have a significant effect on drivers' delay tolerance as related to increased risk taking (23).

2.3 Urban Arterial Level Of Service

This research uses an urban arterial setting in an extension of the driver serviceability modelling. Therefore a review of the traditional bases of arterial level of service is appropriate at this time.

Arterials are signalized urban and suburban through routes, that provide varying degrees of access to abutting properties. The great extent of arterials are a product of rapid suburban growth and development over the last four decades. Arterials reflect the highly scattered nature of trip making and the near total dependence on private vehicles for suburban travel needs. The growth in arterial demand is expected to continue well into the next century (1). Arterial congestion delays are also increasingly a suburban problem on both the central business district radials and circumferential commuting routes.

The 1985 Highway Capacity Manual (11) presents the current theory and criteria for arterial level of service. Signalized intersection capacity is generally considered to be the key factor in all urban capacity considerations (24). Researchers and practitioners have encountered difficulties in associating LOS with volume in interrupted flow. Average travel speed has been viewed as a relatively insensitive measure of level of service, as evident in the limited speed changes in levels A through D (13,25,26). A potentially more sensitive operational criteria is thought to be a more direct measure of delay, such as a delay ratio, although this is not currently done in practice (11,13,27,28). The current LOS criteria do however include delay as a measure of effectiveness for signalized arterial

intersections (11,24).

The urban arterial environment is characterized by interrupted traffic flow operation, due to intersection delays, and nonrecurring incidents such as accidents, vehicle breakdowns, illegal parking, maintenance or construction work, alternate street closures, and emergency or special events. Interrupted traffic flow is therefore appropriately described by speed over an extended length of roadway (11,28). Arterial LOS is related to travel speeds as a reflection of the combined effect of midblock free flow, signal approach delays and driveway friction. The greater the difference between the actual average travel speed and the ideal average travel speed the lower is the level of service. The traditional arterial level of service criteria and associated general characteristics are presented in Tables 2-2, 2-3, 2-4, and 2-5.

The average travel speed criteria is calculated through dividing the extended length of an arterial street by the corresponding overall travel time. The single most important parameter is the average spacing of signalized intersections. The analyses of extended lengths of arterial streets reflect the cumulative delay impact of signalized intersections stops. Intersection delay aspects include considerations of effective green time, cycle length, quality of signal progression and presence of left turn bays.

Table 2-2: Arterial Level Of Criteria (11)			
ARTERIAL CLASS	I	II	III
Range of Free Flow Speeds (kph)	72 to 56	56 to 48	48 to 40
Typical Free Flow Speeds (kph)	64	53	43
LEVEL OF SERVICE	AVERAGE TRAVEL SPEED (kph)		
A	≥ 56	≥ 48	≥ 40
B	≥ 45	≥ 38	≥ 30
C	≥ 35	≥ 29	≥ 21
D	≥ 27	≥ 22	≥ 14
E	≥ 21	≥ 16	≥ 11
F	< 21	< 16	< 11

Table 2-3: Arterial LOS Characteristics (11)

LOS A describes primarily free flow operations at average travel speeds usually about 90 percent of the free flow speed for the arterial class. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Stopped delay at signalized intersections is minimal.

LOS B represents reasonably unimpeded operations at average travel speeds usually about 70 percent of the free flow speed for the arterial class. The ability to maneuver within the traffic stream is only slightly restricted and stopped delays are not bothersome. Drivers are not subjected to appreciable tension.

LOS C represents stable operations. However, ability to maneuver and change lanes in midblock locations may be more restricted than in LOS B, and longer queues and/or adverse signal coordination may contribute to lower average travel speeds of about 50 percent of the average travel flow speed for the arterial class. Motorists will experience an appreciable tension while driving.

LOS D borders on a range in which small increases in flow may cause substantial increases in approach delay and hence decreases in arterial speed. This may be due to adverse signal progression, inappropriate signal timing, high volumes, or some combination of these. Average travel speeds are about 40 percent of free flow speed.

LOS E is characterized by significant approach delays and average travel delays and average travel speeds of one third the free flow speed or lower. Such operations are caused by some combination of adverse progression, high signal density, excessive queuing at critical intersections, and inappropriate signal timing.

LOS F characterizes arterial flow at extremely low speeds below one third to one quarter of the free flow speed. Intersection congestion is likely at critical signalized locations, with high approach delays resulting. Adverse progression is frequently a contributor to this condition.

Table 2-4: Arterial Classifications (11)

AN AID IN ESTABLISHING ARTERIAL CLASSIFICATION				
CRITERIA	FUNCTIONAL CATEGORY			
	PRINCIPAL ARTERIALS	MINOR ARTERIALS		
Mobility function	Very important	Important		
Access function	Very minor	Substantial		
Points connected	Freeways, important activity centers, major traffic generators	Principal arterials		
Predominant trips served	Relatively long trips between above points and through trips entering, leaving, and going through the city	Trips of moderate lengths within relatively small geographical areas		
CRITERIA	DESIGN CATEGORY			
	SUBURBAN DESIGN	INTERMEDIATE	URBAN DESIGN	
Control of access	Partial to almost full	Partial	Little or no control	
Arterial type	Multilane divided; undivided or two-lane with shoulders	Multilane divided or undivided; one-way; two-lane	Undivided one-way; two-way, two or more lanes	
Parking	No parking	Some parking	Parking permitted	
Separate left-turn lanes	Yes	Some	No	
Signals per mile	1 to 4	4 to 8	8 to 12	
Speed limits	40 to 45 mph	30 to 40 mph	25 to 35 mph	
Pedestrian interference	None	None	Some	
Roadside development	Low density	Moderate	High density	

**Table 2-5: Arterial Classes According To Their
Function And Design Category (11)**

DESIGN CATEGORY	FUNCTIONAL CATEGORY	
	PRINCIPAL ARTERIAL	MINOR ARTERIAL
Typical Suburban Design	I	II
Intermediate Design	II	III
Typical Urban Design	III	III

Vehicle operation is also affected by the arterial environment and vehicle interaction. "The arterial environment includes the geometric characteristics of the facility and adjacent land uses. The number of lanes and lane width, type of median, access point density, and spacing between signalized intersections are among the environmental factors, as well as the existence of parking, level of pedestrian activity, speed limit, and population of the city."(11). Vehicle interaction is affected by traffic density, the proportion of trucks and buses, and turning movements. This interaction affects the operation of vehicles at intersections and, to a lesser extent, between signals.

Intersection approach and stopped delays are a reflection of the traffic signal effects as related to the intersection geometrics. These flow disruption delays have considerable effect on traffic movement and quality of service. Cumulative intersection delay for a given section can seriously impede the arterial's ability to move traffic effectively. Intersection approach delays include both stopped time, and acceleration and deceleration times. Signalized intersection saturation flow rate is approximately 1800 vehicles per hour of green time per lane (11). Signalized intersection LOS criteria have been developed and related to the average stopped delay per vehicle for a 15

minute analysis period. Signalized intersection LOS criteria are presented in Table 2-6. These delay ranges have not been qualified by driver subjective valuations (11).

Table 2-6: Level Of Service Criteria For Signalized Intersections (11)

Level Of Service	Stopped Delay Per Vehicle (seconds)
A	≤ 5.0
B	5.1 to 15.0
C	15.1 to 25.0
D	25.1 to 40.0
E	40.1 to 60.0
F	> 60.0

The Canadian Capacity Guide For Signalized Intersections (24) identifies average intersection delay as a comparative measure for evaluating the effectiveness of a complete intersection. The guide defines average intersection delay as "the average waiting time which will be experienced by a passenger car unit approaching the intersection during the defined analysis period" (24). Threshold average approach delay values related to the relative acceptability of delays are summarized in Table 2-7. The threshold delay values of Table 2-7 which include both approach and stopped delay are not directly comparable to the average stopped delay criteria of Table 2-6, which exclude approach delays.

Table 2-7: Threshold Delay Value Descriptions (24)	
Average Delay (seconds)	Description
< 30	Acceptable Operation
30 to 60	Excessive Waiting Time
> 60	Usually Not Acceptable

The intersection delay criteria suggests that delay is characteristic of congested arterial operation. The use of intersection delay is consistent with the average travel speed criteria over extended lengths of roadway, in that delay is an integral element of travel time.

Environmental considerations influence the drivers' perception of safe speed. Under low flow conditions the average perceived safe speed would approximate the free flow speed. This will generally be close to the posted speed limit. The average running speed will generally be lower than the posted speed limits during high demand periods, due largely to intersection approach and stopped delays. The Highway Capacity Manual reports that drivers' will tolerate one LOS poorer for intersection effects, than on the through sections (11).

2.4 Deficiencies In Current Level Of Service Approach

A fundamental deficiency in the current approach to traffic performance evaluations is the inability to relate the drivers' trip experience to their perception of

service quality. The current LOS criteria do not provide a satisfactory basis for applications requiring an understanding of the qualitative relationship between the drivers' perceived service quality and the trip experience.

This is evident in the rural two lane highway LOS criteria (Table 2-1) of percent time delay and average travel speed which do not provide a basis to distinguish the quality of service experienced by drivers. The lack of a linkage to the relative frustration effects experienced by drivers, is particularly evident in platooning conditions (20). Similarly, the arterial level of service traffic movement effectiveness criteria presented in Table 2-2 gauged in terms of average travel speed, are only qualified by vague quality of service commentaries for LOS B and C (as underlined in Table 2-3).

The evaluation of traffic performance requires not only the traditional level of service measures, but also a basis for evaluating the drivers perception of the quality of service experienced on a trip. There are currently no professionally accepted methods of averaging or aggregating traditional levels of service within a travel corridor or for a typical trip (29). This deficiency has been attributed to the complexities of aggregating both the effects of roadway elements and different roadway functional classifications; due in part to differences in LOS evaluations (29).

The trip experience description advanced in this research may provide an overall context for the coordination of the traditional LOS evaluations.

The effectiveness of traffic performance evaluations could be enhanced through the inclusion of the driver serviceability approach. The understanding of relationships underlying driver serviceability would facilitate an integrated approach to traffic performance evaluations and roadway management. This would be achieved through the development of further traffic performance guidelines reflecting the drivers' perception of quality of service. The traditional LOS criteria would continue to feature in the key role of traffic movement effectiveness evaluations.

2.5 Driver Stress

2.5.1 Driver Stress Overview

In this research driver stress followed the general definition of being the adverse mental and physiological effects experienced by an enroute driver (30). Struggling through congested traffic, maneuvering in high speed traffic or coping with unforeseen travel delays make significant stress demands on the body (31). Excessive stress can overtax coping reserves, and thereby adversely affect performance, health, and the quality of life (31,32). Consequent-

ly, serviceability criteria reflecting the drivers' perspective will become increasingly appropriate.

A trip experience is characterized by driving situations. The driving task requires the driver's active observation of, and participation in the roadway environment. The driving situations encountered will contribute to both the driver's immediate awareness and longer term knowledge. Drivers generally react and adapt to most driving situations (33). Their behaviour reflects a dynamic balance between immediate safety risk and traffic pressure limits (34). The safety limit refers to actions that are hazardous in view of the prevailing situation, such as taking advantage of an inadequate passing opportunity. Conversely, the traffic pressure or capacity limit would be apparent in a driver not taking advantage of an adequate passing opportunity. The largely subconscious balancing actions between these limits vary depending upon the driver, the particular traffic situation, and the accepted social and traffic behavioural norms. Driver behaviour will range between those aggressive drivers pushing the limits of safety, to those defensive drivers hedging the capacity limit. An extreme imbalance would result in either a traffic accident at the safety limit, or ineffective traffic movement behaviour at the capacity limit. The driver's balancing ability will determine their relative success at

achieving immediate driving objectives, such as maintaining vehicle control.

The balancing action between the safety and capacity limits occurs in the presence of traffic movement constraints such as congestion limitations or unforeseen delays. Physiological reactions will be consequences of exposure to such stressors (31). Torres (35) describes stress as a psychological and physiological state associated with such considerations as uncertainty, greater concentration, and increased attention and readiness to combat the unexpected. These stress considerations would be elements of the balancing action between the safety and capacity limits. Elevated physiological arousal and negative emotional reactions have been associated with travel impedance (31,35). Furthermore, the stressful nature of driving on congested roadways or being subjected to unforeseen delays can have adverse impacts on health, psychological adjustment and driver performance (31,35).

Driving an automobile requires a combination of mental and physical skills commensurate to the corresponding task demand loads. The driving task can be characterized through control, guidance, and navigation activities (36). The control activity refers to the immediate vehicle-road interaction, through the manipulation of speed and direction. The guidance activity refers to remaining on the road

safely with reference to traffic control information and devices, and other traffic. The navigation activity refers to the enroute reference and processing of directional information to reach a destination.

The driver's perception of the roadway environment will be framed by travel expectations based upon their current observations of traffic conditions, the roadway, and environment, relative to both the immediate past and longer range experience, and cognitive abilities (37). The driver's perception of service quality can also be influenced by the comfort of the vehicle (37). However, drivers would be expected to experience similar physiological response changes to similar travel conditions (31).

2.5.2 Driver Stress Research

Research from the 1950s through early 1970s establishes a basis for the study of instantaneous physiological response correlates of driver stress (38,30). Research was directed primarily towards studying driving as an example of a complex task within the framework of experimental psychology, with limited application transfers to traffic engineering.

Hallmark driver stress research includes that of Michaels (39,40) in which he studied tension responses of drivers on urban streets and expressways, using galvanic skin reflexes (GSR). His early research (39) dealt with the

potential of using the magnitude and frequency of the GSR physiological response as a means of differentiating types of traffic interference and urban street characteristics. He observed that highest GSR tension responses were associated with actual or incipient traffic conflicts including approaching, turning, and crossing and merging vehicles, and traffic signals, and in stream pedestrians. He found that higher GSR amplitude corresponded to greater speed differentials between the test vehicle and the other vehicle in the traffic event. Lesser GSR tension response was evident for fixed objects, parked vehicles and traffic islands. He concluded that tension responses are directly related to the complexity of the traffic situation, and inversely related to the predictability of the actions of other drivers.

Michaels' later research (40) dealt with the evaluation of driver GSR tension response relative to different highway designs. He found that the higher the highway standard of geometrics and access control, the lower the magnitude and frequency of GSR response. The GSR responses were also related to free through stable flow ranges of traffic volumes. He noted that tension responses rose sharply as traffic volume approached practical capacity, and tentatively presented this relationship as a possible proxy for comfort and convenience. Michaels confirmed his earlier conclusion that tension responses are directly

related to the complexity of the traffic situation, and inversely related to the predictability of the actions of other drivers. He goes on to suggest that GSR may have potential as a behavioural measure of highway operational efficiency.

Other pertinent driver stress research includes that of:

- i. Hulbert (41) who followed a similar line of research in determining that GSR tracings were related to actual and potential traffic path interruptions. The GSR tracings were rated according to relative pattern changes, before and after the interruptions.
- ii. Surti and Gervais (42) who researched the application of physiological response between alternate routes as a basis for route diversions. They found that the magnitude and frequency of GSR were similar between a freeway and alternate street near practical capacity. Beyond practical capacity the freeway had comparably higher driver stress than the surface street, as evident in significantly higher GSR values. The researchers concluded on the basis of their findings that there is a stress basis for route diversion, and that alternate route options should be attractive to informed drivers.
- iii. Taylor (43) who researched drivers' GSR as related to the risk of accidents. The magnitude and frequency of

responses were found to be associated with apparent traffic events. Further a measure of GSR frequency per mile was found to be similar to the pre-existing accident rate (accidents per mile of travel) for the test sections. He also found that GSR activity showed a greater relationship to the driver's experience than road conditions.

- iv. Preston (44) who undertook similar research in evaluating the relationship between the driver's insurance classification and GSR frequency per mile, on both rural and urban roads. Significant response differences, in a ratio of urban to rural responses, were found between high and low risk drivers.
- v. Brown and Huffman (45) who investigated driver physiological responses of GSR, heart rate and eye movement in relation to different driving applications. Significant differences in physiological responses were evident among the applications of rural two lane highway, four lane expressway, four lane business district, and residential area environments during both day and night. Drivers exhibited higher levels of arousal in daylight heavy traffic conditions, than during night moderately heavy traffic. The GSR rate was found to be significantly lower for the rural highway application, and at night for all applications.

The researchers note that the least useful measure of arousal appeared to be heart rate, as evident in the similarity of results between the different applications. The researchers recommended that responses should be converted to proportions for evaluation, through taking the prestimulus and peak response levels into account.

- vi. Helander (46,47) who investigated the relationships between continuous measures of GSR, heart rate, and muscle activity related to traffic event task load on a rural highway. He found that GSR and heart rate are primarily induced by the mental effort of the driving task, although both response measures could be affected by an immediate physical effort. The physical effort for example refers to the exertion required to maneuver or brake a vehicle. He also noted that GSR, as a rapidly responsive measure, is appropriate for applications where task demand levels are changing rapidly.
- vii. Rutley and Mace (48) who evaluated heart rate as a potential instantaneous measure of driver stress related to different road layout designs. They determined that "heart rate changes can be used as a measure of the stress induced by various road junction designs."(48). They note that the interpretation of the relationship between heart rate and psychological

stress must recognize the potential influence of physical vehicle control movement effects on heart rate.

viii. Weir and Allen (49) who investigated the use of physiological response measures extracted from an electrocardiogram (ECG) and heart rate to describe driving task performance levels. Drivers responses were monitored for exposure to wind gust and roadway irregularity conditions. Both the ECG and heart rate were found to provide comprehensive measures of driver stress level. The researchers noted that heart rate response is best described in terms of both increasing or decreasing trends and rate changes.

ix. Cleveland (50) who evaluated driver tension related to rural intersection illumination through measuring GSR. Significant response differences were observed for subjects driving through a rural interchange at night, as related to the presence or absence of illumination. Higher GSR magnitude was evident with no illumination, and higher GSR frequency was associated with intersections of greater complexity.

x. Torres (35) who considered that covert physiological responses could be effective in the identification of roadway characteristics that affect driver stress. He researched the potential application of the GSR physiological response measure as a correlate of driver

stress attributable to moving traffic situations. He determined that a positive relationship between GSR and urban arterial traffic events was evident in the free though stable traffic ranges. Traffic events included potential or actual parking movements, passing or slowing maneuvers, crossing or tailgating vehicles, pedestrian movements, and traffic signal changes. He found that magnitude of GSR change could be reliably associated with transitory traffic events. On the basis of his observations he inferred that the higher the average value of GSR the greater the driver tension and discomfort. The overt physical responses to maneuver or brake the vehicle to avoid actual or incipient traffic events were also measured. Examples of these physical responses include steering wheel reversals, brake applications, or accelerator movement as related to some evasive vehicle action. These physical responses were found to be characteristic of conflicts in both free and stable flow traffic movement regimes. Torres notes that physiological reactions occur in response to moving traffic situations, and may also occur where the driver actions are limited. This inference was based upon the observation of the decreased magnitude and frequency of physical response in stop and go traffic typical of congested or

delay situations. He also found that the GSR occurrence of drivers was higher than passengers for the same event.

The basis for the continuous physiological monitoring of drivers is well founded in practice as evident in the foregoing review. Although these fast acting physiological measures have traditionally been associated with stimuli of a momentary nature, they may have the potential for conveying information that describes physiological changes at longer intervals (51). However the use of a physiological baseline shift as a measure of an extended event has a seen limited application.

Related research includes that of Stokols (52) into trait anxiety who found that commuter exposure to traffic congestion is associated with significant differences in the mood, physiology and task performance of commuters. It was concluded that the greater the congestion impedance, as described through both travel distance and travel time, the greater was the increase in blood pressure. In that research the systolic and diastolic blood pressure and heart rate readings were taken on three consecutive days on arrival at work to measure activation levels, and related to mid-morning baseline measures. These baseline measures were however taken in a setting unrelated to the commuting envi-

ronment. The physiological response changes were then evaluated in the context of the corresponding commuting time and distance. The research notes that baseline measures taken prior to the trip may enable a clearer assessment of the relationships between both prevailing and routine travel impedance, and chronic and commuting specific arousal. The researchers go on to speculate that commuting stress may be related to a discrepancy between the commuters expectations and the actual experience of travel constraints.

Peripheral research relating to comparative physiological reactions includes that of:

- i. Platt (53) on heart rate as a measure of driver psychological stress under varied driving conditions. He found a significant increase in the variability of heart rate over a 25 minute period of driving under adverse weather and road conditions. He noted that on a routine 1.5 hour interstate trip in daylight and light traffic, that heart rate measured at 10 minute intervals dropped significantly for extended periods. He also noted on an extended 12 hour trip (divided into 1.5 hour intervals) that heart rate variability diminished, and was likely attributable to the fatigue effects of the very long trip.
- ii. Hulbert (54) on the evaluation of the effects of

driver fatigue. He summarizes that in laboratory simulated driving conditions that a fatigued subject would exhibit less GSR and respiration reaction in response to a traffic event than when alert. Subject fatigue in that research was brought about through a 24 hour sleepless period.

- iii. Ettema (55) on the effects of mental task load. He concluded that a systematic increase occurs in both systolic and diastolic blood pressure due to the intensity and duration of a mental task load. The mental task load used was that of a binary response choice to random high or low tones, through pressing a pedal with the corresponding foot. The constant blood pressure increases were found to occur in both short three minutes periods and in longer lasting experiments with a four hour duration. Although the blood pressure increases of the short periods were noted, they were found to occur within the normal physiological range. However, the prolonged mental load of the longer term experiments indicated a more significant increase in blood pressure. The research also cites similar blood pressure response for a railway controller who exhibited blood pressure increases related to both normal and emergency situations lasting for "some hours". He also notes that the "Increase in blood pressure, together

with changes in other physiological phenomena such as heart rate, sinus arrhythmia, etc., indicate that mental load may alter the level of activity of the autonomic nervous system."

- iv. Ax (56) on the presence of physiological response changes over extended periods of time, in sleep deprivation research. In that research comparatively higher GSR levels were measured when performing the same task before and after an extended period of wakefulness.

2.5.3 Driver Stress Monitoring

In the modelling of the driver serviceability approach it was appropriate to capture as much physiological stress information as possible. The different physiological measures provide greater versatility in the modelling data base, than could be achieved through monitoring and evaluating fewer measures.

A potential instrument for the simultaneous recording of the driver's physiological conditions of the trip experience is the polygraph. The polygraph records physiological changes as a function of conscious and subconscious stress (32,57). The polygraph evolved over a period of 90 years (58). It's underlying principles are founded on development and experimentation in the fields of medicine, physiology and psychology. It operates on the

premise that a stressor will cause direct measurable physiological changes.

The polygraph hardcopy output consists of graphical tracings of thoracic and abdominal respiration, blood pressure and pulse, and galvanic skin response.

Respiration air volume intake changes are monitored through measuring the relative expansion and contraction in a pneumatic tubes around the subject's chest and abdomen.

Blood pressure and pulse are measured through the application of a blood pressure cuff around the subject's upper arm, as in a medical examination. It may be also be measured in the leg. Blood pressure is technically the pressure of blood against the arterial walls. Pressure will rise and fall corresponding to the heart's outflow contraction and inflow expansion strokes. Respectively these are the systolic and diastolic pressures.

The heart rate or pulse is a measure of the number of beats per unit time. The time unit is usually one minute. Heart rate can also be interpreted in terms of the variability or standard deviation of the heart rate.

GSR is a measure of the change in electrical conductance or resistance of the subject's epidermal skin layer. As stress precipitates perspiration increases, the electrical conductance increases and resistance falls. It is generally measured through attaching a set of electrodes to

a subject's finger tips, and monitoring the changes in either electrical conductivity or resistance of a millivolt current. The electrical differences are measured through the variation in pathway conductance or resistance between the two finger tips, through the fingers and palm. The GSR is also known as the galvanic skin reflex, electrodermal response (EDR), electrodermal skin response (ESR), and skin conductance response (SCR).

The instrument and constituent parts have been successfully used in behavioural studies generally (59,60), and for drivers specifically (35). Stress monitoring can be conducted and evaluated in such a manner to enable consistent interpretations of the findings (57). The numerical scoring of chart output increases objectivity and aids in decreasing risk of interpretation bias (57).

Chapter 3

Formulation Of The Research Problem

3.1 Overview

The provision of transportation facilities and services can have significant implications on the users' quality of life. The rapid growth in travel demand relative to limiting infrastructure budgets requires a critical rethinking of the perspectives and practices that guided facility warrants and developments over the past two decades (61). This situation may in part be addressed through the development of broader measures of facility performance reflecting the users' perspective.

Roadway traffic performance evaluations are based on the traditional traffic movement effectiveness approaches. The modelling of driver serviceability advanced in this research should be viewed as a complement to the traditional traffic movement models and criteria. The modelling of driver serviceability relates the drivers' perceptions of service quality to the trip experience. As previously presented, the trip experience encompasses all events that the driver encounters that contribute to their basis of knowledge. These include direct observation and participation. An example of direct observation would be an awareness of the weather, scenery and informational signing not

of immediate impact in the driving task. Examples of participation would include the balancing of safety and capacity limits by the driver (34).

The traffic movement models are well founded in theory and practice, as evident in the substantially greater evolution of the quantitative measures of the traditional (LOS) criteria (11,13,62). These include such parameters as speed, density and flow as the basis for evaluating facility performance and capacity utilization. As intended, the current LOS criteria are useful for transportation engineers and planners in facility planning and design applications (63). The limited qualitative allusions associated with the traditional LOS criteria provide neither a consistent or objective basis for describing quality of service, for use by the public and their governments (27). This inadequacy in traffic performance evaluations had been considered relatively inconsequential until the looming funding restraints of the late 1980s (64). Consequently, further traffic performance guidelines portraying the drivers' perspective are increasingly required.

The development of a substantive driver serviceability basis has been limited through the comparative difficulty in setting consistent definitions of service and quality, and establishing consistent and complementary performance criteria. Consequently there has been very limited practical application of the driver serviceability approach.

This research addresses the need through modelling driver serviceability. Modelling will provide the necessary consistent basis for assessing traffic performance from the driver perspective of quality of service. Rural two lane highway and urban arterial settings are addressed in the modelling, and the development of preliminary serviceability guidelines. These advances also enhance the general understanding of the driver serviceability approach.

This research focused on automobile drivers, as they are the greater proportion of roadway users in Canada and the United States. This is evident in the typical 80 to 85 percent proportion of automobiles in the urban traffic mix being compounded by a low average occupancy rate of approximately 1.5 persons per vehicle (13). Although comparable rural data are unavailable, automobiles are described as being the greatest traffic component using the rural principal arterial system (64).

The following sections present the serviceability philosophy and conceptual model as preludes to the modelling of driver serviceability.

3.2 Serviceability Philosophy and Conceptual Model

3.2.1 Serviceability Philosophy

Driver satisfaction is an integral element in the concept of roadway service. Over the years, researchers have attempted to develop consistent measures of effectiveness related to driver satisfaction (11). Conceptually, driver satisfaction has been related to relative comfort and convenience, reliability, safety, cost, and travel time (65).

The missing cornerstone of a driver serviceability philosophy and model has been the determination of practical and consistent linkages between the driver's perceptions of service quality and the experienced service.

Teply (34) identified two levels of traffic behaviour. The first level relates to pretrip travel decisions including such things as trip utility, route and mode choice, and the evaluation of expected problems. The second level is the enroute traffic behaviour described by the balancing of immediate safety and traffic pressure constraints, as reviewed in Section 2.5.1.

Intuitively driver satisfaction will be higher when performance is satisfactory. Although drivers will adapt to varying degrees of less than desirable prevailing conditions, their relative acceptance will be gauged against some initial expectation of service. Therefore it is postulated that this likely pretrip expectation could form the

basis for gauging the quality of service experienced on the trip, and thus could be the underpinning for modelling driver serviceability.

A precursor to modelling driver serviceability was the identification of the most appropriate parameter(s) against which quality of service could be reliably gauged. The relationships among these parameters would describe the linkage between the trip experience and perceived quality of service. Although time based parameters such as speed and delay are currently applied to level of service criteria (11) it was felt that these were sufficiently vague as related to driver's perception of service quality that a general review and clarification was appropriate. The review centred around a series of structured driver interviews and surveys relating to serviceability considerations that could feature in driver perception of quality of service. The serviceability consideration interviews are summarized in Appendix C.

Those interviewed and surveyed included professional and nonprofessional drivers, transportation planners and engineers, and lay people. The featuring of professional drivers in these reviews was seen as an advantage in that their trip experiences covered a much broader range than the average driver.

The objective of the interview process was to solicit a

general serviceability focus from drivers, to clarify and elaborate upon the limited background literature. There was no intention to undertake a definitive study of quality of service considerations. Consequently, coarse interview techniques and survey questionnaires corresponding to a general rather than definitive review of driver quality of service were used.

The most important serviceability consideration identified was safety. In the interpretation of the findings safety was viewed as being paramount to driving, as evident in the extent to which Canadian and American drivers take safety for granted in using public roadways (66). Consequently the presence or likelihood of safety was viewed as being a prerequisite to the occurrence of the driver serviceability process.

The further general focus of the interview responses relating to serviceability was oriented towards considerations of travel reliability and travel time. Reliability was construed as the ability to predict the experiences of the trip. Travel time was described through such measures as speed and delay. These were further seen to be affected by such things as the availability of passing opportunities, weather, and road surface conditions. In the course of the follow up serviceability questionnaire it became increasingly apparent that a speed based derivative of the travel time consideration was the appropriate basis of a driver

serviceability focus. The travel time and reliability orientation of the interview responses is corroborated to some extent by research relating to interviews with San Francisco area commuters (37). These interviews revealed that both the extent and uncertainty of congestion and delay were viewed as major contributors to stress (37).

Although each travel experience is truly unique with respect to the prevailing traffic and background conditions, each trip entails the expenditure of time. The traditional level of service criteria recognize the expenditure of time through the use of criteria such as average travel speed and delay as related to traffic conditions. However, these criteria do not explicitly reflect unusual delays attributable to weather or construction, and more importantly fail to recognize that quality of service is apparently perceived relative to the drivers expectations of trip conditions.

On the basis of the general focus and findings of these interviews and surveys, and in view of speculations in the reviewed literature (29), it was hypothesized that the driver's perception of the quality of experienced service would be more appropriately based on overall trip time. Criteria determined on an overall trip basis would not distinguish dynamic serviceability changes during the trip, such as a particular intersection delay or segment

congestion. However the criteria would reflect these in the aggregated effects of the trip experience, through descriptions of the overall performance outcome and service quality perceptions. The closest analogy with the current level of service criteria would be that of travel speed determined over extended lengths of roadway.

The pretrip expectation of trip time provides a point of reference for gauging the quality of service of the trip experience. The relationship between the predicted and actual travel times could be described through the concept of travel time predictability. Travel time predictability would reflect the relative extent of the driver's awareness of enroute conditions. This would be evident in the travel time difference between the driver's initial prediction and actual outcome. The driver's perception of service quality would be related to the travel time predictability description of their trip experience. Ranges of service quality could provide a basis for evaluating traffic performance from a driver serviceability approach.

Travel time predictability has a high importance as evident in Rowe's observation that "The impact on the motorist of nonrecurring congestion is much more than just added delay. It is the uncertainty of variable travel times that can be longer than average, necessitating either the allowance of a greater time cushion in travel plans or the acceptance of frequent lateness to appointments. This

uncertainty provides at least as much aggravation and stress to the motorist as recurring congestion, which at least is predictable." (67). The presence of such stressful conditions were cited by commuting motorists as a motivation for a shift to ride sharing from single vehicle usage (68).

The travel time predictability parameter effectively captures the essence of the trip experience through the confounding of prevailing trip condition effects into the travel time outcome. This confounding concept is consistent with the use of overall descriptions to reflect the aggregate effect of multiple inputs in conditions of uncertain outcome (69).

The predictability of speed, as a function of travel time given trip length, would in effect present the same basis for gauging quality of service. The development and use of the time based travel time predictability measure of service quality is in keeping with the general observation of Yagar and Van Aerde (19) that " speed is a service basis inherent to our society".

Conceptually travel time predictability may have application to trip links, as well as the overall trip depending upon the driver's reference in framing travel expectations. In trip applications of short duration or singular purpose the overall context would seem most practical.

Very long travel times are also conceptually consistent with the application of travel time predictability. The driver's perception of service quality would continue to be gauged against their expectation of travel time, regardless of the actual travel time outcome. A very long actual travel time that differs significantly from the expected travel time would not result in the default of the concept, but rather a very low value of travel time predictability and therefore associated quality of service.

The forethought in the driver's decision to travel would include consideration of the travel choice consequences. A fully informed driver, would in predicting travel time, set a reference point against which service quality will be gauged for that trip at that time. Should the driver determine that the prediction is within an acceptable range for that particular trip, the driver would be expected to choose to travel under the supposed prevailing conditions. This does not discount the possibility of unexpected delays due to unforeseeable circumstances, but rather the net effect would be a proportionate increase in travel time and a reduction in travel time predictability.

The driver's choice of departure time would be influenced by both the prediction of travel time for a particular trip, and the implications of late arrival at the trip destination. Serviceability would continue to be relative to the extent to which trip performance achieves their

predictions, despite for example, late arrival as a consequence of late departure. A driver that departs late would likely continue to gauge serviceability on the basis of their initial travel time prediction. However the range of acceptable travel time predictability may depend upon the purpose of the trip, as related to the implications of a late arrival.

Should a driver be unable to achieve an acceptable level of travel time predictability that driver would either continue to perceive poor service quality or divert in either time or space to more predictable travel alternatives. Observations of travel pattern and modal choice behaviour related to traffic disruptions associated with major highway construction (70), tend to confirm this hypothesis. Motorists tended to resist less familiar and therefore less predictable routing alternatives, in favour of their known route despite it's greater levels of delay or congestion (70). A modal shift from private cars to public transit buses also occurred despite longer transit travel times, due to the more predictable nature of the scheduled service than the variable construction disruptions (70). Similarly, service reliability was felt to be more important than absolute travel time or direct travel costs in airport access modal choice (71).

Driver intolerance of congested conditions may then be

viewed as an intolerance of the effects on travel time predictability, as opposed to the congestion itself. Potentially, this view has significant implications to the supply and management of roadway facilities; in that if travel time predictability can be increased to acceptable levels, congestion will be more tolerable and major facility supply decisions subject to further qualification.

Driver perception research peripheral to the "Two-Lane Highway Capacity And Level Of Service Research Project"(18) by the Transportation Association of Canada (TAC) corroborate this concept to some extent. Drivers were found to be able to differentiate between rated traffic conditions and perceived quality of service. Of the drivers that rated the platooning delay traffic condition as poor (LOS E) only 20 percent considered the condition to be very or extremely annoying, and 40 percent expressed no annoyance at all. The report speculates that those drivers familiar with the route may have anticipated platoon delays and would therefore rate the traffic condition as poor without being particularly annoyed (18). However, the collected data did not include the drivers' trip expectations or prediction of travel time. TAC's further evaluation of the driver perception data was limited due to budgetary and time constraints.

If drivers base route diversions, or modal choice on predictability of travel time there are also significant

implications to transportation planning model applications, that incorporate trip time as a key factor. Examples of these can be found in the Gravity Model used for trip distribution, the Logit Model used for modal split, and the all or nothing and capacity restrained traffic assignment procedures (72). The use of travel time predictability in these models and procedures would require not only the assumption that drivers have an awareness of what the shortest link is, but also that they have the appropriate background to make knowledgeable predictions.

3.2.2 Conceptual Model

This research is founded upon the hypothesis that drivers evaluate the quality of service of their trip experience. Theoretically the trip experience could be described through any number of trip conditions or events. Practically however the driver serviceability approach must be gauged against common performance measures, to enable the comparison of quality of service between different trips or roadway settings. For example an absolute criterion of travel time has limited transferability compared to a relative measure of performance such as travel time predictability or speed.

Conceptually driver serviceability would be modelled through quality of service valuations of the trip experience, as described by:

$$\text{Serviceability} = f(\text{Trip Experience}) \quad (3.1).$$

Although a trip experience will be affected by a considerable number of both foreseen and unforeseen conditions and events, the aggregate effect of these inputs could be captured in a common performance measure.

The driver serviceability concept is illustrated in Figures 3-1 and 3-2. In this research it was hypothesized that trip experience could be described through travel time predictability. The outcome of travel time predictability is inextricably linked to the trip experience. Travel time predictability effectively represents all prevailing background conditions through their respective effects on the outcome of travel time. It was further hypothesized, that the driver serviceability process could be described by a consistent relationship between the driver's travel time predictability and their subjective valuation of service quality.

Also shown in Figure 3-1 and 3-2 is that the aggregate driver, environmental and roadway states contribute to the trip experience and therefore determine the outcome of travel time predictability. Driver state was defined as those considerations within the driver's immediate control, such as previous driving experience generally, route familiarity specifically, vehicle climate control and ride comfort. Environmental and roadway state was defined as those factors beyond the immediate control of the driver including

Figure 3-1: A Driver Serviceability Concept

Figure 3-2: Travel Time Predictability Perspective

such things as roadway, weather, and traffic conditions. The aggregate effect of the prevailing environmental and roadway state will be evident in the actual travel time outcome, and will therefore be reflected in travel time predictability. As a description of the trip experience travel time predictability could be linked to the driver's subjective service valuations.

In formulating the conceptual model it was felt that the driver serviceability approach would be more meaningful through the development of a parallel objective description of the trip experience. The descriptions of travel time predictability and the corresponding physiological correlates of stress would provide linkages between the trip experience and the subjective valuation of service. The physiological description would provide an additional objective basis to augment the interpretation of the serviceability process. These relationships are illustrated in Figure 3-1. The linkage shown between travel time predictability and the physiological stress correlates recognizes that a relationship could exist, through travel time prediction being considered as an element of the driver state.

In this research the measures of physiological baseline changes are described as stress correlates of the trip experience. This description reflects the principle that although stress can not be measured directly, that it may be

inferred on the basis of physiological measures (73).

The physiological description of the trip experience used in this research was the baseline change between pre-trip and posttrip recordings. Although the theoretical basis for baseline change is limited (as reviewed in Section 2.5), it's application in this research provides a novel secondary description of the trip experience. As previously noted, the reader is cautioned in further application of physiological baseline change until research efforts can expand upon the limited theoretical basis.

The driver's predictive ability and their knowledge of prevailing environmental and roadway conditions are the basis of their prediction of travel time. This prediction is in turn an element of the travel time predictability description of the trip experience. These relationships are illustrated in the travel time predictability perspective of Figure 3-2.

The prediction of travel time requires both a knowledge of the typical travel time and an awareness of atypical prevailing conditions that could cause delay. The typical travel time for the travel period would include recurrent delays associated with traffic conditions. Examples of the recurrent delays would include passing opportunity availability in the rural setting, and traffic control signal delays in the urban setting. The atypical conditions would

include programmed and non-programmed delays. Examples of programmed delays would generally be related to construction, rehabilitation or maintenance operations. Non-programmed delay examples would be related to weather, accidents and vehicle breakdowns. Although not programmed, weather and significant accidents could, and should, enter into the travel time prediction if there is a timely means of conveying the information to drivers. In effect the exceptional or unusual will become routine, and therefore more predictable and acceptable.

An analogy of note in modelling driver serviceability was found in the pavement serviceability concept, reviewed in Appendix D. Pavement serviceability is described through a relationship between objective mechanical measures of pavement roughness, cracking and rutting, and qualitative ratings of ride comfort (12). This relationship enables the evaluation of pavement serviceability through making comparatively rapid objective measurements and determining the correlated qualitative rating. This approach is much more practical than having a panel rate each pavement section, each time a serviceability evaluation is required. The analogies in this research to the objective pavement measures are travel time predictability and the physiological stress correlates. The subjective valuation of service in this research is analogous to the qualitative description of ride comfort.

3.3 Input Requirements

3.3.1 General

Scientific research can follow either survey or experimentation courses of investigation. This research followed the survey approach in an endeavour to develop realistic descriptions of the drivers' trip experience. Consequently all modelling information was developed on the basis of field observations of actual trip experiences. This contrasts with the experimental course of investigation in which the hypothesized inputs would be manipulated in the presence of controlled background conditions. The underlying experimental relationships would then be discovered through an assessment of the effects of varying the key inputs. In the development of this research it was felt that experimental manipulation could significantly affect the realism of the trip experience, and thereby generate questionable results.

A further perceived disadvantage of the experimental approach was that the systematic identification and control of the enumerable background conditions was impractical and unrealistic. Although the use of driving simulators in a laboratory setting could control these inputs, it could prove difficult to simulate the crucial expectation and passage of time that occurs in a real world trip experience. This concern reflects the theory of ecological cue validity which suggests that perceptions are less accu-

rate in artificial environments, due to the lack of natural cues presented in the proper context (74).

In subscribing to the survey approach it was desirable that the modelling inputs be reflective of driver serviceability, practically measurable in field surveys, and consistent enough to permit statistical aggregation and evaluation. Subsequently the correlational method was applied to identify and evaluate the underlying relationships between trip experience and quality of service. The input parameters included the driver's travel time predictability, subjective valuation of service quality, and physiological baseline changes between the start and end of the trip.

3.3.2 Travel Time Predictability

Quality of service was gauged against the performance criterion of travel time predictability. The parameter of travel time predictability is in effect the relative extent of travel time prediction error. This requires the driver's pretrip prediction (i.e. estimate) of trip travel time and the measurement of the actual travel time at the end of the trip. The driver makes a travel time prediction given known, or presumed, route characteristics and an understanding of the prevailing environmental conditions. The extent to which the prediction is realized will form the basis of the quality of service valuation.

3.3.3 Subjective Quality Of Service Valuation

The subjective valuation of service provides a qualitative description of the trip experience. The development of ranges of service quality based upon valuation similarities provide comprehensible benchmarks for applications of the driver serviceability approach. These ranges of service quality in relation to the corresponding values of travel time predictability form the basis of the preliminary driver serviceability guidelines.

3.3.4 Physiological Correlates

The physiological correlates of stress provide an additional objective description of the trip experience. In the early stages of the modelling it was thought that these physiological correlates of stress were potential performance criteria. Consequently the required data were collected and evaluated.

In the endeavour to more closely replicate the trip experience, baseline shift measures were used rather than continuous physiological measures. This was largely a consequence of pre-pilot study driver reports that the continuous monitoring overwhelmed other elements of the trip experience. This was largely attributed by the subjects to be caused by monitoring attachment discomfort, over prolonged periods of time.

Although the theory for baseline shift is limited as presented in Section 2.5, sufficient basis was felt to exist

to provide a foundation for this research application. A key hypothesis in applying physiological baseline change to describe the total trip experience, was that although a driver would exhibit transitory responses to the mental and physical demands of immediate driving stimuli throughout the trip, that the cumulative effect of these events would be reflected in a baseline shift measure.

The baseline shift measure was founded on the differences between the physiological baseline measures recorded at the start and end of each trip. The baseline shift which provides a physiological description for the overall trip experience, reflects both the mental and physical demands encountered.

There could inherently be monitoring procedure effects present in the recorded physiological measures. Although inseparable from the trip experience effects, it was assumed that the use of consistent pretrip and posttrip monitoring procedures and the subsequent determination of a relative measure of physiological baseline change would effectively cancel out any monitoring artifacts.

The physiological levels and patterns measured to evaluate baseline change included galvanic skin response (GSR), thoracic and abdominal respiration, heart rate and blood pressure. The physiological baseline patterns were measured and evaluated in view of background environmental,

roadway and driver characteristics.

3.3.5 Traffic Parameter

The modelling of driver serviceability and the preliminary serviceability guidelines developed in the course of this research necessarily required a practical linkage to the current LOS guidelines. On review it was felt that average travel speed was the most appropriate traffic movement effectiveness parameter, as the travel time basis is a common input to both the traditional LOS criteria and the travel time predictability perspective.

3.3.6 Background Conditions

Research resource limitations necessarily restricted the number of background environmental, roadway and driver characteristics that could be evaluated. The background conditions were therefore controlled to the fullest extent possible, without noticeably impinging upon the realism of the trip experience. Only those background conditions viewed as potentially providing significant interpretative capabilities in the modelling process were recorded and reviewed. However the effects of all background conditions are reflected in the model relationships through their aggregate effects on travel time predictability, physiological baseline change variables, and subjective valuation of service quality.

3.4 Research Location Basis

The initial modelling of driver serviceability was based upon a rural two lane highway setting, as it appeared that the underlying driver serviceability process could be similar between roadway environments. Further, that the rural setting would permit the observation of relative physiological baseline changes and subjective valuations that occurred over long sections of roadway. This enabled observations of change over comparably longer periods of time than would generally be expected in the urban arterial environment.

It was also felt that the comparatively greater complexity and ambiguity of peripheral activity in the urban arterial environment could initially cloud the recognition and development of the underlying serviceability relationships. However, having initially modelled driver serviceability it was considered necessary and appropriate to extend the modelling relationships through an urban arterial setting.

Chapter 4
Data Collection Process
- Rural Two Lane Highway Setting

4.1 Overview

A pilot survey consisting of 19 observations was undertaken during November 1990. On the basis of the experience and results gained through this survey, the full scale survey program was undertaken from November 1990 through May 1991. A total of 117 trip observations were made in the rural setting, for use in the initial driver serviceability modelling. A spreadsheet summary of the rural data base is presented in Appendix E.

Each trip observation included the recording of the driver's travel time prediction, actual travel time, subjective valuation, and significant background conditions, and the physiological baseline measurements at the beginning and end of the trip.

The use of the subjects in this research parallels trip experience reality, in that a driver's perceptions of a trip are likely to be framed in the context of previous driving experience generally and on a particular route specifically. The subject drivers in effect reflected their previous experience through their travel time predictions.

4.2 Survey Protocol

4.2.1 General

During the course of the research safety was considered paramount. At no time were the subjects deceived or placed in any real or imagined jeopardy as a consequence of the research. Realistic results for the modelling necessarily required that the environment be as normal as possible, not withstanding the monitoring of service quality perceptions and physiological baseline measures at the beginning and end of the trip. Subjects were assured that the environment was as normal as possible and not being manipulated. This was ensured through all trip observations being done directly by the researcher.

The survey protocol of this research was approved by the Carleton University Ethics Committee.

4.2.2 Pretrip Protocol

The subject drivers pretrip briefing included a discussion of:

- i. The intent of the research to develop a basis for enhancing traffic performance evaluations, through the modelling of driver serviceability and the related determination of driver serviceability ranges.
- ii. The physiological measurements of galvanic skin response, respiration, blood pressure and heart rate at the beginning and end of the trip using the portable polygraph and blood pressure monitor. The method of

monitoring each measurement was briefly described including the placement of sensors.

- iii. The prediction of trip travel time using trip end points, coinciding with clearly identified monitoring locations.
- iv. The completion of a serviceability questionnaire relating to trip perceptions and experience.
- v. That the subject driver could choose to not participate or cease participation at any time.

The subject drivers then drove to the defined trip origin, to ensure that they were fully familiar and comfortable with the vehicle they were driving.

4.2.3 Trip Protocol

The drivers were requested to follow their normal driving practice, and to ignore the survey as much as possible. The drivers were further assured that neither driving skill nor traffic law compliance were being tested or recorded as elements of the research. Although it was the intent of the survey to cease the respective trip observation should any erratic or unsafe driving behaviour become apparent, it was not acted upon as such behaviour did not occur.

The people in the test vehicle were limited to the subject driver and the researcher. There were no discussions throughout the trip relating to either the research general-

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ly or survey specifically.

There were no scheduled breaks in the trips beyond those that had midtrip destination monitoring, inasmuch as the vehicles were fully fueled and drivers rested. For those occurrences where a subject was used on a return trip observation an intervening break period of at least the duration of the preceding trip was used. The use and length of the break period at the trip destination was used to minimize or eliminate any immediate carry over effects for the return trip. These immediate carryover effects could for example be caused by travel time prediction errors or at an extreme by involvement in a traffic accident. There were no instances of late arrival attributable to late departure.

The monitoring of physiological measures was done at the trip destination as soon as safely possible. The monitoring locations at the trip origin and destination were sited such that the survey vehicle could be parked out of the traffic stream and the monitoring carried out without interruption. The ongoing refinement of the survey procedures and data requirements, resulted in the time required at the beginning and end of the trip for the physiological measurements and completion of the survey questionnaire dropping from an average of 20 minutes each in the pilot survey, to 15 minutes each in the full scale survey.

The serviceability questionnaire was completed immediately following a typical 10 minute period for the physiological measurements. The survey questionnaire format is presented in Appendix F. At the trip origin the background information and the subjects travel time prediction were entered on the questionnaire by the researcher, within a five minute period. Similarly, the posttrip enroute information was noted and the rating questions asked and recorded, by the researcher over a typical five minute period.

The subjective service quality valuation section of the questionnaire was based upon the serviceability consideration interviews of Appendix C, used in the development of the model concept. On completion of the trip the driver was requested to describe the experienced service as either being unacceptable (poor), acceptable (tolerable), or acceptable (good). The driver was further asked to rate the quality of experienced service on a 1 through 10 point scale, to the nearest half point.

The subject drivers were requested to estimate their travel time by their usual methods. In common usage this may be referred to as the estimated time of arrival (ETA). In making this request the researcher endeavoured to minimize conveying any emphasis as to the apparent importance of this parameter, through the asking of the question in much the same manner as the preceding biographical information questions. The trip test location end points were clearly

identified by name and shown on a map. Trip distances were also available to the drivers on request, to assist their travel time predictions. The travel time predictions were primarily based on mental processes. A limited number of trip observations included driver travel time predictions through long hand calculations or the use of calculators. No distinction was made in the survey records as to the method, as it was the extent to which the prediction was achieved that was of direct interest, rather the effects of the method of calculation.

The predicted and actual times were recorded to the nearest minute, as it was felt unlikely that a driver would relate to any further precision in making travel time predictions. The actual travel time was recorded to the nearest minute on a stop watch starting and ending as the vehicle entered and exited the highway respectively.

It has been noted that the posttrip perceived elapsed time and actual travel time can differ (70). Initially the survey attempted to identify if a distinction existed between perceived and actual travel time. It was observed that all drivers used either their personal watches or vehicle time clocks to monitor their travel as a normal activity. In effect a driver then is fairly aware of the passage of actual time, both throughout and at the conclusion of the trip. Consequently perceived travel time does

not appear to apply in this situation, as the actual elapsed travel time is readily available.

Travel time could be affected by such factors as weather conditions, road surface conditions, maintenance and rehabilitation operations, and traffic. These causes are often inter-related due to for example the combination of bad weather, snow clearing and heavy traffic. Consequently, the questionnaire had provision for the recording of traffic, weather, road, and any unusual conditions reported by the driver or observed by the researcher. All survey trips were restricted to safe road conditions.

The background factors that could be controlled were; through limiting their potential effects to the fullest extent possible. These limitations were primarily related to ensuring that research aspects did not interfere with the driving task, or affect the trip experience. Uncontrollable factors associated with the driving task such as traffic and weather conditions were not restricted, but were clearly noted in the enroute information section of the survey questionnaire.

Road surface conditions were recorded as it was felt that these could affect travel time predictability, driver subjective valuation and physiological baseline changes. The definitions used to describe road surface conditions were in accordance with the British Columbia Ministry of Transportation and Highways (MoTH) terminology. The four

main categories used to describe the predominate road surface condition for each test link were:

- i. Bare - Pavement bare.
- ii. Wet - Pavement bare and wet.
Due to rain or snow melt.
- iii. Snow Covered - Pavement is covered in new snow.
Plowing and sanding in progress.
- iv. Compact Snow - Pavement is covered in snow.
and Ice Snow is compact, well traveled.

These conditions represent logical deteriorations in road surface conditions that would be readily recognized by the general driving population.

Similarly predominate weather conditions were recorded for each trip observation. Condition descriptions included clear, rain, sleet, snow, and fog. The rationale behind this categorization was that weather conditions effects would relate primarily to the extent of visibility.

The surveys were restricted to daylight hours for both safety reasons and to minimize the database variability, due to possible night driving effects. Further, as the majority of travel occurs during daylight hours (10), it was felt appropriate to restrict this initial driver serviceability research to daylight driving. However, the effects of night travel are of interest and should be pursued in future research.

The make and model of vehicles used in this research were not distinguished in that the drivers had full choice

in their selection, of either their own vehicle or one from the MoTH vehicle pool. All vehicles did however have similar amenities of automatic transmissions, and power steering and brakes. The preferred vehicle types for ease of subject monitoring were found to be minivans and sport utility wagons, due to their larger interiors. Typical survey vehicles of these types are shown in Figure 4-1.

The physiological measures were monitored at the start of each trip to establish the baseline from which change is calculated. At the end of the trip the same parameters were remeasured and relative baseline change determined.

The subject's physiological measures were monitored while they remained in the drivers position in the vehicle. A Stoelting Ultrascibe polygraph was used to measure galvanic skin response (GSR), and thoracic and abdominal respiration. The researcher received training on the operation of the instrument at the Canadian Police College in Ottawa. The portability of the polygraph and it's dc power supply enabled this research application. The manufacturer's brochure for the polygraph used in this research is presented in Appendix G. Figure 4-2 shows the typical placement of the polygraph on the rear seat, behind the driver. Figure 4-2 also shows the monitor attachments and typical setup.

Initial attempts to use the polygraph to monitor heart

Figure 4-1: Preferred Types of Test Vehicle

Chrysler Minivan

General Motors Sport Utility Wagon

Figure 4-2: Typical Polygraph Monitoring Setup

Polygraph Positioned Behind Driver

GSR And Respiration Monitoring

rate and blood pressure were found to be impractical. Consequently a digital electronic blood pressure monitor (Lumiscope Model 1060) with pulse meter and mikeless cuff was purchased and successfully used. The typical monitoring setup is shown in Figure 4-3.

Although recorded on different instruments, all physiological measurements generally began within two minutes and were completed within a maximum ten minute period of the vehicle stopping. Although the posttrip physiological activation levels would be expected to decay somewhat in this short elapsed interval between stopping the vehicle and commencing the polygraph monitoring, the evaluation of baseline shift remains relative. This relativity is achieved through a consistent datum of using similar setup and monitoring periods in measuring the trip starting and ending baseline measures. The setup periods were minimized through both ensuring that the monitors were ready, and the refinement of the sensor placement procedures.

The first of the physiological measurements were blood pressure and heart rate using the electronic blood pressure monitor. The mikeless cuff was placed on the right upper arm of the driver. These were generally accomplished within the first two minutes after stopping the vehicle.

On completion of the blood pressure and heart rate monitoring, the polygraph thoracic and abdominal pneumo-

Figure 4-3: Typical Blood Pressure Monitoring Setup

graph tubes were placed on the upper and lower chest, respectively (75). The latter is placed just above the stomach area. The two placements are used to sense and record both shallow (chest) and deep (stomach) breathing.

The polygraph GSR finger contact plates were then placed on the palm side tips of the first and third fingers of the subject's right hand. The GSR contacts were used without conductive gel. The plates were wiped before attaching to ensure that they were clean and dry. The signal sensed and recorded by the GSR channel is produced by the subject's skin resistance to the sensing current. Skin resistance decreases would be recorded as upward pen movements in the tracing output (75).

On completion of the sensor placement which typically required three to four minutes, the connections were made to the respective polygraph channel. These connections were done quickly as the polygraph was securely positioned on the rear seat of the vehicle throughout the trip. The respiration and GSR measures were then monitored over a typical five minute period.

The pretrip sensitivity levels were set through adjusting the control switch to achieve a pattern size of approximately ten chart divisions, to achieve tracings that would not be bounded by the pen travel limit of approximately 45 chart divisions (75). The sensitivity controls were held at the same level for the pretrip and posttrip moni-

toring, to ensure that the respective tracings were comparable records. The application of this sensitivity level setting precluded the requirement for either the automatic or manual recentring of the tracing. Consequently, although the automatic setting was selected, recentring did not occur as there were no tracings recorded at the limits of pen travel. Future applications should also ensure that pen travel limits are not reached as the tracing would not be representative through a combination of the ceiling and recentring effects.

Each polygraph monitoring was continued for four minutes beyond that time at which relatively similar patterns became apparent. At the polygraph speed of 15.24 centimetres per minute the four minute records used were approximately 61 centimetres in length. The initial period of the polygraph physiological monitoring was not used as it appeared that initially the patterns were somewhat affected as a consequence of placing the sensors. This initial period was generally about one minute in length.

During the physiological monitoring period the subjects were required to refrain from verbal and physical activity, to minimize the possibility of recording unrelated responses. The subjects were not allowed to see their physiological results during tests given the potential of alteration through inadvertent feedback. Similarly the

researcher ensured that no bias or test expectations were conveyed to the subject driver during the test, as these also had potential to be translated to performance cues.

A typical section of the polygraph tracing is presented in Appendix F. The measurement parameters used in evaluation of the values and patterns are illustrated on the tracing. The highs and lows evident on the GSR tracing illustrate the importance and reason for maintaining the same level of recording sensitivity on the polygraph to collect relative baseline measures. As the extent of these highs and lows are a reflection of the sensitivity, inconsistent settings would exaggerate the difference between the tracings recorded before and after a trip. The GSR pattern evident in this tracing may have reflected a response to traffic passing the monitoring site, magnified by the particular sensitivity level used for that trip. This relative pattern would be superimposed upon the trip experience baseline.

The physiological data collection forms presented in Appendix F underwent considerable revision through the course of the research as the physiological baseline change measures were refined.

The average travel speed was determined for each trip observation, to enable a comparison with the traditional level of service criteria. The average travel speed was determined through the measurement of the actual travel time

to traverse the trip length. The time frame began and ended as the test vehicle entered the highway at the trip origin, and exited the highway at the trip destination, respectively. The same value of actual travel time was used in the determination of travel time predictability. The travel distance was derived from the MoTH Landmark Kilometre Inventory to the nearest tenth of a kilometre. This inventory presents the lengths of segments bounded by defined landmarks, such as intersection and bridge locations. This information was used to determine distance rather than using the vehicle odometer readings as it was both reliable and readily accessible, and in view of possible odometer variation between vehicles. The latter concern could be overcome with the calibration of test vehicle odometers.

4.2.4 Posttrip Protocol

On completion of the posttrip physiological measurements and the serviceability questionnaire the debriefing included a review of:

- i. The intent of the research as discussed in the pretrip briefing (i.e. to develop a basis for enhancing traffic performance evaluations).
- ii. The physiological monitoring procedures as related to the pretrip briefing.
- iii. The subjects entitlement to review the findings on completion of the research. They were informed that

the findings would be presented to those that participated, and further that they could request copies of any papers that are developed on the basis of the research. The results and implications of the trip survey results specifically or the research in general were not discussed in response to any questions from the subject that could affect their use in subsequent trip surveys.

4.3 Subject Base

In the development of this research it was recognized that it was not possible to use a subject base that was characteristic of the general driving population. This constraint was due to a combination of the practical and resource limitations in accessing a diverse subject base representative of the general driving population. The subject drivers by virtue of similarities of age, education and driving experience may be assumed to be a homogeneous subgroup of the general driving population.

This subject bias enabled the modelling of driver serviceability through limiting the likelihood of the underlying relationships being obscured, through the initial use of a wider cross section of drivers. This bias does however limit the applicability of the preliminary driver serviceability guidelines. Subsequent research could build upon the identified fundamentals through determining

the effects on a wider cross section of drivers.

The subject drivers were largely drawn from MoTH staff members in the course of business travel. The trip observations were largely concurrent to regular work related trips. As such there were no contrived trip purposes in the course of this survey.

The selection of which trips to use in the course of this survey was primarily based on the scheduled meetings that the subject drivers had near the trip destinations. The scheduling of these meetings was entirely independent of the potential use of the trip in this research.

All subjects were volunteers and received no monetary compensation for their participation. Test subjects were required to be apparently physically healthy and emotionally stable. Similarly, drivers that either had been or appeared to have been exposed to drugs or alcohol, were fatigued, physically uncomfortable, intimidated or in an emotional state were not used as subjects.

Those subjects that had participated in the general serviceability interviews and subsequent Serviceability Questionnaire application (Section 3.2 and Appendix C) were not used as subjects in these driver field surveys.

Eleven subjects were used in the survey. Nine subjects were male and two female. A total of 117 trip observations were made over a seven month period. The number of trip observations per subject ranged from seven to eighteen,

with an average of eleven. The characteristics of the subject base are summarized in Table 4-1.

Table 4-1: Subject Characteristics		
Characteristic	Range	Average
Age (years)	21 - 47	30.0
Driving Experience (years)	5 - 30	12.6
Route Experience (trips within last month)	0 - 5	2.2

Biographical information recorded for the subject drivers included sex, age, and driving and route experience. This information is presented in the Appendix E rural highway database.

Initially, the survey sample size including both the number of subjects and trip observations per subject was based upon the literature review of the related research and consultations with Carleton University's Statistical Consulting Centre. The actual sample size requirement was however subject to revision, as data variability became apparent with the progress of the research.

4.4 Survey Locations

The study was undertaken on Highway 97 between the cities of Prince George, Quesnel, and Williams Lake. Highway 97 is the primary north south link through British Columbia. The British Columbia Ministry of Finance and Corporate Relations, Planning and Statistics Division esti-

mates that these cities have 1991 catchment area populations of 86,000, 23,000, and 35,600 respectively.

A map of the survey route is presented in Figure 4-4. Figures 4-5, 4-6 and 4-7 present photographs of typical views of geometric alignments and cross sections on the route. The boxed numbers in Figure 4-4 refer to the approximate locations of corresponding photograph numbers.

Table 4-2 summarizes the trip links, and corresponding lengths used in the survey.

Table 4-2: Trip Link Lengths	
Trip Link	Length (km)
Prince George - Hixon	56.8
Hixon - Quesnel	65.5
Prince George - Quesnel	122.3
Quesnel - Williams Lake	109.5
Prince George - Williams Lake	231.8

The applicable trip link is recorded for each trip observation. This information is included in the rural database summary, presented in Appendix E.

The surveyed links would best be characterized (76) as being rural arterial undivided with a design speed of 100 kilometres per hour (RAU100) through most of the section surveyed. The notable exceptions are through the City of Quesnel, which is best described as being urban arterial undivided with a design speed of 50 kilometres per hour (UAU50) for 3.9 kilometres and urban arterial undivided with design speeds of 70 to 80 kilometres per hour (UAU70 to

Figure 4-4: Rural Setting Survey Locations

Figure 4-5: Highway 97 Photographs 1 And 2

Photo 1. North View - September 1990.

Photo 2. North View - September 1990.

Figure 4-6: Highway 97 Photographs 3 And 4

Photo 3. North View, Quesnel - April 1991.

Photo 4. South View - June 1991.

Figure 4-7: Highway 97 Photographs 5 And 6

Photo 5. North View, McLeese Lake - May 1991.

Photo 6. North View - June 1991.

UAU80) for 8.2 kilometres through the urban area; and in the City of Williams Lake which is best described as urban arterial undivided with a design speed of 60 kilometres per hour (UAU60) for 1.9 kilometres. The Hixon and McLeese Lake settlements also have 2.9 and 2.3 kilometres of UAU60 respectively. These small settlement sections are characterized by a limited highway commercial strip catering to the motoring public. The posted speed limit is 90 kilometres per hour on the rural sections of the highway.

Those elements that are not RAU100 account for less than six percent of the Prince George to Quesnel link, and less than eleven percent of the Quesnel to Williams Lake link. As these percentages are comparatively small no attempt was made to isolate any particular effects, inasmuch as considerably more disruption would be realized through the starting and stopping of the surveys to eliminate these sections. The limiting of monitoring periods to the beginning and end of the trip facilitated trip continuity and more realistic travel conditions.

Highway 97 through these sections experiences average daily traffic ranging from 2,000 to 3,000 to 4,000 vehicles per day, in December, May, and August respectively (10). The section of Highway 97 through Quesnel experiences average daily traffic of 10,000 vehicles per day in August. Exposure to the latter would feature only in the Quesnel to Williams Lake link, as the Prince George to Quesnel, and

Hixon to Quesnel links terminate north of the urban section. During the peak summer season the traffic mix is characterized by a composition of approximately 25 percent heavy and 75 percent light vehicles. The heavy vehicles can be further broken down as being 15 percent heavy trucks and 10 percent recreational vehicles.

The highway cross section is predominately two lanes, each 3.6 metres in width, with 1.0 metre paved shoulders. A typical cross section is presented in Figure 4-8. All major intersections have left turn channelization, as shown in the typical plan view presented in Figure 4-9.

The highway from Williams Lake to Quesnel runs through rolling terrain. The Quesnel to Hixon to Prince George links run through a range of level to rolling terrain. Adjacent land use for all links consists of forest, farm land, pasture and range land, and very small communities. The three principal cities defining the links are characterized by urban fringe areas of low density residential development.

The survey sites were located in the proximity of the trip origin and destination, shown in Figure 4-4 and described in Table 4-3. These survey sites were located such that the survey vehicle could be positioned safely outside of the traffic stream and the physiological monitoring carried out without interruption.

Figure 4-8: Typical Cross Section (75)

SECTION 4-8
A. Recovery Zone
B. Shoulder
C. Base
D. Subgrade

1. The width of the recovery zone is 3.0 m.
2. The width of the shoulder is 1.0 m.
3. The width of the base is 1.0 m.
4. The width of the subgrade is 1.0 m.
5. The width of the ditch is 1.0 m.

Figure 4-9: Typical Major Intersection Plan View (75)

NOTES:

1. See Design Manual No. C-1-10 for on-street control points.
2. 'C' Length required for vehicle storage.
3. Traffic analysis will indicate when a parallel right turn deceleration lane is warranted.
4. Traffic analysis will indicate left turn requirements and type of treatment (see 401).
5. Island Cuts: 1.8 m for Rural Highways
1.2 m for Urban Highways
6. Design width 'e' is for WB 15 vehicles for other conditions
see template sheet plus 1.0 m
7. 'd' variable - minimum 6.0 m
8. Into design of roads should anticipate future widening of
Minor Road left turn slip (see inset) if appropriate. Otherwise
minimum dimension of island is 5.0 m on any side
9. Deceleration is assumed to occur mostly in the through lanes
turning lanes function more as storage areas
10. The 'D' & 'd' values are appropriate for turn lane
design shown they are site specific and require the designer
to overlay a detailed turning template in each situation
Refer to C-1-10 for control points

Angle	Exit		Entrance	
	θ_1	θ_2	θ_1	θ_2
70°-80°	18	50	70°-78°	18 50
81°-87°	20	50	77°-83°	20 50
88°-97°	22	50	84°-92°	22 50
98°-100°	25	50	93°-95°	25 50
101°-103°	37	-	98°-99°	34 -
104°-108°	39	-	102°-105°	40 -
107°-110°	47	-	106°-110°	45 -

Angle	θ_1	θ_2
18	71	-
20	68	-
22	65	-
25	63	-
34	63	-
37	59	-
39	59	-
40	59	-
45	58	-
47	58	-
50	57	-

Table 4-3: Highway 97 Survey Sites

City	Survey Site Proximity
Prince George	Intersection of Sintich Road
Hixon	Truck Stop
Quesnel	Government Weigh Scale
Williams Lake	Junction of Highway 20

Chapter 5

Development Of The Travel Time Predictability

Perspective - Rural Two Lane Highway Setting

5.1 Overview

This research was based upon the survey approach in an endeavour to develop realistic descriptions of the drivers' trip experience. The multiple trip experience inputs were captured through the development and use of parameters that would reflect their aggregate effect.

The survey information describing the drivers' trip experience was evaluated through a correlational approach. In this approach the role of statistical evaluations features prominently in the interpretation of results. Although the theory applies to driver serviceability in general, the particular findings are most representative within the bounds of the surveyed settings and conditions.

The modelling of driver serviceability was based upon the evaluation and interpretation of corresponding trip experience measures within the context of potentially significant background conditions. The principal measures included travel time predictability, subjective valuation, physiological baseline changes and average travel speed.

As presented in Section 3.2.2, the modelling of driver

serviceability follows the general formulation that:

$$\text{Serviceability} = f(\text{Trip Experience}) \quad (3.1)$$

The trip experience is related to the subjective valuation of service quality through the travel time predictability perspective, either directly or through the combined relationship with the physiological stress correlates. A generalized driver serviceability model and the travel time predictability perspective were illustrated in Figures 3-1 and 3-2, respectively.

Travel time predictability was previously defined as the extent to which travel time predictions are achieved. Travel time predictability reflects the aggregated effects of the trip experience, including all background characteristics such as road conditions, driver background, and trip purpose through the outcome of travel time.

As discussed in Chapter 4, the travel time predictability perspective was developed on the basis of the rural two lane highway setting. This was done to minimize the possibility of the underlying serviceability relationships being initially obscured in a more complex and active roadway setting such as an urban arterial. Such a setting is characterized by significantly greater traffic and peripheral activity than the rural highway environment. However, following the rural development of the travel time predictability perspective it was extended to the urban arterial setting.

Preliminary serviceability guidelines for the rural two lane highway setting were also developed. These guidelines provide a refined basis for more realistically evaluating the drivers' perceptions of trip experience service quality.

5.2 Data Analyses

5.2.1 Overview

This section covers the development of the travel time predictability perspective based upon the two lane rural highway setting. The database consisting of 117 trip observations, is summarized in Appendix E.

The findings of this research are necessarily based on statistical inferences due to the inherent uncertainty in collecting, analyzing, and interpreting numerical data.

The analyses are based on the total 117 trip observations, except as noted in the evaluation of subgroups within the database.

As presented in Section 4.1 each survey trip observation included recording the driver's travel time prediction, actual travel time, subjective valuation, and significant background conditions, and the physiological baseline measurements at the beginning and end of the trip.

5.2.2 Driver Travel Time Predictability

Driver travel time predictability was defined as the extent to which the trip travel time prediction is achieved. Travel time predictability was determined through comparing predicted and actual travel times in the formulation:

Travel Time Predictability =

$$\left[\frac{(\text{Estimated Travel Time} - \text{Actual Travel Time})}{\text{Actual Travel Time}} \right] \quad (5.1)$$

A score of zero would indicate a correct estimate of the required travel time. Negative scores would indicate an underestimate, and positive scores would indicate an overestimate of the required travel time. These scores would be manifested in the driver arriving either on time, too late, or too early, respectively.

The predictability formulation accepts theoretical scores from -1.0 to positive infinity. The -1.0 value indicates an actual travel time that is infinitely longer than the estimated travel time. Practically the range of scores observed was between -0.64 and +0.52. The explanation of the score range between a theoretical range of -1.0 to 1.0 is presented in Table 5-1.

Table 5-1: Predictability Score Descriptions

Score	Actual Travel Time
-1.0	Underestimate = infinitely longer than estimated
-0.5	Underestimate = 2.00 times longer than estimated
0.0	Correct = the same time as estimated
+0.5	Overestimate = 0.67 times shorter than estimated
+1.0	Overestimate = 0.50 times shorter than estimated

5.2.3 Driver Physiological Inputs

The physiological baseline inputs needed for the serviceability modelling are recordings that will permit the evaluation of relative change in baseline levels. The methods of monitoring and measurement used in this research were developed to both reflect the driver serviceability approach and be consistently measurable.

As presented in Section 4.2, the physiological measures that were attainable in the course of this research included the galvanic skin response (GSR), abdominal and thoracic respiration, blood pressure and pulse. The GSR and respiration tracings were recorded using a polygraph instrument. The blood pressure and pulse were recorded on an electronic blood pressure monitor with a digital readout. The use of this monitor was due to difficulties in developing interpretable measures for these inputs from the polygraph tracing. Typical physiological tracings and the baseline record form are presented in Appendix F.

The measurement of the polygraph tracings posed a significant challenge. Polygraph records were evaluated for

a four minute period of near stable tracings, at the beginning and end of the trip. The evaluation did not include the initial period of each tracing, where the subject was likely being affected by either the immediately preceding driving maneuvers or the attaching of the sensors. This initial period ranged in length from approximately one to two minutes. Each polygraph tracing required about thirty minutes to evaluate.

The respective physiological baseline measures used in this research were:

- i. GSR - tracing length for the stable period,
measured using a Dietzgen Plan Measure
- ii. Respiration - α , where

$$\alpha = \frac{(\text{average wave height})}{(\text{average wavelength})}$$

- iii. Blood Pressure - β , known as Pulse Pressure, where

$$\beta = (\text{systolic} - \text{diastolic}) \text{ mm Hg}$$

- iv. Heart Rate - pulse per minute.

The comparison of physiological baseline changes to the trip experience requires that the posttrip measure be evaluated relative to the pretrip value. The relative change for the respective measures followed the general formulation:

Physiological Baseline Change =

$$\left[\frac{(\text{posttrip parameter}) - (\text{pretrip parameter})}{(\text{pretrip parameter})} \right] [100] \quad (5.2)$$

The large volume of observed and calculated physiological data necessarily required a process to identify significant information. The data analyses processes considered were multiple regression and factor analysis. Multiple regression was not used due to the significant presence of multicollinear independent variables. Mason and Lind (78) point out that significant multicollinearity would violate a key assumption of multiple regression, that the independent variables not be highly correlated. Consequently, the process found to be most appropriate was the factor analysis procedure.

In effect the driver's physiological baseline shift, is calculated using the physiological records collected at the trip beginning and end. Factor analysis is then used to determine statistical aggregate(s) of the respective baseline shift measures. These measures can not be either individually or collectively directly attributed to either the mental, emotional or physical loads placed upon the driver. However as these loads are inextricable elements of the trip experience, the use of the aggregate baseline change measure in effect represents the collective reaction. The use of this aggregate measure requires no differentiation as to load cause, as it is the overall effect of the trip experience that is of interest in the modelling of serviceability.

Basically, the factor analysis data reduction procedures recognize that several interrelated variables would be more appropriately described by a single general factor. A review of the factor analysis application in this research is presented in Appendix H. This process was available in the Statistical Package for the Social Sciences for personal computers (SPSS/PC+ Version 3.1) software package (79,80). Other statistical procedures were done using the Statistical Graphics System (Statgraphics Version 3.0) software package (81). Both software packages were used through Carleton University site licenses.

A matrix of Pearson correlation coefficients for the tracing indices for galvanic skin response (GSR), abdominal respiration, thoracic respiration, heart rate and blood pressure was developed as the initial step in the analyses, as presented in Table 5-2. It can be observed that the abdominal and thoracic respiration measurements are strongly correlated, as are GSR, heart rate and blood pressure.

Having obtained the correlations of the physiological baseline changes, factor analysis was used to arrange the indices into groups of factors each of which is composed of highly intercorrelated values. Two significant factors representing aggregates of the physiological baseline changes were identified through this process.

**Table 5-2: Physiological Change
Correlation Matrix**

	GSR	ARES	TRES	HR	BP
GSR	1.00	0.55*	0.56*	0.71*	0.65*
ARES		1.00	0.93*	0.48*	0.46*
TRES			1.00	0.47*	0.44*
HR				1.00	0.85*
BP					1.00

★ .05 One-Tailed Significance

GSR = GSR
 ARES = Abdominal Respiration
 TRES = Thoracic Respiration
 HR = Heart Rate
 BP = Blood Pressure

The primary and secondary factors are identified as Factor 1 (FC1) and Factor 2 (FC2) respectively. As evident in the physiological correlation matrix, and the subsequent factor analysis summarized in Appendix H, GSR, heart rate, and blood pressure variables provide a comparably greater contribution to Factor 1 values than the respiration measures. The reverse is apparent in the composition of Factor 2 values, in which the respiration measures provide the comparably greater contribution. The primary factor FC1 was found to account for approximately 69 percent of the variance associated with the underlying relative physiological baseline changes. The secondary factor FC2 accounted for a further 20 percent of the associated variance.

These factors indicate the presence of baseline change between the pretrip and posttrip recorded physiologi-

cal measures. The presence of this change is consistent with what would be expected on the basis of the limited theoretical background and previous research applications (52,53,54,55). The expectations of physiological change over extended periods of time for the Factor 1 parameters, of blood pressure and heart rate (52,53,55) and to a lesser extent GSR (54,56), are founded on more research endeavours than that of respiration baseline change (54) which underlies Factor 2.

The calculated values for Factors 1 (FC1) and 2 (FC2) are presented in Appendix E for each trip observation. The value of each factor for each trip observation, describes the aggregate physiological baseline shift. In effect the factor value summarizes the change in physiological activation levels that correspond to the trip experience.

5.2.4 Observation Balance

The number of trip observations per subject was evaluated to assess if the trip observation imbalance was affecting the calculation of the physiological baseline response change factors. This evaluation was a consequence of the concern that should individuals be over represented in the subject base and be predisposed to a particular physiological pattern, then the calculated factor values would not be representative. The subsequent analysis of such unbalanced data would be difficult and could lead to

uninformative results.

The number of trip observations per subject is summarized in Table 5-3.

Table 5-3: Trip Observations Per Subject												
Subject	1	2	3	4	5	6	7	8	9	10	11	Total
Observations	10	13	18	8	13	9	7	7	16	8	8	117

This evaluation was done through a paired comparison (78) of the factor values determined on the basis of the balanced sample, and the corresponding trip observation factor values determined on the basis of the complete sample. The balanced sample was done through using equal subject representation. The first seven trip observations for each of the eleven subjects were used, for a total balanced sample of 77.

A paired comparison was completed using the mean and standard deviation of the difference between the balanced Factor 1 and Factor 2 values (FC1B and FC2B), and the corresponding Factor 1 and Factor 2 trip observation values (FC1 and FC2) calculated on the basis of the complete sample of 117. The comparison does not require that the compared samples have the same variance. The results of the experimental balance check are presented in Table 5-4.

Table 5-4: Experimental Balance Check				
Comparison	$\bar{x}$	s	$Z_{0.95}$	95% Level of Confidence
FC1 - FC1B	0.09	7.45	0.11	Accept H_0
FC2 - FC2B	0.18	4.73	0.32	Accept H_0
$H_0: u_d = 0 \quad H_1: u_d \neq 0$				

On the basis of this evaluation it was inferred that the difference in the number of trip observations per subject was not distorting the determination of either of the physiological baseline constructs at a 95 percent level of confidence. Consequently it was deemed appropriate to use the complete survey of 117 trip observations in the development of the model.

5.2.5 Observation Independence

The effect of the repeated use of subjects on trip observation independence was also assessed. The most significant implications of the lack of trip observation independence would be the violation of the regression assumption of the independence of the error term (82), and a substantial increase in the apparent Type 1 error (83). The independence issue was addressed through an assessment of autocorrelation between subsequent observations for each subject. A significant presence of autocorrelation could also affect the application of factor analysis. A basic premise of correlation based statistical applications,

including factor analysis, is that all trip observations have either no or comparable levels of autocorrelation (84).

The assessment of trip observation independence was done through the determination of the extent to which autocorrelation was present between subsequent trip observations for each subject for the three main parameters of travel time predictability (Pred), subjective valuation (Subj), and the primary physiological factor (FC1). Similarly the extent of autocorrelation was also evaluated for the five underlying physiological baseline variables of GSR, abdominal and thoracic respiration, heart rate and blood pressure used in the factor analysis calculation of FC1.

The extent of autocorrelation was described through the calculation of the Durbin - Watson statistic (82). The statistic is calculated from the equation:

$$d = \left[\frac{\sum_{t=2}^n (e_t - e_{t-1})^2}{\sum_{t=1}^n e_t^2} \right] \quad (5.3)$$

where:

d = the Durbin-Watson statistic

e_t = the residual (difference between the observed and predicted dependent value) in time period t

e_{t-1} = the residual in time period $(t - 1)$.

Positive autocorrelation would result from successive residual values that are close together, and be indicated by

a small value of the Durbin-Watson statistic. Conversely negative autocorrelation is a result of successive residual values that are far apart, and is described by a comparably large value of the Durbin-Watson statistic. The interpretations of the statistic are summarized in Table 5-5. The statistic bounds used are for a sample size of 15. The effect of using the criteria for a larger sample size is to be more critical in detecting the presence of autocorrelation in the smaller number of trip observations.

Table 5-5: Durbin-Watson Interpretation	
Durbin-Watson Statistic	AutoCorrelation Interpretation
0.00 - 0.95	Positive
0.95 - 1.25	Inconclusive
1.25 - 2.75	No Evidence
2.75 - 3.05	Inconclusive
3.05 - 4.00	Negative

The Durbin-Watson statistics for the main model parameters are summarized in Table 5-6.

**Table 5-6: Rural Model Parameters
- Autocorrelation**

Subject	n	Pred	Subj	FC1
1	10	1.84	1.98	1.34
2	13	2.04	2.11	2.30
3	18	2.29	1.91	2.44
4	8	1.80	2.59	1.11
5	13	2.62	2.72	2.17
6	9	2.80*	0.81	2.72
7	7	1.94	2.16	1.85
8	7	2.90*	2.31	2.99*
9	16	2.19	2.44	2.23
10	8	2.06	2.99*	2.65
11	8	2.46	1.28	1.42

(-) Negative () No Evidence
(+) Positive (*) Inconclusive

Similarly the physiological baseline change inputs were assessed for autocorrelation, with the results as presented in Table 5-7.

**Table 5-7: Rural Physiological Change
Variables - Autocorrelation**

Subject	n	GSR	ARES	TRES	HR	BP
1	10	2.40	2.40	2.47	2.25	1.83
2	13	2.04	2.29	1.87	2.41	2.27
3	18	2.27	2.36	2.27	2.52	2.79*
4	8	2.61	3.36-	3.44-	1.41	1.76
5	13	1.88	2.15	1.85	2.32	2.22
6	9	2.34	2.23	2.09	2.72	2.32
7	7	1.57	1.51	1.87	1.65	1.91
8	7	3.03*	2.25	2.46	3.15-	2.96*
9	16	1.51	1.73	1.81	1.74	2.18
10	8	2.43	1.42	1.82	1.65	2.32
11	8	2.11	1.35	1.86	2.40	1.71

(-) Negative () No Evidence
(+) Positive (*) Inconclusive

As there was no significant evidence of autocorrelation in either the model parameter or physiological databases, the data were judged to be substantially independent. The comparatively low proportional presence of those observations demonstrating inconclusive or negative autocorrelation indicates that there was likely very limited carryover effect between subsequent trip observations of the same subject.

5.2.6 Observation Normalcy

The statistical applications used in the development of the model generally had the normalcy of the data as an underlying assumption. Consequently, the greater the extent to which the sample distributions compare to a normal distribution the more appropriate the applications. The normalcy requirements are noted in the appropriate applications. The normalcy of the three main parameters of travel time predictability, the subjective valuation, and the primary physiological construct (FC1) were assessed through the determination of the chi-square statistic (78).

The chi-square statistic describing the comparison of the observed to expected class frequencies was computed for each parameter using the respective sample mean and standard deviation, and ten class intervals for the data spread as compared to a standard normal distribution curve. The

chi-square statistic was calculated as:

$$\chi^2 = \sum \left[\frac{(f_o - f_e)^2}{f_e} \right] \quad (5.4)$$

where:

χ^2 = the chi square statistic

f_o = the observed number of observations in a given class

f_e = the expected number of observations in the same class based on a standard normal distribution.

The level of significance for each assessment was determined against the hypotheses of :

H_o : The data are normal

H_a : The data are not normal.

The rural database findings are summarized in Table 5-8.

Table 5-8: Rural Model Parameters - Normalcy Evaluation			
Parameter	df	χ^2	Sig.Level
Predictability	3	4.81	0.187
Subjective	4	19.27	0.001
FC1	4	6.41	0.170

On the basis of these analyses it was inferred that the travel time predictability and physiological construct FC1 databases followed normal distributions at a 0.05 level of significance. It was inferred that the subjective valuation database did not follow a normal distribution.

5.2.7 Observation Consistency

The patterns of the physiological baseline measures were assessed to determine if the measures used provided a consistent means of evaluating physiological baseline changes. Consistency in this evaluation refers to the assessment of the ability of the respective physiological records to provide replicable measures of change.

The physiological change for each trip observation was evaluated through a paired sample test (83,85). This statistical test was most appropriate as neither required independent samples or equal population variances. The change for each type of physiological observation was determined as the difference between the respective pretrip and posttrip measurements.

As the 117 differences for each physiological measure in the rural setting, exceed the 30 case threshold, the Z statistic was used in evaluating the significance of the differences. The Z statistic could be calculated through:

$$Z = \left[\frac{[\bar{x} - (u_1 - u_2)]}{(s/\sqrt{n})} \right] \quad (5.5)$$

and through rewriting the equation the minimum sample size can be calculated through:

$$n = \left[\frac{(Z)(s)}{[\bar{x} - (u_1 - u_2)]} \right]^2 \quad (5.5)$$

where:

$\bar{x}$ = sample average

u_1 = pretrip population mean

u_2 = post trip population mean

s = sample standard deviation

n = sample size.

The differences could be assessed at a 95 percent level of confidence using Equation 5.5 and the hypotheses of:

$$H_0: u_1 - u_2 = 0$$

$$H_a: u_1 - u_2 < 0.$$

The 95 percent level of confidence, also described as a five percent level of significance (α of 0.05), relates to the Type 1 error, which is the probability of rejecting the null hypothesis when it is true. The rejection of the null hypothesis infers that the groups differ when they actually do not. Conversely, the acceptance of the null hypothesis would infer that there is not a significant difference between the pretrip and posttrip values. The use of the less than sign in the alternate hypothesis indicates the assessment of increased baseline levels between the pretrip and posttrip measurements.

In a further assessment of the hypotheses testing, the Type 2 error could be used in each comparison. The Type 2 error (β) is the probability of accepting the null hypothesis as true when it is actually false. The inverse rela-

tion between the occurrence of Types 1 and 2 errors are heavily dependent upon sample size (83). The relationship between Type 1 and Type 2 errors is particularly sensitive when the sample size is less than 20. When the sample size is large, Type 2 error is generally not at issue.

In this research application the probability of Types 1 and 2 errors were equated to 0.05, meaning that there is a 95 percent level of confidence that if the null hypothesis is either accepted or rejected that the correct action has occurred. Given α and β the minimum sample size was determined using Equation 5.5, for a value of $Z_{0.95}$ of 1.65 and the null hypothesis difference of 0. A required sample size greater than that surveyed would indicate that either the α or β levels had been compromised. The results of the rural setting are presented in Table 5-9.

Table 5-9: Evaluation of Rural Baseline Change Differences			
Difference	$\bar{x}$	s	n
GSR	-25.95	16.37	5
ARES	- 0.28	0.18	5
TRES	- 0.17	0.13	7
HR	-18.67	14.55	7
BP	- 7.16	3.83	4

The comparatively small minimum sample size required at the 95 percent levels of confidence, relative to the total number of trip observations of 117, indicates the consistent presence of an increase between the pretrip and posttrip

measurements. The findings of significant differences in the physiological baseline changes also indicates that these measurements have descriptive ability in relating baseline levels. However, these findings can not establish the cause within the trip experience of the measured changes. That cause or combination of causes can not be known with absolute certainty, but rather may only be inferred from the correlations with other trip experience parameters as presented in Section 5.3.

5.2.8 Driver Subjective Valuation

The subjective quality of service valuations were evaluated to determine if an apparent relationship was evident between the subjective descriptions and the subjective scores. As reviewed in Section 4.2, drivers were requested to select the most appropriate quality of service description category and subcategory, and identify a corresponding score between 1 and 10 to the nearest half point. A summary of the findings is illustrated in Figure 5-1. Discernible patterns can be seen in the spread of scores relative to the descriptions.

The categorization of the driver perception of quality of service requires the assumption of an appropriate continuous scale, to which a driver may gauge their experienced service. It was further assumed that drivers have the ability to perceive their quality of service through a

Figure 5-1: Subjective Valuation Ranges

	POOR	TOLERABLE	GOOD
Maximum	4.5	7.0	9.5
Minimum	2.0	3.5	5.0
Average	3.0	5.0	7.5

SUBJECTIVE RESPONSE DESCRIPTION

consistent discrimination process to the nearest half point on a ten point interval scale; and that they could differentiate between the three subjective service category descriptions of unacceptable (poor), acceptable (tolerable), and acceptable (good). The valuation of service was assumed to follow a probabilistic normal distribution, in that the boundaries of each service description are not necessarily perceived at the same points on the continuous scale.

The development of serviceability ranges required the determination of confidence intervals for the scores relative to the descriptions. Statistical parameters of mean and standard deviation were determined for each subjective description category in the development of confidence intervals. The suitability of data aggregations were assessed at confidence limits of 95 percent. The 95 percent confidence intervals for the subjective quality of service descriptions are presented in Table 5-10.

Table 5-10: Serviceability Description Ranges - 95 Percent Confidence Intervals				
Description	95% Interval	n	$\bar{x}$	s
Unacceptable (Poor)	Scores ≤ 3.5	10	3.05	0.79
Acceptable (Tolerable)	$5.0 \leq \text{Scores} \leq 5.5$	37	5.01	0.72
Acceptable (Good)	Score ≥ 7.0	70	7.45	1.31

Generally these findings corroborate the initial survey assumption that quality of service can be consistently

categorized and valuated, on a ten point interval scale.

As the tolerable description has scores closely clustered around a mid level of indifference of approximately 5.0, the tolerable range was defined as that area between the poor and good descriptions. Consequently the serviceability descriptions and ranges for the rural two lane highway setting are as presented in Table 5-11.

Table 5-11: Serviceability Description Ranges	
Description	Range
Unacceptable (Poor)	Score < 3.5
Acceptable (Tolerable)	$3.5 \leq \text{Score} \leq 7.0$
Acceptable (Good)	Score > 7.0

5.2.9 Traffic Parameters

Average travel speed was found to be the most practical and consistent parameter to link the preliminary serviceability guidelines based upon travel time predictability and the traditional LOS criteria (11). The linkage is evident in the integral time basis of both parameters. Average travel speed was calculated as the measured travel distance divided by the measured travel time. The enroute trip conditions that affect travel time predictability will also directly affect average speed through any travel time changes. The predictability of travel time can in effect be viewed as the predictability of average speed, when the common travel distance between predicted and actual average speed is factored out. Average travel speeds corresponding

to the trip observations are also presented in Appendix E.

5.2.10 Background Conditions

The significant background conditions were reviewed in the development of the travel time predictability perspective. These background conditions were reviewed to provide indications of their respective implications in the development of the model, rather than as definitive assessments of their effects. The ranges and trends of the background conditions, including the subject, driving experience, route experience, weather, and road surface conditions, were related to corresponding values of travel time predictability and subjective valuation to enable further explanation of the principal underlying relationships. The statistical significance of the ranges and trends of the background conditions were not evaluated in this research, as they neither feature directly in the modelling or the preliminary serviceability guidelines. The background conditions are however implicitly included in the travel time predictability parameter through their aggregate effects on travel time outcome. The key interrelationships between the subjective valuation, travel time predictability, and the physiological baseline change factor are evaluated in Sections 5.3 and 5.4.

Figure 5-2 illustrates the travel time predictability demonstrated by the 11 subjects. It can be seen that 8 of

Figure 5-2: Subject Predictability

the 11 drivers demonstrate predictability that tends toward an overestimate or underestimate of travel time to similar extents. Of the remaining three drivers, subjects 7 and 10 consistently underestimate and subject 11 overestimates travel time. The subjective response of the test subjects was also reviewed to determine if there was a propensity of any subject to assess service quality in a narrow range. As illustrated in Figure 5-3, the subjects assessed service quality no less than 2.0, and no greater than 9.5, with ranges between 5.0 and 7.5. No trends that could be seen to affect the model development were apparent.

Figure 5-4 illustrates the relationship between travel time predictability and driving experience. The driving experience ranges were based on the five year groupings used by automobile insurance companies for reviewing and assigning risk. No significant trends were observed, although longer term drivers demonstrated a tendency towards underestimating travel time. Subjective response relative to driving experience was also reviewed as presented in Figure 5-5, also with no apparent trend.

Travel time predictability as a consequence of the frequency of route experience (in the previous month) was also reviewed, as illustrated in Figure 5-6. The absence of apparent trends, likely indicates that predictability is more affected by current information than route familiarity. Similarly, subjective valuation shows no apparent trend

Figure 5-3: Subject
vs Subjective Valuation

Figure 5-4: Driving Experience
vs Predictability

Figure 5-5: Driving Experience
vs Subjective Valuation

Figure 5-6: Route Experience
vs Predictability

related to the frequency of route experience in the previous month, as illustrated in Figure 5-7.

Figure 5-8 illustrates the relationship between travel time predictability and road surface conditions. Average predictability tends to underestimate travel time for wet and light snow road conditions. This may be attributable to drivers being unrealistically optimistic, in that inadequate allowances are made for the additional travel time required due to the deteriorated conditions. The wider predictability range for compact snow and ice conditions could be attributed to unexpected caution requirements due to safety and vehicle control considerations. The wide range of predictability related to dry road surface conditions could be attributed to comparatively greater traffic volumes when driving conditions are more favourable, and that road works are also more likely when road conditions are good. Figure 5-9 illustrates subjective valuation ranges related to road surface conditions, with no trend apparent. However it is interesting to note that poor road surface conditions demonstrate ranges comparable to dry conditions. These observations could indicate that informative road surface condition information is either not readily available or not used properly in travel time predictions.

Figure 5-10 illustrates the effects of weather conditions on travel time predictability. The wide predictability range of the clear weather conditions tends to confirm

Figure 5-7: Route Experience
vs Subjective Valuation

Figure 5-8: Road Conditions
vs Predictability

Figure 5-9: Road Conditions
vs Subjective Valuation

ROAD SURFACE CONDITION

Figure 5-10: Weather Conditions
vs Predictability

WEATHER CONDITIONS

the observation related to dry surface conditions. Of interest is that drivers tend toward underestimating travel time in snow conditions, and overestimating travel time in sleet. This could also be attributable to vehicle control and safety considerations, in that snow and sleet conditions are worse and better respectively, than expected. It follows that although drivers are affected by weather and road conditions through the effects on travel time predictability, that these effects could be diminished through adequate information for more accurate travel time predictions. The subjective valuation ranges related to weather conditions are presented in Figure 5-11, with no apparent trends evident. It is interesting to note that clear and snow conditions have comparable subjective valuation ranges. This may be indicative of drivers gauging their perception of service quality relative to their expectations of conditions enroute. This would tend to substantiate the use of the travel time predictability perspective as a basis for modelling driver serviceability.

5.3 Rural Two Lane Highway Model Linkages

The initial step in developing the linkages among the principal model variables was to draw scatterplots of the data points and determine the inter-correlations.

These scatterplots are presented in Figures 5-12 through 5-21.

**Figure 5-11: Weather Conditions
vs Subjective Valuation**

WEATHER CONDITIONS

Figure 5-12: Predictability
vs Factor 1 (FC1)

**Figure 5-13: Factor 1 (FC1)
vs Subjective Valuation**

Figure 5-14: Predictability
vs Subjective Valuation

Figure 5-15: Average Speed
vs Predictability

Figure 5-16: Average Speed
vs Subjective Valuation

Figure 5-17: Factor 1 (FC1)
vs Factor 2 (FC2)

Figure 5-18: Average Speed
vs Factor 2 (FC2)

Figure 5-19: Factor 2 (FC2)
vs Subjective Valuation

Figure 5-20: Average Speed
vs Factor 1 (FC1)

Figure 5-21: Predictability
vs Factor 2 (FC2)

The Figure 5-12 scatterplot of the physiological baseline change (Factor 1) versus travel time predictability clearly indicates a consistent linear pattern between these variables. Consistent patterns are also evident in the curvilinear relationships of subjective valuation versus Factor 1 (FC1), and subjective valuation versus travel time predictability in Figures 5-13 and 5-14 respectively.

A Pearson correlation coefficient matrix of the primary study parameters was prepared to assess the inter-relationships of the variables. The coefficient of correlation by definition estimates the strength of the linear association between two variables. The strength of correlations can be described through the spectrum illustrated in Table 5-12.

Table 5-12: Correlation Descriptions (86)				
Perfect	Moderate		No	Perfect
-1.00	-0.50	0.00	+0.50	+1.00
Strong	Weak	Weak	Strong	

This correlation definition applies to linear or linearly transformed regressions solved through the method of least squares. However as the definition does not apply directly for the curvilinear relationships between travel time predictability and the physiological baseline change (Factor 1), and predictability and subjective valuation, the Pearson correlation coefficient was evaluated as the extent to which the independent predicted values from a polynomial

regression compared to the corresponding observed values. The goodness of fit of a curvilinear regression may be described through the correlation between the observed and predicted values of the dependent variable (80,85). Graphically this is the linear comparison of observed dependent versus predicted independent values. For a perfect correlation of 1.0 this would result in a 45 degree angle between the plotted line and the observed and predicted axes. The respective correlation coefficients should then be interpreted as an assessment of the extent to which the parameters are related, be that relationship linear or curvilinear.

The Pearson correlation coefficient matrix of Factor 1, Factor 2, travel time predictability, subjective valuation, and average speed is presented in Table 5-13.

Table 5-13: Model Parameter
Correlation Matrix

	FC1	FC2	PRED	ASPD	SUBJ
FC1	1.00	0.53*	0.85*	0.47*	0.81*
FC2		1.00	0.50*	0.79*	0.01
PRED			1.00	0.39*	0.71*
ASPD				1.00	0.01
SUBJ					1.00

* .05 One-Tailed Significance

FC1 = Physiological Change Factor 1
 FC2 = Physiological Change Factor 2
 PRED = Travel Time Predictability
 ASPD = Average Travel Speed
 SUBJ = Subjective Service Valuation

The most significant correlations in the moderate to strong range in this matrix are:

- i. Factor 1 vs Subjective Valuation 0.81
- ii. Predictability vs Subjective Valuation 0.71
- iii. Predictability vs Factor 1 0.85
- iv. Factor 2 vs Average Speed 0.79.

The corresponding 95 percent confidence intervals for these correlations, determined through Fisher Z transformations, are:

- i. Factor 1 vs Subjective Valuation $0.74 \leq r \leq 0.87$
- ii. Predictability vs Subjective Valuation $0.61 \leq r \leq 0.79$
- iii. Predictability vs Factor 1 $0.79 \leq r \leq 0.89$
- iv. Factor 2 vs Average Speed $0.71 \leq r \leq 0.85$.

As the lower bounds of the 95 percent confidence intervals continue to fall within the moderate range of correlation further assurance of the strength and consistency of the relationships is evident.

The first three relationships describe the basis for modelling driver serviceability. Figures 5-22 and 5-23 present three dimensional scatterplots of these relationships. Both figures illustrate the relationships between the parameters. The driver subjective service quality valuations are highest in the predictability range approaching a correct travel time prediction. The corresponding physiological baseline change factor trend levels out in this range, and rises with increasing underestimates of

Figure 5-22: Plot of Factor 1 (FC1) vs Predictability
vs Subjective Valuation

Figure 5-23: Plot of Subjective Valuation vs Predictability
vs Factor 1 (FC1)

travel time and drops towards increasing overestimates of travel time.

On the basis of the very low correlation between average speed and subjective valuation it was inferred that speed and its travel time basis are not appropriate gauges for quality of service. However, the travel time component of speed features in the travel time predictability description of the trip experience.

The Factor 2 (FC2) versus average speed relationship has no apparent role in this modelling of serviceability. Factor 2 was identified in Section 5.2.3 as the secondary physiological baseline change factor, that was predominately influenced by the measures of respiration change. In Table 5-13 FC2 although correlated strongly with average speed, shows weak to no correlation with predictability and subjective service quality valuation. The absence of a correlation with subjective service quality valuation precludes the use of the Factor 2 versus speed relationship as a modelling basis. An explanation of the moderate relationship between average speed and Factor 2 could be that the parameters are related descriptions of some characteristic of the trip experience, for example vehicle control.

The plotted average speed data of Figures 5-15, 5-16, 5-18 and 5-20 illustrates a propensity for drivers to exceed the posted speed limit of 90 kilometres per hour. On first

appearances it would appear that drivers exceeding the speed limit are doing so as a result of facility deficiencies, such as incorrect speed posting or making up for limited passing opportunities. It could also be inferred that the speeding driver may be endeavoring to decrease the risk of arriving late to compensate for an underestimate of travel time. Another reasonable explanation could be that the speeding is characteristic behaviour consistent with that environment. In this regard, generally drivers have a tendency to exceed the posted speed limit up to the enforcement tolerance level. On British Columbia's rural highways this tolerance allowed 10 to 15 kilometres per hour over the speed limit during the survey period, before a ticket was issued. Given that this was accepted behaviour it likely featured in the driver's initial prediction of travel time and their subsequent behaviour.

On the basis of the significance of the observed linkages it follows that extrapolations may be made in the subsequent development of the functional model. These extrapolations are qualified for similar driver subject groups and roadway settings with some confidence within the observed range of travel time predictability.

5.4 Rural Two Lane Highway Model

5.4.1 Model

The keys to the modelling of driver serviceability are the interrelationships between travel time predictability, subjective valuation, and Factor 1 (FC1). The development of equations describing the relationships between these parameters was predicated by the evident correlations. The correlations can only provide a basis for the inference of the presence of causal relationships between these parameters.

Scatterplots of these relationships were previously presented in Figures 5-12, 5-13 and 5-14. As reviewed, inspection of the data point dispersion indicated that a linear relationship was apparent between Factor 1 and travel time predictability. The relationships between subjective valuation and Factor 1, and subjective valuation and travel time predictability appeared to be more appropriately described by a polynomial regression.

The application of a polynomial regression to describe a data set is based on the principal of "seeking a polynomial of lowest possible degree that "adequately" describes the data", as noted by Miller and Freund (85). Often it is possible to determine the degree of polynomial through an inspection of the data (85). However, the subjective valuation versus travel time predictability and subjective valuation versus the physiological baseline change (Factor 1),

relationships were evaluated using the F statistic to determine if the residual variance in successive polynomial predictions was significant (85). A residual is the difference between an observed and predicted value. The assessment is done against a null hypothesis that there is no difference in the residual variance between the successive degrees of polynomial prediction. The formulation used was:

$$F = \left[\frac{\sigma_1^2 - \sigma_2^2}{\sigma_2^2} \right] \quad (5.6)$$

where:

F = F statistic

σ_1^2 = the residual variance of polynomial of
order j

σ_2^2 = the residual variance of polynomial of
order (j+1)

with degrees of freedom = (1, n-3).

The procedure is customarily terminated after two successive steps have not produced results (85). The results for the two relationships are summarized in Table 5-14.

On the basis of these findings it was determined that second order polynomials would be appropriate to describe the subjective valuation versus travel time predictability, and subjective valuation versus the physiological baseline change (Factor 1) relationships.

Table 5-14: Order of Polynomial Regressions			
Relationship	Order of Equation	F	H ₀
Subj=f(FC1)	2 vs 1	1.68	Accept
	3 vs 2	0.04	Accept
Subj=f(Pred)	2 vs 1	0.47	Accept
	3 vs 2	0.08	Accept
* at 95% Level of Confidence			

The equations of the respective relationships were then determined to be:

- i. Factor 1 versus Travel Time Predictability
(Figure 5-12)

$$FC1 = -1.93 - 47.31(PRED) \quad (5.7)$$

- ii. Subjective Valuation versus Factor 1
(Figure 5-13)

$$SUBJ = 7.49 - 0.05(FC1) - 0.01(FC1)^2 \quad (5.8)$$

- iii. Subjective versus Travel Time Predictability
(Figure 5-14)

$$SUBJ = 7.17 + 0.27(PRED) - 18.50(PRED)^2 \quad (5.9).$$

A plot of the Equation 5.7 linear regression is presented in Figure 5-24. In the travel time predictability range corresponding to high tolerable to good, the relative physiological baseline change approaches zero. The relatively low constant term in view of the wide range of Factor 1, is consistent with this observation. As predictability tends toward overestimates a negative physiological baseline change would be evident. Conversely as predictability

Figure 5-24: Regression of Factor 1 (FC1) on
Predictability - Equation 5.7

tends toward underestimates a positive physiological baseline change would be evident.

Plots of the observed subjective valuations versus the subjective valuations as predicted by Equations 5.8 and 5.9 are presented in Figures 5-25 and 5-26, respectively. It should be noted that the graphs illustrate the observed subjective valuations as reported to the nearest 0.5, versus the unrounded subjective valuations predicted by the equations. An application of these equations would require the rounding of the predicted subjective valuation to the nearest 0.5 to be both practical and consistent. The interpretation of the equations and graphs would be that although drivers perceive and describe quality of service as being good, that drivers do not make the finer distinction in valuations above the lower boundary range of 7.0 to 7.5, in the rural two lane highway setting. This range falls within the acceptable range of service quality, at the subboundary between the tolerable and good subjective service quality descriptions.

In Equation 5.8 subjective valuation as a function of Factor 1 decreases as the Factor 1 values shift away from zero. Factor 1 values near zero indicate that the driver's physiological baseline measures are near constant between the baseline pretrip and posttrip levels, and therefore showing no change.

Figure 5-25: Regression of Subjective Valuation
- Equation 5.8 = $f(\text{Factor 1 (FC1)})$

Figure 5-26: Regression of Subjective Valuation
- Equation 5.9 = $t(\text{Predictability})$

In Equation 5.9 subjective valuation as a function of travel time predictability, decreases with increasing prediction error. This clearly indicates that drivers who are unable to predict travel time within an acceptable range are likely to perceive poor quality of service. Serviceability then being inversely proportional to travel time prediction error.

In the statistical evaluation of the model regression equations the Pearson coefficients of correlation and determination, and significance of the explanatory power were assessed. The summary of results is presented in Table 5-15.

Table 5-15: Regression Statistic Summary					
Relationship		R	R^2	F	$F_{0.95}$
5.7	FC1=f(Pred)	0.85	0.72	300.78	Significant
5.8	Subj=f(FC1)	0.81	0.66	110.15	Significant
5.9	Subj=f(Pred)	0.71	0.50	56.97	Significant

The regression summary for the second and third order equations reflect the linear relationship (coefficients of correlation (R) and determination (R^2)) between the observed and predicted dependent variable (85).

The correlation between the Factor 1 and travel time predictability parameters (Equation 5.7) does not necessarily imply causation. It is possible that the apparent association between the variables rather reflects concomitant processes of the trip experience.

The F statistic refers to the F test for overall fit of the regression equations. The value of F relates the variation explained by the regression relative to that unexplained variation inherent in the regression relationship, through a ratio of mean square errors (87). The explanatory value of the regression is evident in the high values of F, all of which exceed the minimum value of unity. These were assessed at a 95 percent level of confidence.

The coefficient of determination value, the square of the correlation coefficient, describes the proportion of variance in the dependent variable that is associated with the variance in the independent variables, through the regression relationship. The higher the coefficient of determination value the greater the explanatory value of the regression. In reviewing the equations it appears that the strongest relationship occurs in the underlying Factor 1 versus travel time predictability equation. Further that subjective valuation is described to a greater extent by it's relationship with Factor 1, compared to travel time predictability.

These relationships demonstrated a consistent basis for modelling driver serviceability, as illustrated in Figures 3-2 and 3-3. The relationship between subjective valuation and travel time predictability (Equation 5.9) was selected as the primary description of the driver service-

ability process. This relationship provides a direct quality of service description of the trip experience. The parallel combined relationships between the physiological measure and travel time predictability (Equation 5.7) and in turn, between the physiological measure and service quality valuation (Equation 5.8) provided a less direct, secondary description of the overall relationship between the trip experience and service quality valuation.

These secondary relationships not only provided further explanation of the driver serviceability process, but in effect validated the primary relationship between subjective valuation and travel time predictability. This was done through a comparison of the subjective valuations predicted through the equations of the primary relationship versus the combined secondary relationships. The secondary relationships were combined through the substitution of Equation 5.7 into Equation 5.8. This combined equation is:

$$\begin{aligned} \text{SUBJ} = & \{7.49 - 0.05[-1.93 - 47.31(\text{PRED})] \\ & - 0.01[-1.93 - 47.31(\text{PRED})]^2\} \end{aligned} \quad (5.10.1)$$

which simplifies to:

$$\text{SUBJ} = 7.55 + 0.54(\text{PRED}) - 22.38(\text{PRED})^2 \quad (5.10.2).$$

Figure 5-27 presents a plot between the subjective valuation predictions of the primary relationship of Equation 5.9 on the horizontal axis, and that of the combined secondary relationships of Equation 5.10 on the vertical axis. The

Figure 5-27: Driver Serviceability Model
- Primary vs Secondary Relationships

plot illustrates the similarity between the primary and combined secondary relationships, as evident in the point dispersion near the 45 degree line (describing a perfect relationship), with a correlation value of 0.95. Although greater discrepancies occur at predicted subjective valuations less than 3.0, this was not viewed critically given the comparative rarity of observed subjective valuations in this range.

The primary relationship is however more practical as it's application would not require the time consuming collection and interpretation of physiological data. This direct relationship also circumvents the interpretative and methodological problems associated with the limited bases for the application of physiological baseline shift measures; as reviewed in Section 2.5. Furthermore, it presents a viable description of the travel time predictability perspective for the modelling of driver serviceability.

Caution should be exercised in interpreting the foregoing relationships as causative, as the associations may rather be a consequence of the travel time predictability parameter, primary physiological factor, and subjective valuations being concurrent descriptions of a common entity. This view is consistent with the basis of this research, in that the common entity being described is the trip experience.

5.4.2 Sample Size

This application of statistics necessarily requires some level of confidence in the parameter relationships used to develop the model. This level of confidence is directly linked to the sample size.

In the development of the model the sample size was monitored in the course of the field survey, as related to the data spread of the three principal parameters of travel time predictability, subjective valuation, and the physiological baseline change (Factor 1). This approach was used to determine when an appropriately sized sample had been achieved.

The formulation used in the calculation of sample size was:

$$n = \left[\frac{Z_{\alpha/2}(s)}{E} \right]^2 \quad (5.11)$$

where:

n = sample size

$Z_{\alpha/2}$ = Z standard deviations

s = sample standard deviation

E = allowable parameter error (82).

In the development of the model this equation was evaluated at a 95 percent level of confidence. The key allowable error in the model relationships is that of the subjective

valuation. The maximum allowable error was set at 0.5 in accordance with the subject drivers having been requested to gauge service quality to the nearest half point interval on a ten point scale. The variable sections of Equations 5.8 and 5.9 were equated to the allowable 0.5 error, to determine the corresponding allowable errors in the physiological baseline change (Factor 1) and travel time predictability, respectively. These then were used in the above equation to determine the minimum sample size. Sample size was also checked against the data spread for subjective valuation in itself, using the 0.5 allowable error. The sample size findings are summarized in Table 5-16. It is evident that the 117 trip observations used in the development of the model exceed the governing minimum sample size of 54 by a comfortable margin, at a 95 percent level of confidence.

Table 5-16: Sample Size Review		
Parameter	Standard Deviation	Minimum Sample Size*
Predictive	0.21	8
FCI	11.78	21
Subjective	1.87	54
* at a 95% level of confidence		

5.5 Preliminary Rural Two Lane Highway Serviceability Guidelines

The relationship between travel time predictability and subjective valuation provides the backdrop for the development of quality of service ranges, as the basis for the preliminary driver serviceability guidelines.

The rural two lane highway preliminary driver serviceability guidelines are presented in Table 5-17, and illustrated in Figure 5-28. The quality of service bounds for travel time predictability were calculated through Equation 5.9 using the serviceability description ranges presented in Table 5-11. This relationship is of most direct practical application, as both parameters are readily measured and understood by both transportation professionals and lay people. This relationship is also less subject to the content interpretations of the parallel combined relationships between subjective valuation, physiological baseline change (Factor 1), and travel time predictability (Equation 5.10).

Figure 5-28 presents the descriptive ranges of perceived service quality as gauged against the subjective valuation range from 1.0 through 10.0 on the vertical axis, and travel time predictability on the horizontal axis. The polynomial regression of Equation 5.9 describing this relationship is presented as the base curve for illustrating the quality of service ranges. However, this base

3

PM-1 3 1/2"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Table 5-17: Preliminary Rural Two Lane Highway Serviceability Guidelines			
Quality Of Service	Estimated Travel Time	Subjective Valuation	Travel Time Predictability
Poor	Way Under	Subj < 3.5	Pred < -0.44
Tolerable	Somewhat Under	3.5 ≤ Subj ≤ 7.0	-0.44 ≤ Pred < -0.09
Good	Slightly Under	Subj > 7.0	-0.09 ≤ Pred < 0.00
Good	Slightly Over	Subj > 7.0	0.00 ≤ Pred < 0.11
Tolerable	Somewhat Over	3.5 ≤ Subj ≤ 7.0	0.11 ≤ Pred < 0.45
Poor	Way Over	Subj < 3.5	Pred ≥ 0.45

Figure 5-28: Rural Two Lane
Highway Serviceability Guidelines

curve illustration neither conveys the range of observed data (Section 5.2.8, Figure 5-14) or describes the upper bound of the good quality of service range. That upper bound was by practice set at 10.0 in through the surveys (Section 4.2.3).

A review of the Figure 5-28 relationship between service quality valuations and predictability indicates that the greater the success of travel time predictability, the greater will be the perceived quality of service. An interpretative example would be a travel time predictability underestimate of 20 percent (-0.2) would fall within the tolerable range of perceived service quality at a subjective valuation of about 6.5. Similarly a travel time predictability overestimate of 5 percent (0.05) would fall within the good range of perceived service quality at a subjective valuation in excess of 7.0.

The interpretation of these preliminary guidelines are only appropriate within the bounds of the observed range of predictability, in the context of a roadway setting similar to that of the rural two lane highway that was used in this modelling.

With reference to Table 5-17 and Figure 5-28 it may be inferred that an improvement in travel time predictability would increase the drivers' perception of service quality. For example increasing a driver's predictability from a 15 percent underestimate to between a 10 percent underestimate

and a 10 percent overestimate may increase the perception of service quality from the tolerable to good range. Relatively greater service quality increases could be realized through improving those predictions that fall into the poor quality of service category. The potential of this inference, and the means of application should be the subject of future research. The British Columbia Ministry of Transportation and Highways is currently interested in pursuing this line of research in an endeavour to have drivers realize their highest potential perceptions of service, within the context of existing infrastructure. This interest is a direct consequence of funding limitations for new construction for the foreseeable future.

The preliminary driver serviceability guidelines were compared to the traditional LOS categories presented in Table 2-1.

A cursory comparison to the percent time delay criteria was inconclusive. The two way traffic volumes through this section of highway were identified as ranging from approximately 2,000 to 4,000 vehicles per day in the winter and summer respectively. These daily volumes equate to design hourly volumes of 300 to 600, using the formulation of:

$$DHV = (k)(AADT) \quad (5.11)$$

where:

DHV = two way design hourly volume

k = adjustment factor of 0.15 on main rural highways

AADT = average annual daily traffic (13).

The application of the empirical relationship between percent time delay and flow (11) presented in Figure 2-1, results in estimated average percent time delays of 15 to 40 percent. This line of comparison was not pursued further as these values did not differentiate between the traditional LOS ranges of A through D, without the added comparison of average travel speed.

The comparison of the traditional level of service described by average travel speed and the preliminary driver serviceability guidelines is illustrated in Figure 5-29. This comparison illustrates the two dimensional interpretation of traffic performance, which includes traffic movement effectiveness and quality of service. The scatterplot of Figure 5-15 provides the backdrop for the service overlays. The traditional average speed criteria extracted from Table 2-1 (11) is described along on the x axis, with the LOS ranges bounded by the dashed vertical lines. The travel time predictability basis of this research is described along the y axis, with the quality of service ranges bounded by the solid horizontal lines.

In this study, it would appear that the traditional LOS

Figure 5-29: LOS vs Quality Of Service

criteria of speed does not accurately describe the quality of service experienced by drivers. This is evident in the number of data points that fall in the higher traditional LOS categories of A through C that would be categorized as being only poor through tolerable levels of quality of service, on the basis of this research. This in part demonstrates the previously noted shortcoming in traffic performance evaluations without reference to the driver serviceability approach.

The preliminary serviceability guidelines realistically characterize the drivers' perception of service quality, given the extent to which their travel time expectations are achieved. These guidelines are the outcome of the significant advance in the understanding of the underlying driver serviceability process. The guidelines form a basis for the potential realization of greater driver satisfaction for given travel conditions. They are not a substitute for the traditional traffic movement effectiveness criteria, in applications such as facility sizing.

Chapter 6

Extension Of The Travel Time Predictability

Perspective - Urban Arterial Setting

6.1 Overview

The greater value in the development of the travel time predictability perspective, for modelling driver serviceability, will be it's wider application to roadway environments beyond the initial two lane rural highway setting. The modelling approach was extended to an urban arterial setting with this objective in mind. As previously discussed the rationale for using the rural setting for the development of the travel time predictability perspective was to gain the opportunity of observing the drivers' trip experience effects over longer time periods and with less peripheral activity, than present in an urban setting. It was theorized the comparatively greater urban peripheral activity and shorter trips could initially obscure the recognition and development of the underlying serviceability relationships.

The extension of the travel time predictability perspective required the evaluation of comparable survey data to determine if the interrelationships between the three major model parameters were consistent and statistically similar. These major parameters were travel time predictability, subjective service quality valuation, and

the primary physiological baseline change factor (Factor 1).

6.2 Data Collection

6.2.1 Overview

The data collection processes used in this extension were the same as those undertaken for the initial serviceability modelling, as presented in Section 4.2. Similarly, each survey trip observation included the recording of the driver's travel time prediction, actual travel time, subjective valuation, and significant background conditions, and the physiological baseline measurements at the beginning and end of the trip. All background condition references are in accordance with those developed and used in the rural survey. The urban arterial database is presented in Appendix I.

6.2.2 Subject Base

The subject base consisted of six British Columbia Ministry of Transportation and Highways employees. Four subjects were male and two female. Five trip observations per subject, for a total of 30, were made over an accumulated period of eight days in February through April 1991. The trip observations consisted of the same information elements collected during the rural survey. Table 6-1 summarizes the general characteristics of the subject base.

Table 6-1: Subject Characteristics

Characteristic	Range	Average
Age (years)	22 - 38	34.6
Driving Experience (years)	5 - 19	14.6
Route Experience (trips within last month)	0 - 7	3.0

Unlike the rural trip observations, the urban surveys did not coincide with actual work related trips. However the surveys generally occurred during regular work hours.

6.2.3 Survey Locations

The selection of an urban arterial setting for this research followed the 1985 Highway Capacity arterial definition of "facilities with signalized intersection spacing of 2 miles or less and turning movements at intersections that usually do not exceed 20 percent of total traffic volumes" (11).

The urban arterial location selected to extend the modelling of driver serviceability was Kingsway Avenue (Highway 99/1A) located in Greater Vancouver. The trip endpoints were selected as the intersection of principal cross streets. The specific links used in the research ran from Broadway Avenue in Vancouver, to Metrotown in Burnaby, to West 10th in New Westminster. The links are 8.5 and 5.2 kilometres long respectively, for a total length of 13.7 kilometres. A map of the section of roadway used in this research is presented in Figure 6-1.

Figure 6-1: Urban Setting Survey Locations

Figures 6-2, 6-3, and 6-4 present views of typical geometrics, cross sections, and intersection treatments. The boxed numbers in Figure 6-1 refer to the approximate locations of corresponding photograph numbers. The survey sites were located in parking lots in the vicinity of each trip origin and destination.

The Kingsway Avenue test section could further be characterized as being of typical urban design (Arterial Class III), with a free flow speed of 40 to 55 kilometres per hour (25 to 35 mph) (11). The section of Kingsway Avenue used in this research would be described by the Transportation Association of Canada classification UAU50 (76). A typical cross section is presented in Figure 6-5 (77). The major intersections have left turn channelization and signalization treatments. A typical major intersection plan view is presented in Figure 6-6 (77). The roadway operates off peak with two lanes in each direction. During the peak morning and afternoon periods this is supplemented through much of the study length by an additional lane in each direction, through an on street parking prohibition. The link experiences average daily traffic volumes in the order of 35,000 vehicles per day (10).

Figure 6-2: Kingsway Avenue Photographs 1 And 2

Photo 1. South View, Knight Street - April 1991.

Photo 2. South View, Victoria Drive - April 1991.

Figure 6-3: Kingsway Avenue Photographs 3 And 4

Photo 3. North View, Nanaimo Street - April 1991.

Photo 4. North View, Tyne Street - April 1991.

Figure 6-4: Kingsway Avenue Photographs 5 And 6

Photo 5. North View, Metrotown - April 1991.

Photo 6. South View, 12th Avenue - April 1991.

Figure 6-5: Typical Cross Section (75)

Figure 6-6: Typical Major Intersection Plan View (75)

6.3 Data Analyses

6.3.1 Overview

The data analyses used in this urban modelling were the same as those used in the rural model development. Principally, these included the use of factor analysis to determine the physiological baseline change factors, and statistical procedures to assess the underlying serviceability relationships and develop the preliminary serviceability guidelines.

6.3.2 Driver Travel Time Predictability

The travel time predictability range of each driver subject was reviewed to determine if apparent patterns were present. The travel time predictability was calculated in accordance with Equation 5.1. Figure 6-7 presents a summary of the subjects' travel time predictability ranges. As evident in the rural observations most subjects tended towards a range of travel time predictability bounded by comparable underestimates and overestimates. However subjects 4 and 6 tended toward overestimating and underestimating, respectively. The pattern of travel time predictability relative to driving experience is presented in Figure 6-8, with no trend apparent.

Figure 6-9 presents a summary of travel time predictability related to the frequency of route experience, in the previous month. No notable trends in predictability were evident. Consequently, there was no apparent indication

Figure 6-7: Subject Predictability

Maximum	0.19	0.12	0.27	0.13	0.13	0.00
Minimum	-0.24	-0.50	-0.45	-0.30	-0.35	-0.29

SUBJECT

Figure 6-8: Driving Experience
vs Predictability

DRIVING EXPERIENCE (years)

**Figure 6-9: Route Experience
vs Predictability**

	0	1	2	3	4	5	6	7
Maximum	-0.05	-0.30	0.10	0.27	0.12	-0.11	-0.10	0.19
Minimum	-0.38	-0.50	-0.25	-0.44	-0.09	-0.29	-0.35	-0.15
Average	-0.21	-0.42	-0.02	-0.01	0.02	-0.23	-0.20	0.02

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that route experience was effective in improving travel time predictability through a greater awareness of recurrent conditions.

6.3.3 Driver Physiological Inputs

A correlation matrix for the urban setting physiological measures of galvanic skin response (GSR), abdominal respiration, thoracic respiration, heart rate and blood pressure are presented in Table 6-2. The comparison of the urban and rural correlations with reference to Tables 6-2 and 5-2 respectively, indicate similar correlation patterns, although the urban levels are slightly lower.

Table 6-2: Physiological Change Correlation Matrix					
	GSR	ARES	TRES	HR	BP
GSR	1.00	0.50*	0.48*	0.67*	0.52*
ARES		1.00	0.95*	0.29	0.36
TRES			1.00	0.32	0.31
HR				1.00	0.71*
BP					1.00
* .05 One-Tailed Significance					
GSR = GSR					
ARES = Abdominal Respiration					
TRES = Thoracic Respiration					
HR = Heart Rate					
BP = Blood Pressure					

The factor analysis was applied to the physiological data in accordance with Section 5.2.3. The factor analysis findings are presented in Appendix H. In the analysis two significant physiological baseline change factors were

identified, as evident in the rural highway setting. The primary and secondary factors were similarly identified as Factor 1 (FC1) and Factor 2 (FC2) respectively. The factor values are presented in Appendix I for each trip observation. As evident in the rural setting Factor 1 values were more heavily influenced by the GSR, heart rate, and blood pressure variables, than the respiration variables. Also as in the rural setting the reverse was apparent for Factor 2, in that the respiration variables have considerably greater influence on the values of this factor. Factor 1 and Factor 2 were found to account for approximately 61 percent and 24 percent respectively, of the variance associated with the underlying physiological baseline changes.

6.3.4 Observation Balance

The number of trip observations per subject was evaluated to assess if the trip observation imbalance was affecting the calculation of the physiological baseline response change factors, in accordance with the analyses of Section 5.2.4. Initially 41 trip observations were made as summarized in Table 6-3.

Table 6-3: Initial Sample - Observations Per Subject							
Subject	1	2	3	4	5	6	Total
Observations	7	11	6	5	7	5	41

This evaluation was done through a paired comparison (78) of the factor values determined on the basis of the complete sample of 41 trip observations, and the corresponding observation factor values determined on the basis of a balanced sample. The balanced sample was based upon the first five trip observations per subject, for a total of 30.

The findings of the paired comparison are summarized in Table 6-4. The comparison was completed using the mean and standard deviation of the difference between the balanced Factor 1 and Factor 2 values (FC1B and FC2B) based upon the balanced sample of 30, and the corresponding Factor 1 and Factor 2 trip observation values (FC1 and FC2) based upon the total sample of 41.

Table 6-4: Experimental Balance Check				
Comparison	$\bar{x}$	s	$z_{0.95}$	95% Level of Confidence
FC1 - FC1B	0.43	0.56	4.18	Reject H_0
FC2 - FC2B	0.78	0.65	6.52	Reject H_0
$H_0: u_d = 0 \quad H_1: u_d \neq 0$				

On the basis of this evaluation it was inferred that a subject imbalance in the initial 41 trip observation sample was producing a distortion in the factor analysis calculation of the physiological baseline change factors, at a 95 percent level of confidence. Consequently the urban data was balanced through the use of only the first five trip observations per subject, for a total sample size of 30.

Subsequent references to Factor 1 (FC1) and Factor 2 (FC2) refer to those calculated on the basis of the balanced number of trip observations per subject.

6.3.5 Observation Independence

The extent of trip observation independence in the urban database was evaluated through the assessment of the presence of autocorrelation in the model parameters and physiological baseline inputs, in accordance with that completed for the rural setting in Section 5.2.5. The results are summarized in Tables 6-5 and 6-6.

**Table 6-5: Urban Model Parameters
- Autocorrelation**

Subject	n	Pred	Subj	FC1
1	5	2.43	3.47-	2.75
2	5	1.59	1.72	1.46
3	5	2.35	3.51-	2.45
4	5	2.63	2.85*	2.91*
5	5	3.06*	2.08	2.82*
6	5	2.89*	2.77*	3.15-
(-) Negative () No Evidence (+) Positive (*) Inconclusive				

Table 6-6: Urban Physiological Change Variables - Autocorrelation						
Subject	n	GSR	ARES	TRES	HR	BP
1	5	2.70	2.46	2.08	2.55	3.61-
2	5	1.42	2.26	2.44	1.62	1.48
3	5	2.95*	3.41-	3.38-	2.68	2.77*
4	5	3.50-	3.45-	3.57-	3.59-	2.98
5	5	2.98*	3.03*	2.61	3.60-	1.63
6	5	3.21-	2.37	2.05	3.51-	3.36-
(-) Negative () No Evidence (+) Positive (*) Inconclusive						

The urban physiological baseline inputs demonstrated comparably higher incidence of inconclusive or negative autocorrelation than the rural setting. These results could be attributable to the comparably shorter intervals between subsequent observations of a subject in the urban setting, resulting in a carryover effect. These findings potentially indicate that the independence of the urban trip observations could be of concern. However as the role of the urban setting was limited to the extension of the travel time predictability perspective, the independence concern while noted was not viewed as critical. Further research could address the concern of observation independence through ensuring that each subject is tested only once, on each section of roadway.

6.3.6 Observation Normalcy

The normalcy of the main parameters of the urban database were assessed in accordance with the evaluation of Section 5.2.6. The findings are presented in Table 6-7.

Table 6-7: Urban Model Parameters - Normalcy Evaluation			
Parameter	df	χ^2	Sig.Level
Predictability	1	1.01	0.314
Subjective	1	4.41	0.036
FC1	1	4.54	0.033

On the basis of this evaluation it was inferred at a 0.05 level of significance that the travel time predictability followed a normal distribution pattern, and that the subjective valuation and primary physiological change construct FC1 followed near normal distribution patterns.

6.3.7 Observation Consistency

The descriptive ability of the physiological baseline changes were evaluated in accordance with the paired sample analyses of Section 5.2.7. The Z statistic was also used as the sample size meets the 30 observation threshold in the assessment of the significance of the paired sample differences. This assessment was done at a 95 percent level of confidence for both Type 1 and Type 2 errors using the hypotheses of:

$$H_0: u_1 - u_2 = 0$$

$$H_a: u_1 - u_2 < 0.$$

The results of the analyses are summarized in Table 6-8.

Table 6-8: Evaluation of Urban Baseline Change Differences			
Difference	$\bar{x}$	s	n
GSR	-28.99	12.97	3
ARES	- 0.21	0.14	5
TRES	- 0.30	0.16	4
HR	-22.05	8.74	2
BP	- 7.25	3.85	4

The required sample sizes to achieve the 95 percent level of confidence for a balanced Type 1 and Type 2 error are less than the sample size available of 30 observations. The inference of this finding is that the physiological measures effectively capture the change in baseline levels, between the pretrip and posttrip monitoring. However as previously noted, this inference can not be extended to attributing the cause(s) of the physiological baseline changes.

6.3.8 Driver Subjective Valuation

The functional model development analyses of Section 5.2.8 were similarly applied to the review of the subjective valuations and corresponding descriptions in the urban arterial environment. This was done to determine if a relationship was evident between the subjective response descriptions and valuations, and if so to determine appropriate serviceability ranges. A summary of the findings is

illustrated in Figure 6-10. As evident in the rural highway setting discernible ranges can be seen in the urban arterial valuation spread relative to the descriptive categories.

Serviceability ranges were developed using 95 percent confidence intervals. Table 6-9 presents these intervals and the corresponding number of observations, mean and standard deviation as related to the service quality descriptions. The consistency evident in the subjective categorization and valuation of service further corroborates the initial survey assumptions for gauging driver quality of service perceptions. These assumptions included the use of three descriptive service categories and a ten point interval scale.

Table 6-9: Serviceability Description Ranges - 95 Percent Confidence Intervals				
Description	95% Interval	n	$\bar{x}$	s
Unacceptable (Poor)	Score ≤ 4.0	9	3.39	0.97
Acceptable (Tolerable)	$6.0 \leq \text{Score} \leq 7.0$	8	6.50	0.88
Acceptable (Good)	Score ≥ 8.0	13	8.19	0.42

As observed in the rural setting tolerable scores clustered around a central value, although the urban arterial category break points are somewhat higher. Consequently, in accordance with the approach used in the rural modelling, the acceptable (tolerable) range was defined as that range which lies between the unacceptable (poor), and

Figure 6-10: Subjective Valuation Ranges

acceptable (good) categories. The resulting serviceability ranges for the urban arterial setting are then as presented in Table 6-10.

Table 6-10: Serviceability Description Ranges		
Description	Range	
Unacceptable (Poor)	Score < 4.0	
Acceptable (Tolerable)	4.0 ≤ Score ≤ 8.0	
Acceptable (Good)	Score > 8.0	

Subjective valuation ranges for each subject are presented in Figure 6-11. These ranges exhibit approximately a five point spread, with an individual low of 1 and a high of 9.

Figure 6-12 presents a summary of subjective valuation reports relative to driving experience. No trends were apparent, although both the least and most experienced categories demonstrated a tendency to slightly higher subjective valuations. Figure 6-13 illustrates the absence of apparent trends between subjective valuation and the frequency of route experience, in the previous month.

6.3.9 Traffic Parameters

The traffic movement effectiveness parameter used to link the findings of this research to the traditional arterial level of service criteria was the average travel speed, as presented in Table 2-2 (11).

**Figure 6-11: Subject
vs Subjective Valuation**

**Figure 6-12: Driving Experience
vs Subjective Valuation**

Figure 6-13: Route Experience
vs Subjective Valuation

ROUTE FREQUENCY IN PREVIOUS MONTH

6.3.10 Background Conditions

The background conditions identified in the rural modelling were used in the urban survey. As it happened the weather and road surface conditions were naturally controlled inasmuch as the weather in Vancouver during the survey periods was clear, with a corresponding dry road surface condition. Consequently a review of the effects of weather and road conditions on travel time predictability and subjective valuations was not applicable.

6.3.11 Urban Arterial Model Linkages

The inter-relationships among the three key parameters of travel time predictability, subjective valuation and the physiological baseline change Factor 1 (FC1), identified in the model development stage are illustrated in three dimensional scatterplots of Figures 6-14 and 6-15. These figures show similar patterns to those observed in the rural setting (Figures 5-22 and 5-23). Again it is evident that subjective valuations are higher in a range of travel time predictability corresponding to more accurate predictions, and in a physiological baseline change factor (FC1) range approaching zero.

Scatterplots of the trip experience parameters are presented in Figures 6-16 through 6-25. As evident in the rural setting, curvilinear relationships are apparent between subjective valuation versus the physiological baseline change (Factor 1) (Figure 6-17), and subjective valua-

Figure 6-14: Plot of Factor 1 (FC1) vs Predictability
vs Subjective Valuation

Figure 6-15: Plot of Subjective Valuation vs Predictability
vs Factor 1 (FC1)

Figure 6-16: Predictability
vs Factor 1 (FC1)

**Figure 6-17: Factor 1 (FC1)
vs Subjective Valuation**

Figure 6-18: Predictability
vs Subjective Valuation

**Figure 6-19: Average Speed
vs Predictability**

Figure 6-20: Average Speed
vs Subjective Valuation

Figure 6-22: Average Speed
vs Factor 2 (FC2)

Figure 6-24: Average Speed
vs Factor 1 (FC1)

tion versus travel time predictability (Figure 6-18). The correlation matrix for the trip experience parameters is presented in Table 6-11. As discussed in Section 5.3, the goodness of fit of a curvilinear regression may be described through the correlation between the observed and predicted values of the dependent variable (80,85). The predicted value, for a particular trip observation, was calculated through the applicable polynomial regression using the observed value of the independent variable.

**Table 6-11: Model Parameter
Correlation Matrix**

	FC1	FC2	PRED	ASPD	SUBJ
FC1	1.00	0.45*	0.97*	0.48*	0.91*
FC2		1.00	0.45*	0.88*	0.24
PRED			1.00	0.44*	0.89*
ASPD				1.00	0.22
SUBJ					1.00

* .05 One-Tailed Significance

FC1 = Physiological Change Factor 1
 FC2 = Physiological Change Factor 2
 PRED = Predictability
 ASPD = Average Travel Speed
 SUBJ = Subjective Service Valuation

The commonality of the key relationships among the physiological baseline change Factor 1 (FC1), travel time predictability and subjective valuation are evident in the correlation matrix. The urban data scatterplots of the key relationships in Figures 6-16, 6-17, and 6-18 also portray similar patterns to those evident in the rural modelling.

Similarities between the rural and urban settings also of note are the strong correlation between the secondary physiological baseline change Factor 2 (FC2) and average speed, and the associated weak and moderate correlations between subjective valuation and Factor 2, and average speed respectively.

The determination of the order of polynomial regression to describe the relationships of subjective valuation versus travel time predictability, and subjective valuation versus the physiological baseline change Factor 1, were undertaken in accordance with the evaluations of Section 5.4.1. The F statistic was used to determine if the residual variance between observed and predicted values in successive polynomial predictions was significant. The assessment was also done at a 95 percent level of confidence. The findings are summarized in Table 6-12.

Table 6-12: Order of Polynomial Regressions			
Relationship	Order of Equation	F	H ₀
Subj=f(FC1)	2 vs 1	1.42	Accept
	3 vs 2	0.54	Accept
Subj=f(Pred)	2 vs 1	1.14	Accept
	3 vs 2	0.21	Accept
- 95% Level of Confidence			

On the basis of these findings it was determined that second order polynomials would also be appropriate to de-

scribe the urban arterial relationships of subjective valuation versus the physiological baseline change (Factor 1) and subjective valuation versus travel time predictability. The equations describing these relationships were determined to be:

- i. Factor 1 versus Travel Time Predictability
(Figure 6-16)

$$FC1 = -4.93 - 51.35(PRED) \quad (6.1)$$

- ii. Subjective Valuation versus Factor 1
(Figure 6-17)

$$SUBJ = 7.44 - 0.12(FC1) - 0.01(FC1)^2 \quad (6.2)$$

- iii. Subjective versus Travel Time Predictability
(Figure 6-18)

$$SUBJ = 7.81 + 1.61(PRED) - 25.44(PRED)^2 \quad (6.3).$$

In the statistical evaluation of the model regression equations the coefficients of correlation and determination, and the significance of the explanatory power were assessed. The summary of results is presented in Table 6-13.

Table 6-13: Regression Statistic Summary				
Relationship	R	R ²	F	F _{0.95}
6.1 FC1=f(Pred)	0.96	0.93	400.44	Significant
6.2 Subj=f(FC1)	0.90	0.82	66.98	Significant
6.3 Subj=f(Pred)	0.89	0.79	56.23	Significant

The regression summary for the second and third order equations reflect the linear relationship (coefficients of

correlation (R) and determination (R^2)) between the observed and predicted dependent variable (85). The F statistic refers to the F test for overall fit of the regression equations. The F value relates the variation explained by the regression relative to that unexplained variation inherent in the regression relationship, through a ratio of mean square errors (87). The explanatory value of the regression is evident in the high values of F , all of which exceed the minimum value of unity. These were assessed at a 95 percent level of confidence.

The plot of the Equation 6.1 regression of Factor 1 (FC1) on predictability is presented in Figure 6-26. The correlations for the polynomial Equations 6.2 and 6.3 describe the goodness of fit of these regressions, through an assessment of the extent to which the predicted subjective valuations and corresponding observed subjective valuations compare to a straight line, using the least squares regression method. A perfect correlation of 1.0 would describe a 45 degree angle between the observed and predicted axes (80,85). Graphs of regression assessments for Equations 6.2 and 6.3 are presented in Figures 6-27 and 6-28, respectively.

These equations are limited to a range of subjective valuations less than approximately 8.0, as evident in the constant terms of the equations and in Figures 6-27 and 6-28. The 8.0 limit also describes the lower bound of the

Figure 6-26: Regression of Factor 1 (FC1) on Predictability - Equation 6.1

Figure 6-27: Regression of Subjective Valuation
- Equation 6.2 = $f(\text{Factor 1 (FC1)})$

Figure 6-28: Regression of Subjective Valuation
- Equation 6.3 = $f(\text{Predictability})$

good quality of service range. An interpretation of these regressions and the underlying observations is that drivers generally would not rate good service much higher than the lower bound of the category.

It is evident that predictive and reliable regressions can be developed to describe the travel time predictability perspective for modelling driver serviceability in an urban arterial setting. As discussed for the rural setting the primary model relationship is that between travel time predictability and subjective valuation, as described by Equation 6.3. This relationship is key to any practical application of the driver serviceability methodology; because travel time predictability provides a direct unequivocal description of the trip experience and is comparably easy to record and interpret.

The description of the trip experience through the combined relationship of travel time predictability, physiological baseline change and subjective valuation presents two problems that preclude its practical application. The first is a theoretical problem of only being able to infer the relationship between the trip experience and physiological baseline change. Although the measure appears to have merit, further physiological research should pursue it's basis and application. The second is a practical problem of realistically monitoring physiological condition as an input to the modelling of driver serviceability. The

input to the modelling of driver serviceability. The physiological monitoring using the available technology is inefficient, due to the time required to both record and interpret the results.

6.3.12 Sample Size

The sample size was assessed in accordance with the evaluation of Section 5.4.2, to ensure that an appropriate number of trip observations had been obtained to for modelling driver serviceability.

The level of confidence was determined based on the sample size of 30 trip observations, for the three principal parameters of travel time predictability, subjective valuation, and the physiological baseline change (Factor 1).

As done in Section 5.4.2, the key allowable error in the model relationships was that of the subjective valuation. The maximum allowable error was set at 0.5 in accordance with the subjects having been requested to assess service quality to the nearest half point interval, on a ten point scale. The variable sections of Equations 6.2 and 6.3 were equated to the 0.5 error, to determine the corresponding allowable errors in the physiological baseline change (Factor 1), and travel time predictability respectively. The equations were then used in the calculation

of sample size where:

$$n = \left[\frac{t_{\alpha/2}(s)}{E} \right]^2 \quad (6.4)$$

where:

n = sample size

$t_{\alpha/2}$ = t standard deviations

s = sample standard deviation

E = allowable parameter error (85).

The sample size was also checked against the data spread for subjective valuation in itself, using the 0.5 allowable error. The sample size level of confidence findings are summarized in Table 6-14.

Table 6-14: Sample Size Review			
Parameter	Standard Deviation	Minimum Sample Size	Level of Confidence
Predictive	0.21	16	0.95
FC1	10.72	30	0.91
Subjective	2.17	30	0.78

On the basis of this review, it was concluded that an appropriate sample size had been achieved with respect to the travel time predictability and physiological baseline response change Factor 1 variables, as the levels of confidence meet or approach the 95 percent level of confidence used in the rural modelling. Although the 0.78 level of confidence associated with the subjective valuation is

comparably less than travel time predictability and Factor 1 (FC1), it is deemed sufficiently high for use in this extension of the travel time predictability perspective. On the basis of these levels of confidence it was consequently concluded that the 30 trip observations in the urban arterial setting provided an appropriately sized sample for statistical validity.

6.4 Results

6.4.1 Overview

The extension of the travel time predictability perspective was based upon a comparison of the underlying model relationships between the rural two lane highway and urban arterial settings. Similarity hypotheses were developed and translated into testable format and statistically evaluated to determine if similarities existed between the two settings.

6.4.2 Physiological Baseline Change

The rural model (Equation 5.7) was used to predict the physiological baseline change (Factor 1) as a function of observed urban travel time predictability. The predicted Factor 1 values were then compared to the observed Factor 1 values. This comparison of the predicted and observed Factor 1 values is plotted in Figure 6-29. The plot corresponds to a correlation of 0.97. This correlation compares to the rural setting (Equation 5.7) correlation

value of 0.85. The correlation is interpreted as the goodness of fit of the observed relative to predicted values (80,85) of Factor 1. The 95 percent level of confidence for the correlation between the urban observed Factor 1 values and the Factor 1 values predicted through the rural model is then:

$$0.94 \leq r \leq 0.98.$$

This range describes a strong correlation.

6.4.3 Subjective Valuation

The rural model relationship (Equation 5.8) predicting subjective valuations on the basis of the observed urban physiological baseline change (Factor 1) was compared to the observed urban subjective valuations. This comparison of the predicted and observed subjective valuations resulting in a correlation of 0.85, is plotted in Figure 6-30. The corresponding 95 percent confidence interval for the correlation is:

$$0.71 \leq r \leq 0.93.$$

This range describes a moderate to strong correlation.

Similarly the comparison of the predicted subjective valuation, as a function of travel time predictability (Equation 5.9), and the observed urban subjective valuations results in a correlation of 0.89. This comparison is illustrated in Figure 6-31. The corresponding 95 percent confidence interval for the correlation is:

$$0.78 \leq r \leq 0.95.$$

**Figure 6-30: Model Predictive Ability
- Subjective Valuation**

Figure 6-31: Model Predictive Ability
- Subjective Valuation

The subjective valuation ranges of the rural and urban settings were compared using the t distribution for differences in the means and the F test for differences in the sample variances. These comparisons were carried out at a 95 percent level of confidence. The evaluations for the means and variances are summarized in Tables 6-15 and 6-16 respectively.

Table 6-15: Summary of The Comparison of Subjective Valuation Means							
Category	Rural			Urban			95% Level of Confidence
	n	$\bar{x}$	s	n	$\bar{x}$	s	
Poor	10	3.05	0.79	9	3.39	0.97	Accept Ho
Tolerable	37	5.01	0.72	8	6.50	0.88	Reject Ho
Good	70	7.45	1.31	13	8.19	0.42	Reject Ho
Ho: $\mu_1 - \mu_2 = 0$				H1: $\mu_1 - \mu_2 > 0$			

Table 6-16: Summary of The Comparison of Subjective Valuation Variances		
Category	F	95% Level of Confidence
Poor	1.51	Reject Ho
Tolerable	1.49	Reject Ho
Good	9.73	Accept Ho
Ho: $s_1^2 = s_2^2$		
H1: $s_1^2 < s_2^2$		

The comparison of the quality of service valuation ranges between the rural and urban settings clearly indicates a difference. This is evident in the mean and vari-

ance differences for the tolerable and good categories. The poor category demonstrates similarity in both mean and variance statistics, indicating that both settings consider poor service quality at similar valuations.

In view of the statistical differences between the subjective valuation ranges of the rural and urban settings, it would be inappropriate to apply the preliminary rural two lane highway serviceability guidelines to the urban arterial setting. However, the modelling of driver serviceability based upon the travel time predictability perspective continues to be consistent and appropriate. The driver's perception of the quality of service experienced on a trip can be described through it's relationship to travel time predictability. The urban findings follow the pattern identified in the rural analyses whereby drivers having chosen the route and time period for travel, have framed their expectations of service quality through their predictions of travel time. The closer the final travel time to matching that prediction the greater will be the perceived serviceability. The great similarity between the key relationships of the rural and urban settings potentially presents a common basis for the wider application of the travel time predictability perspective, to other roadway settings.

6.5 Preliminary Urban Arterial Serviceability Guidelines

In view of the noted differences in the subjective valuation ranges between the rural and urban settings, it was felt that the use of the primary rural relationship (Equation 5.9) to describe the urban setting would be less representative than using the corresponding urban relationship (Equation 6.3). Consequently, it may be interpreted that there is not a general travel time predictability equation common to all roadway settings, for modelling driver serviceability.

The preliminary urban arterial serviceability guidelines are presented in Table 6-17 and illustrated in Figure 6-32. These guidelines reflect the travel time predictability perspective for modelling driver serviceability, in common with the rural two lane highway setting. The quality of service bounds for travel time predictability were calculated through Equation 6.3 using the serviceability description ranges presented in Table 6-10.

As presented in Figure 5-28 for the rural highway setting, Figure 6-32 illustrates similar information for the urban arterial setting. The quality of service descriptions are related to the subjective valuation range from 1 through 10 on the vertical axis, and travel time predictability on the horizontal axis. The base curve depicts the relationship between subjective valuation and travel time predictability through the polynomial regression of Equation

Table 6-17: Preliminary Urban Arterial Serviceability Guidelines

Quality Of Service	Estimated Travel Time	Subjective Valuation	Travel Time Predictability
Poor	Way Under	Subj < 4.0	Pred < -0.36
Tolerable	Somewhat Under	4.0 ≤ Subj ≤ 8.0	-0.36 ≤ Pred < -0.02
Good	Slightly Under	Subj > 8.0	-0.02 ≤ Pred < 0.00
Good	Slightly Over	Subj > 8.0	0.00 ≤ Pred < 0.09
Tolerable	Somewhat Over	4.0 ≤ Subj ≤ 8.0	0.09 ≤ Pred < 0.42
Poor	Way Over	Subj < 4.0	Pred ≥ 0.42

**Figure 6-32: Urban Arterial
Serviceability Guidelines**

6.3. This regression slightly misrepresents the base relationship in the good range, as evident in the slight mismatch between the curve and the 8.0 bound of the good range of service. As subjective valuation was gauged using a 0.5 interval, this discrepancy was rationalized as 8.0 being the round off of the 0.5 interval between 7.75 to 8.25. Therefore the corresponding range of travel time predictability could be determined through Equation 6.3 using the subjective valuation value of 7.75. It is this range that is presented for the good quality of service category in Table 6-17 and Figure 6-32.

The interpretation of these preliminary guidelines are only appropriate within the bounds of the observed range of predictability, in the context of a roadway setting similar to that of the urban arterial used in this research.

An interpretative example of the preliminary serviceability guidelines in Table 6-17 and Figure 6-32 would be that a travel time predictability underestimate of 20 percent (-0.20) would fall within the tolerable range of perceived service quality at a subjective valuation of about 6.5. Similarly an overestimate of 5 percent (0.05) would fall within the good range of perceived service quality at a subjective valuation in excess of 8.0.

A comparison between the traditional LOS criteria (11) as described by average travel speed and the preliminary serviceability guidelines presented in this section is

illustrated in Figure 6-33. As in Section 5.5, this comparison illustrates the two dimensional interpretation of traffic performance, which includes traffic movement effectiveness and quality of service. The scatterplot of Figure 6-19 provides the backdrop for the service overlays. The traditional average speed criteria extracted from Table 2-2 (11) is described along on the x axis, with the LOS ranges bounded by the dashed vertical lines. The travel time predictability basis of this research is described along the y axis, with the quality of service ranges bounded by the solid horizontal lines.

Disparities similar to those found in the rural highway setting are evident in the urban arterial setting. Of note are the number of observations which would fall into the traditional LOS A category, that are characterized by drivers as being only borderline poor to tolerable, on the basis of the findings of this research. The inference of this comparison is that the preliminary urban arterial serviceability guidelines provide more realistic descriptions of driver serviceability than the traditional LOS criteria.

The rural highway and urban arterial preliminary serviceability guidelines of Table 5-17 and 6-17, and Figures 5-28 and 6-32 were compared. The notable difference between the guidelines are the higher subjective valuation

Figure 6-33: LOS vs Quality Of Service

limits in the urban setting. This difference ranges from 0.5 to 1.0 on the subjective valuation scale. An interpretation of this difference could be that urban drivers are less tolerant of arriving late, as also evident in a lower bound of good service at an underestimate of two percent (-0.02) compared to the rural bound at nine percent (-0.09). Similarly, the urban drivers appear to be slightly less tolerant of overestimating actual travel time and arriving early, as evident in the lower urban bound of the tolerable range of service at nine percent (0.09) compared to the rural bound of eleven percent (0.11).

The relatively lower tolerance of travel time predictability in the urban arterial setting may be attributable to a number of reasons. Hypothetical interpretations of the different subjective valuation ranges of service quality in the context of travel time predictability include:

- i. That in the rural highway setting the drivers are generally not traveling the route daily, and therefore are not exposed to the same extent of random occurrences; which in the urban environment apparently decrease the drivers' acceptance range of travel time predictability.
- ii. That although the implications of poor travel time predictability on the longer rural links generally could equate to longer absolute travel times, that this is

more than offset by less stressful driving activity. The less stressful driving activity could for example be attributed to longer headways between vehicles, and significantly less stop and go traffic activity on the rural highway.

- iii. The greater sensitivity of the urban drivers may be a consequence of an increased potential for unforeseen travel disruptions to affect travel time predictions.
- iv. That subjective valuation may be related to trip purpose. As previously noted the rural trip observations were concurrent to work related trips, compared to the urban trip observations which were solely research driven.

Chapter 7

Discussion Of The Travel Time Predictability Perspective

7.1 Overview

The travel time predictability perspective enables consistent and meaningful descriptions of driver quality of service perceptions. In the course of this research it has been determined that driver quality of service valuations are related to the driver's relative achievement of trip travel time predictability.

The findings that the underlying relationships among travel time predictability, subjective valuation and physiological baseline change (Factor 1) are statistically similar between the rural and urban settings, demonstrates that common serviceability processes underlie driver perception of quality of service. The inter-relationship of these processes is illustrated in the driver serviceability concept and travel time predictability perspective of Figures 3-1 and 3-2 respectively.

The similarities between the primary rural and urban models (Equations 5.9 and 6.3) relating quality of service to travel time predictability demonstrates that this perspective is both a common and an appropriate basis for modelling driver serviceability. However, the notable differences in quality of service ranges implies that the relative acceptability of travel time predictabil-

ity may be related to roadway setting. Consequently, the determination of serviceability ranges corresponding to roadway setting as characterized by functional classification (76) may be appropriate. In this regard, this research presents preliminary serviceability guidelines for both the two lane rural highway and urban arterial settings in Sections 5.5 and 6.5 respectively.

The findings of this extension to the urban arterial setting confirms the research thesis that driver serviceability can be consistently modelled through descriptions of the quality of service relationships underlying trip experience. Further that serviceability effectiveness ranges associated with these relationships can be developed on the basis of the modelling.

The combined relationship of travel time predictability, physiological baseline change and subjective valuation does not appear to have a further role in the development of this serviceability approach. The primary relationship (as described in Equations 5.9 and 6.3) is more practical as it's application requires neither the time consuming collection or interpretation of physiological data.

The wider scale application of this modelling approach will require that the database be broadened to include a wider cross section of drivers, background and environmental conditions, roadway settings, and trip purposes.

The driver serviceability modelling approach and the

derived preliminary serviceability guidelines developed through this research begin to address a shortcoming in current traffic performance evaluations. These developments could contribute to traffic performance evaluations through realistically portraying the drivers' perception of quality of service. The travel time predictability perspective could likely be applied to the assessment of existing travel conditions experienced by drivers, and be extended to facility management. The facility management contribution would be through the enhancement of drivers' travel time predictability, and their consequent realization of the highest practical perception of quality of service.

7.2 Limitations

7.2.1 Overview

The modelling of driver serviceability through the travel time predictability perspective appears to be consistent between the research settings. However, future applications should confirm the similarity of the proposed setting before extending the findings of this research. These findings are more meaningful within the bounds of the surveyed conditions. The underlying relationships between travel time predictability and quality of service should be refined as necessary. These confirmations or refinements could be achieved through following the survey procedures and modelling methodology developed in the course of this

research.

7.2.2 Physiological Relationships

The physiological relationships determined in the course of this research should be interpreted in the context of the limited theoretical basis for the presence and evaluation of physiological baseline change. In this context, the secondary relationship between physiological baseline change (Factor 1) and the subjective valuation of service quality appears consistent between the rural and urban settings.

Any extension of the physiological stream of this research will necessarily require considerable investigation into the fundamentals of physiological baseline change as a consequence of a prolonged event, such as the trip experience used in this research.

The physiological baseline change observed in this research may also be a consequence of events beyond the trip experience. A possible event could be that the subject drivers were reacting to the end of the trip in itself. The noted baseline change would then be a consequence of the anticipated end of the trip, rather than the trip experience they have just completed. Similarly the subjects' end of trip anticipation could have included elements of a "white coat syndrome", in which a proportion of the observed physiological reactions are associated with the pending or actual monitoring.

7.2.3 Roadway Setting

Driver serviceability was modelled on the underlying relationships between travel time predictability, subjective quality of service valuation, and physiological baseline change on a rural two lane highway. The underlying model relationships were subsequently extended to an urban arterial setting, with different serviceability valuation ranges identified.

The notable difference between the rural and urban setting serviceability ranges may be a consequence of the nature of the trip and the greater peripheral activity in the urban arterial environment. This difference did not appear to have any direct effect on the underlying driver serviceability relationships.

On the basis of the observed differences in serviceability valuation ranges between the roadway settings, it would not be unreasonable to expect that similar differences would be observed between other roadway classifications. Consequently each roadway classification may have characteristic serviceability valuation ranges, as related to differences in the relative acceptance of travel time predictability. These potential differences should be explored to greater lengths in future research.

7.2.4 Trip Purpose

Travel time predictability tolerances may also be characteristic of the driver's trip purpose. For example the tolerance range of a trucker endeavouring to achieve a repetitive schedule, would intuitively be different than that of a tourist travelling the same route for the first time. Consequently, the affects of trip purpose should be investigated in the further development of driver service-ability guidelines.

7.2.5 Subject Base

The subject base for the modelling was limited to available subjects. Although the driving and route experience for the subject drivers demonstrated little apparent effect on the model relationships, the effects of a wider cross section of the general driving population should be explored. This cross section should include among others drivers that use a route often, and the elderly. Should notable differences be observed the model relationships should be enhanced to reflect the general driving population.

7.2.6 Background Conditions

The background conditions recorded included road surface and weather conditions. Road surface and weather conditions for the initial modelling in the rural setting covered a range of dry through wet, snow covered, to compact snow and ice, with corresponding weather conditions. Howev-

er the modelling in the urban setting was limited to dry road surface conditions by virtue of the favourable clear weather in Vancouver during the survey periods.

In the rural setting review of drivers' travel time predictability, it was noted that narrower predictability ranges were evident for the wet and light snow conditions than either dry, or compact snow and ice conditions. This may be attributable to drivers being able to more closely predict travel time due to a more limited range of potential enroute conditions, such as evident in a wet or light snow covered road surface. A greater range of potential enroute conditions would occur for example with dry surface conditions when there is more likelihood of road work, or for compact snow and ice conditions when greater than expected caution may be required.

7.3 Conceptual Applications

7.3.1 Overview

The modelling of driver serviceability through the travel time predictability perspective and the subsequent derivation of serviceability guidelines have potential application in traffic performance evaluations, and a role in the enhancement of the drivers' perception of quality of service.

The application of the travel time predictability perspective requires a general understanding of the underly-

ing equation, and knowledge of the travel time characteristics of the trip under consideration. Figure 7-1 presents a graphical representation of the travel time predictability relationship:

Travel Time Predictability =

$$\left[\frac{(\text{Estimated Travel Time} - \text{Actual Travel Time})}{\text{Actual Travel Time}} \right] \quad (5.1).$$

The travel time predictability perspective has the greatest practical application in that area of this graph which lies towards the centre of the curve. The stable relationship between travel time predictability and travel time in this area could enable predictability improvements, through drivers estimating travel time closer to the actual travel time. In the upper overestimate range very large increases in predictability will be a consequence of relatively small changes in actual travel time. Conversely in the lower underestimate range, very large changes in travel time will produce relatively small changes in travel time predictability. The instability of these outer ranges of the curve preclude further practical application in these areas. The observations of this research lie in the practical range of travel time predictability, towards the centre of the curve.

A hypothetical trip travel time distribution is superimposed on the travel time predictability versus actual

Figure 7-1: Conceptual Application of Travel Time Predictability

travel time curve. The average travel time of this distribution is aligned with the correct prediction of travel time, which is the point at which actual and estimated travel times are equal. The travel time predictability limits which bound the application range would be defined through setting a level of confidence range for the travel time distribution. This application range would be the focus of further developmental work for enhancing quality of service perceptions through travel time predictability improvements. If the initial application range does not fall within the good or tolerable serviceability ranges, remedial improvements or a lower level of confidence for travel time would be required to achieve an application range coincident with the desirable quality of service ranges.

Comprehensive evaluations of traffic performance require consideration of both the drivers' perception of quality of service addressed in this research, and the traditional traffic movement effectiveness criteria. The approaches should be viewed as complementary elements of a coordinated roadway management strategy. However as the respective theory and modelling address different approaches, care should be exercised in their application.

The sizing of a roadway should be based upon the traditional traffic movement effectiveness approaches, which relate to the relative efficiencies of traffic movement (11). However, the planning and programming of road-

way modification projects effectively gains an additional basis for the evaluation of traffic performance through the modelling of driver serviceability. The application of the travel time predictability perspective to common trip lengths and travel patterns could provide an overall corridor context for roadway modifications. Currently modification projects predicated on the basis of the traditional LOS criteria tend to be somewhat disjointed, due to different interpretations of traffic movement effectiveness for different roadway elements. The closest linkage to the traditional LOS criteria was found to be average travel speed, which shares the common basis of actual time with travel time predictability. This observation is consistent with the recent revision to Chapter 7 of the Highway Capacity Manual (11); which now uses speed rather than volume as the key predictor of level of service on multilane rural and suburban highways.

Potential improvements to drivers' perceptions of quality of service, through facilitating their travel time predictability, could be characterized as an example of the soft benefits to be realized in roadway management. Although these benefits differ from the hard benefits relating to increased traffic movement effectiveness, both are integral to a comprehensive roadway management approach.

The potential benefits associated with the driver

serviceability approach should feature more prominently in roadway management practices, as the prevalence of restricted funding increasingly limits the likelihood of major infrastructure modifications. The driver serviceability approach is not a panacea for avoiding dealing with traffic movement inefficiencies. Rather, the approach provides the means to realize improved quality of service from the drivers' perspective, while roadway modification projects await funding and construction programming. That is, facility expansion investments should only occur with traffic movement efficiency at issue, with due regard to the serviceability perception potential of drivers. The potential of greater driver quality of service perceptions through improved travel time predictability, may be realized for considerably less cost than roadway upgrading to increase vehicular traffic movement.

7.3.2 Design Applications

Conceptually the travel time predictability perspective has the potential for rationalizing the requirement and placement of passing lanes on two lane rural highways.

An illustrative example to put this role into context would be the evaluation of passing lane requirements for a two lane rural highway link 90 kilometres in length with a posted speed of 100 km/hr, and median peak period speeds of 92 km/hr and 80 km/hr for southbound and northbound traffic, respectively. The median speeds would be determined through

surveys of the overall link travel time. These speeds would reflect the effects of prevailing traffic volumes, geometric and terrain effects as related to the supply of passing opportunities.

The application of the travel time predictability value defining the underestimate boundary between Tolerable and Good quality of service of -0.09 (Table 5-17) to Equation 5.1 provides a basis for this evaluation. In this application the time associated with the posted speed is viewed as the estimated travel time and the median speed time is viewed as the actual travel time. The former would reflect an expectation drivers' may have, to travel at least at the posted speed. Equation 5.1 was rewritten through substituting speed into the equation:

Travel Time Predictability =

$$\left[\frac{(\text{Estimated Travel Time} - \text{Actual Travel Time})}{\text{Actual Travel Time}} \right] \quad (5.1)$$

in which:

$$\text{Travel Time} = \frac{\text{Trip Length}}{\text{Speed}} \quad (7.1)$$

becomes:

$$\text{Pred} = \frac{(v_m - v_p)}{v_p} \quad (7.2)$$

where:

Pred = travel time predictability

v_m = median surveyed travel speed

v_p = posted speed limit.

The evaluations to be done include:

i. Are passing lanes required?

Southbound -

$$\text{Pred} = \frac{(92 - 100)}{100} \quad (7.2)$$

$$\text{Pred} = -0.08$$

As this value is greater than the Tolerable-Good service boundary of -0.09, quality of service is not at issue and the provision of passing lanes to improve travel time predictability is not necessary.

Northbound -

$$\text{Pred} = \frac{(80 - 100)}{100} \quad (7.2)$$

$$\text{Pred} = -0.20$$

As this value is less than the Tolerable-Good service boundary of -0.09, quality of service is at issue. Travel time predictability improvements could address this deficiency.

ii. What is an appropriate spacing for the northbound passing lanes?

The speed equating to the Tolerable-Good service boundary of -0.09 through Equation (7.2) is 91 km/hr. This represents

the practical service speed to be achieved through the provision of passing lanes. Theoretically the achievement of the posted speed would require continuous passing opportunities (i.e. four laning) if the posted speed is not to be exceeded. Travel times for the 90 kilometre long link are 67.5 minutes for the 80 km/hr median surveyed speed and 59.3 minutes for the 91 km/hr service speed. Consequently, the provision of passing lanes must effect a trip time recovery of 8.2 minutes, which is the difference between the two travel times. A passing lane of recommended minimum length of 1.5 kilometres (11) has a travel time of 67.5 seconds at the median speed of 80 km/hr, and 54 seconds at the posted speed of 100 km/hr. The net effect is a time recovery per passing lane of 13.5 seconds. The number of passing lanes required for the link to achieve service speed of 91 km/hr would be the quotient of the required time recovery for the trip and the time recovery per passing lane, which is:

$$\text{Number Of Lanes} = \frac{(67.5 - 59.3)\text{minutes}}{(67.5 - 54.0)\text{seconds}} \quad (7.3)$$

$$\text{Number Of Lanes} = \frac{492 \text{ seconds}}{13.5 \text{ seconds}}$$

$$\text{Number Of Lanes} = 36.$$

The spacing of passing lanes uniformly throughout the 90 kilometre link would result in passing lanes spaced at 2.5 kilometre intervals. A spacing of 2.5 kilometres would

reflect the low median surveyed speed. In the supply of passing lanes other passing opportunities would be explored, such as ensuring that no passing zones are in fact warranted, and existing passing and climbing lanes are of adequate length. The latter refers to the effect of passing lane length in increasing the time recovery. For example a 2 kilometre long passing lane would decrease the required number of passing lanes to 27, at a spacing of approximately 3.5 kilometres. Construction costs and terrain limitations would result in longer passing lanes at greater intervals to the same effect as the determined spacing.

Another strategy to improve quality of service would be to facilitate the drivers' predictive ability through providing an appropriate expectation of speed. If the posted speed were dropped to 90 km/hr to reflect the prevailing operating conditions the number of passing lanes required drops to 14 at a spacing of approximately 6.5 kilometres. The calculations correspond to the previous example, through the substitution of a posted speed of 90 km/hr for 100 km/hr. The reduction in passing lane requirements from 36 to 14 would represent a considerable construction cost savings, and would therefore make this an attractive strategy.

7.3.3 Operational Applications

Operational applications refer to the improvement of drivers' travel time predictability through the enhancement of their predictive ability. Generally, improvements to the drivers' travel time predictive ability would be appropriate when perceived service quality drops to the unacceptable (poor) range. Quality of service perceptions would be improved through agency programs that would advance information collection, interpretation and dissemination procedures. The effectiveness of these programs would also require that drivers be educated as to the potential use and benefit of this information to them in their travels. Driver awareness of enroute conditions would enable them to make informed travel decisions and expectations. Although predictive ability enhancements would intuitively reach a practical limit, the continuing role of travel time information awareness would be to enable drivers to form realistic travel expectations. Drivers could use the travel time predictability perspective in decisions ranging from routing to residential location choices.

Passing lane construction on a section of rural two lane highway could also be deferred through operational betterments such as informative signing to increase and maintain drivers' travel time predictability and serviceability perception. An example of informative signing would be the consistent posting of the distance to the next pass-

ing lane. With reference to the rural two lane highway preliminary serviceability guidelines of Table 5-17, it may be interpreted that for borderline cases a five percent improvement in travel time predictability could decidedly influence a driver's perception towards the next higher valuation range. For a trip travel time of 90 minutes this would equate to a modest predictability improvement requirement of some five minutes. An improvement of this extent should be achievable through either increased access to route background and current enroute travel information, or increased passing opportunities to reduce unforeseen delay. From the driver serviceability approach, the cost of providing information to assist drivers has only to be less than that cost of prov'ding the additional passing opportunities to be the more cost effective solution. The cost of the latter can approach and exceed 500 to 750 thousand dollars per kilometre for the construction of a passing lane through rolling terrain.

A notable option for enhancing predictive ability is through the provision of more timely and informative travel information. Timeliness refers to real time information access to current or forecast conditions. Informative refers to the accessibility and quality of information. Examples would range from the in vehicle real time systems to the publication of road maps and brochures that present

navigation information useful for predicting travel time. The incremental cost for initiatives such as the development and publication of trip link travel times relative to travel period, would likely be low compared to most roadway agency operational budgets.

Travel information improvements would be implemented to increase driver awareness of travel conditions and the related implications for travel time. These could be based upon the monitoring of subject highway links to identify not only problem situations and prevailing conditions, but the corresponding travel time implications. The ideal for a driver travel time prediction information system would be an in vehicle real time process, which could access both recurrent background and current information. Recurrent background information would include such factors as congestion associated delays. The current information relating to temporary programmed and non-programmed situations would include the potential effects of construction or weather conditions, respectively. For example, programmed construction delay information could include the type of activity, the boundaries of the work, and the associated travel delays.

There are currently a number of demand management research initiatives and applications relating to the provision of roadway information to drivers. The application focus has been to increase traffic movement effectiveness

through the informed diversion of drivers. Research has shown that traffic diversion behaviour is influenced by the source of the information, expected delay, regular travel time, and alternate route awareness (88). Generally, driver concern over additional unexpected delay was found to be proportional to the expected delay (88). The extent and reliability of both initial and alternate route information was found to be crucial to diversion effectiveness (88). Lower reliability was attached to commercial radio reports than changeable message signing (88). Despite this concern, drivers were found to be more likely to make use of radio report information than to rely upon their immediate observations of delay (88). Although not specifically directed at driver serviceability, decreased congestion and more informed driver decisions stand to improve their travel time predictability and therefore quality of service.

The potential of intelligent vehicle highway systems using advanced real time information and communications systems to improve traffic utilization of roadways has been demonstrated (89,90). An application example is the Ministry of Transportation of Ontario development of the Traffic and Road Information System for the metropolitan Toronto area. This system will collect and distribute real time information to road users to assist them in avoiding traffic congestion through more informed travel decisions

(91). The travel time predictability perspective provides a basis for evaluating the effectiveness of these systems with respect to driver quality of service, through assessing their effect on travel time predictability. For example, expensive system improvements with a marginal effect on travel time predictability may not be an appropriate investment, in the context of an objective to improve driver quality of service.

Currently the British Columbia Ministry of Transportation and Highways (MoTH) has an information program to assist the traveling public. This program is similar to that provided in a number of other provinces. The service has both toll free telephone and a computer based online information access to a centralized road report database. Information is accessible on a 24 hour, province wide basis. The cornerstone of the information program is the consistent and timely reporting of route conditions by the maintenance contractors. This requirement for the scheduled reporting of information in a standard format contributes to the reliability of both the information and system operation.

These road reports include any expected delays due to weather or construction for primary highway corridors. Although the likelihood of delays is presented, the related extent of delay that a motorist could anticipate is not. It would seem that this limited approach could be somewhat

counter productive inasmuch as drivers are placed in a position of predicting a contingency for delays with very limited information. This would be contrary to travel time predictability, as evident in the finding that the closer a driver can predict the travel time outcome the greater will be their perception of service quality. Another system shortcoming is a concern over quality assurance and the timeliness of reports in the central database. Route planning benefits can only be fully realized with current and forecast roadway and weather conditions, particularly during major storms.

Information collection and dissemination procedures are being enhanced through more reliable media access to the database, cellular phone access, and the implementation of standardized local telephone numbers in the more heavily populated areas of the province. Improvements in media broadcasting of road conditions are viewed as key elements, particularly during storm and inclement weather periods. The cable television public information and weather channels, and local radio are seen as the primary means of conveying information to the driving public.

MoTH is also evaluating the potential of enhancing the overhead changeable message signing at key locations, to display enroute information. These would also aid the motorists' ability to predict travel time enroute, as well

as convey road condition information in the interests of safety. In conjunction with this initiative MoTH is evaluating the benefits and necessary procedures for having commercial drivers radio into local MoTH radio centres to provide real time information. This information would be used in the updating of message signing, provided to commercial television and radio, and available through the telephone and online information system. Low power transmitters may also have potential for conveying centrally updated route information in the proximity of a highway. These initiatives have the potential of facilitating travel time predictability through the provision of accurate, timely information; thereby increasing drivers' perceptions of quality of service.

Other MoTH initiatives include the review of the informational distance signing and the rationalization of speed zones.

The distance signing review includes the determination of most effective placement interval to provide motorists a basis for estimating link travel time. Similarly, the distance signing to passing lanes is being reviewed for consistency. For example the consistent posting of two kilometre advance notice of passing lanes would enable a driver to position themselves to make the most of the approaching passing opportunity. Further, advising the driver of the distance to the next passing lane, at the end

of a passing lane, would enable them to plan their interim travel strategy with respect to passing or following behaviour. Distance signing for common routes may also be complemented through a correspondence with map information and odometer settings. In this regard drivers zero their odometer at a sign advising of the route start, with map landmarks and further distance signing reported against the elapsed distance. Map information can also facilitate trip planning through reporting typical travel times corresponding to route segments and travel periods.

The rationalization of speed zones refers to the review of existing speed zones, primarily through settled areas, to ensure that speeds are appropriate to adjacent land use. It has been found that many of the existing zones are inappropriate, given past highway modifications and changes in adjacent land use and access. It is anticipated that a consistent approach to signing and speed zoning will facilitate driver's predictive ability, inasmuch as drivers would have a reasonable expectation of speed.

Similarly increased awareness of highway maintenance standards such as snow clearing response times would facilitate drivers forming more realistic predictions of travel time.

In all travel information enhancements it should be clearly recognized that the presentation of this information

should not detract from information needs relating to vehicle control. Consequently it would be most appropriate to concentrate efforts on improving travel time predictions in the pretrip planning stage, where the primacy of the other information needs are limited or nonexistent (92). Considerable research is necessary to increase the understanding of drivers information requirements and the processes to communicate that information to them (90).

7.3.4 Planning Application

The travel time predictability perspective may also have potential application in transportation planning trip distribution, modal split, and traffic assignment models based upon travel time (65,72). The application of travel time predictability in these models may enhance their descriptive ability through more realistically portraying driver choice behaviour.

A simplistic example could be an application to the Gravity Model (13):

$$T_{ij} = \frac{P_i A_j F_{ij} K_{ij}}{\sum (A_j F_{ij} K_{ij})} \quad (7.4)$$

4

PM-1 3 1/2"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

where:

T_{ij} = trip interchange from zone i to zone j

P_i = total trips produced in zone i

A_j = total trips attracted to zone j

F_{ij} = calibration factor for
trip interchange zone i to zone j

K_{ij} = socioeconomic adjustment factor for
trip interchange zone i to zone j.

The trip interchange between zones is a function of trip volumes in both zones and an inverse function of the time or distance separating them. The inverse function refers to the calibration factor of the form:

$$F_{ij} = \frac{1}{d_{ij}^2} \quad (7.5)$$

$$F_{ij} = \frac{1}{t_{ij}} \quad (7.6)$$

where:

d = distance between zone centroids

t = travel time between zone centroids.

The application of travel time predictability would be in the calibration factor in lieu of either time or distance between zones. The data for determining the travel time predictability for common routes between zones could be collected in conjunction with an Origin-Destination Survey. The data from a selected sub sample would require the travelers to note their expected and actual travel times over a given period.

The calibration factor would take the form of:

$$F_{ij} = f (\text{Travel Time Predictability}) \quad (7.7)$$

This calibration factor would result in the trip interchange value increasing as travel time predictability approached a correct prediction.

If travel time predictability were used to describe route reliability, and should route reliability feature as a consideration in trip interchange between zones, the management of travel time predictability could result in the selective redistribution of trips. These trips would then be expected to redistribute to the more reliable routes of greater travel time predictability.

Further research will be required to evaluate the potential of travel time predictability in this application and other transportation planning models.

Chapter 8

Conclusions And Recommendations

8.1 Conclusions

Increasingly restrained public funding will require more comprehensive traffic performance evaluations to aid the rationalization of roadway infrastructure supply. Traffic management should pursue a service balance between the traditional orientation of vehicular movement effectiveness, and driver serviceability. The effect would be the achievement of the most efficient use of existing facilities, in terms of both traffic movement and the drivers' perception of the experienced service. However, traditional traffic performance evaluations do not address driver quality of service perceptions of the trip experience.

The goal of this research, to facilitate the enhancement of traffic performance evaluations and roadway management applications, was achieved through the modelling of driver serviceability. Although driver serviceability and traffic movement effectiveness are distinct evaluative approaches, they provide a complementary basis for reporting traffic performance.

The two parallel research streams followed in the modelling of driver serviceability are illustrated in Figure 1-3. The final development stream features the primary driver serviceability relationship between the trip expe-

rience description of travel time predictability and the perceived quality of service. Travel time predictability provides a direct and practical basis for describing driver quality of service of the trip experience. This research stream was developed when it became evident that the initial concept relating physiological measures to perceptions of the trip experience had theoretical and practical limitations. As noted in the Introduction, the reader is cautioned that the findings associated with the initial concept should be viewed in the context of the very limited theoretical basis for evaluating physiological baseline change.

The primary driver serviceability relationship relates the trip experience description of travel time predictability to the perceived quality of service. Driver perception of the quality of service experienced for a trip can be consistently modelled through the travel time predictability perspective. Travel time predictability reflects the aggregate effects of trip background and enroute conditions.

The travel time predictability perspective was developed on the basis of a rural two lane highway setting and extended to an urban arterial setting. Quality of service can be described through a relationship between drivers' travel time predictability and subjective valuation. Drivers clearly frame their perceptions of service

quality relative to trip experience, as described by the extent to which travel time predictions are achieved. Drivers have the potential to make both knowledgeable travel time predictions, and rational quality of service descriptions and valuations.

The travel time predictability perspective realistically represents the driver serviceability process in the rural two lane highway and urban arterial settings, within the bounds of prevailing survey conditions. Although the key relationships can be consistently modelled, different subjective valuation ranges were evident between the settings. Drivers in the rural highway setting appear to be somewhat more accepting of lower predictability levels than those in the urban arterial setting. This may reflect that different roadway settings could be characterized by disparate travel and background conditions. For example, an urban arterial setting may generally be characterized by heightened driver awareness; perhaps due to the greater traffic conflict potential and peripheral activity.

Preliminary driver serviceability guidelines were derived from the modelling of the travel time predictability perspective, for both the rural two lane highway and urban arterial settings. Driver serviceability guidelines provide a basis for the maintenance or enhancement of drivers' perceived quality of service. Current and accurate

route information provides a basis for drivers to realistically frame their service expectations; and thereby realize the potential of higher service quality perceptions of the trip experience. The corollary being that the full service potential of a roadway, as related to drivers' perceptions, is not being realized if driver quality of service expectations are formed on the basis of incomplete knowledge of enroute travel conditions.

Driver serviceability can also be described through a less direct, secondary description of the trip experience through the combined relationships between travel time predictability, the primary driver stress correlate, and the subjective valuation of service quality. This parallel description in effect validates the presence of the primary relationship between driver's travel time predictability and subjective valuation of service quality.

It is possible to consistently record and evaluate relative physiological baseline changes associated with the trip experience. The physiological measures of galvanic skin response, and thoracic and abdominal respiration were monitored using a portable polygraph. The blood pressure and heart rate were monitored using a portable blood pressure monitor with pulse meter. The physiological baseline changes were gauged from the posttrip measures relative to the pretrip baseline levels.

An aggregate physiological baseline change factor can

be determined through factor analysis procedures. This factor can be related to the trip experience travel time predictability and subjective valuation of service quality. The relationships were found to be statistically significant for both the rural two lane highway and urban arterial settings. The similarities observed between the rural and urban settings supports the concept of there being common relationships underlying driver serviceability.

This research establishes a clear direction to follow in the pursuit of more effective traffic performance evaluations and management, through the inclusion of the driver serviceability approach. The driver serviceability approach provides a further basis for the rationalization of facility supply decisions. The traditional LOS theory and criteria continue to provide the necessary basis for describing and evaluating traffic movement effectiveness.

Extensions of this research could facilitate roadway agencies in enabling drivers to realize greater perceptions of service quality, through improving the drivers' travel time predictability. Potentially these travel time predictability improvements could be achieved through more timely and informative road and traffic condition reports. This additional service quality perception is a traffic management benefit to be realized from existing infrastructure, through accessing driver serviceability potential

heretofore largely untapped.

Future developmental work should build upon the driver serviceability modelling advances of this research. Extensions of the travel time predictability perspective would enable the application of the driver serviceability approach to other background conditions and roadway settings.

8.2 Recommendations For Future Research

8.2.1 Short Term Research Objectives

There is a definite need for advancing the modelling of driver serviceability, and the underlying travel time predictability perspective developed in the course of this research. These findings generate considerable further research potential.

Further research would not only reconfirm the modelling fundamentals through applications to other roadway classifications and background conditions, but would also explore the most effective means of applying the driver serviceability approach to facility evaluation and management applications. There is considerable public benefit to be achieved through facilitating drivers travel time predictability, and thereby having them realize greater perceptions of service quality. Although this applies to all roadways generally, the effect is likely to be more pronounced on urban facilities due to the greater number of drivers affected and

infrastructure costs. Further research should explore the effects of a wider cross section of the general driving population, as related to trip purpose, regional traits, sex, age, and driving experience.

Research should also determine the improvement potential of drivers' travel time predictability, as related to their perception of service quality. Complementary research should identify the key roadway conditions that affect travel time predictability, and evaluate the most practical and effective means through which drivers' predictive ability may be improved. This should include both the extent to which these improvements are necessary and the related identification of realistic improvement expectations. Improvement expectations would address the type and extent of information required by drivers, to develop travel time predictions that would achieve acceptable qualities of service. These findings would provide guidance for agencies in the development and implementation of enhanced travel information programs.

Further study should explore the relationships between the driver serviceability approach of this research, and the traditional traffic movement effectiveness approaches. This would go beyond the linkage used in this research between travel time predictability and average travel speed. This would take the form of both identifying and evaluating those traditional parameters that most affect

travel time predictability. An example may be the range of travel time predictability associated with a traffic flow range on a facility of particular type and characteristics.

8.2.2 Longer Term Research Objectives

In the longer term there may be benefit in applying the travel time predictability perspective to other transportation modes. Specifically, the finding that driver quality of service valuations are closely linked to travel time predictability, may form a basis for modelling user serviceability. Future research should address not only the mode specific extent to which quality of service valuations may be a function of travel time predictability, but also whether the relationship can be a general foundation for evaluating user serviceability. For example in a public transit or an air travel application, the enhancement of the users' perception of service quality may be realized through increasing their travel time predictability. This could potentially be achieved through improvements to the presentation of information enabling passengers to reliably estimate their processing and enroute times.

In a multiple link or multi mode trip it may also prove possible to differentiate between the effects of travel time predictability on discrete trip elements, for example the terminal access link versus the air travel link. This ability would aid in identifying those elements where modi-

fications could be made to best effect in addressing the users' perception of service quality.

Research should be pursued to determine if travel time predictability is appropriate for use in transportation planning trip distribution, modal split and traffic assignment models. In this regard, travel time predictability would be used to enhance the descriptive ability of those models largely based upon travel time.

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Abbreviations

AADT	- average annual daily traffic
AASHO	- American Association of State Highway Officials
AASHTO	- American Association of State Highway and Transportation Officials (formerly AASHO)
ARES	- abdominal respiration
BP	- blood pressure
DHV	- design hourly volume
ETA	- estimated time of arrival
F	- F statistic
FC1	- Factor 1
FC2	- Factor 2
FC1B	- balanced Factor 1
FC2B	- balanced Factor 2
GSR	- galvanic skin response (galvanic skin reflexes) (or electrodermal response (EDR), or electrodermal skin response (ESR), or skin conductance response (SCR))
HR	- heart rate
ITE	- Institute of Transportation Engineers
km	- kilometres
km/h	- kilometres per hour
LOS	- Level Of Service
MoTH	- British Columbia Ministry of Transportation and Highways
phf	- peak hour factor
Pred	- travel time predictability
R	- coefficient of correlation

- R^2 - coefficient of determination
- RAU## - Rural Arterial Undivided, design speed of ## km/h
- RCI - Ride Comfort Index
- SDI - Surface Distress Index
- SPSS - Statistical Package for the Social Sciences
(or SPSS/PC+)
- Subj - subjective valuation
- TAC - Transportation Association of Canada
(formerly Roads and Transportation Association
of Canada (RTAC))
- TRB - Transportation Research Board
(formerly Highway Research Board (HRB))
- TRES - thoracic respiration
- TSM - Transportation System Management
- UAU## - Urban Arterial Undivided, design speed of ## km/h
- v/c - volume to capacity ratio

Nomenclature

AADT	- average annual daily traffic
C	- capacity (passenger cars per hour)
d	- Durbin-Watson statistic
DHV	- two way design hourly volume
e_t	- residual (difference between the observed and predicted dependent value) in time period t
e_{t-1}	- residual in time period (t - 1)
E	- allowable parameter error
E_t	- truck equivalents factor
F	- physical measurements of pavement distress
F	- F statistic
f_d	- adjustment factor for directional distribution
f_e	- the expected number of observations in the same class
f_g	- adjustment factor grade effects
f_{HV}	- adjustment factor for heavy vehicles
f_o	- observed number of observations in a given class
f_w	- adjustment factor for restricted lane and shoulder widths
k	- adjustment factor
n	- sample size
N	- number of lanes
P_t	- percentage of trucks
R	- measures of pavement roughness
s	- sample standard deviation
SF_i	- total service flow rate in both directions for LOS i (vph)

SV	- service volume (vehicles per hour per hour per lane)
$t_{\alpha/2}$	- t standard deviations
T	- adjustment factor for trucks
T_c	- truck adjustment factor at capacity
T_1	- truck adjustment factor for LOS 1
v/c	- volume to capacity ratio
$(v/c)_i$	- ratio of flow rate to ideal capacity for LOS i
W	- adjustment factor for substandard lane width
u_1	- pretrip population mean
u_2	- posttrip population mean
$\bar{x}$	- sample mean
$z_{\alpha/2}$	- Z standard deviations
α	- measure of respiration baseline change
β	- measure of blood pressure baseline change
σ_1^2	- residual variance of polynomial of order j
σ_2^2	- residual variance of polynomial of order (j+1)
χ^2	- chi square statistic

Glossary

Artifact - the residual effects of the monitoring procedures on physiological measures.

Confounding - the collapsing or aggregating of the multiple input effects into the travel time predictability description of the trip experience.

Driver Serviceability - the drivers' gauging of the relative acceptability of the trip experience, as described by quality of service valuations. These subjective valuations include complementary characterizations of the experienced service, through a qualitative description and quantitative score.

Stress Response Correlates - the presence of stress can only be inferred from physiological measures.

Traffic Movement Effectiveness - operational measures that describe the relative effectiveness of traffic movement, including parameters such as speed, density, flow, or delay.

Travel Time Predictability - the relative extent to which trip travel time prediction is achieved.

Trip Experience - encompasses all events that the driver encounters that contribute to their awareness and knowledge. These events may be experienced through both direct observation and participation. An example of direct observation would be an awareness of the weather, scenery and informational signing not of immediate impact in the driving task. Examples of participation include the driver's

balancing of safety and capacity limits, and travel time predictability.

Trip Observation - the surveys and measures related to each trip, including the prediction and measurement of travel time, subjective valuation of service, the pretrip and posttrip physiological measurements, biographical information, and descriptions of enroute conditions.

Appendix A: Level Of Service Overview

Appendix A: Level Of Service Overview

Conceptually level of service is intended for use in the assessment of facility service quality as it relates to the users. Practically however the current traffic criteria relate primarily to the perspectives of the facility suppliers and operators.

Ideally, quality of service guidelines should quantify user perspective parameters relative to the prevailing roadway and traffic conditions (A1). These service parameters are generally considered to include factors of speed, travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, operating, and time costs. However in practice, level of service (LOS) criteria have evolved in terms of those concepts and factors that were meaningful to, and easily measured by practitioners. These generally included a volume to capacity measure related to speed for stable flow, and delay for forced flow. Generally speed has been considered as a primary factor as it has significant economic, safety, time, and service implications (A1).

Roadway level of service standards are in a process of continual evolution and refinement. Research has been directed in this regard from the 1930s to the present time (A1,A2). The basis of the current level of service criteria have largely been in place since the 1960s (A3). The pri-

mary references for evaluating level of service are the 1985 Highway Capacity Manual (A2) and the ITE Transportation and Traffic Engineering Handbook (A1). The 1985 Highway Capacity Manual has received world wide distribution, and as such provides a reference for traffic engineering and transportation planning throughout the world.

The current basis of LOS largely dates to the 1965 Highway Capacity Manual (A3) focus on speed and travel time as measures of effectiveness. These LOS criteria relate principally to stable flow conditions, as described by operating speed and a relative volume to capacity measure of congestion. The term congestion is used to describe a facility experiencing demand exceeding capacity. This relative imbalance results in increased delay and travel time, and the consequent reduction in operating speed.

The operating speed ranges and the corresponding traffic flow ranges describe the bounds of the service levels. These service ranges are further qualified by general maneuverability descriptions, and acceptability comments (A4). The LOS concept is illustrated in Figure A-1. As flow is relatively insensitive to speed over much of the upper stable range (A2), the question has arisen as to the appropriateness of speed as a LOS range definer (A5). The volume to capacity ratio as a relative measures of facility congestion facilitates the study of roadways of different capacities.

Figure A-1: General LOS Concept (A1)

Levels of service for highways describe six progressively deteriorating levels from A through F as a function of speed and flow. Level of service is conceptually a measure of the restrictive effects of increased volume upon maneuverability within the traffic stream. Table A-1 presents very general descriptions of LOS characteristics for different highway types (A4). The level of service descriptions apply to average operating conditions within the evaluated section of roadway. Evaluations are generally done with reference to the provision of service during critical demand periods. Generally LOS is usually only at issue during these peak demand periods.

The most evolved LOS guidelines relate to freeway and expressway uninterrupted flow applications; due to the emphasis placed upon the movement of traffic through these high volume facilities. A review of these guidelines provides considerable insight into the basis and application of traditional level of service. The freeway levels of service are presented in Table A-2 and illustrated in Figures A-2 and A-3 (A2). The service categories are described by boundary conditions of the maximum attainable speed related to the volume to capacity level. The corresponding service quality descriptions relating to the level of physical and psychological comfort are presented in Table A-3.

Table A-1: Level Of Service Descriptions (A4)

Level Service	Controlled Access Highways	Multilane Rural without Access Control	Two Lanes	Urban and Suburban Arterials
A	Free flow. Average travel speeds at or greater than 60 mph. Service flow rate of 700 passenger cars per hour per lane.	Average travel speed 57 mph or greater. Under ideal conditions, flow rate is limited to 700 passenger cars per lane per hour or 36 percent of capacity.	Average travel speeds of 50 mph or higher. Most passing maneuvers can be made with little or no delay. Under ideal conditions, a service flow rate of 420 passenger cars per hour, total two way, can be achieved.	Average travel speed of about 90 percent of free flow speed. Stopped delay at signalized intersections is minimal.
B	Reasonably free flow conditions. Average travel speed at greater than 57 mph. Service flow rate not greater than 1,100 passenger cars per hour per lane.	Reasonably free flow. Volume at which actions of preceding vehicle will have some influence on following vehicles. Flow rates will not exceed 54 percent of capacity of 1,100 passenger vehicles per lane per hour at a 53 mph average travel speed under ideal conditions.	Average travel speeds of 55 mph or higher. Flow rates may reach 27 percent of capacity with continuous passing sight distance. Flow rates of 750 passenger cars per hour, total two way, can be carried under ideal conditions.	Average travel speeds drop due to intersection delays and minor vehicular conflicts, but remain at 70 percent of free flow speed. Delay is not unreasonable.
C	Operation stable, but becoming more critical. Average travel speed of 54 mph, service flow at 77 percent of capacity or not more than flow rate of 1,550 passenger cars per hour per lane.	Stable flow to a flow rate not exceeding 71 percent of capacity of 1,400 passenger cars per lane per hour, under ideal conditions, maintaining at least a 50-mph average travel speed.	Flow still stable. Average travel speeds of 52 mph or above with total flow rate under ideal conditions equal to 43 percent of capacity with continuous passing sight distance of 1,200 passenger cars per hour total two way.	Stable operations. Longer queues at signals result in average travel speeds of about 50 percent of free flow speeds. Motorists will experience appreciable delay.

Table II-5. Level-of-service characteristics by highway type.

Level Service	Controlled Access Highways	Multilane Rural without Access Control	Two Lanes	Urban and Suburban Arterials
D	Lower speed range of stable flow. Operation approaches instability and is susceptible to changing conditions. Average travel speeds approx. 46 mph. Service flow rates at 93 percent of capacity. Flow rate cannot exceed 1,850 passenger cars per hour per lane.	Approaching unstable flow at flow rates up to 87 percent of capacity of 1,750 passenger cars per hour at an average travel speed of about 40 mph under ideal conditions.	Approaching unstable flow. Average travel speeds approximately 50 mph. Flow rates, two direction, at 60 percent of capacity with continuous passing opportunity, or 1,600 passenger cars per hour total two way under ideal conditions.	Approaching unstable flow. Average travel speeds drop to 40 percent of free flow speed. Delays at intersections may become critical.
E	Unstable flow. Average travel speeds of 30-35 mph. Flow rate at capacity of 2,000 passenger cars per hour per lane under ideal conditions. Traffic stream cannot dissipate even minor disruptions. Any incident may produce a serious breakdown.	Flow at 100 percent of capacity of 2,000 passenger cars per lane per hour under ideal conditions. Average travel speeds of about 30 mph.	Average travel speeds in neighborhood of 45 mph. Flow rate under ideal conditions total two way, equal to 2,000 passenger cars per hour. Level E may never be attained. Operation may go directly from Level D to Level F.	Average travel speeds 33 percent of free flow speed. Unstable flow. Continuous backup on approaches to intersections.
F	Forced flow. Freeway acts as a storage for vehicles backed up from downstream bottleneck. Average travel speeds range from near 30 mph to stop and go operation.	Forced flow, congested condition with widely varying volume characteristics. Average travel speeds of less than 30 mph.	Forced, congested flow with unpredictable characteristics. Operating speeds less than 45 mph.	Average travel speed between 25 and 33 percent of free flow speed. Vehicular backups and high approach delays at signalized intersections.

Table II-5. Level-of-service characteristics by highway type. (Cont.)

Table A-2: Freeway LOS Criteria (A2)

TABLE 3-1. LEVELS OF SERVICE FOR BASIC FREEWAY SECTIONS

LOS	DENSITY (PC/MI/LN)	70 MPH DESIGN SPEED			60 MPH DESIGN SPEED			50 MPH DESIGN SPEED		
		SPEED ^b (MPH)	v/c	MSF ^a (PCPHPL)	SPEED ^b (MPH)	v/c	MSF ^a (PCPHPL)	SPEED ^b (MPH)	v/c	MSF ^a (PCPHPL)
A	≤ 12	≥ 60	0.35	700	—	—	—	—	—	—
B	≤ 20	≥ 57	0.54	1,100	≥ 50	0.49	1,000	—	—	—
C	≤ 30	≥ 54	0.77	1,550	≥ 47	0.69	1,400	≥ 43	0.67	1,300
D	≤ 42	≥ 46	0.93	1,850	≥ 42	0.84	1,700	≥ 40	0.83	1,600
E	≤ 67	≥ 30	1.00	2,000	≥ 30	1.00	2,000	≥ 28	1.00	1,900
F	> 67	< 30	c	c	< 30	c	c	< 28	c	c

^a Maximum service flow rate per lane under ideal conditions.

^b Average travel speed.

^c Highly variable, unstable.

NOTE: All values of MSF Rounded to the nearest 50 pcph.

Figure A-2: Freeway LOS Criteria Relationships (A2)

• capacity
 •• v/c ratio based on 2000 pcphpl valid only for 60 and 70-MPH design speeds

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Thesis contains black & white
illustrations which when microfilmed
may lose their significance. The
hardcopy of the thesis is available
upon request from Carleton
University Library.

Figure A-3: Freeway LOS Illustrations (A2)

BASIC FREEWAY SEGMENTS

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Illustration 3-5 Level-of-service A.

Illustration 3-8 Level-of-service D

Illustration 3-6 Level-of-service B

Illustration 3-9 Level-of-service I

Illustration 3-7 Level-of-service C

Illustration 3-10 Level-of-service F

**Table A-3: Freeway Level Of Service
Quality Descriptions (A2)**

Level Of Service	Quality Description: Level Of Physical And Psychological Comfort
A	High
B	High
C	Noticeable Increase In Tension
D	Drastically Reduced
E	Extremely Poor
F	No Description Reported

However, these rather vague descriptions do not provide any basis for gauging the corresponding driver perception of quality of service.

A facility is sized or evaluated for service during particular peak demand periods. Evaluations, are as a matter of course, based on demand relative to capacity. The 1985 Highway Capacity Manual (A2) defines capacity as the maximum sustained 15 minute rate of flow, at which traffic can pass a point on a uniform segment under prevailing traffic and roadway conditions in a single direction. Traffic conditions refer to the amount and distribution of traffic on available lanes by direction. Roadway conditions refer to the type of facility, environment, the number and width of lanes, lateral clearance, design speed and alignment.

Capacity analysis (A2) is based on potential traffic under ideal conditions, and adjusted to reflect the prevailing conditions. Analyses procedures presume the presence

of good pavement and weather conditions, and no traffic incidents. Adjustments for these highly variable conditions are necessarily judgment calls. Adjustments are made if there is a substantial presence of heavy vehicles, whereby these are converted to passenger car equivalents. The operating characteristics of buses are similar to those of passenger cars under through flow conditions. The length of buses does however affect capacity through the pre-emption of usable road length. Large trucks have a more pronounced effect on capacity through limited weight to horsepower performance potential and longer lengths. This is of more concern on significant grades or in forced flow stop and go traffic conditions.

Traffic conditions refer to the demand volume, peaking characteristics, operating speed, and the composition of the traffic stream. Traffic demand volumes are referred to in terms of the average annual daily traffic (AADT) on a 24 hour basis, and as the design hourly volume (DHV). Within the peak design hour of demand, peaking characteristics are represented by the peak hour factor (phf). This factor is the ratio of the volume occurring during the peak hour to the maximum rate of flow during a given time period within that hour, adjusted to an hourly volume. The short term peaks within the hour represent the periods of greatest demand, which translate into higher hourly flows. The peak interval and peaking characteristics are a function of the

facility type and temporal demand. American experience has found that a five to six minute basis for the peak hour factor is appropriate for urban freeways and expressways (A1). The 1985 Highway Capacity Manual uses a fifteen minute basis for determining peak hour flow volumes (A2).

Roadway conditions refer to geometric aspects including grades, lane width, roadside obstructions, and average highway speed. Road grade will affect LOS through the differential speeding or slowing of traffic components, and the consequent impedance of faster vehicles in the traffic mix. The effect is a function of the grade length and magnitude, and vehicle performance potential. Adjustments can be made for narrow lanes or limited lateral clearance at road edges. Edge obstructions and narrow lanes increase driver caution causing the selection of relatively longer headways and slower speeds than otherwise warranted. In much the same manner poor weather or substandard visibility will also cause drivers to slow down and increase spacing. Currently researchers are investigating the effects of weather on traffic movement (A6).

A multilane facility such as a freeway will under ideal conditions have a capacity of about 2,000 passenger cars per lane per hour. The 1991 amendment to the Highway Capacity Manual (A7) will see this rise to 2200 passenger cars per lane per hour, based on observations that the 2000 capacity

is exceeded on a consistent and continuous basis. (A7)
Ideal conditions are however quite rare. The current general capacity equation for a roadway is:

$$C = (2,000)(N)(W)(T) \quad (A.1)$$

where:

C = the capacity (passenger cars per hour)

N = the number of lanes

W = the adjustment factor for substandard lane width

T = the adjustment factor for trucks.

The truck adjustment factor reflects the percentage of trucks present in the traffic stream, and gradient considerations through a truck equivalents factor. The truck factor can be expressed as:

$$T = \left[\frac{100}{[100 - P_t + (E_t)(P_t)]} \right] \quad (A.2)$$

where:

P_t = the percentage of trucks

E_t = the truck equivalents factor.

LOS criteria can also be used to determine service volumes. These are the volume of traffic a particular section of roadway can accommodate at a given LOS. This can be expressed for a given LOS as:

$$SV = (C)(v/c)(T_L/T_C) \quad (A.3)$$

where:

SV = the service volume (vehicles per hour per lane)

C = the capacity

v/c = the volume to capacity ratio for that LOS

T_1 = the truck adjustment factor for that LOS

T_C = the truck adjustment factor at capacity.

The adjustment factors, developed from empirical studies, are presented in References (A1,A2).

The volume to capacity ratio (v/c) is a relative measure of congestion, calculated as the design hourly volume divided by the adjusted capacity. The v/c ratio can be used in conjunction with the corresponding operating speed to evaluate the level of service through comparisons to LOS criteria, similar to that presented in Table A-2. When speeds are higher and the volume to capacity ratio lower than boundary conditions, traffic operations are greater than or equal to that level of service. As either boundary is degraded service will deteriorate to the next lower level.

Capacity can be further described as either at practical or ultimate levels. Practical capacity refers to a reasonable LOS in terms of delay and inconvenience, usually designated as LOS C for urban, LOS D for metropolitan, and LOS B for rural applications (A1,A2,A8). These differences imply that urban drivers have an expectation of lesser qualities of service during peak periods, than compared to the higher rural service quality expectations of uninterrupted flow. Ultimate capacity refers to impend-

ing breakdowns in flow beyond the ultimate ability of the facility to handle further flow demands due to saturation, at LOS E (A1,A2,A8). Ultimate capacity is also characterized by poor safety, maneuvering freedom, and speed selection. Ultimate capacity in Table A-2 and Figure A-2 would correspond to LOS E with a v/c ratio approaching 1.0 for level terrain, beyond which traffic conditions deteriorate to stop and go forced flow conditions.

In the past roadways were recommended to be designed at LOS C, and adequate to LOS E (A1,A2,A8). However, the determination of what are acceptable levels of service for a particular application are ultimately mandated by government. These mandates range from policy applications through codified service level ordinances. Examples of the latter include those of Florida (A9) and the Regional Municipality of Ottawa-Carleton (A10), both of which establish a basis for enforceable growth management policies through defining LOS D as the minimum level of service for weekday peak periods.

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Appendix B: Stress Overview

Appendix B: Stress Overview

Stress may be described as the nonspecific response of the body due to the exertions, strain, and effort of everyday living (B1). Stress can be the consequence of physical, psychological, or physiological factors. Stress as an inseparable part of our environment may be either productive or counterproductive (B1).

The description of stress requires information as to the probable source and its apparent effects (B2). Environmental conditions such as traffic induced stress fall within the category of physical stressors. Physiological stressors describing the body's fitness level, and psychological stressors related to social or emotional factors, are not of direct concern in this research.

Although all people experience stress, the coping mechanism and ability varies (B1). The stress load of an individual will depend upon the strategies they use to deal with the demands of a particular situation. Complications arise when unusual environmental demands result in excessive stress on a person's mind or body which disturb normal functioning (B1,B3). Excessive stress is considered to have harmful effects on the heart and body, as well as mental and emotional health (B4). People do not function at their best, or feel well, when they have been subjected to excessive stress (B5). The cumulative effects of stress can cause poor health and illness and contribute to diffi-

culties in the home and workplace (B5,B6).

Generally stress adaptation limitations are similar for people in a particular situation if they share a common cultural background, motivation and related experience (B7). Similarly people generally are considered to react in predictable behavioural ranges for similar stimuli sets (B8). The development of models in human factors research is based on the aggregation of observed human behavioural data into these predictable ranges. Illustrative examples include drivers tending to have similar responses in comparable traffic situations (B9), and peak period urban commuters having similar reactions to experienced service for a particular travel mode and corridor (B5).

Stress in humans, as in animals, is attributable to the initiation of flight or fight survival responses when subjected to threatening situations (B4). The particular combination of responses will depend on the circumstances and nature of the real or imagined threatening situation (B4). The presence of these response states can be inferred from generalized physiological response patterns and measurable physiological changes (B4,B7). The physiological response changes are correlates rather than direct measures of stress. Physiological responses can for example include changes in galvanic skin response, respiration, blood pressure, and heart rate, due to the production of expended

energy (B4,B10).

In a stressful situation environmental perception is heightened to increase the quality and quantity of incoming perceptual signals (B1). This enables the body to prepare a response appropriate to the situation. The initiation of coping reactions occurs through the stimulation of the hypothalamus for the nervous system, and the pituitary glands of the endocrine system (B1). These response centres are located in the brain, as shown in Figure B-1 (B11,B12).

A generalized overall perspective of the interaction of stress response systems is shown in Figure B-2 (B11,B12). The hormone release controlled by the response centres effects the nervous and endocrine systems (B11). These systems are control networks for the functioning of internal organs, external appendages, and activities including movement, perception, thoughts and emotion (B11). The respective systems interact in varying combinations as predicated by the situation (B11). Generally, in all but extreme stress situations, bodily function coping reactions occur at the subconscious level (B11). Perceived danger signals are automatically relayed from the brain through the nervous and endocrine systems to the rest of the body (B11). These biochemical transmissions activate coping mechanisms centred on increasing the rate of metabolism to provide reserve muscle energy, for physical exertion as necessary.

Figure B-1: Stress Response Centres (B11, B12)

Figure B-2: Stress Response Systems (B11,B12)

Basic mechanisms include increasing heart and respiration rates, blood pressure, blood sugar levels, and perspiration (B11). Physiological activation reactions will continue for a few minutes after the stimulus has been removed (B11). Repetitive stimulation can result in the adaptation of responses whereby responses diminish as the novelty of the situation wears off (B1). In long or intense stimulus applications or anticipatory periods physiological responses tend to exceed prestimulus levels (B1). This rebound mechanism is also subject to adaptation as dependent on the extent of repetitive stimulation (B1).

The nervous system consists of the central nervous system, composed of the brain, brain stem, and spinal cord; and the peripheral nervous system (B12). The peripheral nervous system consists of the autonomic and somatic nervous systems (B12).

The brain regulates and coordinates sensory impressions, emotional reactions, and voluntary and involuntary movements (B12). Nervous system messages are transmitted via simultaneous electrochemical processing, through trillions of neural connections (B12).

The autonomic nervous system, illustrated in Figure B-3 (B11), regulates the body's internal environment to suit the particular conditions. The autonomic system is further subdivided into sympathetic and parasympathetic components. These are complementary mechanisms, in that the stimulation

Figure B-3: Autonomic Nervous System (B11)

of one and the inhibition of the other have the same overall effects (B1). Basic subconscious physiological stress responses generally affected by autonomic control include heart, respiration, and perspiration rates (B1).

The somatic nervous system illustrated in Figure B-4 is the body's interface with the external environment (B12). The somatic system functions in the context of conscious thought processes. The brain selectively interprets sensory inputs and disregards all irrelevant data (B1).

Endocrine system transmissions are made through hormones released into the blood stream, in response to stress. Endocrine component locations are shown in Figure B-5. The adrenal gland initiates coping responses through the release of epinephrine and norepinephrine hormone into the blood stream, when the subconscious interprets a situation as dangerous (B1). The epinephrine released into the blood stream contributes to the elevation of blood pressure and increased heart rate through a narrowing of the blood vessels and dilation of coronary arteries improving, circulation (B1). Heart rate also increases due to the norepinephrine which stimulates heart nerves directly. The same hormone initiates damp hands and sweating (B1). The perspiration reaction to stress is produced in the sweat glands located in the upper epidermal layer (B1). Body temperature and emotions stimulate the eccrine glands into action. If the stress is of sufficient strength the apocrine glands

Figure B-4: Somatic Nervous System (B11)

Figure B-5: Endocrine System (B12)

contribute to the production of perspiration (B1). It is this reaction that people are usually familiar with as a product of anxiety and tension (B1). Cold sweats for example are generally associated with very strong emotional reactions such as fear bordering on panic (B4).

The emotional reaction to stress is anxiety, which can be further described as being either state or trait related (B3).

State anxiety is characterized by transitory physiological response patterns occur concomitantly with discrete stimuli events (B3). The intensity and duration of the response patterns is dependent upon both the amount of stress and the corresponding extent to which the person interprets threat or danger (B3).

Trait anxiety is characterized by relatively stable physiological response patterns of longer lasting states of activation after an event (B1,B3). The patterns may be attributed to both event stimuli and pre-event stimulus conditions (B3).

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Appendix C: Serviceability Considerations

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Appendix C: Serviceability Considerations

C.1 Serviceability Inputs

C.1.1 Interviews

The initial task in the development of the driver serviceability model was to review the significant considerations that drivers' are apparently perceiving in their subjective quality of service valuations. This review followed a two step interview process including the general interviewing of an initial group, and the subsequent application of a serviceability questionnaire to a larger and broader group of drivers.

This approach was modeled on the Delphi approach (C1,C2) for reaching consensus among experts. That approach is structured to overcome the complications and impediments of face to face group interactions, through iterative independent review and input by the experts. The facilitator is responsible for distilling the input and maintaining the process until substantial consensus is achieved. In the pseudo Delphi approach of this application the researcher became the focus for pooling the experience and rationales of the initial interviewed group. The researcher subsequently applied the direction and focus gained from the general interviews to the development and application of the serviceability survey questionnaire. Consequently the end results of the process are in effect the collective

consensus of the interviewed and surveyed groups.

In the initial general interviews a group of 27 drivers was interviewed to identify likely serviceability considerations. Those interviewed included a cross section of professional and non professional drivers. Transportation engineers and planners, and members of the Regional Transportation Committees were represented in the interviewed group of drivers. These interviews were distilled to identify those factors that appeared to be fundamental considerations for drivers' references to, or gauging of service quality. The general questions used in the initial interviews are presented in Appendix C.2.

Early in the interview process it was found to be more productive to use an interactive approach. The interviewer read the respondent the questions, provided related explanations on request, and made notes of the interviewee's answers. The basic problem overcome through this approach was that of ensuring that the initial questioning did not overly dwell upon the traditional LOS concepts of traffic movement effectiveness. It was generally evident in the limited discussion pertaining to the traditional LOS traffic movement effectiveness criteria, such as flow and capacity, that people without a technical background in transportation planning or traffic engineering had great difficulty in grasping the related concepts. Consequently the interviewer would follow the subject's line of reason-

ing, to assist the person in identifying what their fundamental serviceability considerations appeared to be. An added benefit of the interactive questioning was the timely generation of responses. The interviews took an average of 30 minutes each to complete. The only minor problems encountered related to the scheduling of interviews.

During the interviews subjective service descriptions and valuations were discussed. The modelling of driver serviceability requires the assumption that drivers have the ability to make rational quality of service descriptions and valuations. Recent research related to the perception of operational service noted that subjective level of service categorizations may have to be restricted to three primary descriptions, as related to the limited ability of people to distinguish between more (C3). General characterizations by the interviewed drivers tended to support this observation, in that three levels were seen as being readily comprehensible, and six levels being too refined to be practically meaningful.

The interviewed drivers consistently identified two broad subjective valuation categories of acceptable and unacceptable service. There was a further breakdown noted by many in the acceptable range, between tolerable and good. Tolerable service was described as being mediocre, and falling between good and unacceptable service. Unacceptable

service was further characterized as being poor. Consequently the survey questionnaire of Appendix F.1 reflects the two broad categories of acceptable and unacceptable service; with further descriptions in the acceptable category of good or tolerable, and in the unacceptable category of also being poor.

Generally, other serviceability considerations noted included refinements of the background categories used. Typical examples of these included weather, road surface conditions and road maintenance. Other examples that were not used further in this research included aesthetics and driver courtesy.

The serviceability considerations identified in the initial interviews were further refined through the development and application of a serviceability questionnaire. The format of the serviceability questionnaire is presented in Appendix C.3. Drivers were requested to rate the identified serviceability considerations, on a scale from 0 (no importance) to 10 (much importance), as related to their perspective of roadway service.

The serviceability questionnaires were completed by 100 drivers. These included 50 questionnaires completed by professional drivers at the government weigh scales in Prince George and Quesnel. The balance of 50 questionnaires were completed by drivers stopping at the British Columbia Travel InfoCentres in Prince George and Quesnel. These

locations were selected as being more convenient for the drivers given that they had already committed to stopping. Having requested and received the voluntary participation of a driver, the questionnaires were handed to them for their completion as the researcher waited. The researcher on request provided any elaborations on the questionnaire content. The completed questionnaire was then returned to the researcher. The questionnaires took an average of five minutes each to complete. Those people that participated in the initial general interviews were not part of the subsequent application of this serviceability questionnaire.

An overview summary of the results is presented in Table C-1 and illustrated in Figure C-1. In Table C-1 the serviceability considerations are ranked from highest to lowest importance, on the basis of the average subjective scores. Figure C-1 shows these averages and illustrates the comparative subjective score ranges through the bar lengths.

Although the importance of the safety consideration appears to be seen as paramount to driving, safety is intuitively taken for granted by many Canadian or American drivers in using public roadways (C4). Should the potential of unsafe passage be a major consideration in undertaking a particular trip, it would be unlikely that the lower ranked serviceability considerations would feature in either the trip planning or gauging of the trip experience.

Figure C-1: Serviceability Considerations

Consequently in the development of the model the presence of safety was viewed as being a prerequisite to the occurrence of the driver serviceability process.

Table C-1:Serviceability Considerations	
Description	Average Score
Safety	9.6
Reliability	9.3
Travel Time	8.3
Comfort	6.4
Travel Cost	6.4
Convenience	6.2
Environmental	2.3
Other	0.6

The trip reliability consideration was a close second in rank. In the initial interviews, reliability was construed as the ability to predict the experiences of the trip. The success of their predictions were assessed relative to their expectations. These reliability expectations were found to largely overlap the third ranked travel time consideration, through the effects of unexpected occurrences on travel time. The lower ranked considerations of comfort, convenience and cost may also be reflected in the predominant reliability and travel time expectation. The background environmental consideration relating to such factors as weather and road surface conditions were also noted. These also have a direct linkage to travel time

expectations in that weather and road surface conditions have a direct and significant impact upon travel time.

The finding that travel reliability and time were key considerations of the drivers' perception of serviceability, given the prerequisite of safety, provided clear direction for the modelling of driver serviceability.

C.1.2 Valuation Scaling

Quality of service valuations also require the assumption of an appropriate continuous scale, to which drivers may gauge their experienced service. A continuous scale is appropriate as comfort and quality are viewed as a continuous dimension of experience (C3). The selection between an interval rating scale measuring equal increments, or an ordinal scale of comparative ranking is a common issue in opinion surveys (C5); as related to whether the scaled intervals are equal. As there can be no clear answer without the supporting data (C5), it was decided that an appropriate course of action to follow would be to collect and evaluate interval based data. In the event that the subjective valuation data demonstrated the necessary descriptive ability for modelling driver serviceability, the assumption and use of the interval scale would be validated.

Consequently in the surveys it was initially assumed, and later borne out, that drivers have the ability to perceive their quality of service through a consistent discrimination process to the nearest half point on a ten

point interval scale; and that they could differentiate between the three service category descriptions.

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C.2 Initial Interview Format

September 9, 1990

Section A: Preamble

(To be read to the subject prior to the interview.)

Thank you for your participation in this study.

The Ministry of Transportation and Highways considers that an appropriate level of service must be provided to highway users.

In this regard a study has been initiated to ensure that driver level of service is being accurately represented. The process being followed in the initial stage of the study is to solicit input from users. These users include a cross section of both professional and non professional drivers.

Section B: The Driver

1. How many years have you been a licensed driver? _____
2. Have you ever driven professionally? _____
Type eg: truck, taxi _____
Years: _____
3. How many kilometres would you drive in an average year?
4. What percentage of these would be on:
rural highways _____
rural non highway _____
urban highways _____
urban non highway _____

Section C: Level of Service

5. How do you assess the level of service that a roadway provides? (Generally, how would you describe roadway service that you experience?)

6. How to you predict your travel time? (Examples could include past experience or performance, and radio road reports.)

7. Professional drivers - Do you perceive a difference in how you perceive serviceability when driving professionally (business) as opposed to on your own (nonbusiness or recreational)?

8. All drivers - Do you perceive a difference in how you perceive serviceability as related to different trip purposes? (For example work versus recreational trips).

9. Please provide any further comments that will assist our work on driver level of service.

Thank you for your time and consideration.

C.3 Serviceability Questionnaire

September 23, 1990

Section A: Preamble

The Ministry of Transportation and Highways is undertaking research related to the perception of level of service by drivers on our highways. The purpose is to aid in properly evaluating facilities with a view to providing the best service possible.

Further to discussions with the Regional Transportation Committees, the following were identified as significant considerations in DRIVERS' perception of highway level of service.

I ask that you give me the benefit of your view of this outline, with reference to your last trip on a two lane rural highway, by rating the importance of the described criteria, between 0 and 10. 0 relates to no importance, 1 to little importance, and 10 to much importance. An example of a related trip would be Highway 97 between Prince George and Quesnel.

DESCRIPTION	IMPORTANCE					
	NO					MUCH
Reliability	0	2	4	6	8	10
Comfort	0	2	4	6	8	10
Convenience	0	2	4	6	8	10
Safety	0	2	4	6	8	10
Travel Time	0	2	4	6	8	10
Cost	0	2	4	6	8	10
Environmental Impacts	0	2	4	6	8	10
Other						
_____	0	2	4	6	8	10
_____	0	2	4	6	8	10

Comments:

Appendix D: Pavement Serviceability Concept

Appendix D: Pavement Serviceability Concept

Pavement evaluations are based on a number of criteria including structural capacity, distress, riding comfort, and safety. The Canadian Ride Comfort Index (D1) and American Pavement Present Serviceability Concept (D2), as measures of riding comfort, provide an example of a user serviceability perspective in the modelling of driver serviceability.

The concept is that of describing the serviceability of the pavement in terms of a Ride Comfort Index (RCI) or Present Serviceability Index (PSI). Qualitative ratings of the pavements' surface condition by a panel of users are correlated with objective measures of roughness, cracking and rutting. This enables pavement serviceability evaluations through making comparatively rapid mechanical measurements and determining the correlated RCI or PSI, as opposed to having a panel rate each pavement section each time a serviceability evaluation is required. It is generally considered to be both impractical and expensive to evaluate serviceability using a rating panel, except on a very limited basis.

The PSI scale ranges from 0 at an impassable condition to 5 for near perfect conditions. Similarly the RCI is divided into five sections subjectively described as very poor through very good, with a corresponding 10 point scale. Generally neither extreme is encountered. The level of

acceptability is dependent in part on the intended use of the pavement. For example less roughness would be acceptable on high speed roadways.

The average of the panel ratings (PSR) were correlated with AASHO Road Test measurements of roughness, patching, and cracking. The general form of the service function is:

$$PSI = f(R, F) \quad (D.1)$$

where: PSI = Present Serviceability Index

R = measures of roughness

F = physical measurements of roughness,
cracking, and rutting (D2).

This serviceability concept has been successfully applied in pavement management systems (D2). In that application the concept enables the estimation of the remaining service life of the pavement, within reasonable limits. This serviceability concept has also been adopted directly into pavement design methods (D2).

Appendix D References

- D1. Roads and Transportation Association of Canada, Pavement Management Guide, Ottawa, 1977.
- D2. Yoder, E.J., Witczak, M.W., Principles Of Pavement Design, John Wiley and Sons, Toronto, 1975.

Appendix E: Rural Highway Database

E.1 Database E-2

E.2 Database Key E-5

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000
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Appendix E.2: Database Key - Rural Setting

1. Test No: Trip Observation Number
2. Date: Date Of Survey
3. Trip: Trip Coding (Origin/Destination)

From	Prince George	Hixon	To Quesnel	Williams Lake
Prince George	X	i	2	3
Hixon	4	X	5	-
Quesnel	7	8	X	9
Williams Lake	10	-	12	X

4. Physiological Response: GSR - Galvanic Skin Response
 ResTh - Respiration Thoracic
 ResAb - Respiration Abdominal
 HR - Heart Rate
 BP - Blood Pressure
5. Phys Score: FC1 - Factor 1 Score
 FC2 - Factor 2 Score
6. Predictability: TEs - Estimated Trip Time
 TAc - Actual Trip Time
 $\text{Score} = (\text{TEs} - \text{TAc}) / (\text{TAc})$
7. Avg Speed: Average Speed = $(\text{Trip Distance}) / (\text{Trip Time})$
8. Subj Score: Subjective Score 1 - 10
9. Subj Descr: Subjective Description
 - A.G. = Acceptable (Good)
 - A.T. = Acceptable (Tolerable)
 - U.P. = Unacceptable (Poor)
10. Environ: Environment
 - Wea (Predominate Weather Condition)
 - 1 = Clear
 - 2 = Rain
 - 3 = Sleet
 - 4 = Snow
 - 5 = Fog
 - Rd (Predominate Road Surface Condition)
 - 1 = Dry
 - 2 = Wet
 - 3 = Light (New) Snow
 - 4 = Compact (Old) Snow

11. Biographical: Sub - Subject Number
Sex - 1 = Male
 - 2 = Female
Age - To Nearest Year
DrE - Driving Experience (To Nearest Year)
RtE - Route Experience (Frequency)
 - One Way Trips In Previous Month,
 Either Direction

Appendix F: Survey Record Formats

F.1	Survey Questionnaire	F-2
F.2	Polygraph Tracing	F-7
F.3	Physiological Baseline Record	F-8

F.1 Survey Questionnaire

The following questionnaire was designed with regard to the information requirements and constraints of this research. The questionnaires were completed for each trip observation.

The monitoring of physiological responses was done at the trip origin and destination as soon as safely possible. The background and serviceability sections were completed immediately following the measurement of physiological responses.

The background and serviceability sections are presented as integral elements of the survey questionnaire. Provision was made for the recording of traffic, climatic, and any unusual enroute conditions reported by the driver or noted by the researcher. The background parameters and responses are related to corresponding serviceability, traffic, and baseline stress response data for further evaluation.

Carleton University
Department of Civil Engineering

Background and Serviceability Questionnaires

General Instructions

1. We are interested in the serviceability opinion of the subject driver only, so please do not discuss the traffic or test conditions, other than initial enquiries prior to the pretest physiological monitoring. DO NOT influence the driver's opinion in any way. BE OBJECTIVE.
2. Complete one survey form for each serviceability - stress observation.
3. Have all questions answered fully, and in order. Do not alter the questions.
4. Section A is to be completed before taking the initial physiological measures. It is essential that the subject has estimated trip parameters prior to the physiological measurements.
5. Section B is to be completed at the end of the trip, immediately following the measurement of physiological responses.

=====

Part A: Background Questionnaire

- To Be Done Prior To The Start Of Stress Test.

A.1 General

1. Test Number: _____
2. Date of Survey: _____
4. Surveyor: _____
5. Test Subject: _____

=====

A.2 Biographical

1. Sex: Male _____ Female _____
2. Age: _____ (to the nearest whole year)
3. Are you in good health? Yes _____, No _____
5. Are you subject to the following conditions?
Yes _____ No _____
 - a. High blood pressure _____
 - b. Excessive perspiration _____
6. Licensed Driver For: _____ (to the nearest whole year)
7. How often have you driven this test trip route in the last month? _____
8. How often have you driven this route under similar conditions within the last month? _____
9. Travel Purpose: Work Related _____
Non Work Related _____
10. Other Comments:

A.3 - Travel Time Information

1. Subject's Travel Time Estimate: _____ (to nearest minute)
- Note: Clearly indicate where the test location starts and terminates. It is critical that the subject be familiar with these. The subject can be informed of the link length if so asked.
2. Subject's method of Trip Travel Time Estimation:
- Calculated _____; Link length supplied Y _____; N _____
- Prior Knowledge _____
- Other (describe) _____

Part B: Level Of Service SurveyB.1 Enroute Information

1. Trip Origin/Destination: _____ ; _____
Observation Point Locations Origin - Destination: _____ ; _____
2. Trip Start Time _____
Trip End Time _____
Trip Total Time _____
3. Enroute Stops and Interruptions:
Description and extent of Delay(s)

4. Environmental: (predominate condition)
 - Weather _____
 - Road Surface _____
 - Other _____
5. Traffic Conditions: (predominate description)

6. General Description Of Unusual Conditions:

7. Other Comments: _____

B.2 - Level Of Service Rating Form

- 1.1 This trip from _____ (location of initial baseline measurements) to _____ (location of final measurements) would best be described as being:
- a. acceptable
 - b. unacceptable/poor (skip 1.2)
- 1.2 Having described the level of service as acceptable, the level of acceptability could best be further described as:
- a. good
 - b. tolerable
- 2.0 On a scale of 1 to 10, with 1 being the worst and 10 being the best, rate the level of service you experienced on this trip.
- _____ (to the nearest 0.5)
- 3.0 Do you (test subject) have any comments regarding the test or test procedures? (point form)

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Response Measures
 Oscillation - Average Wave Height
 Average Wave Length
 GSR tracing is not for single response period

Appendix G: Polygraph Manufacturer's Technical Brochure

★ ★ ★ UltraScribe AT International

Innovation to make it first—Quality to make it last!

**The People
Who Set
the Industry
Standard
Just
Raised It!**

ALL NEW FEATURES:

Now there's a polygraph so accurate and convenient to operate that it defines a new industry standard...and it's from the same company that set the standard: Stoelting.

The new advanced technology UltraScribe AT has all the reliability of Stoelting's legendary polygraphs—plus it is virtually effortless to operate, and produces incredibly superior tracings.

CLC Push Button/ Memory Re-Centering

Establish the Baseline—Pneumo, GSR, Cardio—you want in the same measurement on conventional instruments, and you need not ever touch the centering controls again.

Each time you turn on the instrument, it returns the pen to the desired baseline simply by pressing the CLC button. And, you don't have to manually re-center during a recording. If a pen reaches its excursion limit, just press the CLC button and the pen will instantly return to the Baseline you selected.

All Voltage/ Battery Operation

Exclusively from Stoelting, the UltraScribe AT International operates on any AC power, anywhere in the world—automatically!

Simply plug the UltraScribe AT International into any available power. Its field proven power supply automatically accommodates any voltage from 88 to 280 volts, either 50 or 60 Hz.

When AC power is not available, just switch to the optional, rechargeable, Battery Pack. Up to 18 hours of continuous operation is provided for instruments with four recording channels.

Advanced Technology Cardio

Stoelting's legendary mechanical cardios have been improved! State-of-the-art electronics combines the traditional subtleties of amplitude suppression and discrete notch shift with the greater convenience and sensitivity of electronic recording.

Optional Computer Compatibility

UltraScribe AT offers the future built in. Optional computer compatibility lets you start now to experience benefits of computer disk chart storage, being certain you can also utilize future computer assisted innovations.

Stoelting
SINCE 1886

☆☆☆ UltraScribe AT International...!

Stoelting's Design Philosophy: to Answer Your Needs

Stoelting's concept in engineering begins with your needs first. UltraScribe AT was not only designed to superbly record physiological reactions, but also be easy to use. This means making sure it is user-friendly...satisfying to own, trouble-free, effortless to maintain and operate day to day.

History Repeats Itself...

It's not surprising that the company that invented the electronic multi-function recording channel should be the one to take it to a breakthrough level of performance. By combining new technologies with the fundamentals of good polygraph design, Stoelting has again created the standard for the next generation of polygraphs. The tradition of quality and leadership continues.

Simply the Best!

UltraScribe AT...a polygraph whose overall integrity of design makes it demonstrably superior to any other. The result of Stoelting's total commitment to producing an instrument of uncompromising quality, it sets the standard of excellence for those who won't settle for less.

Advanced Technology Multi-Function

Engineered for Accurate Analysis of
Difficult Measurements

Suddenly, electronic polygraph recording has taken 3 giant strides:

1. **Unprecedented Convenience.** Push Button/Memory Re-Centering makes instrument operation virtually effortless. The ingenious CLC circuit (Patent Pending) eliminates one of the many tasks in conducting a polygraph examination. Now you are free to concentrate on subject observation, question timing and chart marking.

2. **Unprecedented Sensitivity.** Faithfully and accurately records even the most subtle physiological changes. Completely linear, there are no selective enhancement controls to distort the tracing and destroy chart credibility.

3. **Unprecedented Flexibility.** All polygraph parameters—Pneumo, GSR, and Cardio—can be recorded on all channels.

Recording channels with CLC Push Button/Memory Re-Centering are offered in 2 models:

• **Multifunction:** for recording Pneumo, Cardio, CAM plus GSR when used with the optional GSR Converter/No. 183360.

• **All Function:** for recording Pneumo, Cardio and GSR.

CLC Circuit Push Button/Memory Re-Centering

The CLC circuit (Pat. Pending) eliminates manual pen centering before each exam and re-centering during the test. But it does not alter or distort the physiological signal in any way.

You establish the baseline you want in the conventional manner. The CLC circuit remembers that baseline and each time the instrument is turned on. You simply press the push button to return the pen to the baseline you previously selected. If during the exam, a pen reaches its excursion limit, simply press the CLC button and the pen will instantly and precisely return to its original baseline.

There are no compromises or loss of flexibility with CLC Push Button/Memory Re-Centering. New baselines can be established as required and pens can be re-centered manually if needed.

Each recording channel has a built in CLC circuit so every polygraph parameter—Pneumo, Cardio, GSR, CAM—benefits from this remarkable innovation.

And CLC should not be confused with GSR "Auto" mode. All baseline information is preserved along with response amplitude, character and shape. Except for more precise, quicker re-centering, the tracing for every parameter is identical to what it would be without the CLC circuit.

Advanced Technology Cardio

Stoelting's new advanced technology cardio combine the legendary qualities of Stoelting's mechanical cardio modules with the convenience of electronic recording.

The traditional subtleties of amplitude suppression and diastolic notch shift associated with mechanical cardio tracings are faithfully repeated in the new AT Cardio.

It Simply Works Better!

Recording Channels

And, with Stoelting's exclusive linear design, the resulting chart is an exact, faithful reproduction of the subject's physiological reaction. There is no alteration or distortion resulting from "selective" enhancement controls found on other instruments.

Operating reliably at pressures as low as 30 mm Hg, its greater sensitivity permits reliable and comfortable examination of all subjects.

Advanced Technology CAM (Cardio Activity Monitor)

The patented CAM (Pat. No. 4,030,484) allows continuous monitoring of any person no matter how sensitive. It indicates both blood pressure and blood volume changes and like the Cardio, it also shows the diastolic notch. But since it is a more "active" measure, it provides clear indications of deception previously undetectable or too subtle to be seen in the Cardio tracing. And, since CAM is such an active module, CFC Push Button Re-Centering is particularly valuable.

Advanced Technology Pneumo

The solid state circuits produce recordings of superb fidelity from all subjects, heavy or shallow breathers, men or women. The sensitivity control permits optimum recording size for easier chart reading. Unreadably small recordings and bothersome repositioning of the pneumographs are eliminated.

Calibration Countermeasure Control

An exclusive "self test" feature provides quick, easy module calibration. All recording module electronics, including the pen motor, are checked for proper functioning by simply pressing a button. The built in test capability is also of significant value during an exam in determining whether "unusual" chart patterns are the result of countermeasures or of instrument malfunction.

Choice of 2 Inking Systems

Simply put, Stoelting offers you a choice of inking systems that eliminate all of the mess and inconvenience of traditional methods.

Ultrafine Pens—So ingenious they were awarded two U.S. Patents, (Pat Nos. 3,371,880 and 4,017,871). Ultrafine Pens are a complete self-contained inking system. The built in refillable reservoir holds enough ink for a line 2 miles long! Operation is automatic. No pen starting, draining or cleaning is ever required.

Surprisingly economical, they are available in your choice of 4 high visibility colors. And Ultrafine Pens are used with inexpensive, readily available, standard chart paper.

Capillary Pens—Unless otherwise specified, the UltraScribe AT is supplied with conventional capillary pens and ink bottles. Their special design insures clear free operation.

Automatic All Voltage/Battery Operation

Now, the superb UltraScribe AT International can be used anywhere in the world!

Exclusive Stoelting power supply automatically accommodates from 88 to 250 volts, either 50 or 60 Hz.

And if AC power is not available, the optional Battery Pack provides 18 hours of continuous operation for instruments with 4 electronic recording channels. A built-in gauge shows the charge level of the Ni-Cad batteries so unexpected loss of battery power is eliminated. And, since the instrument recharges through its built-in power supply, no separate charger is necessary.

Battery Packs available in 2 models:

1. Battery Module: The same shape and size as a recording module, it becomes the "fifth" channel. There is no loss of room for accessories, supplies and case files in UltraScribe's generous storage compartments. Fits all Standard size and Executive UltraScribe AT's and may be easily removed if desired.

2. Battery Pack: Fits securely in the chart paper storage compartment of all Standard size UltraScribe AT's. Is especially easy to remove.

Chart drive and instrument operation remains constant, with either AC or battery operation, regardless of voltage or frequency fluctuations.

Optional Computer Compatibility

UltraScribe AT offers the future built in. Optional computer compatibility lets you start now to experience benefits of computer disk chart storage. Being certain you can also utilize future computer assisted innovations.

Professional Accessories Group

Save 30% by purchasing accessories as a group. Individual accessories may be ordered separately either with instrument or subsequently.

- R3000 Professional Accessories Group**
Calibration Fixture, Stimulus Marker & CAM Transducer \$450.00
- R3002 Same as No. R3000 except fits Executive UltraScribes** \$450.00
- R0101 Professional Accessories Group**
Calibration Fixture and Stimulus Marker only \$195.00
- R3003 Same as No. R0101 except fits Executive UltraScribes** \$195.00

Stimulus Marker, Pneumatic
New, rent, inexpensive pneumatic stimulus marker. When ordered with UltraScribe it will be installed at top of chart, unless bottom is specified. It is available if ordered case only.

R3300 Stimulus Marker \$125.00

CAM Transducer
(Part No. 4030, 454) All Multifunction Channels contain built-in circuitry for the CAM. Only the CAM Transducer accessory must be ordered separately.

R0120 CAM Transducer \$450.00

Calibration Fixture

A low calibration check of all channels is an instant. When ordered with instrument, comes installed. If ordered later, can be installed by pneumatic means.

- R0070 Calibration Fixture, Std. Case** \$165.00
- R0075 Calibration Fixture, Exec. Case** \$165.00
- R0080 Calibration Fixture, Deck Top** \$165.00

Stoelting

1350 S. Kostner Avenue, Chicago, IL 60623-1156 U.S.A. (312) 522-4500

Ordering Guide

All instruments are furnished complete with catheter, pneumograph tubes, GSR mechanisms, pens and an extra roll of chart paper. UltraLine Pens (including 2 extra pens) may be substituted for conventional capillary pens at no extra cost. To specify instrument with UltraLine pens, add the letter "U" to the catalog number of the instrument being ordered.

The standard full size case measures 21 x 11 x 7 inches and provides 450 cubic inches of storage space for the optional calibration fixture, accessories and supplies. The Executive case measures 18 x 12 x 5 1/2 inches and has sufficient storage space to accommodate a built-in calibration fixture, attachments and roll of chart paper. Professional Accessories, listed at left, should be ordered separately, if desired.

Instruments with 10 inch chart or Thermal Pens are not available in the Executive Case.

ALL ELECTRONIC

4 Recording Channels

- R0409 UltraScribe AT International Standard Case 8 inch chart** \$4,650.00
- 1 CLC Multifunction Pneumo/CAM 1 CLC GSR
- 1 CLC Allfunction Pneumo, Cardio, GSR 1 CLC Multifunction Cardio/CAM

- R1409 Executive UltraScribe AT International, same as No. R0409 except in Attache Case** \$4,650.00

5 Recording Channels

- R0509 UltraScribe AT International Standard Case 8 inch chart** \$5,425.00
- 2 CLC Multifunction Pneumo/CAM 1 CLC Allfunction Cardio/GSR
- 1 CLC GSR 1 CLC Multifunction Cardio/CAM

- R1509 Executive UltraScribe AT International, same as No. R0509 except in Attache Case** \$5,425.00

- R0509-10 UltraScribe AT International, same as No. R0509 except with 10 inch chart** \$5,795.00

6 Recording Channels

- R0609-10 UltraScribe AT International Standard Case 10 inch chart** \$6,600.00
- 3 CLC Multifunction Pneumo/Movement Chart 1 CLC Allfunction Cardio/GSR
- 1 CLC GSR 1 CLC Multifunction Cardio/CAM

ELECTRONIC AND MECHANICAL

- R0449 UltraScribe AT International, Standard Case 8 inch chart** \$3,825.00
- 2 Mechanical Pneumo 1 CLC Multifunction Cardio/CAM
- 1 CLC GSR

- R1449 Executive UltraScribe AT International, same as No. R0449 except in Attache Case** \$3,825.00

- R0469 UltraScribe AT International Standard Case 8 inch Chart** \$4,125.00
- 1 Mechanical Pneumo 1 CLC GSR
- 1 CLC Allfunction Pneumo/GSR 1 CLC Multifunction Cardio/CAM

- R1469 Executive UltraScribe AT International, same as No. R0469 except in Attache Case** \$4,125.00

5 Recording Channels

- R0549 UltraScribe AT International Standard Case 8 inch Chart** \$4,775.00
- 1 Mechanical Pneumo 1 CLC GSR
- 1 CLC Allfunction Pneumo/GSR 1 Mechanical Cardio
- 1 CLC Multifunction Cardio/CAM

- R1549 Executive UltraScribe AT International, same as No. R0549 except in Attache Case** \$4,775.00

- R0549-10 Executive UltraScribe AT International, same as No. R0549 except with 10 inch Chart** \$5,125.00

ALL MECHANICAL

- R0489 UltraScribe AT International Standard Case 8 inch Chart** \$3,825.00
- 2 Mechanical Pneumo 1 Mechanical Cardio
- 1 CLC GSR

- R1489 Executive UltraScribe AT International, same as No. R0489 except in Attache Case** \$3,825.00

Re-Chargeable Ni-Cad Battery Packs

Both models provide up to 18 hours of continuous operation for instrument with 4 channels and 4 recording channels. The Ni-Cad batteries are automatically recharged when the instrument is plugged into any AC outlet.

- R3206 Battery Module Fits in any 4 channel UltraScribe AT as in Attache Case** \$475.00

- R3207 Battery Pack Fits any UltraScribe AT in Standard Case. Battery Pack is used in carrying case. Storage compartment for easy removal.** \$475.00

Specifications

Avoid unwanted limitations by using complete UltraScribe specifications.

Power: Instrument shall contain a universal power supply to operate from 100 to 240 volts, 50 or 60 Hz. Shall also accept a rechargeable Ni-Cad Battery for operation for up to 18 hours of instrument operation. The power switch shall have an indicator light.

Mechanical Cardio & Pneumo: Pen movement shall be free floating, non-loaded.

Electronic Recording Channels: Each channel shall have a built-in attenuator for gain control. It shall be capable of recording either 10 mm/sec. or 5 mm/sec. CAM or 10 mm/sec. or 5 mm/sec. GSR. The instrument shall not require removal of the channels or changing gain for the different recording modes. The instrument shall have a counterbalance control. There shall be no external connections for the channels.

Wide Trace GSR: Extended range of 6 to 10 mm/sec. Pen movement shall not exceed 15 mm/sec. The instrument shall have a full 5 inch tracing sweep. The only slow tracing shall be 1 mm/sec.

Inking System: Shall accommodate pens with a built-in reservoir for ink. The instrument shall have a 10,000 pen life.

Chart Drive: Shall be removable module with a built-in battery.

General: Instrument shall contain a modulator for pen movement. There shall be a built-in pilot light. A detachable power cord shall be provided.

Appendix H: Factor Analysis Application

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Appendix H: Factor Analysis Application

H.1 Overview

Factor analysis is a statistical technique that enables the measurement of complex characteristics, through aggregating a series of underlying related variables. The factor constructs of the aggregated series, effectively simplify a data set of correlated complex variables. The factors may be used as new variables in themselves for further analyses. The family of techniques were originally developed for psychological research data reduction, but are now routinely applied to a range of scientific applications (H1). -

The determination of these factors (H1,H2) is based upon the principal that correlated variables have an underlying common factor. The process is basically that of determining the intercorrelations of the directly measured variables for each trip observation, and then arranging highly intercorrelated variables into groups. A factor is a composite variable which underlies the variance in a set of variables. The effect is then to reduce the number of variables into a smaller number of factors. The resulting factor(s) in effect represents a cluster(s) of interrelated variables describing the complex characteristic(s) that are being investigated. The evaluation of the observed variables is then effectively simplified through the use of these general factor constructs as the research variables.

5 of/de 5

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

Factor analysis procedures include the indication of the number and descriptive ability of the distinct factors.

Computer software applications feature prominently in factor analysis due to the extensive data handling and calculation procedure requirements. The state of the art software used in this research was the Statistical Package for the Social Sciences (SPSS/PC+) (H2,H3).

H.2 Research Application

Factor analysis was used in this research to develop an aggregate measure of the physiological baseline changes. This construct was based upon the observed changes in the physiological variables of galvanic skin response (GSR), abdominal and thoracic respiration, blood pressure and heart rate between the beginning and end of the trip. Each of the physiological variables was monitored, measured, and evaluated in accordance with Sections 4.2 and 5.2 for the model development, and Sections 6.2 and 6.3 for the extension of the modelling. Factor analysis applications do not require that the input parameters follow normal distributions (H4). Consequently the physiological input parameters were not evaluated for normalcy.

The factor analysis process used in the development of the physiological baseline change factors is illustrated in Figure H-1, and summarized in the following discussion.

The first step in factor analysis required the prepara-

tion of a correlation matrix for the observed physiological variable changes. These are presented in Tables H-1 and H-2 for the rural and urban databases respectively.

**Table H-1: Rural Database -
Correlation Matrix**

	GSR	ARES	TRES	HR	BP
GSR	1.00	0.55*	0.56*	0.71*	0.65*
ARES		1.00	0.93*	0.48*	0.46*
TRES			1.00	0.47*	0.44*
HR				1.00	0.85*
BP					1.00

* .05 One-Tailed Significance

GSR = GSR
 ARES = Abdominal Respiration
 TRES = Thoracic Respiration
 HR = Heart Rate
 BP = Blood Pressure

**Table H-2: Urban Database -
Correlation Matrix**

	GSR	ARES	TRES	HR	BP
GSR	1.00	0.50*	0.48*	0.67*	0.52*
ARES		1.00	0.95*	0.29	0.36
TRES			1.00	0.32	0.31
HR				1.00	0.71*
BP					1.00

* .05 One-Tailed Significance

GSR = GSR
 ARES = Abdominal Respiration
 TRES = Thoracic Respiration
 HR = Heart Rate
 BP = Blood Pressure

Figure H-1: Factor Analysis Research Application

The distinct factors were then extracted through the principal components procedure. Initially the factor which describes the maximum variance in all variables was calculated. Additional factors were then determined such that each subsequent factor could not be correlated with the preceding factors. These independent factors are referred to as being orthogonal.

In theory, the number of distinct factors is equal to the number of variables. Each subsequent factor will describe progressively smaller patterns of variation which the preceding, more descriptive factors failed to capture. Practically to realize the full effect of factor analysis data reduction, factor thresholds based on descriptive ability are defined. The eigenvalue statistic is used to define the factor thresholds and thereby the number of identified factors. The descriptive ability of a factor is described by the variable's eigenvalue divided by the number of variables. This quotient describes the amount of variance explained by that factor. A summary of the factors and eigenvalues are presented in Tables H-3 and H-4, for the rural and urban databases respectively. Generally the default eigenvalue cutoff is set at 1.00 in the SPSS software. This recognizes that a factor with an eigenvalue greater than or equal to 1.00 accounts for at least its proportional share of the original variance. In view of the rural Factor 2 having an eigenvalue of 0.99, it was felt

to be sufficiently close to the cutoff to merit inclusion in further analyses.

Table H-3: Rural Database - Factor Summary			
Factor	Eigenvalue	Percent of Variation	Cumulative Percent
1	3.443	68.9	68.9
2	0.985	19.7	88.6
3	0.359	7.2	95.7
4	0.143	2.9	98.6
5	0.070	1.4	100.0

Table H-4: Urban Database - Factor Summary			
Factor	Eigenvalue	Percent of Variation	Cumulative Percent
1	3.044	60.9	60.9
2	1.215	24.3	85.2
3	0.457	9.1	94.3
4	0.240	4.8	99.2
5	0.044	0.9	100.0

Although the initial factor solution identifies the principal patterns of variation, distinctive variable clusters are not necessarily identified. Therefore, at this point in factor analysis there is an option for factor rotation which allows the correlation of factors. This rotation of the initial factors enables the identification of the distinctive variable clusters, necessary for determining factor scores. Consequently, as this research application required factor scoring of each trip observation, the rotation option was invoked. The oblique rotation procedure chosen enables a variable to both load more heavily

ly on the more strongly correlated factor, and yet remain a component of the lesser correlated factor. This relationship between the factors is evident in a correlation of 0.53 and 0.45 between the primary (Factor 1) and secondary (Factor 2) factors identified in the principal components analysis procedure, for the rural and urban settings respectively.

The communality statistics for the physiological change variables are presented Tables H-5 and H-6. This statistic describes the proportion of variable variance that is accounted for by the combination of all the factors. The balance not accounted for by the factor combination would be the difference between 1.00 and the communality value.

**Table H-5: Rural Database -
Variable Communality**

Variable	Communality
GSR	0.729
ARES	0.958
TRES	0.961
HR	0.905
BP	0.875
GSR = GSR	
ARES = Abdominal Respiration	
TRES = Thoracic Respiration	
HR = Heart Rate	
BP = Blood Pressure	

**Table H-6: Urban Database -
Variable Communalities**

Variable	Communality
GSR	0.705
ARES	0.969
TRES	0.964
HR	0.866
BP	0.755
GSR = GSR ARES = Abdominal Respiration TRES = Thoracic Respiration HR = Heart Rate BP = Blood Pressure	

The structure matrix presents the underlying variables correlation with the factor constructs. These are summarized in Tables H-7 and H-8 for the rural and urban settings respectively.

**Table H-7: Rural Database -
Structure Matrix**

Variable	Factor 1	Factor 2
GSR	0.807	0.583
ARES	0.428	0.979
TRES	0.427	0.981
HR	0.955	0.402
BP	0.945	0.325
GSR = GSR ARES = Abdominal Respiration TRES = Thoracic Respiration HR = Heart Rate BP = Blood Pressure		

**Table H-8: Urban Database -
Structure Matrix**

Variable	Factor 1	Factor 2
GSR	0.804	-0.542
ARES	0.403	-0.984
TRES	0.386	-0.982
HR	0.927	-0.299
BP	0.868	-0.310
GSR = GSR		
ARES = Abdominal Respiration		
TRES = Thoracic Respiration		
HR = Heart Rate		
BP = Blood Pressure		

The composition of the factors is also evident in the structure matrices. The GSR, heart rate, and blood pressure variables provide a comparably greater contribution to Factor 1, than the respiration variables. The reverse is apparent in the composition of Factor 2, in which the respiration variables provide the greater contribution.

The pattern matrix presents the regression coefficients of each variable for each factor, produced when the variable is regressed on the factors. These coefficients are affected by the intercorrelations among the factors. These are summarized in Tables H-9 and H-10 for the rural and urban settings respectively.

**Table H-9: Rural Database -
Pattern Matrix**

Variable	Factor 1	Factor 2
GSR	0.682	0.288
ARES	0.005	0.977
TRES	0.003	0.980
HR	0.961	-0.014
BP	0.994	-0.105
GSR = GSR		
ARES = Abdominal Respiration		
TRES = Thoracic Respiration		
HR = Heart Rate		
BP = Blood Pressure		

**Table H-10: Urban Database -
Pattern Matrix**

Variable	Factor 1	Factor 2
GSR	0.700	-0.263
ARES	0.013	-0.979
TRES	-0.006	-0.984
HR	0.960	0.083
BP	0.885	0.042
GSR = GSR		
ARES = Abdominal Respiration		
TRES = Thoracic Respiration		
HR = Heart Rate		
BP = Blood Pressure		

Having determined the distinct factors, factor scores were determined for each trip observation. These factor scores were calculated as the sum of the products of the respective physiological baseline change variable factor score coefficients and the observed variable values. The resulting factor scores for the physiological baseline

change factors were identified as physiological baseline change Factor 1 (FC1) and Factor 2 (FC2). The trip observation scores for these Factors are presented in Appendix E and I for the rural and urban settings, respectively.

For further information the reader is directed to References H1, H2, H3 and H4.

Appendix H References

- H1. Goddard, J., Kirby, A., An Introduction To Factor Analysis, University of Newcastle Upon Tyne, England, 1979.
- H2. Hedderston, J., SPSSx Made Simple, Wadsworth Publishing Company, Belmont, California, 1987.
- H3. Norusis, M.J., The SPSS Guide To Data Analysis, SPSS Incorporated, Chicago, 1987.
- H4. Harman, H., Modern Factor Analysis, The University of Chicago Press, Chicago, 1976.

Appendix I: Urban Arterial Database

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Time	Lat	Long	Alt	Temp	Hum	Wind	Dir	Speed	Pressure	Clouds	Vis	Remarks
1 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
2 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
3 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
4 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
5 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
6 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
7 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
8 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
9 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
10 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
11 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
12 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
13 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
14 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
15 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
16 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
17 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
18 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
19 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
20 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
21 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
22 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
23 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
24 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
25 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
26 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
27 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
28 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
29 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173
30 Apr 06:00	4 44	173 39	173	4.0	4.0	173	173	173	173	173	173	173

Appendix I.2: Database Key - Urban Setting

1. Test No: Trip Observation Number
2. Date: Date Of Survey
3. Trip: Trip Coding (Origin/Destination,

	To		
From	Broadway Ave.	Metrotown	West 10th Street
Broadway Ave.	X	1	2
West 10th St.	3	4	X

4. Physiological Response:
 - GSR - Galvanic Skin Response
 - ResTh - Respiration Thoracic
 - ResAb - Respiration Abdominal
 - HR - Heart Rate
 - BP - Blood Pressure
5. Phys Score:
 - FC1 - Factor 1 Score
 - FC2 - Factor 2 Score
6. Predictability:
 - TEs - Estimated Trip Time
 - TAc - Actual Trip Time
 - Score = $(TEs - TAc) / (TAc)$
7. Avg Speed: Average Speed = $(\text{Trip Distance}) / (\text{Trip Time})$
8. Subj Score: Subjective Score 1 - 10
9. Subj Descr: Subjective Description
 - A.G. = Acceptable (Good)
 - A.T. = Acceptable (Tolerable)
 - U.P. = Unacceptable (Poor)
10. Environ: Environment
 - Wea (Predominate Weather Condition)
 - 1 = Clear
 - 2 = Rain
 - 3 = Sleet
 - 4 = Snow
 - 5 = Fog
 - Rd (Predominate Road Surface Condition)
 - 1 = Dry
 - 2 = Wet
 - 3 = Light (New) Snow
 - 4 = Compact (Old) Snow

11. Biographical: Sub - Subject Number
Sex - 1 = Male
 - 2 = Female
Age - To Nearest Year
DrE - Driving Experience (To Nearest Year)
RtE - Route Experience (Frequency)
 - One Way Trips In Previous Month,
 Either Direction

END

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FIN

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Chapter 1

Introduction

1.1 Overview

The performance of roadway traffic depends not only upon the effectiveness of vehicular movement, but equally or perhaps more importantly the drivers' perceptions of the experienced quality of service. Both approaches should be integral elements in comprehensive traffic evaluations.

Comprehensive traffic evaluations are of particular importance in the prevailing economic climate, which will be increasingly characterized by major capital funding restraints. A comprehensive understanding of how a transportation facility's operation affects the users, as well as higher level societal benefit and cost considerations, is necessary to make the most effective application of the limited funding available.

Consequently, traffic performance evaluations should reflect not only the traditional vehicular movement effectiveness approaches, but also the driver serviceability* approach. This research addresses the latter through modelling driver trip experience perceptions. The driver serviceability approach refers to the drivers' gauging of the relative acceptability of the trip experience, as -----

* See Glossary for definitions of unusual terminology.

described by quality of service valuations. The trip experience encompasses all events that the driver encounters, through direct observation and participation.

1.2 A Major Need In Current Traffic Performance Evaluations

Traffic performance evaluations are fundamental to the rationalization of roadway infrastructure management and supply. The increasing need for comprehensive traffic evaluations can largely be attributed to the problems of unprecedented traffic growth, being compounded through restrained public funding.

However, a notable impediment to achieving comprehensive traffic performance evaluations is the absence of a well founded driver serviceability approach. Traffic performance evaluations without due consideration of automobile drivers' perceptions of quality of service are misleading, and could result in inappropriate facilities.

Mobility is the cornerstone of a region's economy as well as an indication of the quality of life it offers. However, the supporting transportation infrastructure to provide this mobility function is generally by nature and scope, an expensive draw upon public resources. Governments are increasingly faced with difficult choices in the balancing of limited funding against competing public service needs. Consequently transportation engineers will be pressured to arrive at innovative solutions to the grow-

ing dilemma of budget shortfalls while providing tolerable levels of service for the driving public. In view of a general trend towards decreasing roadway funding from all levels of government (1,2)*, the solution increasingly focuses upon concerns of just what tolerable levels of service are.

The increasing traffic congestion associated with the growing urbanization throughout the industrialized world, has been recognized as one of the central issues of the next decade (1,3,4). In 1983 55 percent of urban freeway travel and 40 percent of urban arterial travel occurred under congested conditions in the United States (5). The Transportation Research Board (4) has pointed out that improvements are necessary in the quality of service experienced by users, as well as the provision of additional facility capacity to address the congestion issue properly. Metropolitan and suburban congestion have been identified as one of the critical transportation problems facing users, the public, policy makers, transportation professionals, and safety organizations (1,6,7).

Urban traffic growth has been attributed to a combination of the rate of suburban development, increased automobile ownership and roadway construction (2). An example of urban traffic growth can be found in Vancouver, British

* See the listed references at the end of the thesis.

Columbia which has experienced annual average growth in inbound vehicular traffic of four percent per year between 1971 and 1990, despite current central business district transit usage of approximately 40 percent (8). Through the 1970s and 1980s the number of registered automobiles and licensed drivers doubled in Canada (2). The effect of increased automobile usage also impacts service on the rural primary highway network. For example, in British Columbia the main routes of this network experienced typical average annual traffic growth rates of three to seven percent between 1981 and 1989 (9,10) prompting public demands for roadway capacity modifications.

An informed roadway management decision requires the evaluation of roadway performance. Currently these evaluations include the traditional level of service (LOS)* criteria for vehicular traffic movement effectiveness (11), and pavement ride serviceability (12) through the gauging of the respective service provided. Roadway performance evaluations could be enhanced through the additional comprehension provided through the drivers' perspective of service quality.

Generalized roadway management relationships are presented in Figure 1-1. This figure illustrates the

* See Abbreviations listing for explanation.

Figure 1-1: Roadway Management Relationships

distinction in roles between the traditional traffic movement models and the currently lacking driver serviceability approach. The supply of roadway infrastructure should generally be based upon the comprehensive evaluation of three considerations. These considerations include economic and vehicular traffic movement effectiveness, and driver serviceability. The application of economic assessments, and the evaluation of traditional traffic movement effectiveness are both well developed in theory and routinely applied in practice. However, the driver serviceability approach although acknowledged as an important element of roadway performance, is neither well understood or realistically applied in practice.

The role of economic evaluations must continue to feature prominently in major facility expenditure decisions. These evaluations generally take the form of a social benefit - cost assessment of the economic effectiveness of a facility. These assessments would include not only directly associated construction, driver delay, and vehicle operating costs, but the extent to which the facility addresses social and economic requirements. An ineffective facility has the potential of becoming both a large and continual drain on public resources. This drain could include initial capital, ongoing life cycle maintenance and rehabilitation costs, and indirect incremental user costs.

Traffic management practice should also reflect the driver serviceability approach through the maintenance or enhancement of drivers' perceived quality of experienced service. This approach is consistent with the traditional roadway management objective of optimizing the roadway investment, through rehabilitation and maintenance programs. Traffic management should pursue a service balance between the traditional orientation of vehicular movement effectiveness, and the driver serviceability approach. The effect could be the achievement of the most efficient use of existing facilities, in terms of both traffic movement and the drivers' perception of the experienced service. This view fits within the Transportation System Management (TSM) philosophy. The potential practice would not be dissimilar to other TSM approaches to the management and maintenance of the existing system infrastructure through such activities as traffic management, demand management, or enhanced transit.

Transportation engineers now have a relatively thorough understanding of traffic movement level of service, through the ongoing evolution of the science of traffic movement (13). The traditional level of service approaches emphasize roadway and operational characteristics, such as speed, volume to capacity ratio, or delay (11). There is however a notable deficiency in current evaluations of traffic per-

formance through the lack of an objective description of the traffic effects on drivers. Quality of service criteria are generally nonexistent or only inferred through vague maneuverability or delay descriptions associated with traditional LOS criteria (11). Although these descriptions describe the traffic conditions that drivers may encounter, they do not reflect the driver's perception of the quality of the experienced service.

There is an acknowledged requirement for driver oriented quality of service measures to describe both traffic performance and tolerance to driving stress (14). Croft and Clark (15) note that "Research and traffic engineers have long recognized the need for methods of comparing the effects of various design options and traffic controls on the quality of traffic flow and levels of service in a qualitative manner." The American Association of State Highway and Transportation Officials (AASHTO) (16) in 1973 discussed establishing acceptable levels of congestion. These included an objective that operating conditions should provide a degree of freedom from driver tension. Driver tension was felt to be induced by driving task demands ranging from the frustration of slower moving traffic through the fear of high speed and high volume traffic.

1.3 Need For Modelling Driver Serviceability

In view of the missing driver serviceability approach it was recognized that the modelling of driver perceptions of the experienced quality of service was necessary.

The modelling of driver serviceability including the development of the underlying philosophy, rationale and approach, and the consequent serviceability guidelines have the potential of effectively enhancing roadway performance evaluations. The application of this approach will provide transportation engineers with the additional understanding of the quality of service experienced by drivers.

Although distinct, driver serviceability and traffic movement effectiveness approaches are complementary elements of effective roadway performance evaluations and management. Consequently the role of this driver serviceability modelling is to complement the traditional level of service approaches and criteria, not to replace them.

1.4 Problem Statement

1.4.1 Overview

The overall development and implementation of the driver serviceability approach will necessarily be both a long and involved program. The role of this research within that overall program is illustrated in Figure 1-2. This research covers the block titled "Modelling The Driver

**Figure 1-2: Driver Serviceability Approach
Developmental Overview**

Serviceability Approach". The future research would build upon the foundations herein, and lead to the implementation of the driver serviceability approach.

The modelling was developed and extended to a functional level to verify the existence and potential of the driver serviceability approach. The development of a consistent modelling methodology enables the standardized description of the serviceability processes underlying the trip experience.

The future verification and confirmation of the findings of this research would enable practical implementation of driver serviceability modelling and serviceability guidelines. The future research would both broaden and extend the underlying relationships between trip experience and quality of service. Those extensions should include other roadway classifications and background conditions, and potential facility management applications.

1.4.2 Goal

The goal of this research was to facilitate the enhancement of traffic performance evaluations and roadway management applications, through the modelling of the driver serviceability approach.

The thesis of this research is that the driver serviceability approach can be consistently modelled through descriptions of the quality of service relationships underlying trip experience. Further that serviceability effec-

tiveness ranges associated with these relationships can be developed on the basis of the modelling.

1.4.3 Objectives

The primary objectives of this research were to:

- i. Develop a modelling approach to realistically and consistently describe the drivers' perception of trip experience service quality.
- ii. Develop and demonstrate a practical basis for setting driver serviceability guidelines to complement current vehicular traffic movement effectiveness measures. This includes the development of driver serviceability descriptions that are both meaningful and usable by transportation engineers, and nontechnical people.

The supporting secondary objectives were to:

- i. Systematically identify and measure corresponding model input considerations including the drivers' description of the trip experience through their quality of service valuations and physiological correlates of stress; within the background context of the driver, roadway, environmental, and traffic characteristics.
- ii. Develop appropriate survey procedures for monitoring and evaluating drivers' physiological measures.
- iii. Develop interpretation and analysis procedures to enable the development of a functional model, and subsequent identification of preliminary serviceability ranges.

1.4.4 Scope

Driver serviceability was initially modelled on the basis of research on a rural two lane highway setting, and further extended through an urban arterial setting. Although the rationale and approach apply to driver serviceability generally, the particular findings are most relevant to automobile drivers and roadway settings similar to those used in the modelling.

The intent of this research is to develop and demonstrate the modelling of driver serviceability. The research is of sufficient depth to provide preliminary driver serviceability guidelines for both the rural two lane highway and urban arterial settings. However, the original and theoretical nature of this research requires that any further application of the driver serviceability fundamentals, or wide scale implementation of the driver serviceability guidelines, be a consequence of further developmental research.

1.5 Development Of The Thesis

There are two parallel streams of research in this thesis, as illustrated in Figure 1-3. The parallel streams include the initial research concept of linking physiological measures to quality of service perceptions, and the final research development stream describing driver quality of service through a relationship between travel time pre-

Figure 1-3: Thesis Development - Two Parallel Streams of Research

dictability and the subjective valuation of the trip experience.

The final research development stream was added as theoretical and practical problems became evident for the initial physiological concept. This final development stream was a consequence of a refocusing of trip experience relationships and the determination that travel time predictability was a more direct and practical basis for describing driver quality of service. Although the initial research concept was taken to a logical conclusion as a possible basis for further research, the reader is cautioned that the theoretical background and previous research applications for evaluating physiological baseline change are very limited.

1.6 Organization Of The Thesis

Chapter 2 presents a literature review of the pertinent background used as a foundation for this research. The review includes research and practice in vehicular level of service and driver stress.

Chapter 3 presents the formulation of the research problem. This includes a discussion of the driver serviceability philosophy, the preliminary identification of serviceability parameters, and a conceptual driver serviceability model. A review of the input requirements is also presented.

Chapter 4 presents the data collection process including the field survey protocol and a review of the subject base and survey locations.

Chapter 5 presents the development of the driver serviceability modelling process. The presentation includes the evaluation of serviceability parameters, the development and analyses of survey data, and the linkages underlying driver serviceability. Preliminary serviceability guidelines for a rural two lane highways are developed and presented.

Chapter 6 extends the driver serviceability modelling to an urban arterial setting. Preliminary serviceability guidelines for urban arterial streets are developed and presented.

Chapter 7 presents a discussion of the driver serviceability modelling. This includes a general review of the limitations, and the presentation of conceptual applications.

Chapter 8 presents a summary of results, conclusions and recommendations for future research on the modelling of driver serviceability.

The references, lists of abbreviations and nomenclature, and a glossary of unusual terminology are presented. Appendices covering supporting material are also presented for further reference.

Chapter 2

Background

2.1 Overview

Roadway facilities should be designed and evaluated with consideration of the impacts users will experience (14). Conceptually traffic level of service (LOS) is defined as a qualitative measure describing both operational conditions within a traffic stream, and their perception by motorists (11). The two elements of traffic performance should therefore include both descriptions of vehicular movement effectiveness, and that related to the drivers' perception of the quality of experienced service.

The traffic movement effectiveness element has received and continues to receive the attention it warrants. The drivers' perception of the trip experience has however been limited to generalizations that the less effective the movement of traffic, the lower will be the drivers' perception of service quality. The trip experience encompasses all events that the driver encounters that contribute to their awareness and knowledge. These events may be experienced through both direct observation and participation. The focus of this research is the redress of this limitation, through the development of a fundamental understanding of the driver serviceability approach.

This chapter presents a review of the pertinent background in roadway level of service and driver stress as a foundation for this research. Further related information is presented in the Appendix A and B overviews of the general fundamentals of traffic level of service and human stress, respectively.

2.2 Rural Two Lane Highway Level Of Service

The initial modelling of driver serviceability was based upon a rural two lane highway setting. Therefore a review of the traditional basis of level of service is necessary.

The three basic LOS criteria generally accepted for evaluating rural two lane highways are the average travel speed, percent time delay, and a measure of capacity utilization (11). The average travel speed is calculated through dividing the section length by the average vehicle travel time. A field measure of percent time delay is the percent of vehicles travelling at less than five second headways. Capacity utilization is calculated as the ratio of traffic flow demand to the capacity of the facility.

The capacity of rural two lane highways is difficult to determine due to the variety of local geometric characteristics. Further, Polus, Craus and Livneh (17) note that "this measurement is so sensitive that it may vary on the basis of traffic demand fluctuations, short variations in

speeds and traffic compositions and other random phenomena, such as weather. An hourly capacity is meaningful only if average conditions exist for an extended period during the peak hour".

The 1985 Highway Capacity Manual (11) level of service criteria are summarized in Table 2-1. The empirical relationships observed between two way traffic volume, speed and delay are presented in Figure 2-1.

The related rural two lane highway two-way service flows can be determined though the general equation:

$$SF_i = (2800)((v/c)_i)(f_d)(f_w)(f_g)(f_{HV}) \quad (2.1)$$

where:

- SF_i = total service flow rate in both directions, for prevailing roadway and traffic conditions, for LOS i, in vph
- $(v/c)_i$ = ratio of flow rate to ideal capacity for LOS i
- f_d = adjustment factor for directional distribution
- f_w = adjustment factor for restricted lane and shoulder widths
- f_g = adjustment factor grade effects
- f_{HV} = adjustment factor for heavy vehicles* (11).

The Transportation Association of Canada (TAC) (18) evaluated the applicability of the Highway Capacity Manual

* See Nomenclature listing for explanation summary.

**Table 2-1: Rural Two Lane Highway Level
Of Service Criteria (11)**

TABLE 8-1 LEVEL-OF-SERVICE CRITERIA FOR GENERAL TWO-LANE HIGHWAY SEGMENTS

LOS	PERCENT TIME DELAY	V/C RATIO ^a																				
		LEVEL TERRAIN						ROLLING TERRAIN						MOUNTAINOUS TERRAIN								
		AVG ^b SPEED	PERCENT NO PASSING ZONES					AVG ^b SPEED	PERCENT NO PASSING ZONES					AVG ^b SPEED	PERCENT NO PASSING ZONES							
			0	20	40	60	80		100	0	20	40	60		80	100	0	20	40	60	80	100
A	< 30	≥ 58	0.15	0.12	0.09	0.07	0.05	0.04	0.03	0.15	0.10	0.07	0.05	0.04	0.03	0.14	0.09	0.07	0.04	0.02	0.01	
B	≤ 45	≥ 55	0.27	0.24	0.21	0.19	0.17	0.16	0.15	0.26	0.23	0.19	0.17	0.15	0.13	0.25	0.20	0.16	0.13	0.12	0.10	
C	≤ 60	≥ 52	0.43	0.39	0.36	0.34	0.33	0.32	0.31	0.42	0.39	0.35	0.32	0.30	0.28	0.40	0.36	0.33	0.28	0.20	0.16	
D	≤ 75	≥ 50	0.64	0.62	0.60	0.59	0.58	0.57	0.56	0.62	0.57	0.52	0.48	0.46	0.43	0.58	0.50	0.45	0.40	0.37	0.33	
E	> 75	≥ 45	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.94	0.92	0.91	0.90	0.90	0.91	0.87	0.84	0.82	0.80	0.78	
F	≥ 100	< 45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

^a Ratio of flow rate to an ideal capacity of 2,800 vph in both directions

^b Average travel speed of all vehicles (in mph) for highways with design speed > 60 mph; for highways with lower design speeds, reduce speed by 4 mph for each 10-mph reduction in design speed below 60 mph; assumes that speed is not restricted to lower values by regulation

Figure 2-1: Rural Two Lane Highway LOS
Criteria Relationships (11)

Source: Highway Capacity Manual, 2000, Chapter 10, Exhibit 10-11, and Exhibit 10-12.

Notes: 1. The dashed line represents the relationship between speed and volume for a two-lane highway with a 12% grade.

(HCM) (11) LOS methodology and criteria to Canadian two lane highways. It was determined that the HCM model was "generally conservative in its platooning, speed and level of service predictions" (18). Consequently, TAC (18) recommends that the terrain (i.e. grade) adjustment factors not be used in computations (Equation 2.1) for use in delay and speed predictions (Figure 2-1) (18).

Traditionally the quality of service on roadways has been inferred from the quantitative LOS traffic movement effectiveness criteria. Research has indicated that drivers perception of serviceability is linked to their relative ability to pass slower moving vehicles, and thereby maintain the uninterrupted flow characterization of rural highway travel (16). In 1973 AASHTO recommended further research to determine whether it may be appropriate to relate percent time delayed to frustration level (16).

The 1985 Highway Capacity Manual (11) introduced percent time delay as a primary measure of effectiveness for rural two lane highways. Percent time delay is defined as "the average percent of time that all vehicles are delayed while traveling in platoons due to their inability to pass " (11). As percent time delay is difficult to measure directly, a surrogate field measure is the percent of vehicles travelling at headways less than five seconds (11). Yagar and Van Aerde (19) point out that percent time delay was

selected on the basis of it "being more sensitive to variation in flow rate than other candidate measures, such as vehicle speeds".

If passing opportunities are limited, drivers will perceive a lower quality of service than when an ample passing supply is available. Morrall and Werner (20) observed that "platoon travel, even at high speeds, results in a build up of driver frustration culminating in some cases with drivers making risky passes." They go on to note that "drivers perceive level of service as one's ability or inability to pass slower moving vehicles, and that ability to overtake is dependent upon the supply of sufficient gaps for passing in the opposing stream, provided sufficient sight distance is available or permitted as dictated by road geometry".(20) Consequently, the ratio of achieved to desired overtakings has been suggested as an additional measure of effectiveness (21,22). It has been observed that passing opportunities limited to 33 percent have a significant effect on drivers' delay tolerance as related to increased risk taking (23).

2.3 Urban Arterial Level Of Service

This research uses an urban arterial setting in an extension of the driver serviceability modelling. Therefore a review of the traditional bases of arterial level of service is appropriate at this time.

Arterials are signalized urban and suburban through routes, that provide varying degrees of access to abutting properties. The great extent of arterials are a product of rapid suburban growth and development over the last four decades. Arterials reflect the highly scattered nature of trip making and the near total dependence on private vehicles for suburban travel needs. The growth in arterial demand is expected to continue well into the next century (1). Arterial congestion delays are also increasingly a suburban problem on both the central business district radials and circumferential commuting routes.

The 1985 Highway Capacity Manual (11) presents the current theory and criteria for arterial level of service. Signalized intersection capacity is generally considered to be the key factor in all urban capacity considerations (24). Researchers and practitioners have encountered difficulties in associating LOS with volume in interrupted flow. Average travel speed has been viewed as a relatively insensitive measure of level of service, as evident in the limited speed changes in levels A through D (13,25,26). A potentially more sensitive operational criteria is thought to be a more direct measure of delay, such as a delay ratio, although this is not currently done in practice (11,13,27,28). The current LOS criteria do however include delay as a measure of effectiveness for signalized arterial

intersections (11,24).

The urban arterial environment is characterized by interrupted traffic flow operation, due to intersection delays, and nonrecurring incidents such as accidents, vehicle breakdowns, illegal parking, maintenance or construction work, alternate street closures, and emergency or special events. Interrupted traffic flow is therefore appropriately described by speed over an extended length of roadway (11,28). Arterial LOS is related to travel speeds as a reflection of the combined effect of midblock free flow, signal approach delays and driveway friction. The greater the difference between the actual average travel speed and the ideal average travel speed the lower is the level of service. The traditional arterial level of service criteria and associated general characteristics are presented in Tables 2-2, 2-3, 2-4, and 2-5.

The average travel speed criteria is calculated through dividing the extended length of an arterial street by the corresponding overall travel time. The single most important parameter is the average spacing of signalized intersections. The analyses of extended lengths of arterial streets reflect the cumulative delay impact of signalized intersections stops. Intersection delay aspects include considerations of effective green time, cycle length, quality of signal progression and presence of left turn bays.

Table 2-2: Arterial Level Of Criteria (11)			
ARTERIAL CLASS	I	II	III
Range of Free Flow Speeds (kph)	72 to 56	56 to 48	48 to 40
Typical Free Flow Speeds (kph)	64	53	43
LEVEL OF SERVICE	AVERAGE TRAVEL SPEED (kph)		
A	≥ 56	≥ 48	≥ 40
B	≥ 45	≥ 38	≥ 30
C	≥ 35	≥ 29	≥ 21
D	≥ 27	≥ 22	≥ 14
E	≥ 21	≥ 16	≥ 11
F	< 21	< 16	< 11

Table 2-3: Arterial LOS Characteristics (11)

LOS A describes primarily free flow operations at average travel speeds usually about 90 percent of the free flow speed for the arterial class. Vehicles are completely unimpeded in their ability to maneuver within the traffic stream. Stopped delay at signalized intersections is minimal.

LOS B represents reasonably unimpeded operations at average travel speeds usually about 70 percent of the free flow speed for the arterial class. The ability to maneuver within the traffic stream is only slightly restricted and stopped delays are not bothersome. Drivers are not subjected to appreciable tension.

LOS C represents stable operations. However, ability to maneuver and change lanes in midblock locations may be more restricted than in LOS B, and longer queues and/or adverse signal coordination may contribute to lower average travel speeds of about 50 percent of the average travel flow speed for the arterial class. Motorists will experience an appreciable tension while driving.

LOS D borders on a range in which small increases in flow may cause substantial increases in approach delay and hence decreases in arterial speed. This may be due to adverse signal progression, inappropriate signal timing, high volumes, or some combination of these. Average travel speeds are about 40 percent of free flow speed.

LOS E is characterized by significant approach delays and average travel delays and average travel speeds of one third the free flow speed or lower. Such operations are caused by some combination or adverse progression, high signal density, excessive queuing at critical intersections, and inappropriate signal timing.

LOS F characterizes arterial flow at extremely low speeds below one third to one quarter of the free flow speed. Intersection congestion is likely at critical signalized locations, with high approach delays resulting. Adverse progression is frequently a contributor to this condition.

Table 2-4: Arterial Classifications (11)

AN AID IN ESTABLISHING ARTERIAL CLASSIFICATION			
CRITERIA	FUNCTIONAL CATEGORY		
	PRINCIPAL ARTERIALS	MINOR ARTERIALS	
Mobility function	Very important	Important	
Access function	Very minor	Substantial	
Points connected	Freeways, important activity centers, major traffic generators	Principal arterials	
Predominant trips served	Relatively long trips between above points and through trips entering, leaving, and going through the city	Trips of moderate lengths within relatively small geographical areas	
CRITERIA	DESIGN CATEGORY		
	SUBURBAN DESIGN	INTERMEDIATE	URBAN DESIGN
Control of access	Partial to almost full	Partial	Little or no control
Arterial type	Multilane divided, undivided or two-lane with shoulders	Multilane divided or undivided; one-way, two-lane	Undivided one-way; two-way, two or more lanes
Parking	No parking	Some parking	Parking permitted
Separate left-turn lanes	Yes	Some	No
Signals per mile	1 to 4	4 to 8	8 to 12
Speed limits	40 to 45 mph	30 to 40 mph	25 to 35 mph
Pedestrian interference	None	None	Some
Roadside development	Low density	Moderate	High density

Table 2-5: Arterial Classes According To Their Function And Design Category (11)		
DESIGN CATEGORY	FUNCTIONAL CATEGORY	
	PRINCIPAL ARTERIAL	MINOR ARTERIAL
Typical Suburban Design	I	II
Intermediate Design	II	III
Typical Urban Design	III	III

Vehicle operation is also affected by the arterial environment and vehicle interaction. "The arterial environment includes the geometric characteristics of the facility and adjacent land uses. The number of lanes and lane width, type of median, access point density, and spacing between signalized intersections are among the environmental factors, as well as the existence of parking, level of pedestrian activity, speed limit, and population of the city."(11). Vehicle interaction is affected by traffic density, the proportion of trucks and buses, and turning movements. This interaction affects the operation of vehicles at intersections and, to a lesser extent, between signals.

Intersection approach and stopped delays are a reflection of the traffic signal effects as related to the intersection geometrics. These flow disruption delays have considerable effect on traffic movement and quality of service. Cumulative intersection delay for a given section can seriously impede the arterial's ability to move traffic effectively. Intersection approach delays include both stopped time, and acceleration and deceleration times. Signalized intersection saturation flow rate is approximately 1800 vehicles per hour of green time per lane (11). Signalized intersection LOS criteria have been developed and related to the average stopped delay per vehicle for a 15

minute analysis period. Signalized intersection LOS criteria are presented in Table 2-6. These delay ranges have not been qualified by driver subjective valuations (11).

Table 2-6: Level Of Service Criteria For Signalized Intersections (11)	
Level Of Service	Stopped Delay Per Vehicle (seconds)
A	≤ 5.0
B	5.1 to 15.0
C	15.1 to 25.0
D	25.1 to 40.0
E	40.1 to 60.0
F	> 60.0

The Canadian Capacity Guide For Signalized Intersections (24) identifies average intersection delay as a comparative measure for evaluating the effectiveness of a complete intersection. The guide defines average intersection delay as "the average waiting time which will be experienced by a passenger car unit approaching the intersection during the defined analysis period" (24). Threshold average approach delay values related to the relative acceptability of delays are summarized in Table 2-7. The threshold delay values of Table 2-7 which include both approach and stopped delay are not directly comparable to the average stopped delay criteria of Table 2-6, which exclude approach delays.

Table 2-7: Threshold Delay Value Descriptions (24)	
Average Delay (seconds)	Description
< 30	Acceptable Operation
30 to 60	Excessive Waiting Time
> 60	Usually Not Acceptable

The intersection delay criteria suggests that delay is characteristic of congested arterial operation. The use of intersection delay is consistent with the average travel speed criteria over extended lengths of roadway, in that delay is an integral element of travel time.

Environmental considerations influence the drivers' perception of safe speed. Under low flow conditions the average perceived safe speed would approximate the free flow speed. This will generally be close to the posted speed limit. The average running speed will generally be lower than the posted speed limits during high demand periods, due largely to intersection approach and stopped delays. The Highway Capacity Manual reports that drivers' will tolerate one LOS poorer for intersection effects, than on the through sections (11).

2.4 Deficiencies In Current Level Of Service Approach

A fundamental deficiency in the current approach to traffic performance evaluations is the inability to relate the drivers' trip experience to their perception of

service quality. The current LOS criteria do not provide a satisfactory basis for applications requiring an understanding of the qualitative relationship between the drivers' perceived service quality and the trip experience.

This is evident in the rural two lane highway LOS criteria (Table 2-1) of percent time delay and average travel speed which do not provide a basis to distinguish the quality of service experienced by drivers. The lack of a linkage to the relative frustration effects experienced by drivers, is particularly evident in platooning conditions (20). Similarly, the arterial level of service traffic movement effectiveness criteria presented in Table 2-2 gauged in terms of average travel speed, are only qualified by vague quality of service commentaries for LOS B and C (as underlined in Table 2-3).

The evaluation of traffic performance requires not only the traditional level of service measures, but also a basis for evaluating the drivers perception of the quality of service experienced on a trip. There are currently no professionally accepted methods of averaging or aggregating traditional levels of service within a travel corridor or for a typical trip (29). This deficiency has been attributed to the complexities of aggregating both the effects of roadway elements and different roadway functional classifications; due in part to differences in LOS evaluations (29).

The trip experience description advanced in this research may provide an overall context for the coordination of the traditional LOS evaluations.

The effectiveness of traffic performance evaluations could be enhanced through the inclusion of the driver serviceability approach. The understanding of relationships underlying driver serviceability would facilitate an integrated approach to traffic performance evaluations and roadway management. This would be achieved through the development of further traffic performance guidelines reflecting the drivers' perception of quality of service. The traditional LOS criteria would continue to feature in the key role of traffic movement effectiveness evaluations.

2.5 Driver Stress

2.5.1 Driver Stress Overview

In this research driver stress followed the general definition of being the adverse mental and physiological effects experienced by an enroute driver (30). Struggling through congested traffic, maneuvering in high speed traffic or coping with unforeseen travel delays make significant stress demands on the body (31). Excessive stress can overtax coping reserves, and thereby adversely affect performance, health, and the quality of life (31,32). Consequent-

ly, serviceability criteria reflecting the drivers' perspective will become increasingly appropriate.

A trip experience is characterized by driving situations. The driving task requires the driver's active observation of, and participation in the roadway environment. The driving situations encountered will contribute to both the driver's immediate awareness and longer term knowledge. Drivers generally react and adapt to most driving situations (33). Their behaviour reflects a dynamic balance between immediate safety risk and traffic pressure limits (34). The safety limit refers to actions that are hazardous in view of the prevailing situation, such as taking advantage of an inadequate passing opportunity. Conversely, the traffic pressure or capacity limit would be apparent in a driver not taking advantage of an adequate passing opportunity. The largely subconscious balancing actions between these limits vary depending upon the driver, the particular traffic situation, and the accepted social and traffic behavioural norms. Driver behaviour will range between those aggressive drivers pushing the limits of safety, to those defensive drivers hedging the capacity limit. An extreme imbalance would result in either a traffic accident at the safety limit, or ineffective traffic movement behaviour at the capacity limit. The driver's balancing ability will determine their relative success at

achieving immediate driving objectives, such as maintaining vehicle control.

The balancing action between the safety and capacity limits occurs in the presence of traffic movement constraints such as congestion limitations or unforeseen delays. Physiological reactions will be consequences of exposure to such stressors (31). Torres (35) describes stress as a psychological and physiological state associated with such considerations as uncertainty, greater concentration, and increased attention and readiness to combat the unexpected. These stress considerations would be elements of the balancing action between the safety and capacity limits. Elevated physiological arousal and negative emotional reactions have been associated with travel impedance (31,35). Furthermore, the stressful nature of driving on congested roadways or being subjected to unforeseen delays can have adverse impacts on health, psychological adjustment and driver performance (31,35).

Driving an automobile requires a combination of mental and physical skills commensurate to the corresponding task demand loads. The driving task can be characterized through control, guidance, and navigation activities (36). The control activity refers to the immediate vehicle-road interaction, through the manipulation of speed and direction. The guidance activity refers to remaining on the road

safely with reference to traffic control information and devices, and other traffic. The navigation activity refers to the enroute reference and processing of directional information to reach a destination.

The driver's perception of the roadway environment will be framed by travel expectations based upon their current observations of traffic conditions, the roadway, and environment, relative to both the immediate past and longer range experience, and cognitive abilities (37). The driver's perception of service quality can also be influenced by the comfort of the vehicle (37). However, drivers would be expected to experience similar physiological response changes to similar travel conditions (31).

2.5.2 Driver Stress Research

Research from the 1950s through early 1970s establishes a basis for the study of instantaneous physiological response correlates of driver stress (38,30). Research was directed primarily towards studying driving as an example of a complex task within the framework of experimental psychology, with limited application transfers to traffic engineering.

Hallmark driver stress research includes that of Michaels (39,40) in which he studied tension responses of drivers on urban streets and expressways, using galvanic skin reflexes (GSR). His early research (39) dealt with the

potential of using the magnitude and frequency of the GSR physiological response as a means of differentiating types of traffic interference and urban street characteristics. He observed that highest GSR tension responses were associated with actual or incipient traffic conflicts including approaching, turning, and crossing and merging vehicles, and traffic signals, and in stream pedestrians. He found that higher GSR amplitude corresponded to greater speed differentials between the test vehicle and the other vehicle in the traffic event. Lesser GSR tension response was evident for fixed objects, parked vehicles and traffic islands. He concluded that tension responses are directly related to the complexity of the traffic situation, and inversely related to the predictability of the actions of other drivers.

Michaels' later research (40) dealt with the evaluation of driver GSR tension response relative to different highway designs. He found that the higher the highway standard of geometrics and access control, the lower the magnitude and frequency of GSR response. The GSR responses were also related to free through stable flow ranges of traffic volumes. He noted that tension responses rose sharply as traffic volume approached practical capacity, and tentatively presented this relationship as a possible proxy for comfort and convenience. Michaels confirmed his earlier conclusion that tension responses are directly

related to the complexity of the traffic situation, and inversely related to the predictability of the actions of other drivers. He goes on to suggest that GSR may have potential as a behavioural measure of highway operational efficiency.

Other pertinent driver stress research includes that of:

- i. Hulbert (41) who followed a similar line of research in determining that GSR tracings were related to actual and potential traffic path interruptions. The GSR tracings were rated according to relative pattern changes, before and after the interruptions.
- ii. Surti and Gervais (42) who researched the application of physiological response between alternate routes as a basis for route diversions. They found that the magnitude and frequency of GSR were similar between a freeway and alternate street near practical capacity. Beyond practical capacity the freeway had comparably higher driver stress than the surface street, as evident in significantly higher GSR values. The researchers concluded on the basis of their findings that there is a stress basis for route diversion, and that alternate route options should be attractive to informed drivers.
- iii. Taylor (43) who researched drivers' GSR as related to the risk of accidents. The magnitude and frequency of

responses were found to be associated with apparent traffic events. Further a measure of GSR frequency per mile was found to be similar to the pre-existing accident rate (accidents per mile of travel) for the test sections. He also found that GSR activity showed a greater relationship to the driver's experience than road conditions.

- iv. Preston (44) who undertook similar research in evaluating the relationship between the driver's insurance classification and GSR frequency per mile, on both rural and urban roads. Significant response differences, in a ratio of urban to rural responses, were found between high and low risk drivers.
- v. Brown and Huffman (45) who investigated driver physiological responses of GSR, heart rate and eye movement in relation to different driving applications. Significant differences in physiological responses were evident among the applications of rural two lane highway, four lane expressway, four lane business district, and residential area environments during both day and night. Drivers exhibited higher levels of arousal in daylight heavy traffic conditions, than during night moderately heavy traffic. The GSR rate was found to be significantly lower for the rural highway application, and at night for all applications.

The researchers note that the least useful measure of arousal appeared to be heart rate, as evident in the similarity of results between the different applications. The researchers recommended that responses should be converted to proportions for evaluation, through taking the prestimulus and peak response levels into account.

- vi. Helander (46,47) who investigated the relationships between continuous measures of GSR, heart rate, and muscle activity related to traffic event task load on a rural highway. He found that GSR and heart rate are primarily induced by the mental effort of the driving task, although both response measures could be affected by an immediate physical effort. The physical effort for example refers to the exertion required to maneuver or brake a vehicle. He also noted that GSR, as a rapidly responsive measure, is appropriate for applications where task demand levels are changing rapidly.
- vii. Rutley and Mace (48) who evaluated heart rate as a potential instantaneous measure of driver stress related to different road layout designs. They determined that "heart rate changes can be used as a measure of the stress induced by various road junction designs."(48). They note that the interpretation of the relationship between heart rate and psychological

stress must recognize the potential influence of physical vehicle control movement effects on heart rate.

viii. Weir and Allen (49) who investigated the use of physiological response measures extracted from an electrocardiogram (ECG) and heart rate to describe driving task performance levels. Drivers responses were monitored for exposure to wind gust and roadway irregularity conditions. Both the ECG and heart rate were found to provide comprehensive measures of driver stress level. The researchers noted that heart rate response is best described in terms of both increasing or decreasing trends and rate changes.

ix. Cleveland (50) who evaluated driver tension related to rural intersection illumination through measuring GSR. Significant response differences were observed for subjects driving through a rural interchange at night, as related to the presence or absence of illumination. Higher GSR magnitude was evident with no illumination, and higher GSR frequency was associated with intersections of greater complexity.

x. Torres (35) who considered that covert physiological responses could be effective in the identification of roadway characteristics that affect driver stress. He researched the potential application of the GSR physiological response measure as a correlate of driver

stress attributable to moving traffic situations. He determined that a positive relationship between GSR and urban arterial traffic events was evident in the free though stable traffic ranges. Traffic events included potential or actual parking movements, passing or slowing maneuvers, crossing or tailgating vehicles, pedestrian movements, and traffic signal changes. He found that magnitude of GSR change could be reliably associated with transitory traffic events. On the basis of his observations he inferred that the higher the average value of GSR the greater the driver tension and discomfort. The overt physical responses to maneuver or brake the vehicle to avoid actual or incipient traffic events were also measured. Examples of these physical responses include steering wheel reversals, brake applications, or accelerator movement as related to some evasive vehicle action. These physical responses were found to be characteristic of conflicts in both free and stable flow traffic movement regimes. Torres notes that physiological reactions occur in response to moving traffic situations, and may also occur where the driver actions are limited. This inference was based upon the observation of the decreased magnitude and frequency of physical response in stop and go traffic typical of congested or

delay situations. He also found that the GSR occurrence of drivers was higher than passengers for the same event.

The basis for the continuous physiological monitoring of drivers is well founded in practice as evident in the foregoing review. Although these fast acting physiological measures have traditionally been associated with stimuli of a momentary nature, they may have the potential for conveying information that describes physiological changes at longer intervals (51). However the use of a physiological baseline shift as a measure of an extended event has a seen limited application.

Related research includes that of Stokols (52) into trait anxiety who found that commuter exposure to traffic congestion is associated with significant differences in the mood, physiology and task performance of commuters. It was concluded that the greater the congestion impedance, as described through both travel distance and travel time, the greater was the increase in blood pressure. In that research the systolic and diastolic blood pressure and heart rate readings were taken on three consecutive days on arrival at work to measure activation levels, and related to mid-morning baseline measures. These baseline measures were however taken in a setting unrelated to the commuting envi-

ronment. The physiological response changes were then evaluated in the context of the corresponding commuting time and distance. The research notes that baseline measures taken prior to the trip may enable a clearer assessment of the relationships between both prevailing and routine travel impedance, and chronic and commuting specific arousal. The researchers go on to speculate that commuting stress may be related to a discrepancy between the commuters expectations and the actual experience of travel constraints.

Peripheral research relating to comparative physiological reactions includes that of:

- i. Platt (53) on heart rate as a measure of driver psychological stress under varied driving conditions. He found a significant increase in the variability of heart rate over a 25 minute period of driving under adverse weather and road conditions. He noted that on a routine 1.5 hour interstate trip in daylight and light traffic, that heart rate measured at 10 minute intervals dropped significantly for extended periods. He also noted on an extended 12 hour trip (divided into 1.5 hour intervals) that heart rate variability diminished, and was likely attributable to the fatigue effects of the very long trip.
- ii. Hulbert (54) on the evaluation of the effects of

driver fatigue. He summarizes that in laboratory simulated driving conditions that a fatigued subject would exhibit less GSR and respiration reaction in response to a traffic event than when alert. Subject fatigue in that research was brought about through a 24 hour sleepless period.

- iii. Ettema (55) on the effects of mental task load. He concluded that a systematic increase occurs in both systolic and diastolic blood pressure due to the intensity and duration of a mental task load. The mental task load used was that of a binary response choice to random high or low tones, through pressing a pedal with the corresponding foot. The constant blood pressure increases were found to occur in both short three minutes periods and in longer lasting experiments with a four hour duration. Although the blood pressure increases of the short periods were noted, they were found to occur within the normal physiological range. However, the prolonged mental load of the longer term experiments indicated a more significant increase in blood pressure. The research also cites similar blood pressure response for a railway controller who exhibited blood pressure increases related to both normal and emergency situations lasting for "some hours". He also notes that the "Increase in blood pressure, together

with changes in other physiological phenomena such as heart rate, sinus arrhythmia, etc., indicate that mental load may alter the level of activity of the autonomic nervous system."

- iv. Ax (56) on the presence of physiological response changes over extended periods of time, in sleep deprivation research. In that research comparatively higher GSR levels were measured when performing the same task before and after an extended period of wakefulness.

2.5.3 Driver Stress Monitoring

In the modelling of the driver serviceability approach it was appropriate to capture as much physiological stress information as possible. The different physiological measures provide greater versatility in the modelling data base, than could be achieved through monitoring and evaluating fewer measures.

A potential instrument for the simultaneous recording of the driver's physiological conditions of the trip experience is the polygraph. The polygraph records physiological changes as a function of conscious and subconscious stress (32,57). The polygraph evolved over a period of 90 years (58). It's underlying principles are founded on development and experimentation in the fields of medicine, physiology and psychology. It operates on the

premise that a stressor will cause direct measurable physiological changes.

The polygraph hardcopy output consists of graphical tracings of thoracic and abdominal respiration, blood pressure and pulse, and galvanic skin response.

Respiration air volume intake changes are monitored through measuring the relative expansion and contraction in a pneumatic tubes around the subject's chest and abdomen.

Blood pressure and pulse are measured through the application of a blood pressure cuff around the subject's upper arm, as in a medical examination. It may be also be measured in the leg. Blood pressure is technically the pressure of blood against the arterial walls. Pressure will rise and fall corresponding to the heart's outflow contraction and inflow expansion strokes. Respectively these are the systolic and diastolic pressures.

The heart rate or pulse is a measure of the number of beats per unit time. The time unit is usually one minute. Heart rate can also be interpreted in terms of the variability or standard deviation of the heart rate.

GSR is a measure of the change in electrical conductance or resistance of the subject's epidermal skin layer. As stress precipitates perspiration increases, the electrical conductance increases and resistance falls. It is generally measured through attaching a set of electrodes to

a subject's finger tips, and monitoring the changes in either electrical conductivity or resistance of a millivolt current. The electrical differences are measured through the variation in pathway conductance or resistance between the two finger tips, through the fingers and palm. The GSR is also known as the galvanic skin reflex, electrodermal response (EDR), electrodermal skin response (ESR), and skin conductance response (SCR).

The instrument and constituent parts have been successfully used in behavioural studies generally (59,60), and for drivers specifically (35). Stress monitoring can be conducted and evaluated in such a manner to enable consistent interpretations of the findings (57). The numerical scoring of chart output increases objectivity and aids in decreasing risk of interpretation bias (57).

Chapter 3

Formulation Of The Research Problem

3.1 Overview

The provision of transportation facilities and services can have significant implications on the users' quality of life. The rapid growth in travel demand relative to limiting infrastructure budgets requires a critical rethinking of the perspectives and practices that guided facility warrants and developments over the past two decades (61). This situation may in part be addressed through the development of broader measures of facility performance reflecting the users' perspective.

Roadway traffic performance evaluations are based on the traditional traffic movement effectiveness approaches. The modelling of driver serviceability advanced in this research should be viewed as a complement to the traditional traffic movement models and criteria. The modelling of driver serviceability relates the drivers' perceptions of service quality to the trip experience. As previously presented, the trip experience encompasses all events that the driver encounters that contribute to their basis of knowledge. These include direct observation and participation. An example of direct observation would be an awareness of the weather, scenery and informational signing not

of immediate impact in the driving task. Examples of participation would include the balancing of safety and capacity limits by the driver (34).

The traffic movement models are well founded in theory and practice, as evident in the substantially greater evolution of the quantitative measures of the traditional (LOS) criteria (11,13,62). These include such parameters as speed, density and flow as the basis for evaluating facility performance and capacity utilization. As intended, the current LOS criteria are useful for transportation engineers and planners in facility planning and design applications (63). The limited qualitative allusions associated with the traditional LOS criteria provide neither a consistent or objective basis for describing quality of service, for use by the public and their governments (27). This inadequacy in traffic performance evaluations had been considered relatively inconsequential until the looming funding restraints of the late 1980s (64). Consequently, further traffic performance guidelines portraying the drivers' perspective are increasingly required.

The development of a substantive driver serviceability basis has been limited through the comparative difficulty in setting consistent definitions of service and quality, and establishing consistent and complementary performance criteria. Consequently there has been very limited practical application of the driver serviceability approach.

This research addresses the need through modelling driver serviceability. Modelling will provide the necessary consistent basis for assessing traffic performance from the driver perspective of quality of service. Rural two lane highway and urban arterial settings are addressed in the modelling, and the development of preliminary serviceability guidelines. These advances also enhance the general understanding of the driver serviceability approach.

This research focused on automobile drivers, as they are the greater proportion of roadway users in Canada and the United States. This is evident in the typical 80 to 85 percent proportion of automobiles in the urban traffic mix being compounded by a low average occupancy rate of approximately 1.5 persons per vehicle (13). Although comparable rural data are unavailable, automobiles are described as being the greatest traffic component using the rural principal arterial system (64).

The following sections present the serviceability philosophy and conceptual model as preludes to the modelling of driver serviceability.

3.2 Serviceability Philosophy and Conceptual Model

3.2.1 Serviceability Philosophy

Driver satisfaction is an integral element in the concept of roadway service. Over the years, researchers have attempted to develop consistent measures of effectiveness related to driver satisfaction (11). Conceptually, driver satisfaction has been related to relative comfort and convenience, reliability, safety, cost, and travel time (65).

The missing cornerstone of a driver serviceability philosophy and model has been the determination of practical and consistent linkages between the driver's perceptions of service quality and the experienced service.

Teply (34) identified two levels of traffic behaviour. The first level relates to pretrip travel decisions including such things as trip utility, route and mode choice, and the evaluation of expected problems. The second level is the enroute traffic behaviour described by the balancing of immediate safety and traffic pressure constraints, as reviewed in Section 2.5.1.

Intuitively driver satisfaction will be higher when performance is satisfactory. Although drivers will adapt to varying degrees of less than desirable prevailing conditions, their relative acceptance will be gauged against some initial expectation of service. Therefore it is postulated that this likely pretrip expectation could form the

basis for gauging the quality of service experienced on the trip, and thus could be the underpinning for modelling driver serviceability.

A precursor to modelling driver serviceability was the identification of the most appropriate parameter(s) against which quality of service could be reliably gauged. The relationships among these parameters would describe the linkage between the trip experience and perceived quality of service. Although time based parameters such as speed and delay are currently applied to level of service criteria (11) it was felt that these were sufficiently vague as related to driver's perception of service quality that a general review and clarification was appropriate. The review centred around a series of structured driver interviews and surveys relating to serviceability considerations that could feature in driver perception of quality of service. The serviceability consideration interviews are summarized in Appendix C.

Those interviewed and surveyed included professional and nonprofessional drivers, transportation planners and engineers, and lay people. The featuring of professional drivers in these reviews was seen as an advantage in that their trip experiences covered a much broader range than the average driver.

The objective of the interview process was to solicit a

general serviceability focus from drivers, to clarify and elaborate upon the limited background literature. There was no intention to undertake a definitive study of quality of service considerations. Consequently, coarse interview techniques and survey questionnaires corresponding to a general rather than definitive review of driver quality of service were used.

The most important serviceability consideration identified was safety. In the interpretation of the findings safety was viewed as being paramount to driving, as evident in the extent to which Canadian and American drivers take safety for granted in using public roadways (66). Consequently the presence or likelihood of safety was viewed as being a prerequisite to the occurrence of the driver serviceability process.

The further general focus of the interview responses relating to serviceability was oriented towards considerations of travel reliability and travel time. Reliability was construed as the ability to predict the experiences of the trip. Travel time was described through such measures as speed and delay. These were further seen to be affected by such things as the availability of passing opportunities, weather, and road surface conditions. In the course of the follow up serviceability questionnaire it became increasingly apparent that a speed based derivative of the travel time consideration was the appropriate basis of a driver

serviceability focus. The travel time and reliability orientation of the interview responses is corroborated to some extent by research relating to interviews with San Francisco area commuters (37). These interviews revealed that both the extent and uncertainty of congestion and delay were viewed as major contributors to stress (37).

Although each travel experience is truly unique with respect to the prevailing traffic and background conditions, each trip entails the expenditure of time. The traditional level of service criteria recognize the expenditure of time through the use of criteria such as average travel speed and delay as related to traffic conditions. However, these criteria do not explicitly reflect unusual delays attributable to weather or construction, and more importantly fail to recognize that quality of service is apparently perceived relative to the drivers expectations of trip conditions.

On the basis of the general focus and findings of these interviews and surveys, and in view of speculations in the reviewed literature (29), it was hypothesized that the driver's perception of the quality of experienced service would be more appropriately based on overall trip time. Criteria determined on an overall trip basis would not distinguish dynamic serviceability changes during the trip, such as a particular intersection delay or segment

congestion. However the criteria would reflect these in the aggregated effects of the trip experience, through descriptions of the overall performance outcome and service quality perceptions. The closest analogy with the current level of service criteria would be that of travel speed determined over extended lengths of roadway.

The pretrip expectation of trip time provides a point of reference for gauging the quality of service of the trip experience. The relationship between the predicted and actual travel times could be described through the concept of travel time predictability. Travel time predictability would reflect the relative extent of the driver's awareness of enroute conditions. This would be evident in the travel time difference between the driver's initial prediction and actual outcome. The driver's perception of service quality would be related to the travel time predictability description of their trip experience. Ranges of service quality could provide a basis for evaluating traffic performance from a driver serviceability approach.

Travel time predictability has a high importance as evident in Rowe's observation that "The impact on the motorist of nonrecurring congestion is much more than just added delay. It is the uncertainty of variable travel times that can be longer than average, necessitating either the allowance of a greater time cushion in travel plans or the acceptance of frequent lateness to appointments. This

uncertainty provides at least as much aggravation and stress to the motorist as recurring congestion, which at least is predictable." (67). The presence of such stressful conditions were cited by commuting motorists as a motivation for a shift to ride sharing from single vehicle usage (68).

The travel time predictability parameter effectively captures the essence of the trip experience through the confounding of prevailing trip condition effects into the travel time outcome. This confounding concept is consistent with the use of overall descriptions to reflect the aggregate effect of multiple inputs in conditions of uncertain outcome (69).

The predictability of speed, as a function of travel time given trip length, would in effect present the same basis for gauging quality of service. The development and use of the time based travel time predictability measure of service quality is in keeping with the general observation of Yagar and Van Aerde (19) that " speed is a service basis inherent to our society".

Conceptually travel time predictability may have application to trip links, as well as the overall trip depending upon the driver's reference in framing travel expectations. In trip applications of short duration or singular purpose the overall context would seem most practical.

Very long travel times are also conceptually consistent with the application of travel time predictability. The driver's perception of service quality would continue to be gauged against their expectation of travel time, regardless of the actual travel time outcome. A very long actual travel time that differs significantly from the expected travel time would not result in the default of the concept, but rather a very low value of travel time predictability and therefore associated quality of service.

The forethought in the driver's decision to travel would include consideration of the travel choice consequences. A fully informed driver, would in predicting travel time, set a reference point against which service quality will be gauged for that trip at that time. Should the driver determine that the prediction is within an acceptable range for that particular trip, the driver would be expected to choose to travel under the supposed prevailing conditions. This does not discount the possibility of unexpected delays due to unforeseeable circumstances, but rather the net effect would be a proportionate increase in travel time and a reduction in travel time predictability.

The driver's choice of departure time would be influenced by both the prediction of travel time for a particular trip, and the implications of late arrival at the trip destination. Serviceability would continue to be relative to the extent to which trip performance achieves their

predictions, despite for example, late arrival as a consequence of late departure. A driver that departs late would likely continue to gauge serviceability on the basis of their initial travel time prediction. However the range of acceptable travel time predictability may depend upon the purpose of the trip, as related to the implications of a late arrival.

Should a driver be unable to achieve an acceptable level of travel time predictability that driver would either continue to perceive poor service quality or divert in either time or space to more predictable travel alternatives. Observations of travel pattern and modal choice behaviour related to traffic disruptions associated with major highway construction (70), tend to confirm this hypothesis. Motorists tended to resist less familiar and therefore less predictable routing alternatives, in favour of their known route despite it's greater levels of delay or congestion (70). A modal shift from private cars to public transit buses also occurred despite longer transit travel times, due to the more predictable nature of the scheduled service than the variable construction disruptions (70). Similarly, service reliability was felt to be more important than absolute travel time or direct travel costs in airport access modal choice (71).

Driver intolerance of congested conditions may then be

viewed as an intolerance of the effects on travel time predictability, as opposed to the congestion itself. Potentially, this view has significant implications to the supply and management of roadway facilities; in that if travel time predictability can be increased to acceptable levels, congestion will be more tolerable and major facility supply decisions subject to further qualification.

Driver perception research peripheral to the "Two-Lane Highway Capacity And Level Of Service Research Project"(18) by the Transportation Association of Canada (TAC) corroborate this concept to some extent. Drivers were found to be able to differentiate between rated traffic conditions and perceived quality of service. Of the drivers that rated the platooning delay traffic condition as poor (LOS E) only 20 percent considered the condition to be very or extremely annoying, and 40 percent expressed no annoyance at all. The report speculates that those drivers familiar with the route may have anticipated platoon delays and would therefore rate the traffic condition as poor without being particularly annoyed (18). However, the collected data did not include the drivers' trip expectations or prediction of travel time. TAC's further evaluation of the driver perception data was limited due to budgetary and time constraints.

If drivers base route diversions, or modal choice on predictability of travel time there are also significant

implications to transportation planning model applications, that incorporate trip time as a key factor. Examples of these can be found in the Gravity Model used for trip distribution, the Logit Model used for modal split, and the all or nothing and capacity restrained traffic assignment procedures (72). The use of travel time predictability in these models and procedures would require not only the assumption that drivers have an awareness of what the shortest link is, but also that they have the appropriate background to make knowledgeable predictions.

3.2.2 Conceptual Model

This research is founded upon the hypothesis that drivers evaluate the quality of service of their trip experience. Theoretically the trip experience could be described through any number of trip conditions or events. Practically however the driver serviceability approach must be gauged against common performance measures, to enable the comparison of quality of service between different trips or roadway settings. For example an absolute criterion of travel time has limited transferability compared to a relative measure of performance such as travel time predictability or speed.

Conceptually driver serviceability would be modelled through quality of service valuations of the trip experience, as described by:

$$\text{Serviceability} = f(\text{Trip Experience}) \quad (3.1).$$

Although a trip experience will be affected by a considerable number of both foreseen and unforeseen conditions and events, the aggregate effect of these inputs could be captured in a common performance measure.

The driver serviceability concept is illustrated in Figures 3-1 and 3-2. In this research it was hypothesized that trip experience could be described through travel time predictability. The outcome of travel time predictability is inextricably linked to the trip experience. Travel time predictability effectively represents all prevailing background conditions through their respective effects on the outcome of travel time. It was further hypothesized, that the driver serviceability process could be described by a consistent relationship between the driver's travel time predictability and their subjective valuation of service quality.

Also shown in Figure 3-1 and 3-2 is that the aggregate driver, environmental and roadway states contribute to the trip experience and therefore determine the outcome of travel time predictability. Driver state was defined as those considerations within the driver's immediate control, such as previous driving experience generally, route familiarity specifically, vehicle climate control and ride comfort. Environmental and roadway state was defined as those factors beyond the immediate control of the driver including

Figure 3-1: A Driver Serviceability Concept

Figure 3-2: Travel Time Predictability Perspective

such things as roadway, weather, and traffic conditions. The aggregate effect of the prevailing environmental and roadway state will be evident in the actual travel time outcome, and will therefore be reflected in travel time predictability. As a description of the trip experience travel time predictability could be linked to the driver's subjective service valuations.

In formulating the conceptual model it was felt that the driver serviceability approach would be more meaningful through the development of a parallel objective description of the trip experience. The descriptions of travel time predictability and the corresponding physiological correlates of stress would provide linkages between the trip experience and the subjective valuation of service. The physiological description would provide an additional objective basis to augment the interpretation of the serviceability process. These relationships are illustrated in Figure 3-1. The linkage shown between travel time predictability and the physiological stress correlates recognizes that a relationship could exist, through travel time prediction being considered as an element of the driver state.

In this research the measures of physiological baseline changes are described as stress correlates of the trip experience. This description reflects the principle that although stress can not be measured directly, that it may be

inferred on the basis of physiological measures (73).

The physiological description of the trip experience used in this research was the baseline change between pre-trip and posttrip recordings. Although the theoretical basis for baseline change is limited (as reviewed in Section 2.5), it's application in this research provides a novel secondary description of the trip experience. As previously noted, the reader is cautioned in further application of physiological baseline change until research efforts can expand upon the limited theoretical basis.

The driver's predictive ability and their knowledge of prevailing environmental and roadway conditions are the basis of their prediction of travel time. This prediction is in turn an element of the travel time predictability description of the trip experience. These relationships are illustrated in the travel time predictability perspective of Figure 3-2.

The prediction of travel time requires both a knowledge of the typical travel time and an awareness of atypical prevailing conditions that could cause delay. The typical travel time for the travel period would include recurrent delays associated with traffic conditions. Examples of the recurrent delays would include passing opportunity availability in the rural setting, and traffic control signal delays in the urban setting. The atypical conditions would

include programmed and non-programmed delays. Examples of programmed delays would generally be related to construction, rehabilitation or maintenance operations. Non-programmed delay examples would be related to weather, accidents and vehicle breakdowns. Although not programmed, weather and significant accidents could, and should, enter into the travel time prediction if there is a timely means of conveying the information to drivers. In effect the exceptional or unusual will become routine, and therefore more predictable and acceptable.

An analogy of note in modelling driver serviceability was found in the pavement serviceability concept, reviewed in Appendix D. Pavement serviceability is described through a relationship between objective mechanical measures of pavement roughness, cracking and rutting, and qualitative ratings of ride comfort (12). This relationship enables the evaluation of pavement serviceability through making comparatively rapid objective measurements and determining the correlated qualitative rating. This approach is much more practical than having a panel rate each pavement section, each time a serviceability evaluation is required. The analogies in this research to the objective pavement measures are travel time predictability and the physiological stress correlates. The subjective valuation of service in this research is analogous to the qualitative description of ride comfort.

3.3 Input Requirements

3.3.1 General

Scientific research can follow either survey or experimentation courses of investigation. This research followed the survey approach in an endeavour to develop realistic descriptions of the drivers' trip experience. Consequently all modelling information was developed on the basis of field observations of actual trip experiences. This contrasts with the experimental course of investigation in which the hypothesized inputs would be manipulated in the presence of controlled background conditions. The underlying experimental relationships would then be discovered through an assessment of the effects of varying the key inputs. In the development of this research it was felt that experimental manipulation could significantly affect the realism of the trip experience, and thereby generate questionable results.

A further perceived disadvantage of the experimental approach was that the systematic identification and control of the enumerable background conditions was impractical and unrealistic. Although the use of driving simulators in a laboratory setting could control these inputs, it could prove difficult to simulate the crucial expectation and passage of time that occurs in a real world trip experience. This concern reflects the theory of ecological cue validity which suggests that perceptions are less accu-

rate in artificial environments, due to the lack of natural cues presented in the proper context (74).

In subscribing to the survey approach it was desirable that the modelling inputs be reflective of driver serviceability, practically measurable in field surveys, and consistent enough to permit statistical aggregation and evaluation. Subsequently the correlational method was applied to identify and evaluate the underlying relationships between trip experience and quality of service. The input parameters included the driver's travel time predictability, subjective valuation of service quality, and physiological baseline changes between the start and end of the trip.

3.3.2 Travel Time Predictability

Quality of service was gauged against the performance criterion of travel time predictability. The parameter of travel time predictability is in effect the relative extent of travel time prediction error. This requires the driver's pretrip prediction (i.e. estimate) of trip travel time and the measurement of the actual travel time at the end of the trip. The driver makes a travel time prediction given known, or presumed, route characteristics and an understanding of the prevailing environmental conditions. The extent to which the prediction is realized will form the basis of the quality of service valuation.

3.3.3 Subjective Quality Of Service Valuation

The subjective valuation of service provides a qualitative description of the trip experience. The development of ranges of service quality based upon valuation similarities provide comprehensible benchmarks for applications of the driver serviceability approach. These ranges of service quality in relation to the corresponding values of travel time predictability form the basis of the preliminary driver serviceability guidelines.

3.3.4 Physiological Correlates

The physiological correlates of stress provide an additional objective description of the trip experience. In the early stages of the modelling it was thought that these physiological correlates of stress were potential performance criteria. Consequently the required data were collected and evaluated.

In the endeavour to more closely replicate the trip experience, baseline shift measures were used rather than continuous physiological measures. This was largely a consequence of pre-pilot study driver reports that the continuous monitoring overwhelmed other elements of the trip experience. This was largely attributed by the subjects to be caused by monitoring attachment discomfort, over prolonged periods of time.

Although the theory for baseline shift is limited as presented in Section 2.5, sufficient basis was felt to exist

to provide a foundation for this research application. A key hypothesis in applying physiological baseline change to describe the total trip experience, was that although a driver would exhibit transitory responses to the mental and physical demands of immediate driving stimuli throughout the trip, that the cumulative effect of these events would be reflected in a baseline shift measure.

The baseline shift measure was founded on the differences between the physiological baseline measures recorded at the start and end of each trip. The baseline shift which provides a physiological description for the overall trip experience, reflects both the mental and physical demands encountered.

There could inherently be monitoring procedure effects present in the recorded physiological measures. Although inseparable from the trip experience effects, it was assumed that the use of consistent pretrip and posttrip monitoring procedures and the subsequent determination of a relative measure of physiological baseline change would effectively cancel out any monitoring artifacts.

The physiological levels and patterns measured to evaluate baseline change included galvanic skin response (GSR), thoracic and abdominal respiration, heart rate and blood pressure. The physiological baseline patterns were measured and evaluated in view of background environmental,

roadway and driver characteristics.

3.3.5 Traffic Parameter

The modelling of driver serviceability and the preliminary serviceability guidelines developed in the course of this research necessarily required a practical linkage to the current LOS guidelines. On review it was felt that average travel speed was the most appropriate traffic movement effectiveness parameter, as the travel time basis is a common input to both the traditional LOS criteria and the travel time predictability perspective.

3.3.6 Background Conditions

Research resource limitations necessarily restricted the number of background environmental, roadway and driver characteristics that could be evaluated. The background conditions were therefore controlled to the fullest extent possible, without noticeably impinging upon the realism of the trip experience. Only those background conditions viewed as potentially providing significant interpretative capabilities in the modelling process were recorded and reviewed. However the effects of all background conditions are reflected in the model relationships through their aggregate effects on travel time predictability, physiological baseline change variables, and subjective valuation of service quality.

3.4 Research Location Basis

The initial modelling of driver serviceability was based upon a rural two lane highway setting, as it appeared that the underlying driver serviceability process could be similar between roadway environments. Further, that the rural setting would permit the observation of relative physiological baseline changes and subjective valuations that occurred over long sections of roadway. This enabled observations of change over comparably longer periods of time than would generally be expected in the urban arterial environment.

It was also felt that the comparatively greater complexity and ambiguity of peripheral activity in the urban arterial environment could initially cloud the recognition and development of the underlying serviceability relationships. However, having initially modelled driver serviceability it was considered necessary and appropriate to extend the modelling relationships through an urban arterial setting.

Chapter 4

Data Collection Process

- Rural Two Lane Highway Setting

4.1 Overview

A pilot survey consisting of 19 observations was undertaken during November 1990. On the basis of the experience and results gained through this survey, the full scale survey program was undertaken from November 1990 through May 1991. A total of 117 trip observations were made in the rural setting, for use in the initial driver serviceability modelling. A spreadsheet summary of the rural data base is presented in Appendix E.

Each trip observation included the recording of the driver's travel time prediction, actual travel time, subjective valuation, and significant background conditions, and the physiological baseline measurements at the beginning and end of the trip.

The use of the subjects in this research parallels trip experience reality, in that a driver's perceptions of a trip are likely to be framed in the context of previous driving experience generally and on a particular route specifically. The subject drivers in effect reflected their previous experience through their travel time predictions.

4.2 Survey Protocol

4.2.1 General

During the course of the research safety was considered paramount. At no time were the subjects deceived or placed in any real or imagined jeopardy as a consequence of the research. Realistic results for the modelling necessarily required that the environment be as normal as possible, notwithstanding the monitoring of service quality perceptions and physiological baseline measures at the beginning and end of the trip. Subjects were assured that the environment was as normal as possible and not being manipulated. This was ensured through all trip observations being done directly by the researcher.

The survey protocol of this research was approved by the Carleton University Ethics Committee.

4.2.2 Pretrip Protocol

The subject drivers pretrip briefing included a discussion of:

- i. The intent of the research to develop a basis for enhancing traffic performance evaluations, through the modelling of driver serviceability and the related determination of driver serviceability ranges.
- ii. The physiological measurements of galvanic skin response, respiration, blood pressure and heart rate at the beginning and end of the trip using the portable polygraph and blood pressure monitor. The method of

monitoring each measurement was briefly described including the placement of sensors.

- iii. The prediction of trip travel time using trip end points, coinciding with clearly identified monitoring locations.
- iv. The completion of a serviceability questionnaire relating to trip perceptions and experience.
- v. That the subject driver could choose to not participate or cease participation at any time.

The subject drivers then drove to the defined trip origin, to ensure that they were fully familiar and comfortable with the vehicle they were driving.

4.2.3 Trip Protocol

The drivers were requested to follow their normal driving practice, and to ignore the survey as much as possible. The drivers were further assured that neither driving skill nor traffic law compliance were being tested or recorded as elements of the research. Although it was the intent of the survey to cease the respective trip observation should any erratic or unsafe driving behaviour become apparent, it was not acted upon as such behaviour did not occur.

The people in the test vehicle were limited to the subject driver and the researcher. There were no discussions throughout the trip relating to either the research general-