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A STUDY OF SPEED VARIATION OF AUTOMOBILES ALONG
A PARKWAY

by

B.J. ROSZELL,
Bachelor of Landscape Architecture

A thesis submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirement for the
degree of Master of Engineering

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Ottawa, Ontario

July 1978

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

"A STUDY OF SPEED VARIATION OF AUTOMOBILES ALONG
A PARKWAY"

submitted by B.J. Roszell (B.L.A.) in partial fulfillment of the
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MASTER OF ENGINEERING

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ABSTRACT

It is accepted that sudden changes in speed along a route cause accidents. There are many causes for these sudden changes in speed, one being route geometry. Leisch has devised a speed profile technique incorporating both the horizontal and vertical alignment, which permits a designer to determine prior to construction where sudden speed changes will occur as a result of inconsistent route alignment. The technique also provides direction for corrective measures.

This thesis analyses the main potential causes of speed variation from the driver's age and sex through to such vehicular characteristics as age, size and condition; as well as the total number of occupants in the vehicle and the route geometry. The purpose of this thesis is to determine what factors most strongly affect a driver's speed patterns along a route. This thesis also delves into the accuracy of Leisch's technique to depict the actual speed profiles of a vehicle along a route. As a result, this work shows that:

1. The location of speed changes is mostly strongly affected by the route geometry,
2. The amount of speed change is not strongly influenced by any one variable. Driver characteristics (age and sex) account for the greatest amount of variation. But these factors do not account for a large portion of the variation.
3. Because of the influence of other factors besides route geometry, Leisch's technique should be further researched to determine a means of incorporating a driver factor.

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CHAPTER 1

INTRODUCTION

1.1 Background

Highway development has been traditionally divided into four phases. These are referred to as the planning phase; the design phase; the construction phase and the maintenance phase. (see Figure 1.1)

The planning phase of highway development addresses such problems as whether to build a highway or an addition; and to what standards. This process involves defining goals. This could be expressed as the need for additional access to an area; or the need to introduce access to an area. Following goal definition, the next step involves carrying out the appropriate traffic forecast studies and then determining alternative courses of action that will fulfill or partially fulfill these goals eg. can a 4 lane freeway satisfy the access problem or can an upgrading of the existing network provide a better solution. Predicting through simulation the performance of each system (determining how adequately the various solutions meet the predicted traffic volumes); and evaluating the economical, financial and other consequences of the various alternatives suggested, a decision then can be reached by comparing the consequences of each course of action.

Next comes the design phase. This stage entails the development of the design expressed in terms of a plan and profile for the continuous

fig. 1.1 - HIGHWAY DEVELOPMENT PROCESS

roadway. Also included at this phase is the design of interchanges, service roads, bridges and drainage structures, and lastly signage, traffic signals and roadway markings. Given the basic solution generated from the planning phase, the designer through the use of an appropriate "design speed" is able to determine the minimum safe geometric standards to be used for the design of the plan and profile.

According to the Roads and Transportation Association of Canada (RTAC) "design speed" is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favourable that the design features of the highway govern. Favourable conditions includes good weather, little or no traffic on the highway; and no effect of speed limit signing. This design speed, once determined for a proposed road, then establishes the geometric design standards to be used for a specified design vehicle. These design standards are modified by the designers to fit the terrain through which the road will pass. The designer in determining the geometry which best fits the lay of the land always stays within the limits of the standards determined by the design speed. Therefore a route usually contains a mixture of high and low or near maximum design standards.

Following completion and acceptance of the design plans, the construction phase serves as implementation to all the work previously done. Following this stage is the maintenance phase which centers around the upkeep of the roadway and its right-of-way.

In the past, there have been three main objectives governing the planning and design phases for a highway. Firstly and most important is the requirement to link points A and B together. Secondly is the requirement to produce an economical route, and thirdly, is the requirement to produce a design which is easy to construct and maintain. In the more recent time frame - the last fifteen years, other objectives have gained prominence as being important in the development of an adequate highway facility such as safety, environmental concerns, and social factors.

The interests of this thesis lie with the objective of safety and how the design phase can better meet or respond to this objective.

Safety requirements are expressed during the design phase, in terms of what road geometry is acceptable and how it best can be combined to form the roadway alignment. In the past, it has been accepted that the safest highway is one in which the geometric design standards are closely adhered to and the geometry is properly coordinated. But some authorities (12) are pointing to another aspect of route geometry which can lead to an unsafe route - it is the mixture of above minimum geometry standards. They feel that this mixture results in inconsistent speeds along a route. For example, a driver is often able to speed along a section of highway at 100 km/h, while along a curve, his speed is reduced to 65 km/h. This changing of speeds along route is believed to be a primary cause of accidents. It has been shown that as the variation in driving speed becomes

greater so does the occurrence of accidents (16). For example, an accident to speed ratio of 2.0 occurs at a 8 km/h reduction, 3.7 ratio at a 16 km/h reduction; 8.9 ratio at a 24 km/h reduction and 15.9 ratio at a 32 km/h reduction (4, 10). Therefore a safer highway can be achieved by eliminating geometric combinations which cause sudden drastic changes in velocity.

A new technique has been devised by Leisch (10) which involves regulating the road geometry to maintain the necessary consistency in operating speed (the highest overall speed at which a driver can travel on a given highway under favourable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section bases (16)) along the road. This technique involves a speed profile which takes into account the joint configuration of the horizontal and vertical alignment and the individual curvatures and gradients. The procedure through the use of this geometric data, identifies the inconsistencies and provides the direction for corrective measures.

Leisch has defined a problem i.e., inconsistent speeds cause accidents. He has also provided a solution in terms of how the roadway geometry can be manipulated to resolve the problem. He indicates "the method for determining speed profiles has been devised from limited data, extensions of minimal research in vehicle operations, empirical speed relations and experience judgements" (10). This statement leads to two questions. First, is road geometry the primary cause of speed

fluctuations, or is the major cause the sex of the driver or the age of the vehicle or possibly a combination of factors? Secondly, assuming the geometry is the controlling factor in speed variations, is the technique proposed by Leisch representative of actual speed patterns?

1.2 Statement of Problem

The purpose of this research is two fold:

1. to determine if the geometric characteristics are the major factors affecting speed variation along a route.
2. if so, to validate Leisch's technique for passenger cars.

Throughout the discussion of this technique, Leisch has assumed that the primary controlling factor in speed fluctuations is the road geometry. If in fact this is incorrect, and the route geometry does not significantly affect speed variation, then this technique is of little use. Therefore, there is a need to determine what are the controlling speed variation factors.

1.3 Scope of Study

Because of the possibility for a great number of variables affecting speed consistency, this study will limit itself to determining the relationship between speed variation of private cars on parkways and the following variables:

- sex of driver;
- age of driver;
- number of occupants in the vehicle;
- size of vehicle;
- age of vehicle;
- physical condition of vehicle;
- horizontal curves;
- vertical grades;
- and tangents.

If the analysis should prove that all or some of the geometric features affect speed variation, then this study will proceed to determine how accurately Leisch's technique depicts the real life situation.

CHAPTER 2

FACTORS AFFECTING SPEED VARIATION

2.1 Introduction

The operating speed on the road is the function of the interaction of numerous variables. These main variables listed below:

(a regrouping of those in section 1.3):

TABLE 2.1 - MAIN FACTORS AFFECTING SPEED VARIATION

1. Physical characteristics or geometry of the route;
2. The posted speed limit on the route;
3. The driver capabilities;
4. The performance capabilities of the vehicle itself;
5. The environment outside of the roadway within which the vehicle and driver must operate.

2.2 Physical Roadway Characteristics

The route geometry is the physical layout of the road and affects the speed at which a vehicle can effectively operate. For each curve and grade, there is a maximum suitable speed at which a vehicle can safely operate. The geometric features which influence the operating speed include:

1. length and steepness of grades;
2. length and radius of horizontal curves;
3. length of vertical curves;
4. and cross-sectional features of the route.

Sight Distance

Before getting into the actual discussion on roadway geometry, sight distance must be defined. Sight distance is used in reference to two types of manoeuvres - stopping and passing. Stopping sight distance is the total distance travelled by a vehicle from the instant the need to stop is visible to the driver until the vehicle actually stops. Passing sight distance is that distance travelled by a vehicle from the time the driver observes a slower vehicle and decides to pass, until the passing vehicle returns to the right-hand lane. This variable must be defined because it serves as the basis for defining all suitable geometric design standards.

2.2.1 Grades

The steepness and length of grades can affect the speed of the vehicle, especially vehicles with low power to weight ratios - i.e. trucks and heavy vehicles. Greater speed reduction on slopes are recorded for these low power to weight ratio vehicles. It has been accepted in the past that the speeds of private automobiles usually are not affected by the length of grade nor by the steepness of the grade. However, Werner (22) in his thesis of 1974, concluded that private automobiles are affected by grades greater than 7%.

2.2.2 Horizontal Curves

In designing a curve the major criterion is to counter the centrifugal force developed when the vehicle moves in a circular path. Therefore horizontal curves affect a driver's speed in three ways:

- a) by restricting the sight distance;
- b) by not providing sufficient superelevation to counteract this centrifugal force;
- c) by not providing sufficiently large enough radius.

2.2.3 Vertical Curves

Vertical curves serve as a transition between different gradients. These curves are designed with consideration for comfortable rates of change in grade, adequate sight distance and a pleasing appearance. A driver's speed can be altered if the sight distances are inadequate or the curve does not provide a comfortable rate of change for the car occupants as they move from one gradient to another.

2.2.4 Cross-Sectional Features - A route's cross-sections includes the following elements:

- a) number of lanes;
- b) cross-slope;
- c) width of lanes;
- d) type and width of shoulders;
- e) median and median openings;
- f) type and condition of pavement surface;
- g) curbs.

If the proper planning has been done, these considerations play a lesser role in reductions of operating speeds. For the experienced driver no problem in speed reduction occurs because of the cross-sections features. But the inexperienced driver may unconsciously slow down if the cross-sectional elements change, especially when the lane width drops.

2.3 Posted Speed Limits

This is a legal control which basically controls the speed of a vehicle when none of the other speed controls affect the operating speed.

2.4 Driver Capabilities

The driver is one of the more important elements affecting speed variation along the route. There are numerous factors listed below which affect the driver's capabilities:

1. physical abilities of the driver;
2. training and experience of the driver;
3. familiarity with the vehicle;
4. sex of driver.

Often a driver's training and experience become obvious when the traffic volumes are high and the driver is in the position of having to react quickly to traffic.

2.5 Vehicle Performance

Again this factor can greatly affect the variation in operating speed along a route and the characteristics which most commonly affect the operating speed are:

1. gross vehicle weight;
2. vehicle power to weight ratio;
3. physical dimensions.

2.5.1 Vehicular Weight and Power Weight Ratio

A vehicle's weight becomes a critical speed variation factor on grades. Heavier vehicles and vehicles with low power to weight ratios lose speed more quickly than do lighter vehicles on grades.

2.5.2 Physical Dimensions

Physical dimensions of a vehicle are generally expressed in terms of length, shape, frontal area; and numbers and configuration of axles for trucks. All these features determine the amount of air resistance to which a vehicle is subjected. This difference in air resistance tends to alter the operating characteristics of the vehicle and thus the possible variations in operating speeds.

2.6 Environment

This is the fifth major factor affecting the operating speed of a vehicle and included under the heading environment, are such aspects as:

1. climatic conditions;
2. traffic conditions;
3. existing land uses along the route.

2.6.1 Climatic Conditions

The weather when severe such as heavy fogs, rain or snow; can drastically alter the speed at which a vehicle operates and its speed variation patterns. But these are major deviations from the standard climatic conditions and only in these situations do variations in operating speeds occur.

2.6.2 Traffic Conditions

Traffic conditions have been studied in great depth and it has been proven that traffic volumes also affect the operating speed and variation in operating speeds substantially (16). As traffic builds up, the velocity and changes in velocity occur (see Figure 2.1).

As well as volume increases affecting velocity, the distribution of traffic volumes among the available lanes can affect the velocity and velocity variation. For example if a slow moving vehicle occupies the passing lane, this driver can effectively control the velocity of all vehicles behind him and cause a major disruption to traffic.

2.6.3 Existing Land Use

Adjacent land use can alter a driver's speed patterns. As density of land use increases, so does the number of merging and diverging manoeuvres and it is these manoeuvres interfering with the through traffic which causes traffic speed to vary. Also if the development is sporadic, the driver will speed up and slow down as the situation warrants.

All these variables, individually or together, can cause sudden changes in speeds along a route. Some of these factors such as environment and driver ability are variables which cannot be controlled by the designer. Fortunately the road geometry is one aspect the designer has some control over and therefore could possibly manipulate to control the speed variation which takes place along a route.

VOLUME - DENSITY SPEED - DENSITY SPEED - VOLUME

fig. 2.1 FUNDAMENTAL TRAFFIC STREAM FLOW CHARACTERISTICS

CHAPTER 3

LEISCH'S SPEED PROFILE TECHNIQUE

3.1 Introduction

A new technique has been devised by Leisch (10) which involves regulating the road geometry to maintain the necessary consistency in operating speed along the road. This technique involves a speed profile which takes into account the joint configuration of the horizontal and vertical alignment and the individual curvatures and gradients. The procedure through the use of this data identifies the inconsistencies and provides the direction for corrective measures.

Leisch's technique utilizes the existing design standards as outlined in A Policy on Geometric Design of Rural Highways - 1965 published by the American Association of State Highway Officials (AASHTO). See figure 3.1 for an illustration of the type of output produced by this technique. Leisch claims that "this development, in addition to distinctly signifying the need to tie the speed profile analysis to design speed application, and to serve as an essential tool to adjust and refine highway improvement towards optimizing operations and improving safety, provides a distinct framework for performing elements of research to calibrate this procedure".

This technique also has the advantage that it can be applied to any type of highway; any sort of speed measurement, eg. the mean, the 90th percentile; various sorts of traffic densities; different vehicle types; and also to intersections and interchanges along a route.

fig 3.1 - DEMONSTRATION OF DEVELOPMENT
OF SPEED PROFILES FOR PASSENGER CARS

3.2 Assumptions

Leisch assumes the following conditions in order to utilize the technique.

3.2.1 Free Flow Conditions - This requires that the traffic volumes be small so the speed at which a vehicle can operate is governed only by the design features of the route. This permits a driver to choose his own operating speed based upon the limitations imposed only by the road geometry i.e. independent of other vehicles in the traffic stream.

3.2.2 Favourable weather conditions - daytime and good weather.

3.2.3 The top average running speed and the average speed are used to develop the speed-profile. The average running speed is defined as the average speed for all vehicles over a specified section of roadway which is determined by dividing the summation of distances by the summations of running times - i.e. the time the vehicle is in motion exclusive of stops. AASHO has established a relationship between the design speed and average running speed. Leisch proposes to use the average running speed as the typical speed at which a driver can negotiate a horizontal curve. In more recent research and the tables shown in the RTAC manual, design speed and average running speed are synonymous up to speeds of 100 km/hr. Therefore, for this research, the more recent work which is incorporated in the RTAC manual shall be used (see table 3.1) i.e., the design speed for a specified curve will represent the speed at which a driver can drive the curve.

The top average speed is defined as the speed possible for free-moving vehicles (cars) on open tangent sections of road, free of other geometric constraints. This speed is affected by weather, type of highway, trip length, adjacent land uses and speed limits. Studies (10) have shown that the top average speed also parallels that design speed. Therefore for purposes of this study the top average speed, the average speed, and the design speed are synonymous.

3.2.4 Passenger Car Acceleration and Deceleration

As a vehicle approaches a curve or departs from a curve, the driver must adjust his speed by either accelerating or decelerating depending on the situation.

Acceleration from a curve is affected by two limiting variables.

- a. The distance and extent to which his view is limited by the road geometry beyond the curve from which the driver is leaving.
- b. The difference between the speed possible preceding the curve and that speed possible beyond the curve.

Leisch has developed tables of the rates of acceleration and deceleration which are based on continuous uninterrupted flow operation along a route. These tables are based on the mechanical

capabilities of a passenger car on a level section of roadway (see Tables 3.2 and 3.3). Since passenger cars are not affected as greatly by grades as are trucks, horizontal curves become the major cause for a passenger car to accelerate and decelerate.

Certain of these assumptions must be made in order to establish a theoretical speed profile with which the empirical data can be compared.

3.3 Operation

In setting up a theoretical speed profile as required by Leisch's technique, the design speed on curves and tangents will be used. These speeds are preferred because it is shown to be more typical of the actual speeds observed on various routes.

RTAC provides a table showing the various design speeds for curvatures and superelevations. Therefore, for each curve the associated design speed can be determined. Table 3.5 provides a complete outline of the above data - the degree of curve or radius, design speeds possible. It is simply a matter of locating the radius of curve being reviewed in the appropriate box at the bottom of the columns and then reading the design speed in the column above. For example, if the curve radius is 120 meters, it is simply a matter of locating minimum radius 120 and reading off the

ACCELERATION RATES AT VARIOUS SPEEDS OF PASSENGER CARS

ACCELERATION RATES OF PASSENGER CARS FROM A POINT ALONG A HIGHWAY WHEN ALIGNMENT AHEAD BECOMES CONDUSIVE TO HIGHER SPEEDS

PERCENTAGE OF ACCELERATION RATES FROM CURVE A FOR CONDITIONS WHEN			
SR-REQUIRED SPEED REDUCTION PRIOR TO LIMITING CURVE POINT 1 TO 2	VIEW PERCEIVED BY DRIVER DEPARTING LIMITING CURVE AT POINT 3		RESTRICTED
	UNRESTRICTED	SEMI RESTRICTED	
15 km/h	50%	40%	20%
15-30 km/h	75%	60%	30%
30 km/h	100%	80%	40%

Table 3.2 BASIS FOR PASSENGER CAR ACCELERATION FOR CONTINUOUS (UNINTERRUPTED-FLOW) OPERATING ON HIGHWAYS

LEGEND

- Deceleration for required speed reduction of 15 MPH (25 km/h) or less (based on deceleration in gear)
- - - Deceleration for required speed reduction of 20 MPH (30 km/h) or more (based on "light" braking)

Table 3.3- DECELERATION OF PASSENGER CARS
APPROACHING A CURVE WHICH LIMITS THE SPEED

design speed at the top of the column - 60 km/h, (table assumes that the driver's approach speed to the curve is the same or greater than the speed into the curve).

On the tangent sections of roadway, the speed profile is based upon the top average speed or design speed.

Between the tangent and curve sections of roadway acceleration and deceleration values are determined according to tables 3.2 and table 3.3 which have been reduced to the nomograph in table 3.4 which serve to determine a driver's speed patterns. An additional feature has been added to this nomograph - the gradient beyond the curve which may affect acceleration. This adjustment is also taken from the AASHO Geometric Design Policy. The degree of visibility is also incorporated in table 3.4. For example, see upper portion of table 3.4.

A speed profile developed from the above data provides a continuous plot of the average speed of vehicles along a highway under free-flowing conditions (see figure 3.2). The configuration of the speed profile combines jointly the horizontal and vertical alignment features and instantly points out where speed changes occur because of the road geometry.

table 3.4 - ACCELERATION OF PASSENGER CARS
 DEPARTING A CURVE WHICH LIMITS SPEED

fig. 3.2 DEMONSTRATION SPEED PROFILE APPLICATION

Table 3.5 RELATIONSHIP BETWEEN CURVE RADII AND DESIGN SPEED

Design speed, km/h	40	50	60	70	80	90	100	110	120	130	140
radius, m	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane	A 2 3.6.4 lane lane
7000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
5000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
4000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
3000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
2000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
1500	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
1200	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
1000	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
900	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
800	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
700	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
600	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
500	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
400	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
350	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
300	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
250	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
210	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
200	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
180	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
160	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
140	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
120	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
100	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
90	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
80	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
70	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
60	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
50	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

$$e_{max} = 0.08$$

Notes

- e is super elevation
- A is spiral parameter in metres
- NC is normal cross section
- RC is remove adverse crown and superelevate at normal rate
- Spiral length, $L = A^2$ - Radius
- Spiral parameters are minimum and higher values should be used where possible.
- Spirals are desirable but not essential above the heavy line
- For 6-lane pavement; above the dashed line use 4-lane values, below the dashed line use 4-lane values $\times 1.15$
- A divided road having a median less than 7 m may be treated as a single pavement.

CHAPTER 4FIELD WORK4.1 Introduction

To verify a theory or hypothesis a researcher is required to collect empirical data which will permit comparisons to be made. These comparisons then serve as tools with which the researcher can conclusively state whether the theory or hypothesis is correct or not.

The hypothesis being tested here, is to determine whether route geometry is a critical influencing factor in speed variation. Therefore the null hypothesis can be stated.

H_0 : route geometry is the most significant variable affecting speed variation, therefore the assumptions Leisch made about speed variation are correct.

H_1 : route geometry is not the most significant variable affecting speed variation, therefore the assumptions Leisch made about speed variation are not correct.

The decision rule to test this hypothesis is a level of significance of .01.

Field data to be collected for testing this hypothesis includes the following variables.

- route geometry
- driver age

- driver sex
- vehicle age
- vehicle size
- vehicle condition
- number of occupants.

The data which is collected must be representative of the situation proposed by the theory. The data must also be free of extraneous variables which can influence the results and therefore lead to erroneous conclusions. These factors when related to this research cover the following aspects.

1. the data to be collected in field;
2. the selection of a suitable route which adheres to Leisch's assumptions and is free of extraneous variables;
3. the technique used to collect the data, must be such that it is able to collect all the necessary data without influencing the results.

This chapter will cover each of the above aspects, plus an additional section on how to apply the field technique, to accurately collect the necessary field data.

4.2 Data Collection

In order to answer the two questions posed by this thesis, various types of field data must be gathered. At the beginning of this report, a wide variety of factors were assumed to have a possible influence on speed inconsistency. These factors are:

- the physical characteristics or geometry of the route;
- the posted speed limit on the route;
- the driver capabilities;
- the performance capabilities of the vehicle;
- the environment outside of the roadway within which the vehicle and the driver must operate.

Field data will be collected on all these factors.

4.2.1 Physical Characteristics of Route

This factor can be sub-divided into the following requirements for analysis in this research project:)

1. a test section with a variety of horizontal curves;
2. a test section with a variety of slopes expressed in terms of length and percent slope as well as a variety of vertical crest curves;
3. a test section with consistent cross-sectional geometry;
4. a test section with consistent pavement type and condition;
5. a test section from which the design plans can be obtained.

1. Horizontal Alignment - As pointed out in the introduction of this report and by various other studies (13) "vehicular speeds are lower on horizontal curves than on tangent alignments".

The components which can affect a vehicle's speed in a horizontal curve are superelevation, sight distance and degree of curve.

The amount of superelevation has been investigated by numerous authorities, to determine its influence in speed reduction.

(18, 19, 17). Their studies indicate faster speeds occur on highly superelevated curves than on flat curves. But the changes were not significant. Because of the complexity of measuring speed variation caused by changes in superelevation, this study shall locate a test section of roadway which utilizes a constant amount of superelevation along the entire route. Thereby eliminating speed variations caused by changes in superelevation.

Influence of sight distance along horizontal curves on speed changes will not be considered in this study. Studies done by Taragin (18, 19) concerning the influence of curvature and sight distance under comparable conditions, indicate that curvature caused nearly three times as great a change in speed as did sight distance. Therefore it appears that the prime criterion for speed changes in horizontal curves is the radius of horizontal curve.

In conclusion, the test section of roadway should contain a variety of horizontal curves, all using the same percent of superelevation.

2. Vertical Alignment The vertical alignment has a marked effect on vehicular speed variation. This speed variation is more pronounced on trucks than on passenger cars. The effect of grades on passenger cars is to reduce speed on upgrades greater than 7 percent (22) and to increase speed on downgrades greater than 3 percent (13). The length of grade is not considered to effect the speeds at which passenger cars operate. Therefore for this study, it will be necessary to seek out a test section of roadway which contains up grades less than 7 percent, and down grades less than 3 percent therefore eliminating the effects of vertical grades.

Concerning the influence of vertical curves, drivers reduce their speed as they approach crest vertical curves. The amount of speed reduction appears to increase at an increasing rate with a decrease in the sight distance (13). Sag curves do not affect speed variation to any great extent (13). The test section of roadway should contain a variety of vertical curves of varying sight distance.

Therefore in terms of vertical alignment requirements, the test section should consist of numerous positive and negative grades as well as varying lengths of vertical crest curves.

There is a need, as well as collecting speed change data on vertical alignment and horizontal curves independently; to collect data on sections of roadway where the two types of alignment are combined such as a horizontal curve on an upgrade section of roadway. There appears to be no data on this specific area in terms of the combined affect on speed changes. Therefore field data will be collected on various combinations of horizontal curves and grades to determine their combined effect on speed variation.

3. Cross-Sectional Geometry From studies on cross-sectional geometric impact on speed variation, there are three factors which can be related directly to speed variation. These three factors are - a sudden change in any one of the cross-sectional elements; the presence of a two lane highway where a driver is constantly meeting traffic travelling in the opposite direction; or some restriction of lateral clearance created by an object on the shoulder of the route (20, 21). For this study, the influence of any of the three cross-sectional elements shall be eliminated by selecting a test section of roadway which is consistent throughout in terms of geometric standards. In carrying out the test runs, there should be no objects on the shoulder of road and the on-coming traffic should be minimal.

4. Pavement - Speed variations tend to appear when the pavement type changes or when the condition of the pavement is very poor (8). These two conditions are controlled by the appropriate maintaining body. Therefore for the test section, the pavement should be consistent, preferably bituminous asphalt and the road surface should be in good condition with no potholes.
5. Design Plans - In order to develop Leisch's theoretical speed profile for the test section, design plans must exist. The presence of such plans implies two things. One, the highway design has been based on a specific design speed from which the posted speed limit is derived. Secondly, plans permit geometric data such as the radius of horizontal curve, length and percent of slope to be extracted for the development of the theoretical speed profile.
6. Summary of Criteria - Therefore, in conclusion from the point of view of the physical characteristics of the test section, the following elements must be present:
 - a variety of radii of horizontal curves;
 - a variety of slopes as well a variety of positive and negative grades;
 - a variety of lengths in vertical crest curves;
 - a variety of roadway sections where the vertical and horizontal alignments are combined;

- a consistency in cross-sectional geometry, superelevation, pavement type and condition;
- a set of design plans which follow standard design format.

4.2.2 Driver Capabilities

To generalize, a driver's influence on speed variation is altered by such variables as sex, age, driving experience and occupation etc. (25, 15). From various studies on driver variables, trip distance has the greatest influence on speed. Passengers in the car and the sex of the driver alter driving speeds to a lesser extent. There is no information to indicate whether these factors or others influence speed consistency along a route. For this study the following driver characteristics will be recorded to determine if they have any impact on speed variation:

- sex;
- age;
- number of passengers in the vehicle;
- and relationship to driver where possible.

The factor of length of trip shall be eliminated from the study because of the difficulty in measuring such a variable.

4.2.3 Vehicular Characteristics

Performance characteristics in the past have generally classified highway motor vehicles as passenger cars, single-unit trucks,

combination trucks and buses. This classification is based on factors of gross weight, power rating expressed in kilowatts and speed manoeuvrability. These factors independently or jointly affect such operating characteristics as maintainable speed, load capacity, safety and service. This study will limit its research to consideration of the passenger car classification (large, intermediate, compact, small and sport) which is based on such factors such as gross weight, power rating and speed manoeuvrability.

1. From various studies carried out on vehicular gross weight, there is no consensus of opinion on whether operating speeds vary with different vehicular weights (8, 7, 10). Lefevre's (8) study indicates that operating speeds do not vary with weight, while Laushe's and Manton's studies (7, 10) suggest that operating speeds tend to be higher for heavier passenger cars. None of these studies shed any light on whether heavier vehicles show greater or lesser tendency to speed changes than do lighter vehicles. Therefore because of the lack of information in this area, this study shall attempt to gather data only on the vehicle classification and speed variation to determine if a relationship exists. When gathering data on this relationship, only vehicles without cargo which includes trailers attached to the back, or luggage strapped to the roof; will be considered.

2. In studying the relationship of speed variation and automobile power, certain studies suggest that operating speed is not affected by the power rating (15). While other studies indicate just the opposite (13). But again none of these studies dwell on the possible relationship of speed variation and the power rating.

The gross weight and power rating can be combined to give the weight/power ratio. This ratio indicates the overall performance characteristics of a vehicle. The ratio specifies the number of kilograms of gross vehicle weight for each kilowatt available for propulsion. A high ratio suggests a very sluggish or slow to accelerate vehicle, while a low ratio suggests a high performance vehicle. This ratio has the ability to alter the speed consistency of a vehicle along a stretch of highway by altering the accelerating and decelerating patterns. The Transportation and Traffic Engineering Handbook has tables showing different acceleration rates for various types of passenger vehicles (1).

The classification of vehicles (large car, intermediate car, compact car, small car, and sports car) will be used to test the hypothesis of whether the weight/power ratio does in fact affect the speed variation of a vehicle.

3. Vehicle manoeuvrability is a third characteristic which can vary within the passenger car classification. Manoeuvrability tends to vary with the size of wheel base. Small cars are better able to negotiate tighter curves than larger vehicles. No studies were found to show whether in fact small wheel based cars have the potential to reduce the number of speed changes. It would appear that a dependent relationship would exist between vehicle manoeuvrability and speed consistency along a route. Therefore this study will analyse this relationship for the passenger car classes previously mentioned.

Besides the factors mentioned above, data will be collected on the age of the passenger cars observed. Various research investigations on highway travel characteristics have shown higher average speed for new cars than for older vehicles (2, 3, 25, 8). The reason given for this occurrence is because new cars have higher velocities, ride more comfortably, travel more smoothly and quietly, handle better, and are generally in better mechanical condition. It is quite likely that a difference in speed consistency will also occur between older and new cars. Therefore data will be gathered from field observation to determine if such a relationship actually exists.

4. Summary of Criteria - In conclusion, the following vehicular data will be collected by means of the vehicular classification to determine if there is a correlation between the

following vehicular characteristics and speed variation:

- weight/power ratio of the observed vehicles;
- wheel base of the observed vehicles;
- age of the observed vehicles.

4.2.4 Environmental Factors

1. The operation of the vehicle on the highway is influenced by random factors independent of the driver's capabilities, the roadway geometry, and the vehicular characteristics. This area includes such variables as land use, traffic volumes, weather, time of day, trip purpose and physical view. As mentioned above these factors occur randomly and are therefore difficult to correlate with speed variation. Studies show that speed varies with season, time of day and the severity of the weather. But there is no conclusive evidence to show any direct relationship between the variability of these factors (15). Therefore for this study, it will be necessary to limit the influence of these factors on speed fluctuations.
2. By utilizing a section of roadway with uniform land use, any variations caused by land use patterns and possibly trip purpose will be eliminated. Likewise by carrying out the research work during sunny days the influence of climate, and time of day will be minimized. As previously mentioned free-flow conditions should exist along the test section of roadway. This eliminates any possible effects other vehicles will have on the observed vehicles.

Therefore in this study it will be necessary to eliminate as many as possible of the environmental factors mentioned above.

3. Summary of Criteria - This will be done by the following means:

- by utilizing a test section of roadway which passes through only one type of land use and caters to a specific trip purpose;
- by collecting data on sunny days;
- by recording vehicular movements under "free-flowing" conditions.

4.2.5 Conclusion: This section has outlined all the necessary field requirements, in order to collect a suitable data base. These factors are summarized below:

- a highway which contains a variety of horizontal curves, and vertical curves as well as combinations of vertical and horizontal alignments;
- a highway which has a continuous type of pavement in good condition; there must also be consistency in the cross-section geometry, and superelevation;
- a highway which caters to one type of trip purpose and passes only through one type of land use area;
- a highway for which standard design plans exist;
- a highway which carries a variety of passenger car vehicles, drivers and number of passengers;

- the variety of drivers will be expressed in terms of age and sex;
- the variety of car vehicles will be expressed in terms of large, intermediate, compact and small;
- the field data will be collected on sunny days under "free-flow" conditions.

4.3 Route Selection - The selection of a test section of highway was based on the criteria associated with the route itself, as well as the vehicles and drivers using the route and the surrounding environment, as was listed on table 2.1. The search for a suitable route was centered around Ottawa, to minimize travel to and from the site.

Besides the criteria previously mentioned on table 2.1, an other factor played an important role in route selection. Some efficient means of gathering the vehicle and driver data had to be devised. Stopping each observed vehicle and recording the data, was ideal, but not practical because it would definitely influence the speed patterns. Since it was necessary for the driver to be unaware that he was being followed, it was felt that this data could best be gathered at a stopping point along the route, such as a restaurant, service station, or rest-area. The vehicle and driver data would be recorded at this stopping point and then the speed profile data would be gathered when the vehicle leaves the stop.

The route selected was located approximately 25 km north of Ottawa in the province of Quebec. The Gatineau Parkway, a parkway route of approximately 65 km in length, was felt to be most suitable for this research. This route passes through the rugged, rocky, tree-covered terrain of the Gatineau Park. The attached photographs indicate what the terrain looks like. Because of the rugged terrain, plus the fact that the route has been designed as a parkway, there is an abundant supply of curves and grades present.

This route was built for recreational reasons. It provides access for the residents and visitors of the region to such recreational activities as picnicking, hiking and general viewing of the scenic landscape. Because the route was built with this purpose in mind, the land use pattern is consistent along the full extent of the route. As well as a constant land use pattern, trip purpose is also unified because the parkway has no destinations other than recreational ones.

Another advantage to selecting this parkway is the fact that it caters to a large variety of users whose primary mode of transport on the parkway is the private passenger cars. This variety will provide a rich source of material for the data base.

fig 4.1 HILLY LANDSCAPE TYPICAL OF GATINEAU PARK

fig. 4.2 ANOTHER PHOTOGRAPH OF TERRAIN IN GATINEAU PARK

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The Gatineau Parkway has been built with numerous belvederes and pull-offs developed adjacent to the route, to afford the users ample opportunities to view the surrounding terrain. These stopping points provide the necessary opportunities to gather the driver and vehicle data.

Traffic conditions are such that on weekends the parkway is operating at near capacity levels of traffic. But during the week, the traffic volumes are well within the level of "free-flow" conditions, which is as previously mentioned a requirement for this research.

This parkway has been designed generally to a parkway 40 standards which meets the design standards shown on table 4.1. The necessary design data is available, from which the theoretical data can be extracted. (see figure 4.3)

The pavement is bituminous asphalt for the extent of the route and the condition of the pavement is excellent. Even though the parkway is only two lanes, there is expected to be little interference from on-coming traffic because of the wide 3.75 m lanes and the paved shoulders. (see figures 4.3, 4.4).

Because the route is so lengthy, only a portion of it will be used for the research project. The section selected, is at the terminus of the parkway - Champlain Lookout. Unfortunately, the

DESIGN SPEED	IMPERIAL	METRIC*
AVERAGE RUNNING SPEED	40 MPH	60 KM/H
MAXIMUM CURVATURE	35 MPH	60 KM/H
MAXIMUM GRADIENT	12°	120 M.
SURFACE WIDTH (2)	10%	10%
ROUNDING	22 FT.	6.8 M.
SHOULDER WIDTH	VAR.	VAR.
SIDE SLOPES	3 FT.	1.0 M.
BACK SLOPES	3:1	3:1
MINIMUM SIGHT DISTANCE	VAR.	VAR.
MINIMUM PASSING SIGHT DISTANCE	275 FT.	85 M.
	1,300 FT.	420 M.

* HARD CONVERSION & NOT YET APPROVED BY THE DEPT. OF INDIAN AND NORTHERN AFFAIRS

Table 4.1 PARKWAY 40 DESIRABLE DESIGN CRITERIA

fig. 4.3 TYPICAL SECTION OF PARKWAY ROUTE

parkway splits approximately 1.6 km south of the Champlain belvedere; one route going to Camp Fortune and the other returning to Hull and Ottawa (see figure 4.5). Because it is impossible to predict which route the user will take, two sets of data were collected - one for each route. There were specific reasons for choosing this portion of the route. This section, besides meeting the criteria for the entire route, has a good variety of geometry as is seen from table 4.2. As one can see there are ample types and combinations of alignment present in these two parkway segments.

These two sections pass through heavily treed areas with next to no visual distractions except for Fortune Lake (see figure 4.7) which lies adjacent to the Camp Fortune route. The attached map points out its location. In the data, any slow down in speed caused by the desire to look at the lake was recorded in the data base.

Besides meeting all the criteria specified in table 2.1, there are other reasons for selecting these sections of roadway. The attached map indicate its exact location. The user must travel approximately 35 to 50 km through the park to reach this destination. By the time the user reaches the lookout he will be well acclimatized to the landscape, thus reducing any effects the scenic terrain may have on his speed patterns. A large pull-out is located at the terminus of the parkway, which will permit the necessary driver and vehicle data to be collected (see figure 4.8). Also because of the size of this pull-out, the data can be collected inconspicuously - at a distance. The attached photograph gives some indication of the size of the lookout and parking lot area.

CATINEAU PARK

fig. 4.5 STUDY AREA GATINEAU PARK SCALE: 1:50,000

CHAMPLAIN
LOOKOUT

HUR
LOOK

D

CHAMPLAIN
LOOKOUT

HURON
LOOKOUT

ROUTE

BLACK
LAKE

1 of

DETAIL OF TEST ROUTES
SCALE 1:50,000 TO 1:100,000

2082

ROUTE 2		% OF TOTAL BY LENGTH	% OF TOTAL BY NUMBER
HORIZONTAL CURVES (RADIUS IN METERS)	0 - 80	27	20
	80 - 120	0	0
	120 - 170	23	17
	170 - 230	2	3
	230 - 300	2	3
	300 - 380	2	3
	380 +	6	5
	TANGENT	41	46
GRADES (PERCENT)	+4-+6	0	0
	+3-+4	7	5
	+2	53	42
	-3--5	40	53

table 4.2 GEOMETRIC VARIATION ALONG TEST ROUTE

fig. 4.8 AERIAL PHOTOGRAPH OF CHAMPLAIN LOOKOUT

It was decided to record the speed profiles of vehicles leaving the belvedere rather than vehicles arriving. This was done to reduce the impact of trip purpose on speed fluctuations. Since the parkway user is now returning home or to some other destination, he will be less likely to be distracted by the surrounding landscape and therefore speed patterns will be more closely attuned to the road geometry rather than the surrounding scenic features.

The lengths of the two test sections varied between 5 and 6.5 km. The section going southward back to Hull and Ottawa was 5 km in length, ending at the pull-off to Black Lake. The second route to Camp Fortune was 6.5 km in length and stopped at the entrance to Camp Fortune. There was no statistical reason for selecting test sections of these lengths except for the presence of turn around points.

4.4 Survey Technique

The principal data necessary to formulate the speed profiles are listed below:

- (1) on horizontal curves - the point of deceleration into a horizontal curve, the amount of deceleration, the fixed speed in the horizontal curve; and the beginning and terminating points of acceleration as well as the final speed reached when departing from the curve.

- (2) on grades - the speed changes which take place and the location of where they occur, and speed changes associated with the vertical crest curves.

This sort of data must be gathered on a variety of lengths and percent grades, as well as on a variety of horizontal curves. Also geometric data is required on situations where the road geometry consists of combined horizontal and vertical alignment. These requirements serve as criteria for the appropriate selection of technique and instrumentation for this project.

Other factors besides those above must be considered in the system used for data collection. The equipment must be economical to obtain and operate. Reliability and easy of operation for project personnel is considered to be important. The technique and hardware must give accurate results. In addition, the equipment should be portable or easy to carry around because of the lengthy time period necessary to collect sufficient data. The system must most of all be inconspicuous to all test subjects so not to influence the speed patterns.

There are various satisfactory systems now presently being used to record speeds of moving vehicles. Various pieces of existing hardware can either sense, measure or record speeds; and in combination form a system capable of recording vehicle's travelling speed. The following describes a number of different systems capable of recording accurately spot-speeds. Two general categories of systems are presently in use - one consists of measuring the time required for a vehicle to travel over a fixed distance;

the second involves the use of radar waves which when bounced off a moving vehicle, can record its actual velocity.

The first technique involves measuring off pre-determined lengths along the roadway, then recording the time required by each vehicle to traverse these known lengths of roadway. Then the formula ds/dt gives a velocity reading. This technique can either be done manually or else by a machine. Manually an observer acts as the sensing and a recording device. He activates a stop watch when the vehicle enters the designated length of roadway and stops the watch when the vehicle leaves the designated area. He then records the results on a suitable form or on a dictating machine.

To assist him, is a Mirror Box or Enoscope. The Enoscope bends the viewer's line of sight so that it is at right angles to the path of vehicle movement as it enters or leaves the observed section of roadway.

The mechanical means of carrying out this same operation involves a sensing device or devices located at the beginning and end of the roadway length. This sensing device usually consists of a pneumatic road tube or electrical pressure sensitive trigger which starts and stops by impulse a timer. The sensing device is coupled with various types of recorders or display units which provide direct readings or a graphic record such as a histogram of the vehicle's speed.

Radar or ultrasonic speed sensing devices fall into a second category as a means of measuring a vehicle's speed. Both these pieces of hardware work on the Doppler principle wherein a radio frequency beam or high energy audio tone is directed on the vehicle and the returning signal is shifted in frequency by the movement of the vehicle. The difference between the transmitted and received frequency is evaluated in terms of km/h. Radar data is usually recorded on a graphic recorder. Ultrasonic hardware must be linked to a central centre by standard telephone circuits. This second system does not require measuring sections of roadway nor does it require any hardware to be strung across the roadway as is the case for the first technique.

A third technique is in use to a lesser degree because it is relatively new. This technique involves the car-follow procedure.

There is now on the market radar equipment which does not have to be fixed when determining the velocity of a vehicle. In other words, this equipment can be placed in a moving vehicle and it follows and records the velocities of other vehicles. The output or recording device usually consists of a graphic recorder.

Of the three techniques discussed, the third has the greatest application to this research. As previously specified this project requires speed data be collected from a variety of road geometrics. For techniques one and two to be applicable would require large numbers of observers or hardware depending on the technique to be made available. This

is neither economical nor realistically possible because of present availability of hardware. Another drawback to the first two techniques deals with the need to keep the hardware as inconspicuous as possible, so not to alter the driver's habits. In the rocky tree-covered terrain surrounding the roadway, it would be very difficult to locate the observers and/or hardware so they would have an unobstructed view of the road and at the same time be hidden from the driver's view. Therefore the third technique is the most feasible. What is required is for the hardware to be located in a vehicle which would simply follow the test vehicles at a specified distance. The data would be recorded on a continuous graphic tape.

Unfortunately, this hardware, being relatively new, is very difficult to obtain. The RCMP which patrols Gatineau Park presently are using a limited number of these sort of radar meters. But they could not be made available for this study.

As a result of the review of possible techniques, it was decided to devise one uniquely for this project. The technique developed, is a modification of a recent photographic technique used for general traffic data collection. This technique is referred to as photo-logging. This system through the use of cameras not only records the visual aspects of the roadway in front of the transporting vehicle, but also records changes in the instrumentation readings. The attached photographs illustrate the type of output produced by this system. All the necessary hardware is contained in a single vehicle which by following another vehicle at a fixed

Technical Details

BASIC EQUIPMENT

CAMERA	Specially modified 16mm Bolex or 35mm Automax
ODOMETER	Electronic Digital display in data box repeated on driver/operator control console
DATA SLATE	Pressure-sensitive embossing tape message or Translucent slate/markings pencil or 3 to 6 digit liquid crystal readout
CONTROL CONSOLE	Full control and correction of all sub-systems from driver/operator position

INSTRUMENT LIGHTING Combination electronic flash-lit reflective displays and self-illuminated displays

INSTRUMENT HOUSING Steel suspension frame Aluminum enclosure with removable front and side panels

CABLES AND CONNECTORS Plastic jacketed multi-conductor cables and MS series connectors

INSTRUCTION MANUAL Complete operation and maintenance manual for 16mm or 35mm systems supplied

TOOL KIT AND SPARES Adjustment tool kit and essential spares supplied

INSTALLATION OPERATOR TRAINING Operator training (two days) at Techwest premises
Operator travel and living expenses not included

TURNKEY Systems including vehicle can be supplied

GUARANTEE Against defective materials and workmanship

16mm Film — At one picture every 1 100 of a mile — 100 ft roll covers 40 miles

35mm Film — At one picture every 1 100 of a mile — 400 ft roll covers 64 miles

Separate information sheets with additional technical details and additional instrument options are available upon request.

Sample Frame, Fully-Instrumented 16mm system

DATA SLATE

SPEEDOMETER

CLOCK

CENTRIFUGAL FORCE

ALTITUDE

ROUGHNESS (Long Interval)

ROUGHNESS (Short Interval)

ROUGHNESS CONTROL INDICATORS

GRADE

DIGITAL COMPASS

DRIVER STRESS

ODOMETER

FRAME INTERVAL INDICATORS

fig. 4.9 OUTPUT FROM PHOTOLOGGING TECHNIQUES

distance is able to record its speed variation through the changes in its own instruments. This can be done by taking photographs at either fixed time intervals or else as the changes in the speed pattern are observed. This technique is ideal in that it provides both a continuous visual picture as well as a graphic read out of the speed changes.

One drawback exists to this photo-logging technique - the availability of the specialized camera hardware. The nearest source was Vancouver. Therefore a modification of this technique was developed by the author for use in this research project. A motor-driven camera was attached to the inside cab of a vehicle, so it focused on the speedometer and odometer. This camera was operated by remote control so not to interfere with the driving of the vehicle. The system operated by following a vehicle at a fixed distance and recording all speed changes of the observed vehicle on film from the instrument readings of the project vehicle (see figures 4.10, 4.11 and 4.12). Thus obtaining both a continuous speed reading and distance location of all observed vehicles travelling through the test section of parkway.

A distance of 90 meters was kept between the research vehicle and the observed vehicle. There were two reasons for this distance.

fig. 4.10 EXAMPLE OF READINGS OBTAINED FROM CAR-FOLLOW TECHNIQUE

fig. 4.11 APPARATUS SET-UP IN FRONTSEAT OF THE TEST VEHICLE

fig. 4.12 APPARATUS SET-UP IN BACKSEAT OF THE TEST VEHICLE

Firstly, one, so that a fixed parameter can be added to the field speed profiles, therefore the two profiles theoretical and empirical will be in phase and secondly, so as not to influence the driving habits of the observed vehicle.

This distance requirement was met by adhering a transparent grid onto the windshield (see figures 4.13 and 4.14). The grid spacing represented the width of a large car 20 meters away. Therefore the driver was always aware of the distance between himself and the observed vehicle.

This grid was calibrated by parking 20 meters behind another vehicle and drawing two lines on the windshield showing the width of the vehicle at 20 meters away. The interval between these two lines served as the spacing interval on the grid.

This system required two project personnel. One drove the vehicle and maintained a known distance behind the observed vehicle, while a second person operated the motor-drive camera, by taking a picture every time a change registered on the speedometer. At one time, it was thought that photographs taken every $1/3$ of a second would be the best way of recording the data. But this solution was dismissed because the additional amounts of film processed, provided little additional information for the development of the speed profiles.

fig. 4.13 GRID ATTACHED TO WINDSHIELD WHICH PERMITS THE PROPER DISTANCE TO BE MAINTAINED BETWEEN THE TEST VEHICLE AND THE OBSERVED VEHICLE.

fig. 4.14 POSITION OF RESEARCHER IN BACKSEAT OF TEST VEHICLE

As well as the motor-drive camera recording the speed-profile data, a second camera was utilized and data forms were used to record the remaining field data required to complete the data base. This second camera took a picture of the observed vehicle and its license number (see figure 4.15). While the form supplied such data as age of driver, number of persons in vehicle (by sex and age), time of day, weather conditions, etc. A copy of this form is seen on figure 4.16, along with the coding used for filling in the form quickly.

4.5 Field Procedure

Because of the amount of data being collected for each driver and vehicle, and the need for accuracy; an organized field procedure was developed. Below is listed the data being collected:

- (1) age of driver;
- (2) sex of driver;
- (3) breakdown of car occupants by number, sex and age - re children or adults;
- (4) make of car;
- (5) age of car;
- (6) time of day;
- (7) weather conditions;
- (8) spot speed variations and locations of these variations.

fig. 4.15 PHOTOGRAPH OF OBSERVED SUBJECT PRIOR TO LEAVING THE LOOKOUT.

DATE: _____	NUMBER: _____
TIME OF DAY: _____	WEATHER: _____
CAR: MAKE: _____	LICENCE #: _____
AGE: _____	CONDITION OF VEHICLE: _____
DRIVER: AGE: _____	SEX: _____
OCCUPANTS: NUMBER: _____	ADULT: MALES: _____ FEMALES: _____
	CHILDREN: _____
STARTING POINT: _____	FINISHING POINT: _____
COMMENTS: _____	

DRIVER AGE : 16 - 20 years (1)
 20 - 35 years (2)
 35 - 50 years (3)
 50+ years (4)

VEHICLE AGE: 1970 (1)
 1970-75 (2)
 1975+ (3)

DRIVER SEX: FEMALE (F)
 MALE (M)

VEHICLE SIZE: LARGE (1)
 INTERMEDIATE (2)
 COMPACT (3)
 SMALL (4)

VEHICLE CONDITION: EXCELLENT (1)
 GOOD (2)
 FAIR (3)

fig. 4.16 DATA FORM USED FOR THE SURVEY

Data collection began by waiting at the belvedere for a subject to arrive. By waiting here our main objective in following cars and observing their speed patterns was disguised from the subjects.

(see figures 4.17 and 4.18)

As mentioned before the field data was collected by two individuals. The role of the first individual was to follow the subject at a fixed distance. This person did not collect any of the above data. This was necessary because being the driver, he was fixed in position behind the camera equipment which had to remain in position. Therefore the responsibility for collecting all the vehicle and driver data rested with the second individual in the back seat. This person was able to get out of the research vehicle and closely approach the observed vehicle under the pretense of looking at the view, thereby collecting some of the necessary data. This second person had an additional camera with which he took a rear shot of the vehicle so the license number was clearly recorded - again this was easy to do because cameras were used quite frequently to take pictures of the landscape.

Once this data was recorded, he returned to the research vehicle and as the subject left the belvedere, it was a simple matter of following behind and recording the necessary spot speed data with the apparatus previously described.

Often more than one vehicle was present at the belvedere. In that situation, it was a matter of collecting the driver and vehicle

FIG. 4.17 CHAMPLAIN LOOKOUT - ENTRANCE TO LOOKOUT, TEST VEHICLE WAITING FOR AN, OBSERVATION VEHICLE TO LEAVE THE LOOKOUT (TEST VEHICLE IN YELLOW).

FIG. 4.18 CHAMPLAIN LOOKOUT - TEST VEHICLE IN THE FOREGROUND WITH POTENTIAL SUBJECTS ADMIRING THE SCENIC VIEW IN THE BACKGROUND.

FIG. 4.19 VIEW FROM LOOKOUT

fig. 4.20 TYPICAL SECTION ALONG THE TEST ROUTE

data on all present and following the first vehicle to leave and discarding the miscellaneous data on the other subjects.

4.6 Sample Size

In an experiment designed to statistically measure a given population through sampling techniques, one must determine a sufficient and economical sampling size. In this study, the population is all car vehicles passing through the test sections of roadway previously referred to. The sampling size more specifically is ascertained by resolving the following question - how many measurements must be made and with what precision, in order to estimate the true mean with an acceptable accuracy at a given level of confidence? In this situation a suitable sample size could only be determined with great difficulty because:

- there are 3 aspects making up speed variation (location of the speed change, magnitude of the speed change and the direction of the speed change). Each of these factors would have to be analyzed independently to determine an acceptable sample size for each.
- It is impossible to determine sample sizes for "students" distribution, because a pilot project study would be necessary to determine an acceptable standard deviation and the 10 day data collection period did not permit this.

Therefore, determination of a suitable sample size was dismissed.

In its place the research team collected as many samples as possible in a 10 day period, with the hope of collecting at least 50 samples.

During this period, 60 subjects were observed and their speed variation patterns recorded. Unfortunately 18 samples had to be rejected because various extraneous factors affected their speed variation patterns, therefore leaving 22 sets of data for route 1, 11 for route 2 and 9 for portions of the two routes making a total sample size of 42.

CHAPTER 5

ANALYSIS

5.1 Introduction

This chapter deals with the data analysis, how it was done, and the results. Two expressions of speed variation were studied by means of analysis of covariance. A third aspect of speed variation was studied through the use of overlays.

Analysis of covariance was used to evaluate the contribution made by each of the categorical variables (nonmetric) and metric variables towards accounting for the variation in the dependent variable (speed variation).

The steps followed in preparing and analyzing the data are listed below:

- 1) defining the variables to be used in the analysis;
- 2) implementing the covariance analysis
- 3) comparing overlays;
- 4) compiling the results of the analysis.

5.2 Variables

Speed variation was divided into three component parts, each requiring independent assessment to determine the impact of route geometry. These component parts are listed below. (see figure 5.1).

fig. 5.1 SPEED PROFILE

1. The location where the speed change takes place along a route.
2. The amount of magnitude of the speed change.
3. The direction of the speed change.

The first two components were analyzed using statistical techniques, while the third relied upon the use of an overlay technique.

The components of speed variation were studied as a function of the following variables.

- route geometry;
- driver's age;
- driver's sex;
- vehicle age;
- vehicle size;
- number of occupants.

Because of the difficulty in accurately measuring a vehicle's condition, this variable was dropped from the analysis.

To statistically analyze each of the first two components and its associated independent variables, mathematical expressions had to be formulated.

Since the data was not sufficiently accurate to warrant comparative examination of sites along the test routes, trends were studied by comparative analysis of route segments. Therefore the mathematical expressions used lend themselves to trend analysis.

Expressions of the dependent components are listed below:

1. Location of speed changes was represented by the frequency of speed change or the number of times a vehicle changed its speed along a selected route segment.
2. The magnitude of the speed change was represented by the following variation term.

$$\text{Magnitude of speed change} = \left[\frac{(X - \bar{X})^2}{n} \right]^{\frac{1}{2}}$$

where: X is a speed measurement taken every kilometers along the route segment.

n is the number of kilometers making up the route segment.

$\bar{X}$ is the sum of measured speeds divided by n.

To extract these measures from the collected speed data, profiles identical to those formulated by Leisch were drawn up. (see figure 5.1). From these profiles the various numeric measures could be formulated.

Expressing the independent variables in mathematical terms was relatively straightforward. Since Leisch's technique is based on geometric variables, it is a simple matter to extract corresponding expressions for frequency of speed change and magnitude of speed change to represent route geometry.

5.3 Results

Because part of the data-base contained categorical data (nonmetric data) as well as integral data or metric data, analysis of

covariance was selected to analyze the data. The nonmetric variables being the driver and vehicle characteristics and the metric variables were the geometric and number of occupants variables. (These variables are expressed as absolute rather than as being a category).

As was indicated in Appendix A, the first step of the analysis was to determine the metric-nonmetric interactions. A correlation matrix utilizing Pearson's correlation coefficient (R^2) was considered to be appropriate. The results of this work are seen on table 5.1. There appears to be no significant interactions between any of the metric and nonmetric variables, with the most significant interaction occurring between variables "number of occupants" and "driver age" (correlation .2542). Therefore, these results indicate that analysis of covariance can be safely carried out on all metric and nonmetric variables listed, without concern for possible metric-nonmetric interactions which would confuse the results.

The results of the analysis of covariance are seen on tables 5.2 through to 5.5. The first table (5.2) displays the results of the analysis between the dependent variable (observed frequency of speed change) and the independent variables (Leisch's frequency of speed change, number of occupants; driver age and sex; vehicle age and size). This table shows the overall model to be significant at the .0021 level. Therefore the variables selected are the ones most likely to influence the location of a speed change and no other possible factors have been omitted. The fact that there are no significant interactions between any of the nonmetric variables, suggests, that none

METRIC	NON-METRIC			
	DRIVER AGE	DRIVER SEX	VEHICLE AGE	VEHICLE SIZE
LEISCH'S FREQUENCY OF SPEED CHANGE	-.0204	.09776	.05881	.03225
LEISCH'S MAGNITUDE OF SPEED CHANGE	.05258	.11361	.15786	.0954
NUMBER OF OCCUPANTS	.2542	.01249	.0809	.2838

Table 5.1 CORRELATION BETWEEN METRIC AND NON-METRIC
VARIABLES

SOURCE OF VARIATION	SUM OF SQUARES	D.F	MEAN SQUARE	F	SIGNIF. OF F
COVARIATES	897.50171	2	448.75073	43.535	.00000
- LEISCH'S FREQUENCY OF SPEED CHANGE	871.75977	1	871.75977	84.573	.0000
- NUMBER OF OCCUPANTS	17.896561	1	17.896561	1.736	.20251
MAIN EFFECTS	197.33447	9	21.926041	2.127	.07671
- DRIVER AGE	61.779800	3	20.593262	1.998	.14676
- DRIVER SEX	4.7252274	1	4.7252274	.458	.50612
- VEHICLE AGE	41.384903	2	20.692444	2.007	.16050
- VEHICLE SIZE	9.8502636	2	4.9251318	.478	.62704
2 WAY INTERACTIONS	58.651123	10	5.8651123	.569	.81979
- DRIVER AGE and DRIVER SEX	.13487738	1	.13487738	.013	.91007
- DRIVER AGE and VEHICLE AGE	10.087976	2	5.0439882	.489	.62018
- DRIVER AGE and VEHICLE SIZE	26.404007	4	6.6010017	.640	.63985
- DRIVER SEX and VEHICLE AGE	1.4469023	1	1.4469023	1.314	.26077
- DRIVER SEX and VEHICLE SIZE	.30828577	1	.30828577	.030	.86444
- VEHICLE AGE and VEHICLE SIZE	2.8859987	2	1.4429980	.140	.87021
EXPLAINED	1153.4873	21	54.927963	5.329	.0021
RESIDUAL	206.15503	20	10.307751		
TOTAL	1359.6423	41	33.162003		

Table 5.2 ANALYSIS OF COVARIANCE FOR THE LOCATION OF THE
SPEED CHANGE

of the nonmetric variables through influencing each other affect the dependent variable. Because this research considers a .01 level to be an acceptable level of significance, the joint additive main effect is also non-significant. Likewise none of the nonmetric variables independently account for any significant portion of the variation present in the dependent variable.

On the other hand, the covariates are very significant (.0000) with Leisch's frequency of speed change variable being the significant factor (.0000).

Table 5.3, the Multiple Classification Analysis elaborates on the statistical findings of table 5.2, by showing both unadjusted and adjusted deviations (the mean of each category expressed as a

deviation from the grand mean) for each nonmetric variable.

The η^2 for each variable indicates the portion of variation in the dependent variable explained by that specific variable.

In this case, driver age accounts for the greatest portion of variation in the observed number of speed changes - 16% (.397²)

by any one nonmetric variable. Vehicle size, vehicle age and driver sex each independently account for 7%, 6% and 2% of the variation in the dependent variable. Leisch's frequency of speed change variable independently accounts for the greatest portion of variation - 70%.

When controlling for the confounding effects of the other variables, the contribution made by each metric variable towards the

2 2
OF/DE

VARIABLE AND CATEGORY	DEVIATIONS UNJUSTED	DEVIATIONS ADJUSTED FOR INDEPENDENTS & COVARIATES
LEISCH'S FREQUENCY OF SPEED CHANGE		BETA .8355443
NUMBER OF OCCUPANTS		BETA -.4434288
DRIVER AGE	ETA .397	BETA .229
16-20	-.64228528	-2.455804
20-35	-1.880948	-.3123474
35-50	.7417603	-.8106384
50+	4.357147	2.793198
DRIVER SEX	ETA .108	BETA .072
MALE	.1992493	.1330566
FEMALE	-1.892853	-1.264755
VEHICLE AGE	ETA .242	BETA .198
<1970	4.857147	-.6060791
1970-1975	-1.489014	-1.625046
1975+	.3571472	.8272095
VEHICLE SIZE	ETA .164	BETA .103
LARGE	-.2792206	-.4613495
INTERMEDIATE	1.357147	.8753967
COMPACT	-.8095245	-.3504181
MULTIPLE R ²		.805
MULTIPLE R		.897

Table 5.3 MULTIPLE CLASSIFICATION TABLE FOR THE FREQUENCY OF SPEED CHANGE

variation in the dependent variable drops. (see column 2).

Driver age still remains the one nonmetric variable accounting for the largest portion of the variation in the dependent variable - 5.24%.

The multiple R, the statistic at the bottom, indicates the overall relationship between the dependent variable and the independent variables, while R^2 represents the portion of variation in the dependent variable explained by the additive effects of all metric and nonmetric variables. Both statistics show the high ability of the independent variables to explain the variation in the dependent variable ($R = .897$ and $R^2 = .805$).

The results from both tables 5.2 and 5.3 show the variable "Leisch's frequency of speed change", to be the one factor most strongly influencing the dependent variable "observed number of speed changes". Driver age is the one nonmetric variable making the largest contribution to the variation of the dependent variable (15%). Because the R^2 and Multiple R register quite high (.805 and .897), the independent variables selected for this analysis are complete in terms of what variables could possibly influence the location of speed changes.

When these results are applied to the purpose of this thesis, one would conclude the following.

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF. OF F
COVARIATES	1.4073896	2	.70369482	.810	.45892
- LEISCH'S MAGNITUDE OF SPEED CHANGE	.8797011	1	.87978011	1.013	.32627
- NUMBER OF OCCUPANTS	1.0915804	1	1.0915804	1.257	.27559
MAIN EFFECTS	8.1674767	9	.90749741	1.045	.44109
- DRIVER AGE	6.7875519	3	2.2625170	2.604	.08022
- DRIVER SEX	.29913686E-01	1	.2991368E-01	.034	.85466
- VEHICLE AGE	.22688717	2	.11344355	.131	.87832
- VEHICLE SIZE	.18386062E-01	2	.91930293E-01	.011	.98948
2 WAY INTERACTIONS	23.115204	10	2.3115196	2.661	.02996
- DRIVER AGE and DRIVER SEX	1.9051580	1	1.9051580	2.193	.15422
- DRIVER AGE and VEHICLE AGE	3.8036184	2	1.9018087	2.189	.13812
- DRIVER AGE and VEHICLE SIZE	1.6495371	4	.41238427	.475	.75381
- DRIVER SEX and VEHICLE AGE	1.4469023	1	1.4469023	1.314	.26077
- DRIVER SEX and VEHICLE SIZE	1.9675522	1	1.9675522	2.265	.147977
- VEHICLE AGE and VEHICLE SIZE	4.7577667	2	2.3788834	2.738	.08889
EXPLAINED	32.690070	21	1.5566702	1.792	.09879
RESIDUAL	17.374680	20	.86873394		
TOTAL	50.064758	41	1.2210913		

Table 5.4 ANALYSIS OF COVARIANCE FOR THE MAGNITUDE OF THE SPEED CHANGE

VARIABLE AND CATEGORY	DEVIATIONS UNJUSTED	DEVIATIONS ADJUSTED FOR INDEPENDENTS & COVARIATES
LEISCH'S MAGNITUDE OF SPEED CHANGE	BETA .1161798	BETA .1161798
NUMBER OF OCCUPANTS		
DRIVER AGE	ETA .358	BETA .413
16-20	1.952573	2.184088
20-35	.999371E-01	.1051207
35-50	-.4091635	-.4836493
50+	.1809483	.2707863
DRIVER SEX		
MALE	ETA .103	BETA .031
FEMALE	.3659058E-01	-.1083374E-01
	-.3476210	.1028404
VEHICLE AGE		
<1970	ETA .070	BETA .137
1970-1975	.1524858	.6698093
1975+	-.1091623	-.3240967E-01
	.4126358E-01	-.3402138E-01
VEHICLE SIZE		
LARGE	ETA .061	BETA .023
INTERMEDIATE	-.3851414E-01	.4044533E-01
COMPACT	.9852886E-01	-.6198883E-02
	-.4762554E-01	-.2025604E-01
MULTIPLE R ²		.191
MULTIPLE R		.437

Table 5.5 MULTIPLE CLASSIFICATION TABLE FOR THE
MAGNITUDE OF SPEED CHANGE

VARIABLE AND CATEGORY	DEVIATIONS UNJUSTED	DEVIATIONS ADJUSTED FOR INDEPENDENTS & COVARIATES
LEISCH'S MAGNITUDE OF SPEED CHANGE	BETA .1161798	BETA .1161798
NUMBER OF OCCUPANTS		
DRIVER AGE	ETA .358	BETA .413
16-20	1.952573	2.184088
20-35	.9999371E-01	.1051207
35-50	-.4091635	-.4836493
50+	.1809483	.2707863
DRIVER SEX		
MALE	ETA .103	BETA .031
FEMALE	.3659058E-01	-.1083374E-01
	-.3476210	.1028404
VEHICLE AGE	ETA .070	BETA .137
<1970	.1524858	.6698093
1970-1975	-.1091623	-.3240967E-01
1975+	.4126358E-01	-.3402138E-01
VEHICLE SIZE	ETA .061	BETA .023
LARGE	-.3851414E-01	.4044533E-01
INTERMEDIATE	.9852886E-01	-.6198883E-02
COMPACT	-.4762554E-01	-.2025604E-01
MULTIPLE R ²		.191
MULTIPLE R		.437

Table 5.5 MULTIPLE CLASSIFICATION TABLE FOR THE
MAGNITUDE OF SPEED CHANGE

any of the main effects account for a significant portion of the total variation. Therefore none of the nonmetric variables influence the dependent variable. Similarly none of the metric or covariates affect the dependent variable.

The Multiple Classification Analysis (table 5.5) shows that driver age is the one single most significant variable, accounting for 12.82% of the variation present in the dependent variable, followed by driver sex, vehicle age, and vehicle size each responsible for 1.06%, .49%, and .372% of the total deviation of the dependent variable. The two metric variables account for 1.35% and 1.3% of the variation. This places these two variables in second and third place i.e., the 2nd and 3rd most significant variables affecting the dependent variable.

Because of the near significant overall two-way interaction, this prohibits further analysis of the data (i.e., the adjusted nonmetric deviations).

The multiple R and R^2 indicate the small amount of explained deviation provided by the metric and nonmetric variables (R^2 - .191 and R - .437).

The results of these two tables suggest little of the deviation in the dependent variable - "magnitude of speed change" was accounted for by the nonmetric and metric variables. The driver characteristics age and sex explain the greatest amount of variation in the dependent variable. Because R and R^2 are small (.437 and .191), the independent variables selected do not

adequately explain the deviation present, and possibly some other variables should be considered.

When applying these results to the thesis purpose the following conclusions can be reached.

1. The variables selected to represent the variation found the magnitude of a speed change do not adequately reflect this variation.
2. Of those variables studied the driver characteristics (age and sex) seem to be the strongest influence on the magnitude of a speed change.
3. Route geometry in terms of the variables studied is the second most significant factor affecting the magnitude of a speed change. But the amount of variation that route geometry accounts for is very small (1.95%).

Therefore Leisch's technique as it presently exists does not reflect the entire complexity of the speed variation component - magnitude of speed change. But from the data analyzed there is no one variable which significantly represents this component. Therefore under the existing circumstances, one can only say that Leisch's technique could somewhat be improved by incorporating a variable to account for driver characteristics.

5.4 Overlays

Besides using analysis of covariance to determine the significant factors influencing speed variation, speed profiles of the observed subjects were drawn up on transparencies, following the

same format and scaling used on Leisch's speed profiles. The purpose for doing this was to determine the accuracy of the statistical results. By categorizing the observed profiles by relevant variables, composite drawings were produced (see Appendix B). One, then could quickly determine the similarities and differences in the patterns. These composite drawings also permitted the third component of speed variation to be studied - the direction of the speed change.

The grouping of profiles by driver age appears to provide the best possible fit when attempting to group all profiles by some common denominator and therefore is the best factor to account for direction of speed change.

Figures 5.2 and 5.3 illustrate the relationship between Leisch's theoretical speed profile and an average field speed profile derived from the collected data, for each of the two routes. These graphs reinforce the statistical findings. As well, they shed some light on the third component of speed variation - the direction of the speed change. It would appear there must be other variables besides route geometry (Leisch's theoretical profile) which influence the direction of the speed change.

5.5 Conclusions

The following conclusions can be drawn from the results of this detailed analysis.

14.5.2 SPEED PROFILE FOR ROUTE 1

fig. 5.3 SPEED PROFILE FOR ROUTE 2

1. Route geometry plays a significant role in the frequency of the speed change.
2. Driver age is the only other variable which significantly affects the frequency of the speed change.
3. Driver variables such as driver age and driver sex are the most significant factors influencing the magnitude of the speed change.
4. Route geometry affects the magnitude of the speed change but to a much lesser degree than the driver characteristics.
5. Driver age seems to be the factor most strongly influencing the direction of speed change.
6. Route geometry does not appear to be a strong influencing factor on the direction of the speed change.
7. Leisch's assumptions are correct when dealing with the aspect of location of the speed change.

Therefore it is assumed to be acceptable as a variable representing the location of the speed change. But it does not incorporate into its diagnostics the driver element which appears to affect speed variation (the magnitude of the change and the direction of the change).

8. Other variables besides those researched in this thesis appear to affect speed variation to a certain extent, especially the magnitude of the speed change.

CHAPTER 6

CONCLUSION

6.1 Summary

As was stated in the introduction of this thesis, the purpose of this research was two fold:

1. to determine if the geometric characteristics are the major cause of speed variation for passenger cars along a parkway.
2. if so, to validate Leisch's technique under these circumstances.

In analysing the first factor, field data was gathered in Gatineau Park. This data pertained to such driver characteristics as age and sex; and such vehicle characteristics as age, size and condition. Route geometry and number of occupants served as additional data, gathered in order to determine what factors most strongly influenced a driver's speed patterns.

Analysis of covariance served as the analytical tool to statistically determine which of the above factor significantly influence one's speed variation patterns. To carry out the analysis, the first step was to break the dependent variable into three components:

1. location of speed variation (frequency);
2. magnitude;
3. direction of speed variation.

Upon carrying out the analysis on the first two factors, a manual overlay technique was carried out to check the statistical results from the covariance analysis, as well possibly providing some greater insights into speed variations patterns and permit analysis of the third component.

6.2 Conclusions

As a result of the above research, the following conclusions can be reached pertaining to the objectives of this research work.

1. Route geometry plays a significant role in the frequency of the speed change.
2. Driver age is the other variable which plays a significant role in the frequency of the speed change.
3. Driver variables such as driver age and driver sex are the most significant factors affecting the size of speed change.

4. Route geometry affects the magnitude of the speed change to a much lesser extent than it does the speed change frequency.
5. Driver age appears to affect the direction of the speed change to a much greater extent than does route geometry.
6. Leisch's technique as it has been formulated is an acceptable technique in determining where speed changes take place.

But since it does not incorporate into its diagnostics the driver element which appears to affect the amount of speed change and the direction of the speed change.

One concludes that the technique should be researched further, so a driver factor can be incorporated into the technique.

6.3 Recommendations

As a conclusion, to the work done to-date, there appears to be certain areas which require further research. Below are listed areas where further research should be undertaken to fully answer the objectives studied by this thesis.

1. Because certain speed patterns appear randomly across the various factors studied as seen through the manual technique, there is need to further assess other possible factors influencing speed variation. The following factors are felt worthy of study, to determine their impact on speed variation:

- mood of driver;
- familiarity with the route;
- trip purpose;
- posted speed limit;
- higher designed highway;
- a route which has fewer geometric changes.

2. Further research into Leisch's technique is requested so driver characteristics i.e. age and sex can be incorporated into the technique.

At present, there are certain recommendations which can be made to the designer, to assist in making a safer highway.

1. Because the speed variation of automobiles occurs where the horizontal alignment changes the designer should carefully check to ensure that adequate sight distances are present in these locations, especially those which could cause speed changes greater than 15km/h.
2. As seen from the results concerning the magnitude of the speed change, there is little the designer can do towards controlling this factor.
3. Likewise the designer has little to do with regulating the direction of the speed change.

GLOSSARY

Average Running Speed - the average speed for all vehicles over a specified section of roadway which is determined by dividing the summation of distances by the summations of running times - i.e. the time the vehicle is in motion exclusive of stops.

Design Speed - the maximum safe speed that can be maintained over a specified section of highway when conditions are so favourable that the design features of the highway govern. Favourable conditions includes good weather, little or no traffic on the highway; and no effect of speed limit signing.

Free-Flow Conditions - the traffic volumes are so small that the speed at which a vehicle can operate is governed only by the design features of the route. This permits a driver to choose his own operating speed based upon the limitations imposed only by the road geometry.

Pearson's Correlation Coefficient - a measure of the linear association between two variable.

Sight Distance - used in reference to two types of manoeuvres - stopping and passing. Stopping sight distance is the total distance travelled by a vehicle from the instant the need to stop is visible to the driver until the vehicle actually stops. Passing sight distance is that distance travelled by a vehicle from the time the driver observes a slower vehicle and decides to pass, until the passing vehicle returns to the right-hand lane.

Top Average Speed - the speed possible for free-moving vehicles (cars) on open tangent sections of road, free of other geometric constraints. This speed is affected by weather, type of highway, trip length, adjacent land uses and speed limits.

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APPENDIX A

Analysis of Covariance

ANALYSIS OF COVARIANCE

Introduction

Analysis of covariance is a statistical technique which analyzes the relationship between a dependent or criterion variable and set of independent variables which are a combination of metric and nonmetric variables. The analysis is based on stepwise multiple regression and creates dummy variables to account for categorical data.

The basis of analysis of covariance is the decomposition of variation into two independent components.

$$SS_y = SS_{\text{between}} + SS_{\text{within}}$$

$$\text{where } SS_y = \sum (Y - \bar{Y})^2$$

in which $\bar{Y}$ is the mean of Y over the whole sample (known as the grand mean), and Y is the summations over all individual cases in each category of the factor A.

$$SS_{\text{between}} = N (\bar{Y} - \bar{\bar{Y}})^2$$

in which $\bar{Y}$ is the mean of Y in the category, and N is the number of cases in category.

$$SS_{\text{within}} = \sum (Y - \bar{Y})^2$$

These formula can be expressed in another way. SS_{between} is that portion of variation in Y due to factor A (it can be rewritten SS_A).

SS_{within} is that portion of variation in Y due to the variation within each category of A (it can be rewritten SS_{error}).

The statistical measure of strength between factor A and Y is the ratio.

$$\eta^2 = \frac{SS_y - SS_{\text{error}}}{SS_y}$$

The value of η^2 will be 1.0 if and only if there is no variability within each category of A and there is some variability between categories. The index will be zero if and only if there is no difference among the means of the three categories. Therefore $\eta^2 = 0$ indicates that factor A has no effect on Y.

The null hypothesis usually tested in variance analysis is $\sigma_1 = \sigma_2 = \sigma_3 = 0$ or $\eta^2 = 0$. This is based on the following sampling theory. If there is no difference between groups in the population, that is $\sigma_1 = \sigma_2 = \sigma_3 = 0$, both SS_A and SS_{error} come from the same source of variation - "error". If samples were drawn randomly, the estimation of the population variance based on the between category variation (SS_A) and the estimate of population variance based on the within category variations (SS_{error}), are independent estimates of the same quantity - the population variance of Y. The F ratio between these two estimates

$$F = \frac{SS_A / (k - 1)}{SS_{\text{error}} / (N - K)} = \frac{MS_A}{MS_{\text{error}}}$$

follows the F distribution, with (k-1), the number of categories in A-1, and (N-K) degrees of freedom.

When dealing with analysis of covariance, there is more than one variable and the overall expression becomes.

$$SS_y = SS_A + SS_B + SS_{AB} + \dots + SS_{error}$$

An interaction, (SS_{AB}) and an additive effect ($SS_A - SS_B$) must also be analyzed besides each independent category.

Normally the order of analysis is as follows.

1. to test for the significance of the overall factors ($SS_A + SS_B + SS_{AB}$).
2. to test the significance of the interaction (SS_{AB}).
3. to test for the significance of each factor ($SS_A, SS_B, \dots$).

The basic output from the analysis of covariance provides the following types of information.

1. η^2 to be used as descriptive indicators of the overall relationship between Y and above components.
2. F ratio and accompanying statistic to be used for testing statistical significance.
3. estimates of effects of differences among the category means, to be used in interpreting the "pattern" of the independent variable effect.

Analysis

To carry out this analysis, a computer package called SPSS, available at Carleton University was used. This package contains nearly all the necessary statistics to carry out analysis of covariance.

Unfortunately there was one draw back. This package did not provide a test for covariate-by-factor interaction. To do this work, required using one of the other statistical packages (REGRESSION) available through SPSS.

Therefore the first step in the analysis was to determine the covariate-by-factor interactions. To carry out this exercise, Pearson product-moment correlation coefficient (r) was used.

$$r = \frac{\sum_{i=1}^n (X_i - \bar{X})(Y_i - \bar{Y})}{\left[\sum_{i=1}^n (X_i - \bar{X})^2 \sum_{i=1}^n (Y_i - \bar{Y})^2 \right]^{1/2}}$$

Where X_i equals the i th observation of variable X , and Y_i represents the i th observation of variable Y . N is the number of observations, $\bar{X}$ represents the mean of X and $\bar{Y}$ represents the mean of variable Y .

Once completed and possible interactions recognized, the classic experimental design approach to analysis of covariance was used to analyze the data. This approach partitions the total sum of squares (corrected for mean) into the following three types:

$SS_{A,B}$ = sum of squares due to additive effects of A and B

SS_{AB} = sum of squares due to the interaction effect - $SS_{A,B,AB} - SS_{A,B}$

SS_{error} = sum of squares due to error - $SS_Y - SS_{A,B,AB}$

Once these partitions are carried out the additive effects of A and B are broken down into separate main effects.

$$SS_{A, \text{ adj for } B} = SS_{A,B} - SS_B$$

$$SS_{B, \text{ adj for } A} = SS_{A,B} - SS_A$$

This approach was selected because one does not know the causal order between variables and one assumes that the main effects are more important than the interaction effects.

In carrying out this assessment interactions of a higher order are of little interest. Therefore only 2-way interactions were considered.

As part of the statistical output from this package program, a multiple classification table was produced. This table provides the means for each category variable expressed as deviations from the grand mean, along with the eta (common correlation ratio) and partial beta statistics (standardized partial regression coefficient). Two sets of these statistics were produced, one in unadjusted form and a second adjusted for variation accounted for by all other nonmetric and metric variables.

The square of eta indicated the proportion of variance explained by a given nonmetric variable (all categories combined).

Accompanying this output, the multiple R value (multiple correlation between the dependent variables and all nonmetric, metric and nonmetric-by-nonmetric interaction term).

APPENDIX B

Results of Overlay Techniques

5

Attached are the composite overlays. Each drawing shows all subjects which fall under the category listed at the top. Each various line represents the signed V.S. distance profile for an individual subject.

5

Fig. 5.2 SPEED PROFILES FROM OBSERVED SUBJECT

1 of

RYED SUBJECTS

28

13083

ROUTE - 1

VARIABLE

CATEGORY

DRIVER AGE - 20-35 years

Fig. 5.3. SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

VIDEO SUBJECTS

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ROUTE 1

VARIABLE

CATEGORY

DRIVER

AGE -

35-50 years

fig. 5.4 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

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OBSERVED SUBJECTS

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ROUTE 1

VARIABLE

CATEGORY

DRIVER

AGE- 50+ years

SPEED - km/h

DISTANCE - km

fig 5.5: SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

OBSERVED SUBJECTS

28

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ROUTE . 1

VARIABLE

CATEGORY

VEHICLE

AGE - 1975 +

fig 5.6 SPEED PROFILES FROM OBSERVED SUBJECTS

28

OBSERVED SUBJECTS

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ROUTE: 1 VARIABLE: CATEGORY: VEHICLE: AGE: 1970-75

fig. 5.7 SPEED PROFILES FROM OBSERVED SUBJECTS

SERVED SUBJECTS

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ROUTE 1

VARIABLE

CATEGORY

VEHICLE

AGE 1970

fig. 5.6 SPEED PROFILES FROM OBSERVED SUBJECTS

OBSERVED SUBJECTS

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ROUTE 1

VARIABLE CATEGORY VEHICLE SIZE - LARGE

fig. 5.9 SPEED. PROFILES FROM OBSERVED SUBJECTS

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OM OBSERVED SUBJECTS

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ROUTE . I VARIABLE CATEGORY . VEHICLE SIZE - INTERMEDIATE

fig. 5.10 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

The graph displays three data series over a horizontal axis labeled 'm' with values 5, 3, 5, 4, 5, 5, 5. The vertical axis is labeled 'IMMEDIATE'. The series are represented by solid, dashed, and dotted lines. The solid line starts at a high value, drops to a low value at m=3, rises to a peak at m=4, and then drops sharply to a low value at m=5. The dashed line starts at a low value, rises to a peak at m=3, drops to a low value at m=4, and then rises to a peak at m=5. The dotted line starts at a high value, drops to a low value at m=3, rises to a peak at m=4, and then drops to a low value at m=5.

5 3 5 4 5 5 5 5 6

m

OBSERVED SUBJECTS

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ROUTE 1

VARIABLE

CATEGORY

VEHICLE SIZE

COMPACT

fig. 5.11 SPEED PROFILES FROM OBSERVED SUBJECT'S

OBSERVED SUBJECTS

28

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fig. 5.12 SPEED PROFILES FROM OBSERVED SUBJECTS

OBSERVED SUBJECTS

28

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ROUTE 2

VARIABLE

CATEGORY

DRIVER AGE - 35-50 years

fig. 5.13 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of

SERVED SUBJECTS

28

ROUTE 2

VARIABLE

CATEGORY

DRIVER

AGE 20-30 years

fig. 5.14 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of

SERVED SUBJECTS

28

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ROUTE 2 VARIABLE CATEGORY VEHICLE AGE 1970-75

fig. 5.15 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

M OBSERVED SUBJECTS

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ROUTE 2 VARIABLE CATEGORY VEHICLE AGE 1975

SPEED - km/h

DISTANCE - km

fig 5.16 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of

SERVED SUBJECTS

28

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ROUTE - 2

VARIABLE CATEGORY, VEHICLE SIZE - LARGE

fig. 5.17 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of 1

OBSERVED SUBJECTS

28

383

ROUTE 2

VARIABLE

CATEGORY

VEHICLE

SIZE - INTERMEDIATE

SPEED - km/h

DISTANCE - km

Fig. 5.18 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of

ATE

SERVED SUBJECTS

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ROUTE 2

VARIABLE

CATEGORY

VEHICLE

SIZE -

COMPACT

fig. 5.19 SPEED PROFILES FROM OBSERVED SUBJECTS

1 of

ERVED SUBJECTS

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FIN