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TRAFFIC MANAGEMENT PERFORMANCE – DEVELOPMENT OF A TRAFFIC FRUSTRATION INDEX

AUSTROADS

Traffic Management Performance – Development of a Traffic Frustration Index

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- Transport South Australia
- Department of Infrastructure, Energy and Resources Tasmania
- Department of Transport and Works Northern Territory
- Department of Urban Services Australian Capital Territory
- Commonwealth Department of Transport and Regional Services
- Australian Local Government Association
- Transit New Zealand

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Foreword

Austroads project Traffic Management Performance Measures was established to determine whether a Traffic Frustration Index, which quantified the events which contributed to driver frustration, would be a useful supplement to measures such as traffic speed and flow in identifying priorities for traffic management interventions and assessing the outcomes of such interventions.

The Traffic Management Performance Measures project proceeded in four stages, each of which was documented in a separate report, viz:

- *Development of a Traffic Flow Index – Literature Review*.
- *Traffic Flow Index – Driver Reactions to Frustrating Situations.* This stage developed and conducted a laboratory experiment to identify situations which drivers regard as frustrating.
- *Development of a Traffic Frustration Index.* This stage developed a Traffic Frustration Index model to incorporate the different types of frustrating event and relate them to travel speed, and
- *Application and Validation of the Traffic Frustration Index*. This report incorporated the evaluation of the model by applying it to a number of different routes at different times of the day and comparing the Traffic Frustration Index to user ratings of traffic conditions on these roads at these times.

The four separate reports have been combined into this consolidated report with an Executive Summary for the entire project included overleaf, along with a sectional table of contents. Additionally, the individual reports' Executive Summaries and table of contents are included at the beginning of each section.

Executive Summary

Introduction and study design

This consolidated report covers the ARRB TR research project RC7111 "*Traffic Management Performance Measures*" funded by Austroads (Project N.RUM.9805).

This investigation set out to discover whether a Traffic Frustration Index which quantified the events which contributed to driver frustration would be a useful supplement to measures such as traffic speed and flow in identifying priorities for traffic management interventions and assessing the outcomes of such interventions.

The project proceeded by four main stages:

- A literature review.
- A laboratory experiment to quantify situations which drivers regarded as frustrating.
- The development of a Traffic Frustration Index (TFI) model to incorporate the different types of frustrating event and relate them to travel speed.
- Evaluation of the model by applying it to a number of different routes at different times of day and comparing the TFI to user ratings of traffic conditions on these roads at these times.

Separate reports for each of the above stages were completed. All of the reports have been consolidated into this report.

Literature review

The literature showed growing recognition of the need to incorporate human factors into the measure of travel flow quality. However, these factors tended to be assumed on the basis of traffic speed and density rather than measured directly. Modellers such as Greenshields (1957) and Guerin (1958) both agree that driver discomfort is caused by restriction to manoeuvre or travel at a desired speed. Greenshields (1957) index was based on frequency and magnitude of speed changes and Guerin's (1958) on the speed distribution of vehicles on the roadway. Neither model measured how much discomfort was caused by each event and whether certain events created more discomfort than others. Other literature explored the human reaction to congestion. Dommerholt et al (1988) conducted experiments with test persons to assess the overtaking behaviour of drivers under varying levels of congestion. Mohktarian and Raney (1997) proved that socio-demographic variables such as gender and family status provided an indication of an individual's tolerance to congestion. Matthews et al (1998) concluded that drivers recently subjected to a major life stressor were more susceptible to accidents. An individual's tendency towards aggression, dislike and alertness was shown to affect their perceptions of the traffic environment and predict what coping strategies they would adopt (ie selecting alternate routes or transport, moving).

Research to date has concentrated more on differences in individual reactions rather than differences in traffic situations. Modellers are still faced with the issue of incorporating the human element into an overall performance measure of travel flow. The main problem faced by modellers lies in deciding what aspects of the human response to traffic situations (eg comfort, effort, stress etc) are the most relevant and the lack of established methods to directly measure the human reactions to traffic. The literature points to a need for modellers to identify what best determines quality of travel flow, to quantify these measurements of the human reaction and to incorporate them into an overall flow index.

Laboratory study of driver frustration ratings

Method and Procedure

A video tape of traffic incidents was prepared using a camera mounted on a tripod situated in front of the front passenger seat in a large sedan car. Most of the driving was done along undivided primary and secondary arterials, the type of road where a traffic index is likely to find the greatest application. All roads were in the eastern inner suburbs of Melbourne. The taping was done in peak and non-peak times so that a range of traffic conditions was recorded.

The tapes were then edited to produce a practice segment lasting approximately 7 minutes, and the main tape which lasted 46 minutes. The incidents incorporated in the tape are:

Type of incident	Number
Stop-intersection signals	18
Stop- pedestrian-operated signals	3
Slow travel	8
Forced lane change-due to parked vehicle	5
Forced lane change-other	5
Other	19

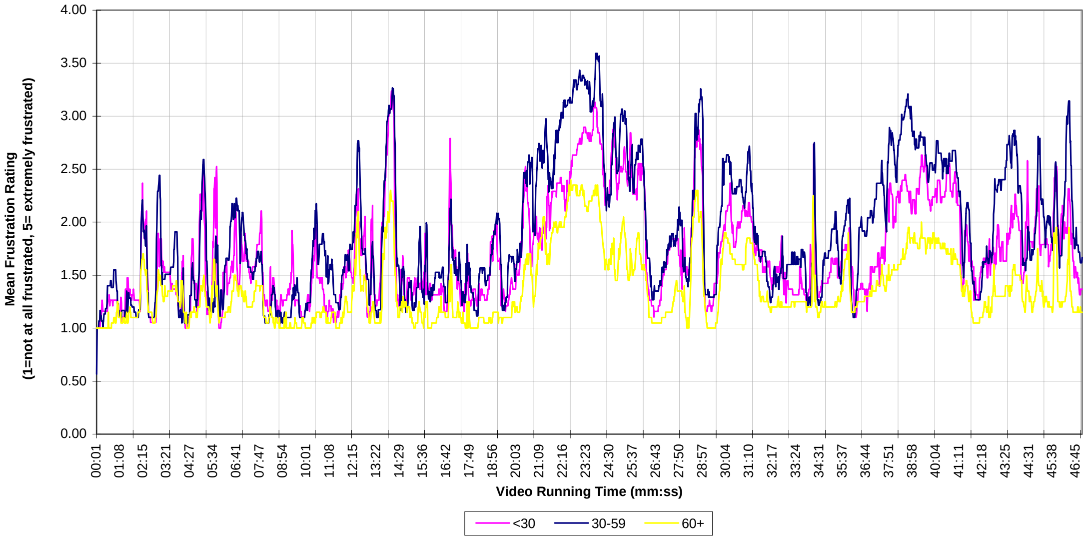
Participants viewed the television monitor and were provided with a small response dial which they could adjust continuously between two extremes labelled ‘Extremely Frustrating’ and ‘Not at all Frustrating’. Participants viewed the tape individually, and adjusted the knob on the dial to reflect the level of frustration they felt with the traffic situation. The position of the knob was sampled once a second, and the results stored in the computer. Five positions of the knob could be distinguished.

Three groups of twenty participants, aged 18-29, 30-59, and 60 and over, took part in the study.

Results and conclusions

The video footage and rating procedure used in the study appeared to provide a valid means of engaging the participants’ emotions and perceptions in relation to traffic situations. The three groups of respondents were highly consistent in the responses they gave to the different situations, although there were differences in the level of frustration expressed by the three groups (see Figure 1). Once the scores were normalised by dividing the score for each second by the overall average for the session, individually for each participant, the differences between the groups disappeared and the pattern appeared very consistent across all groups.

Figure 1 — Mean frustration rating by age group vs time



The growth in frustration over time was examined by taking *the mean normalised frustration rating* (MNFR) for each incident, then plotting it against the duration of the incident. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the MNFR level for uneventful travel.

The results of the ratings study were not as had been anticipated, and do not agree well with currently-held priorities in traffic management. The main features of the responses to different types of incident are:

- Respondents were relatively indifferent to routine stops at traffic signals, and showed relatively little frustration even after fairly long delays. This result was particularly surprising.
- The picture with slow travel is rather more complicated. There is a marked dislike of being forced to travel slowly, but the frustration increases over time at about the same rate as it does for time stopped at traffic signals.
- Forced lane changes are very much disliked, and the dislike appears to be directly proportional to the time spent delayed. Delays due to forced lane changes arising from parked cars increase driver frustration at approximately 26 times the rate for time delayed at intersection signals, and delays due to forced lane changes caused by other factors result in a 20 fold increase over the rate for time delayed at intersections.
- For ‘other’ events, the slope of the regression line was negative and the fit of the regression line poor. It was therefore decided that the most appropriate approach to modelling this type of event would be to add a constant amount for each incident, and multiply that by the duration to determine impact.

The results of this investigation suggest that relatively simple models may adequately predict the relationship between traffic conditions and driver frustration. The implications of the regression results for modelling the relationship between frustration and traffic conditions are discussed.

Developing the Traffic Frustration Index

Seven traffic event groups and an “uneventful travel” group were defined. The frustration ratings for individual events were plotted against the event duration for seven traffic event groups. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the frustration rating level for uneventful travel.

Data used to derive the results given in this report differ from the previous report to some extent. Firstly, the results given in this report are clearly qualified as relevant to a particular road class (undivided road with a speed limit of 60 km/h). Secondly, uneventful travel segments with an average speed less than 30 km/h are now qualified as slow travel. The analysis results indicate that simpler grouping of traffic events (four event types rather than seven) is feasible. The effect of speed change parameters on frustration rating is analysed using the energy factor (E) and equivalent stop value (ESV) parameters. Regression results indicate that the effects of speed change manoeuvres as measured in this study cannot be related to the frustration rating. Therefore, the relationships based on event duration are recommended for practical use.

A Traffic Frustration Index (TFI) is developed based on the use of the frustration ratings for different traffic event types. The numerical values of the Traffic Frustration Index can be directly translated into a level of service (LOS) using tables defined in the report. A simplified outline of the steps involved in calculating the TFI for a given traffic facility is presented in the highlighted section below.

It is recommended that the proposed practical procedure including the simplified event type grouping system described in this report should be tried and refined in the validation of the proposed Traffic Frustration Index. For this purpose, each event type should be defined clearly, including the method to identify the start and end of each event type.

Practical Procedure

A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described below. The use of the recommended event type grouping is assumed.

Input Data

Collect the following input data by driving along the traffic facility and recording the start and end points of each traffic event:

- Event type number (1 to 9) for each traffic event encountered, or event type number = 0 for uneventful travel segments.
- Start and end times of each event and each uneventful travel segment. This will be used to determine the duration of each event and each uneventful travel segment, T_i (seconds). It will also be useful for determining the travel distance, L_i (m) for each event.
- If speed is being recorded manually, record the speed at the start and end of each speed cycle (initial and final speeds, v_i, v_f) and the cruise speed (v_c) for near-constant speed segments. Alternatively record the instantaneous speed at regular short intervals (Δt), e.g. second by second ($\Delta t = 1$ s) using an instrumented car.
- Distance travelled for each uneventful travel segment, L_i (m). With instrumented car surveys, distance for each event can be determined as:

  $$L_i = \mathit{sum}\ (v\ \Delta t) \qquad (3.2.1)$$

  where v is the instantaneous speed (m/s), Δt is the time interval used in the survey (s), and summation is for the duration of the event.

In the case of speeds recorded manually, approximate distance can be calculated from:

$$L_i = 0.5\,(v_i + v_f)\,T_i \qquad (3.2.2)$$

Where

v_i = initial speed (m/s)

v_f = final speed (m/s)

T_i = duration of the event or the uneventful travel segment.

- Total travel distance, L_t (km). This can be calculated by summing distances travelled during each event and uneventful travel segments, L_t = *sum* (L_i) for all events.
- Also record the *speed limit* and other characteristics of the traffic facility to determine the *road class*, and other conditions affecting travel (weather, etc). The speed limit may be used as the free flow speed, v_f (km/h) for the traffic facility. Using this speed, the free-flow travel time per unit distance, t_f (s/km) can be calculated from

$$t_f = 3600 / v_f \qquad (3.2.3)$$

Calculated Parameters

Enter the input data into the TFI application spreadsheet to obtain the TFI value and the corresponding level of service (LOS). The following parameters will be calculated by the application:

- Total distance for uneventful travel, L_b (km)
- Total time for uneventful travel, T_b (km)
- Average speed for uneventful travel, v_b (km/h)
- Travel time per unit distance for uneventful travel, t_b (s/km)
- Total travel time for the trip, T_t (s)
- Average speed for the total trip, v_t (km/h)
- Frustration impact rate for uneventful travel, R_{bT}
- Total frustration impact for event types 1 to 9, *sum* (R_iT_i)
- Total travel distance for event types 1 to 9, (L_t - L_b) (km)
- Frustration impact rate for the total trip, R_T
- Frustration impact ratio, p_R
- Upper limit of frustration impact ratio, p_U
- Free-flow travel time per unit distance, t_f (s/km)
- Traffic Frustration Index (TFI)
- Level of Service (LOS)

Applying and Validating the Traffic Flow Index

Application of the TFI

Measurements were made in both directions on seven road sections during morning peak, the mid-day period between peaks, and the evening peak. All roads were close to the VicRoads Head Office in Kew, Melbourne where persons who made the ratings of travel conditions worked. Measurements taken included the time and distance for the trip (from which uneventful travel was calculated), and the occurrence and duration of a number of traffic events.

Obtaining User Ratings

Staff working in VicRoads Head Office were asked to identify any roads which they used frequently at nominated times of day (morning peak, the mid-day period, and evening peak), and to rate the quality of travel only for trips with which they were familiar. For this survey, the approach to the respondents was made via e-mail, and respondents replied via the same medium. TFI was plotted against user ratings, each individual combination of road, direction of road and time of day constituting a data point in the plot.

Findings

The principal findings of the investigation are:

(i) The Traffic Frustration Index provided a clear differentiation between the different routes used in the study.

(ii) Differentiation by time of day was less clear. This may have been due to taking measurements during school holidays, which possibly resulted in less traffic in peak times than would normally occur.

(iii) There was a moderately good correlation between user ratings of how well the roads performed and TFI, with a correlation of - 0.56.

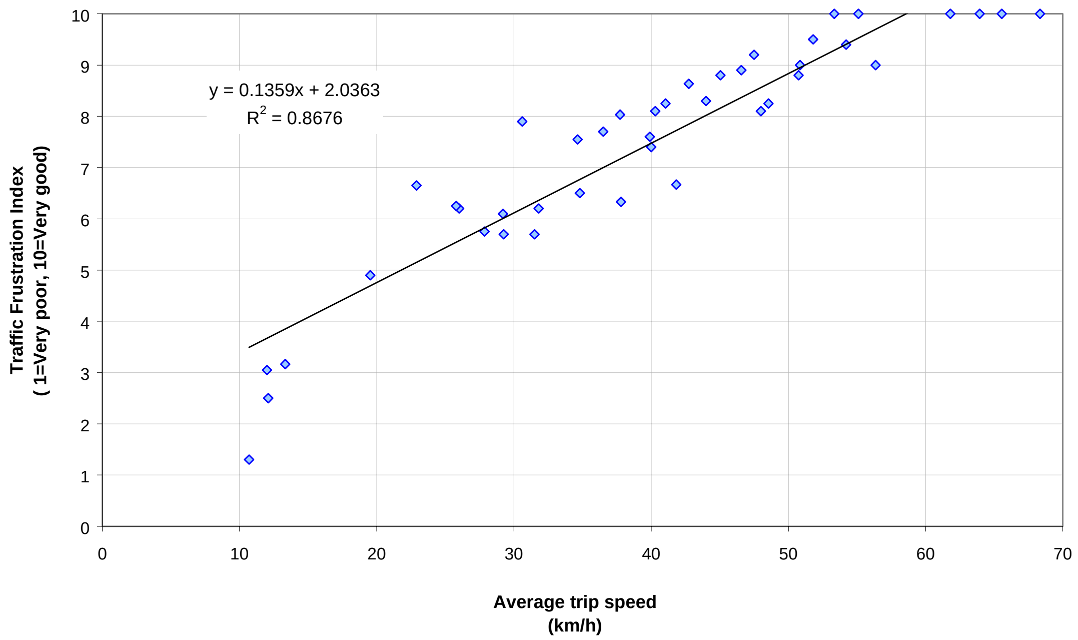
(iv) This correlation was higher for less frequent users than for frequent users (- 0.63 compared with - 0.47).

(v) The correlation was also higher for travel during the day than for travel at peak times (- 0.81 compared with 0.38 for morning peak and 0.68 for evening peak).

(vi) The fact that the traffic measurements were taken during a school holiday period may explain the relatively low correlations between TFI and user ratings especially in the morning peak. School holidays would tend to result in lower traffic flows (hence better TFIs) than normal, while the road users may have been basing their judgements on a memory of average weekday conditions acquired over a long period of time.

(vii) There was a very close correlation between travel speed and TFI (0.96).

Figure 2 — TFI vs Average travel speed (modelled by linear trendline)



Overall Conclusions

(i) The process of developing the TFI, particularly the rating study, indicated the consistency of reactions across a broad cross-section of drivers to different traffic situations. Although there were differences between the groups in the intensity of their frustration ratings, there was strong agreement about which events caused frustration and the point at which the situation started to become frustrating. This approach could be used in assessments of future traffic management initiatives in the future.

(ii) The investigation aimed to discover whether it was worth qualifying traffic speed as a measure of traffic performance by developing a method for quantifying events which frustrate drivers. Although it was demonstrated that different types of events have different impacts on driver frustration, the aggregate of these events correlates closely with travel speed and appears to add little if anything to the prediction of driver satisfaction. In view of this, it is difficult to justify the additional expense and complication of collecting travel time information.

(iii) The TFI does however provide a mechanism to calibrate travel speed in terms of user satisfaction in a manner which does not simply depend on the arbitrary allocation of different satisfaction values to different speeds. This has been calibrated for undivided urban roads in the present investigation. It may be worth establishing similar values for other classes of road as part of future work.

(iv) Further work is required to test the validity and usefulness of the TFI. This includes comparison with data collected out of school holidays, and a desk exercise to estimate the impact of various traffic engineering measures on TFI and average speed.

(v) Further development of the model could include its extension to divided roads and the inclusion of roundabouts.

Section 1

Development of a traffic flow index — Literature Review

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Executive Summary

The present literature review forms the preliminary phase of the ARRB Transport Research project RC7111 *“Traffic Management Performance Measures’* commissioned by AUSTROADS (NRUM9805).

An extensive literature review reveals growing recognition of the need to incorporate human factors into a measure of travel flow quality. Driver comfort, frustration and stress are all relevant issues in the discussion of quality of travel and are identified by modellers such as Guerin (1958) and Greenshields (1957). In formulating standard measures of the quality of traffic flow however, the general tendency of modellers to date has been to simply assume that certain parameters of traffic flow are valid indicators of the travelling public’s annoyance or dissatisfaction (eg average speed, travel time), and to combine these parameters in some intuitive fashion.

The literature suggests that modellers find difficulty in quantifying human factors and in determining what weighting they should be given in the development of a general ‘travel quality’ indicator. The main problem faced by modellers lies in deciding what aspects of the human response to traffic situations (eg comfort, effort, stress etc) are the most relevant and the lack of established methods to directly measure the human reactions to traffic. Furthermore, human factors research to date has concentrated more on differences in individual reactions rather than to differences in traffic situations. The literature points to a need for modellers to identify what best determines quality of travel flow, to quantify these measurements of the human reaction and to incorporate them into an overall flow index.

1. Introduction

The notion of 'quality of travel' has traditionally been quantified by measures such as mean travel time. However, transport modellers are becoming increasingly aware that a measure of quality calls not only for objective measurements of the numerical parameters that define the flow, but subjective responses to travel conditions based on road users' perceptions. Driver comfort, frustration and stress are all relevant issues in the discussion of quality of travel. The literature suggests that modellers find difficulty in quantifying such factors and in determining what weighting they should be given in the development of a general 'travel quality' indicator. In formulating standard measures of the quality of traffic flow, the general tendency of modellers to date has been to simply assume that certain parameters of traffic flow are valid indicators of the travelling public's annoyance or dissatisfaction, and to combine these parameters in some intuitive fashion. A preferable approach would be to investigate which parameters of traffic flow actually relate to driver annoyance or dissatisfaction, and to find some way of combining these factors in order to give each a weighting that reflects the extent to which they relate to annoyance and dissatisfaction. The papers covered in the present review include both types of approach.

2. What is a Traffic Flow Index?

Rust PPK (1996) defines a Traffic Flow Index (TFI) as:

"*… a systematic and objective measure of the complexity of the driving task once a travelling vehicle has been positioned in a traffic lane*"

Essentially, the flow index arose from the need of transport modellers to establish a standard measure of the quality of traffic movements within the transport system. The Level of Service concept defined in the Highway Capacity Manual seeks to achieve the same goal (Transportation Research Board 1994). However, each category of LOS is defined only in terms of the operating speed and the volume to capacity ratio. Rust PPK cite the distinguishing factor in the TFI concept as the fact that it not only relates to operating conditions but is sensitive to driver perspective also. By incorporating human factors, proponents of the TFI claim that it will act as a more meaningful level of service criteria for transport systems. The TFI remains relevant in situations which are not very amenable to analysis using traditional techniques such as in the evaluation of turning lanes, parking bans, S lanes and other traffic control measures. The TFI also provides a basis for measuring and prioritising different traffic management related actions, which may have negative impacts on traffic flow quality. According to Rust PPK, it provides an objective basis to relate to direct motorist rating of travel quality and provides a basis for target setting and performance monitoring of improvement programs. Once well developed and established, the TFI holds the potential of becoming a mechanism for better understanding driver needs and influencing road planning and design decisions accordingly.

In terms of the measurements required to formulate a TFI, Rust PPK (1996) identifies the following possible methods:

- tabulating individual disruptions and their respective probability of occurrence over a given length of road.
- use of an instrumented vehicle to obtain a direct TFI measurement based on an accumulation of lateral and longitudinal accelerations
- use of aerial photographs to formulate a TFI based on lane availability
- use of an automatic instrumented vehicle to monitor the rate at which the driver touches a pedal or moves the steering wheel beyond minor corrections

- use of a microscopic simulation model to model the response of individual vehicles in a traffic stream to other driver actions

An approach based on a TFI should not be thought of as a potential solution to all traffic problems. Rather, the TFI should be considered in relation to other traffic management goals. For example, an arterial roadway with a high TFI value may provide a poor level of access to abutting properties or intersecting roads (eg turn restrictions or long spacing between intersections requiring considerable additional travel). Measures to improve public transport facilities may conflict with improving the TFI (eg priority given to buses re-entering the traffic stream from bus stops). Unless the TFI is clearly acknowledged as a tool to achieve one goal of traffic management which has to be balanced with others. there is a risk that the TFI will be seen as a means of promoting car travel at the expense of other types of road users.

Rust PPK (1996) offer a model for a traffic flow index which incorporates a distinct user-based approach. The need to incorporate the human perception into a measure of travel quality is recognised in even the earliest literature. However, it is not until recently that authors have considered actually measuring, rather than assuming the human reaction. As Rust PPK points out, this raises three important issues:

- what aspects of the human reaction should be measured?
- how could these measurements be facilitated?
- what weighting should they be given in the context of an overall travel flow index?

3. Earlier forms of Travel flow indices

The difficulties in quantifying the human reaction in developing a measure of travel flow quality is apparent in existing literature. Many have tried to indirectly include measures of driver comfort and frustration in their models. Earlier work by Greenshields (1957) and Guerin (1958) study the speed distributions within a traffic stream to monitor the occurrence of events which might be considered annoying for the driver. Despite the relative simplicity of the field measure, both authors agree that average speed and fluctuation in speed are good indicators of the quality of travel flow.

Greenshields (1957) outlines the calculation of a quality index based on three measures of the quality of flow:

1. average speed
2. change in speed (acceleration and deceleration)
3. frequency of change in speed

The first parameter is an indirect measure of travel time. The latter two are labelled ‘frustration factors’. The author posits that the amount of change in speed (both in terms of deceleration and acceleration) and the frequency of these changes required to meet fluctuating traffic conditions are undesirable factors of traffic flow. Therefore, they are deemed irritating to the driver. There is no actual measurement, however, of *how* irritating these factors are. All data was collected using a test car fitted with speed recording devices. Measurements were taken over a one mile length of roadway. A generalised quality Index, Q was defined in terms of average speed (S) , absolute sum of speed changes per mile (Δs) and total number of speed changes (f), in the form:

$$Q = \frac{S}{\Delta s \sqrt{f}}$$

The frequency of speed changes was found to be highly variable and was thereby given less weight than the average speed or speed change. It was assumed that small speed changes were likely to occur fairly often, and that larger changes were likely to happen less often. It was further assumed that these small, frequent changes would be less annoying than the larger, more frequent changes. To accommodate these assumptions in the index, $\sqrt{f}$ was taken to represent frequency in the index calculation.

Q values were calculated for a range of road types and converted into a Quality Rating from 1 to 10. A degree of quality 1 (excellent) corresponded to Q values greater than 3750. A degree of quality of 10 (poor) corresponded to roads with Q values of under 2.5. Greenshields favoured numerical classification over the letter grades used in the Level of Service concept claiming it would be useful for both technical and non-technical audiences. The continuous numerical scale also solved one of problems associated with LOS gradings, where small changes in parameter values or delay estimates could change the LOS grading when they occurred near the boundary.

Guerin (1958) also adopts a numerical scale in his paper outlining the development of a Congestion Rating. In terms of travel flow, Guerin defines high quality as the ability of an individual driver to travel in a manner which is not influenced to any appreciable degree, by other vehicles on the road. Effectively, this agrees with Greenshields' definition. However, where Greenshields related frustration to the magnitude and number of speed changes forced upon the driver, Guerin related it to the density of traffic and the speed distribution of the vehicles on a given roadway. According to Guerin's rating, driver discomfort was directly proportional to density and indirectly proportional to the standard deviation of the speed distribution. A small range of speeds (ie low standard deviation) indicated less variability and little freedom to move other than at the average speed. It was effectively a discomfort factor, similar to that incorporated in Greenshields' model.

It should be noted that Guerin's treatment of speed variability is diametrically opposed to the way in which it is generally treated in traffic engineering. Speed variability is generally deemed undesirable, and there is a widely held belief that crash frequency is related to speed variability. The extent to which such a belied is actually supported by the evidence may be questioned, but that is beyond the scope of the present review. The essential point is that speed variability is held to be undesirable and reducing speed variability is frequently a secondary goal of many traffic engineering measures.

Observations were recorded over a five minute period during which travel time, headways, and spot speed were recorded for every fourth vehicle. Congestion ratings were defined by road type and traffic volume. Unlike the more 'user-friendly' index of 1 to 10 defined by Greenshields, Guerin's ratings were left as calculated ranging from 0 to 200 depending on road type.

The papers by Guerin (1958) and Greenshields (1957) agree that driver discomfort is caused by restriction to manoeuvre or to travel at desired speed. However, their performance measures are defined only by fairly simple traffic parameters. Guerin identifies some possible alternative measures of driver discomfort in the number of overtakings per mile or in the number of lane change opportunities. He posits that the number of overtakings which occur in a given stretch of roadway is related to the degree of inconvenience and that the greater the percentage of time that lane changing is not possible, the higher the level of discomfort. While these more complex measures are only paid lip service in earlier literature, more recent authors have developed methods to both record and incorporate such measures into their flow indices.

4. More recent studies

Levinson (1996) defines a Delay Rate Index (DRI) which is directed at evaluating congestion levels by keying in to differences between actual versus desired travel time for various roadways. A delay rate, expressed in minutes lost per mile, represents the time lost or the increase in travel time resulting from congestion on a given road. The values of delay rate ranged from 0.1 to 10 minutes/mile. Similar to the index presented by Greenshields (1957) a delay rate index (analogous to Level of Service) was defined with a range from 0 to 10. An index of 5 was arbitrarily assigned to represent a delay rate of 1 minute per mile on freeways. A diagonal line was then drawn between index values of 0 and 10 establishing the relationship between delay rate and delay rate index for freeways. Lines for different road classes were drawn approximately parallel to this line, with an index of 5 assigned to a different delay rate for each (eg for a Class I road, an index of 5 was assigned to a delay rate of 2 minutes per mile whereas an index of 5 would correspond to a delay rate of 5 minutes/mile on a CBD street).

Levinson's (1996) DRI is applicable to individual segments, entire routes or entire urban areas in both peak and off peak conditions. The only modification required is in the identification of the base line conditions from which time losses are calculated (ie delay rates). Levinson suggests that a community could establish a Desired Delay Rate Index for various facilities and time periods. The ratio of a desired index to an actual index could identify areas of concern. He also explores the use of a DRI in the development of mobility index.

Levinson explains his selection of delay rate over more standard parameters such as speed by citing the concept that travellers *perceive* travel time. He claims that it is not the average speed a driver is more concerned with but the time he/she spends travelling, especially in congested conditions. There is no indication, however of any direct measurement of these driver perceptions. Levinson also refers to driver perception in his explanation for using a different relationship for each road class. According to his model, for any given delay rate, the DRI will be higher for a freeway than a local road. Levinson finds this difference reasonable, if one considers that slower speeds and longer travel times are more widely accepted on lower class roads. Levinson (1996) tends to assume rather than measure directly, the human factors components in his DRI model. Essentially he has used the basic measure of travel time and presented it in a way that is more considerate of how the average driver assesses traffic conditions.

Slavik et al (1983) posits that the quality of service is related to four main parameters: travel time, comfort, safety and economy. Of these four, only travel time may be measured directly. Comfort, and to a great extent safety and economy are defined in his paper as intangibles which can't be directly measured or quantified. While this seems to echo the opinions of Levinson (1996), Greenshields (1957) and Guerin (1958), Slavik et al (1983) outline a more sophisticated approach. They define two new traffic characteristics as measurable substitutes for comfort and safety: the platooning index and the density of catchpoints.

While the movement of vehicle in a platoon might be smooth and uninterrupted, the close proximity of other vehicles was deemed uncomfortable by Slavik et al. The platooning index (P) reflects loss of freedom to manoeuvre and to choose speed. The index (P) is a simple ratio:

$$P = 100p/v$$

where:

p = proportion of headways less than 2 seconds as measured over a period of time, say five minutes

v = space mean speed, km/h, as measured over the same time period

Space mean speed refers to the average speed of vehicles within the platoon over a given time period.

Calculating for a range of different road classes, Slavik et al (1983) found that values of P tended to fall between 0 and 2.0. A high platooning index occurred when many vehicles travelled at low speeds in long platoons. The platooning index was therefore inversely related to comfort. For each road class, they also found that a positive linear relationship existed between platooning index and density. Rural roads exhibited relatively high platooning indices for a given density and the freeways exhibited relatively low platooning indices for a given density of traffic. This suggested that for any given density, freeways provided users with greater freedom to manoeuvre and to choose their speed than the two lane rural roads observed. Slavik et al suggest that if the platooning index is to be used as a measure of driver comfort, these results indicate that the freeways observed, and perhaps freeways in general, provide drivers with greater driving comfort at a given density of traffic.

The density of catchpoints is based on the interactions which occur between vehicles travelling at different speeds in a given lane. Slavik et al posit that faster vehicles will get closer to the slower ones and try to overtake them. If overtaking is not possible due to insufficient visibility, barrier lanes or too much traffic in adjacent lanes, then these faster vehicles will have to slow down, join a platoon and defer overtaking until a suitable opportunity arises. Where overtaking occurs or where a vehicle is forced to defer overtaking, Slavik et al define a catchpoint. The density of catch points (D) is simply the number of catchpoints which occur on a given length of laneway (say 1km) over a given period of time (say 1 hour). The higher the density of catchpoints, the greater the physical proximity of vehicles within a lane and the greater the speed differences between them- the basic ingredients of an accident. The density of catchpoints (per kmh) is therefore inversely related to safety.

A traffic engineering logger (TEL) and inductive loops buried in each lane were employed to measure arrival times, vehicle length and vehicle class for six road classes. To cover a reasonably broad range of traffic conditions the TEL was used on several two-lane undivided roads and four lane freeways, both in urban and rural areas. Speeds and headways between vehicles passing an observation point on the road were used to calculate the platooning index. The authors assumed each vehicle maintained the same speed over the 1 km length. To calculate the density of catchpoints, Slavik et al (1983) plotted vehicle trajectories for every pair of successive vehicles as determined by their speed and the headway between them. Catch points were defined as the point where the trajectories intersected on the space time diagram. The density was defined as the number of catchpoints occurring per kmh. The average density of catchpoints was calculated as a weighted average of the individual densities from each pair of vehicles (ie first and second, second and third, etc), weighted by headways.

For the sites surveys, the density of catchpoints (points/kmh) tended to fall within 0 and 2000. Similar to the platooning index, the density of catchpoints was found to hold a positive linear relationship with traffic density (veh/km) for each road class. Slavik et al (1983) found that for a given density of traffic, roads built to high standards, exhibited lower values of D than lower standard roads. As a measure of safety, the density of catchpoints thereby indicated that high standard roads were safer than poorly maintained roads, whether they be freeways or two lane undivided roads. Based on the relationship between the two parameters and density, the authors assigned values for platooning index and density of catchpoints to each of the HCM Levels of Service. For example when there were over 1250 catchpoints/kmh on a given road at a given time, the road provided, from a safety point of view, a level of service F. A platooning index of less than 0.3 would define a road, in terms of its comfort, as providing a level of service A. This allowed classification of the comfort and safety attributes of the quality of service into the A to F classes, individually and independently. Slavik et al did not however, combine all four attributes into an overall measure of the quality of the traffic flow.

5. Behavioural studies

The platooning index and density of catch points are indicative of the increasing complexity in quality measures employed in more recent studies. While there is a stronger focus on human factors considerations, there is still a lack of direct measurement. There is a significant body of literature, however, which explores behavioural responses to congestion. Dommerholt et al (1988) conducted experiments with test persons to assess the overtaking behaviour of drivers under varying levels of congestion. Mohktarian et al (1997) studied how behavioural responses to congestion varied with driver sociodemographics. Both these studies employed direct measurement of human perceptions under varying flow conditions. Although they are a useful test of the assumptions that tend to be made regarding human reactions, the findings tend to be qualitative, and used only to validate theory. Modellers are still faced with the issue of incorporating the human element into an overall performance measure of travel flow.

Dommerholt et al (1988) formulate a series of assumptions on the passing or overtaking behaviour of drivers for different traffic volumes. To test the validity of these assumptions, they conducted a series of passing experiments with test subjects. The findings differed significantly from their original theoretical model. The surveys found that drivers did not want to overtake when their desired speed was only marginally higher than the speed of the platoon in which they were driving. Also, the larger the platoon, the less likely drivers were to overtake. In terms of gap acceptance, the original assumption that one critical value was sufficient to represent average behaviour was incorrect. The surveys showed that the gap required for a driver to complete an overtaking manoeuvre increased with average speed and also with the presence of trucks in the traffic stream. The sight distance required also increased with speed.

The findings of this study raise the question of the difference between a driver's freedom to manoeuvre within a traffic stream and a driver's desire to manoeuvre within a traffic stream. Guerin (1958) suggests the use of number of overtakings as a measure of discomfort. However, the findings of Dommerholt would suggest that drivers simply *prefer* not to overtake in certain situations. Slavik et al (1983), in their calculation of the density of catchpoints, assume that all drivers who are travelling faster than the vehicle in front wish to overtake it. However the findings of Dommerholt would suggest that this tendency depends on the speed difference between the two vehicles. The relevance of Dommerholt's findings to general driver behaviour patterns requires further study. However the paper does suggest that driver behaviour may not be a simple function of the standard parameters used to define flows.

Mohktarian et al (1997) explore the variables which affect driver behaviour in congested flow situations. A simple questionnaire survey conducted in Los Angeles was employed to study the relationship between sociodemographics (age, sex, income, etc) and coping strategy. General reactions to congestion ranged from finding alternate routes, to avoiding travel, to the drastic measure of major lifestyle or location changes. The study revealed that people will only adopt the more drastic measure if dissatisfaction continues. More importantly, however, the study revealed that sociodemographics do affect how readily individuals will adopt these changes. Men were found to be less likely to adopt any changes in the face of congestion than women. Mohktarian et al suggest that this may reflect a greater willingness and openness towards change on the part of women. Alternatively, men may perceive their work, and thereby their work trip, as being of greater importance or centrality in the household than do women. It is also possible that reporting patterns may differ between men and women and that women may be more open to reporting their own adoption or consideration of behavioural changes. The authors note that they can only suggest and not confirm such possible explanations.

To a lesser degree than gender differences, Mohktarian et al (1997) found that family status also influenced coping strategies towards congestion. Families without children were more likely to accommodate changes in their work trip departure time (due to congestion and increased travel times) than were families with children. Clearly, households without children have fewer constraints and a greater flexibility with regards to travel behaviour than those with children. In the context of travel quality, the findings of Mohktarian et al suggest that the individual's tolerance to congestion may differ, not only with the actual level of congestion, but more fundamentally according to their sociodemographics.

6. User-based approach

If we are to accept that the human component is relevant in a measure of the quality of travel flow, as is evident in the literature, then we must consider the variables which define it. The suggestion by Mohktarian et al (1997) that the human reaction may also be defined by parameters not directly related to the traffic flow complicates the task further. Direct measurement of the human response is one alternative explored in the following papers.

Macdonald (1979) attempts to develop a measure of driving task demand as a means of quantifying the level of effort expended by the driver- one of the human aspects of system performance. Level of task demand was based on the response rates of test subjects to a stimulus applied while driving. Three tests were conducted- on the road, on a test track and in a laboratory. The field study involved four subjects driving an instrumented vehicle around a designated course, during both the day and night time. The stimuli employed were tones directed at regular intervals to the left or right ear through a set of earphones. The driver was directed to press the corresponding of two pedals with his left foot. The test track survey employed a visual stimulus where the driver was required to give a verbal response. The laboratory study tested subjects behaviour under monetary incentive on effort expenditure. As the secondary tasks were imposed on the driver, response rates and errors on the task were recorded. Measurements of physiological functions such as change in heart beat, pulse rate and electro dermal responses were also taken.

Macdonald’s results showed that secondary task measures appeared to be a sensitive and reliable index of travel demand. Measures of physiological arousal however, did not prove very conclusive. Monetary incentive was found to affect error correction rather than error prevention while driving. In terms of the relevance of driving task demand to level of service, Macdonald reports that measures of driving task demand could be useful in investigating the causes of discrepancies between observed and expected accident rates. For example high task demands, (such as those imposed at intersections) actually exhibit lower than expected accident rates because drivers tend to counteract high demands by reducing speed. Low task demands, such as those imposed on a lightly trafficked freeway, tend to result in excessive speeding and a reduction in safety. Macdonald claims that task demand is a measure of the effort expended by drivers and that effort is clearly a cost of system operation. In terms of incorporation into a performance index, she suggests that task demand should be considered independent components of the level of service such as comfort and convenience.

Matthews et al (1998) explore the phenomenon of driver stress as opposed to driver effort, under different driving situations. Stress is a direct indication of discomfort. Furthermore, the authors posit that stress appears to predispose drivers to a heightened risk of accidents quoting that drivers who have experienced a recent stressful event such as an interpersonal or work related problem or a major life stressor, are five times more likely to cause fatal accidents than are unstressed drivers. In accordance with Slavik et al (1983) and the factors identified in their definition of travel quality, driver stress would appear to offer a measure of both comfort and safety.

The actual effect of stress on driver performance depends on the nature of a driver’s stress reactions and the traffic environment. Matthews et al (1998) employed a multifactorial questionnaire aimed at measuring vulnerability to driver stress called the Driving Behaviour Inventory (DBI). The main factors identified through the DBI were tendencies towards aggression, dislike and alertness. Aggression was related to the irritation and impatience particularly associated with impedance of the driver’s progress by other traffic. Dislike was reflective of feelings of anxiety and unhappiness due a general lack of confidence in difficult situations. Alertness referred to active monitoring for potential hazards. A driving simulator was then employed to test the validity of the DBI results. Subjects were presented with three contexts of driving an open road, following a vehicle with no opportunity to overtake and overtaking cars ahead. Speed, lateral and longitudinal position of vehicle and the state of the controls (brake, steering, accelerator) were logged every 480ms.

Matthews et al (1998) concluded, based on the correlation between DBI measure and driving simulation results, that habitual dislike was associated with lower control skills, greater caution and disturbance of mood. Aggression was related to more frequent and more error prone overtaking. The driver's level of alertness predicted speed of reaction to pedestrian hazards. These findings show how drivers' coping strategies and perceptions of the traffic environment vary across individuals and situations and how the DBI scales can be used to predict them. It is a useful indicator of the traffic environments which generate stress and dangerous driver behaviour- analogous to comfort and safety, respectively. Incorporating a quantitative measure of these physiological and psychological factors into the driving simulation experiment would facilitate incorporation into a quality index. However, this then raises the question of how these measures would be weighted.

7. Conclusion

The literature shows a growing recognition of the need to incorporate human factors into the measure of travel flow quality. However, authors tend to assume rather than directly measure these factors. Frustration and discomfort factors included in calculations are still largely based on parameters of traffic flow such as speed and density. The main problem lies in the lack of established methods to directly measure the human reaction and how to apply the appropriate weights to the different aspects. A further issue is in deciding what aspects of the human response to traffic situations (eg comfort, effort, stress etc) are the most relevant. The human-based approach has generated some literature on the direct measurement of the human perception of the traffic environment via questionnaires, interviews and simulation experiments. These studies show that there are patterns to these reactions. Drivers recently subjected to a major life stressor have been shown to be more susceptible to accidents. An individual's tendency towards aggression, dislike and alertness affects their perceptions of the traffic environment and predicts what coping strategies they will adopt in various situations. Sociodemographics such as gender and family status provide an indication of an individual's tolerance to congestion. The literature points to a need for modellers to identify what best determines quality of travel flow, to quantify these measurements of the human reaction and to incorporate them into an overall flow index.

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Section 2

Traffic flow index — driver reactions to frustrating situations

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Contents

Executive Summary

Background

There is a need for a measure of traffic flow quality which combines objective measurements of the numerical parameters that define the flow with subjective responses to travel conditions based on road users' perceptions. This report describes a laboratory study to determine drivers' responses to a range of potentially frustrating traffic situations. The design of the study was based on experience gained from an earlier pilot study.

Aims

The specific aims of the study were to determine how individuals responded to a range of driving situations by having them make continuous ratings as they viewed a tape of a drive through traffic. The drivers' responses were intended as the basis for modelling driver frustration in response to different traffic situations.

Method and Procedure

A tape of traffic incidents was prepared by taping from a camera mounted on a tripod situated in front of the front passenger seat in a large sedan car. Most of the driving was done along undivided primary and secondary arterials, the type of road where a traffic index is likely to find the greatest application. All roads were in the eastern inner suburbs of Melbourne. The taping was done in peak and non-peak times so that a range of traffic conditions was recorded.

The tapes were then edited to produce a practice segment lasting approximately 7 minutes, and the main tape which lasted 46 minutes. The incidents incorporated in the tape are:

Type of incident	**Number**
Stop-intersection signals	18
Stop- pedestrian-operated signals	3
Slow travel	8
Forced lane change-due to parked vehicle	5
Forced lane change-other	5
Other	19

Participants viewed the television monitor and were provided with a small response dial which they could adjust continuously between two extremes labelled 'Extremely Frustrating' and 'Not at all Frustrating'. Participants viewed the tape individually, and adjusted the knob on the dial to reflect the level of frustration they felt with the traffic situation. The position of the knob was sampled once a second, and the results stored in the computer. Five positions of the knob could be distinguished.

Three groups of twenty participants, aged 18-29, 30-59, and 60 and over, took part in the study.

Results and conclusions

The video footage and rating procedure used in the study appeared to provide a valid means of engaging the participants' emotions and perceptions in relation to traffic situations.
The three groups of respondents were highly consistent in the responses they gave to the different situations, although there were differences in the level of frustration expressed by the three groups. Once the scores were normalised by dividing the score for each second by the overall average for the session, individually for each participant, the differences between the groups disappeared and the pattern appeared very consistent across all groups.

The growth in frustration over time was examined by taking *the mean normalised frustration rating* (MNFR) for each incident, then plotting it against the duration of the incident. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the MNFR level for uneventful travel.

The results of the ratings study were not as had been anticipated, and do not agree well with currently-held priorities in traffic management. The main features of the responses to different types of incident are:

- Respondents were relatively indifferent to routine stops at traffic signals, and showed relatively little frustration even after fairly long delays. This result was particularly surprising.
- The picture with slow travel is rather more complicated. There is a marked dislike of being forced to travel slowly, but the frustration increases over time at about the same rate as it does for time stopped at traffic signals.
- Forced lane changes are very much disliked, and the dislike appears to be directly proportional to the time spent delayed. Delays due to forced lane changes arising from parked cars increase at approximately 26 times the rate for time delayed at intersection signals, and delays due forced lane changes caused by other factors result in a 20 fold increase over the rate for time delayed at intersections.
- For 'other' events, the slope of the regression line was negative and the fit of the regression line poor. It was therefore decided that the most appropriate approach to modelling this type of event would be to add a constant amount for each incident, and multiply that by the duration to determine impact.

The results of this investigation suggest that relatively simple models may adequately predict the relationship between traffic conditions and driver frustration. The implications of the regression results for modelling the relationship between frustration and traffic conditions are discussed.

1. Introduction

The notion of 'quality of travel' has traditionally been quantified by measures such as mean travel time. However, transport modellers are becoming increasingly aware that a measure of quality calls not only for objective measurements of the numerical parameters that define the flow, but subjective responses to travel conditions based on road users' perceptions. Driver comfort, frustration and stress are all relevant issues in the discussion of quality of travel. The literature suggests that modellers find difficulty in quantifying such factors and in determining what weighting they should be given in the development of a general 'travel quality' indicator. In formulating standard measures of the quality of traffic flow, the general tendency of modellers to date has been to simply assume that certain parameters of traffic flow are valid indicators of the travelling public's annoyance or dissatisfaction, and to combine these parameters in some intuitive fashion. A preferable approach would be to investigate which parameters of traffic flow actually relate to driver annoyance or dissatisfaction, and to find some way of combining these factors in order to give each a weighting that reflects the extent to which they relate to annoyance and dissatisfaction.

The present investigation aims to achieve this by:

- reviewing previous work in the field
- determining how drivers respond to delays, slow travel, forced lane changes, and other frustrating events which are likely to be encountered in the course of driving in urban environments
- developing an index which describes quality of travel and which gives appropriate weighting to different types of events, based on the investigation of driver responses and other previous research
- applying this index to typical travel flow situations
- validating the travel flow index by comparing the index for certain trips at certain times against driver assessment of travel quality.

The present document describes the work undertaken to determine drivers' responses to traffic situations. The methods used in this part of the investigation were based on methods trialed in an earlier pilot study in which subjects were shown tapes of traffic situations, and asked to indicate what situations they found frustrating or annoying. Participants were interviewed after they had seen the tapes.

Although there were individual differences in the responses to incidents, there were some situations in which all or almost all of the participants were annoyed or frustrated. Events varied in the time period over which they were recognised as frustrating. Interviews with subjects suggested that most preferred a slow steady trip to one which alternated delays with travel at reasonable speeds, that a build up of successive incidents tended to cause frustration, and that the behaviour of other drivers and their imputed motives were major contributors to frustration.. The pilot study was successful in demonstrating that there appear to be aspects of frustration with traffic that do not depend on travel time alone, and that important aspects of traffic situations could be captured on video sufficiently well for people to feel their ratings of traffic situations reflected how they would feel in that situation.

As the pilot study was carried out on a small budget, there were a number of unsatisfactory features of the apparatus and tapes. It was possible to rectify the majority of these in the present study. The following lessons were learned from the pilot study, and the following improvements incorporated:

- Participants had an inadequate view of the traffic situation, particularly when stopped or moving slowly. This was rectified to some extent in the present study by panning the view to each side, much in the way of natural head and eye movements.
- Participants had difficulty in judging travel speed from the tapes. None of the solutions trialed in the development of the apparatus were satisfactory, and it did not prove possible to provide speed information on the video tape with the equipment available.
- The two levels of frustration used in the pilot study were sufficient to differentiate between situations when responses from participants were combined. In the present study, participants were provided with a control knob on a dial labelled 'not in the least frustrated' at one end of the dial to 'extremely frustrated' at the other, and were free to adjust the knob in a manner which reflected their level of frustration.
- Whichever form of the responses are used in the main study, there is a need to develop clear descriptions to define the points on the scale used, e.g. 'not at all frustrated' and 'extremely frustrated'.
- The method of indicating frustration levels forced on the pilot study by the limitations of the apparatus, ie tapping the appropriate key approximately 1 second intervals, was unsatisfactory. This was rectified in the present investigation by providing the knob and dial, sampling the position of the dial at 1 second intervals, and accumulating the responses in a computer.
- The time-consuming method of transcribing responses which had to be used in the pilot study was overcome by the automatic sampling and recording of the dial position.
- Much of the time in the simulated drive in the pilot study was spent in uneventful driving. More incidents were included in the tapes used in the present investigation.

2. Method

2.1 Apparatus

The apparatus consisted of :

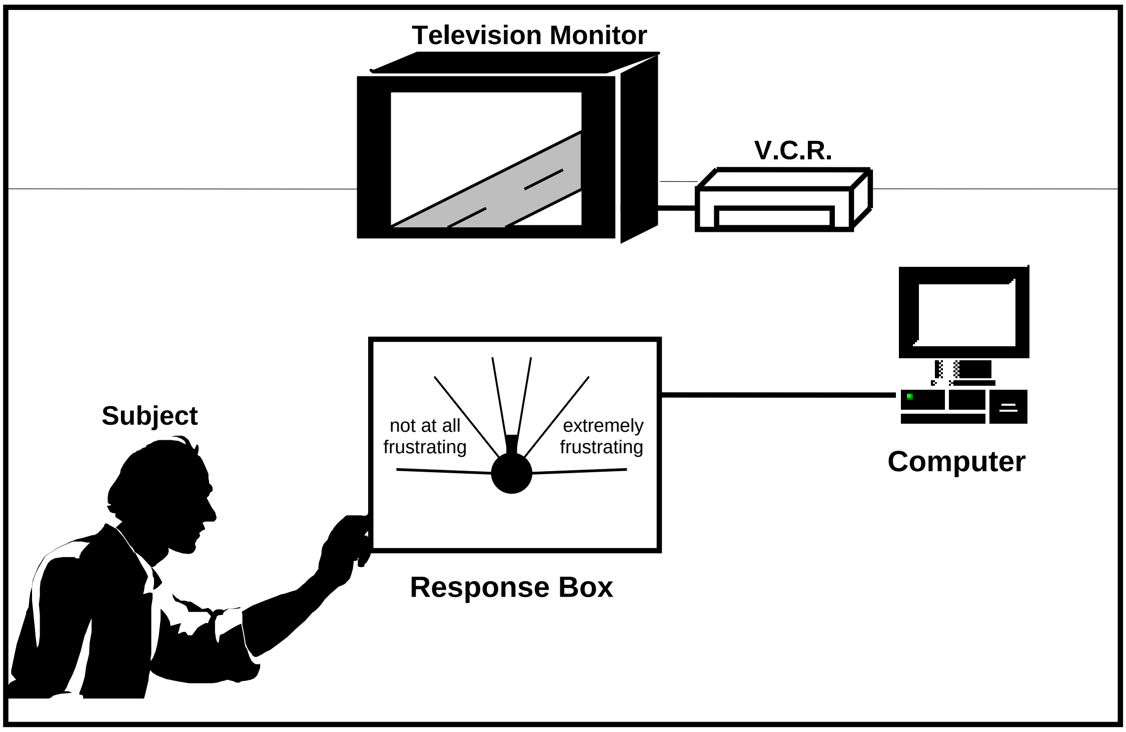
A television with a 48 cm screen and a built-in video recorder, a specially constructed response dial and a computer.

The experimenter started the tape and initiated the computer run at a set point on the tape. This was sufficiently accurate for responses to be matched to events on the tape.

Participants viewed the tape individually, and adjusted the knob on the dial to reflect the level of frustration they felt with the traffic situation. The position of the knob was sampled once a second, and the results stored in the computer. Five positions of the knob could be distinguished. The experimental set-up is shown in Figure 1.

The testing took place in a quiet office, with only the participant and the experimenter present.

Figure 1: Survey set up



2.2 The tape of traffic incidents

The tape of traffic incidents was prepared by taping from a camera mounted on a tripod situated in front of the front passenger seat in a large sedan car. An operator steadied the camera, and panned to the left and right when the vehicle was stopped. Aperture size and focus were controlled automatically by the camera. Most of the driving was done along undivided primary and secondary arterials, the type of road where a traffic index is likely to find the greatest application. All roads were in the eastern inner suburbs of Melbourne. The taping was done in peak and non-peak times so that a range of traffic conditions was recorded.

The tapes were then edited to produce a practice segment lasting approximately 7 minutes, and the main tape which lasted 46 minutes. The incidents incorporated in the tape are:

Type of incident	**Number**
Stop-intersection signals	18
Stop- pedestrian-operated signals	3
Slow travel	8
Forced lane change-parked vehicle	5
Forced lane change-other	5
Other	19

A sequential listing of the incidents and their approximate duration is given in Appendix 1.

2.3 Participants

60 subjects were surveyed and categorised by age into three groups. All were holders of full or provisional licences. Table 1 provides a profile of the survey sample.

All participants were paid $30 to cover travel expenses and compensate for the time required for the study.

Table 1
Survey sample characteristics

Age Group	Sample size	Males	Females	Mean Age	Standard deviation	Hours spent driving per week
<30	20	11	9	25	4.32	9.95
30-59	20	11	9	45	8.18	12.10
60+	20	12	8	65	5.12	15.38

Table 1 shows that for all groups, just over half the participants were men, and that a good spread of ages was achieved, indicated by the standard deviations. The oldest group spent most time driving and the youngest group the least.

2.4 Procedure

Participants in the study reported to ARRB TR's offices where they were met by an experimenter who briefed them on the nature of the task. Specifically, they were informed that the survey was aimed at recording driver frustration and that the video depicted a 46 minute drive in which the subject should imagine themselves as the driver. While 'driving' the subject rated their mood by turning a dial across five levels ranging from 'not at all frustrated' to 'extremely frustrated'. Frustration levels were clearly labelled on the apparatus for easy reference. Subjects appeared to readily accept these anchor points without the need for further elaboration.

A seven minute practice run was prepared to allow subjects to familiarise themselves with the apparatus and the type of scenarios presented on the video. Many commented that some of the delays encountered could have been avoided by better route choice or a more defensive driving style. In response to this, they were told to only rate their frustration at the events occurring and not at the actual driving style itself. Participants also suggested that their frustration levels would vary according to the nature of the drive and how much of a rush they were in. To promote consistency, all subjects were told to consider themselves 'not in any particular hurry', but to compare the experimental drive with a completely uninterrupted trip resulting in minimal travel time between the same origin and destination.

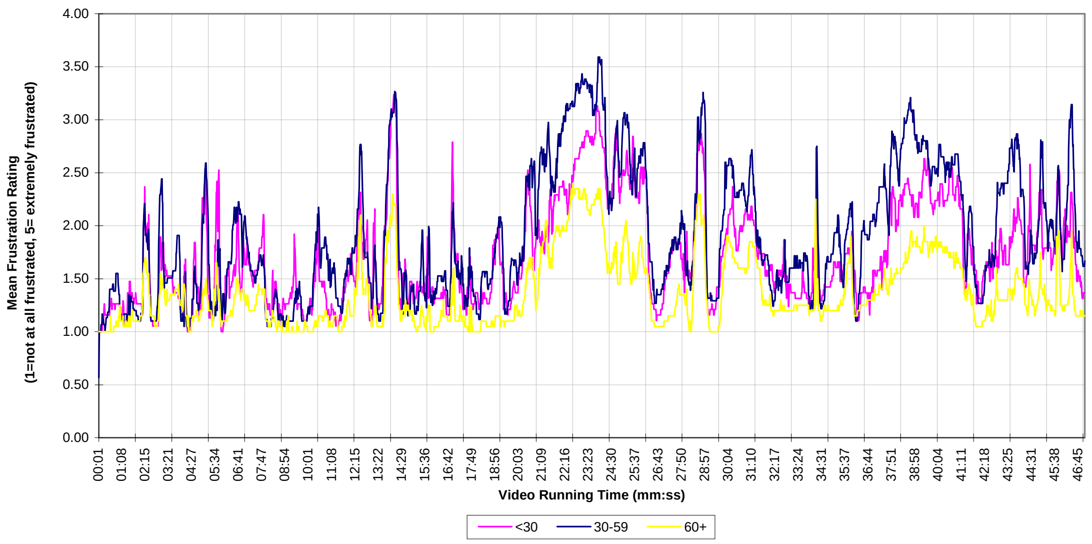
Following the test segment, the experimenter asked a series of questions relating to the subject's demographic profile, the amount they drove, what aspects of driving they considered most frustrating and how they felt their behaviour changed when frustrated.

3. Results

3.1 Overall Ratings of Frustration

The mean ratings for each of the three groups over the whole session is presented in Figure 2. The average ratings are plotted progressively throughout the session. It can be seen that although there are consistent differences among the means, the pattern of variation is identical for the three lines, rising and falling at the same points in the session. Thus it would appear that although the three groups differed in the degree of frustration they characteristically felt, frustration was elicited by the same incidents to a similar degree.

Figure 2: Mean frustration rating by age group vs time



The highest degree of frustration was expressed by the middle age group, and the least degree by the oldest group, with the youngest group expressing a degree of frustration approximately mid-way between these two. Since similar reactions were elicited from the three groups by the traffic situations, the responses have been normalised and combined in the following analysis. As the reason for the investigation is to develop terms for use in modelling user discomfort with the traffic system, the question of individual differences will not be pursued further in the present report.

The frustration ratings for each participant were normalised by taking the average of the participant's ratings over the whole session and then dividing each rating throughout the session by that average. This has the effect of removing the differences between individuals but retaining the differences between events. The normalised ratings were then averaged for each group, and the average normalised scores are shown in Figure 3. It can be seen that the average normalised scores for the three groups are virtually identical. These normalised scores were then averaged across groups to produce mean normalised frustration ratings (MNFR) which form the basis for the main analysis. The average combined normalised ratings are shown in larger scale in Figures 4(a) to (i), which allows each incident to be identified in detail.

Figure 3: Mean normalised frustration rating by age group vs time

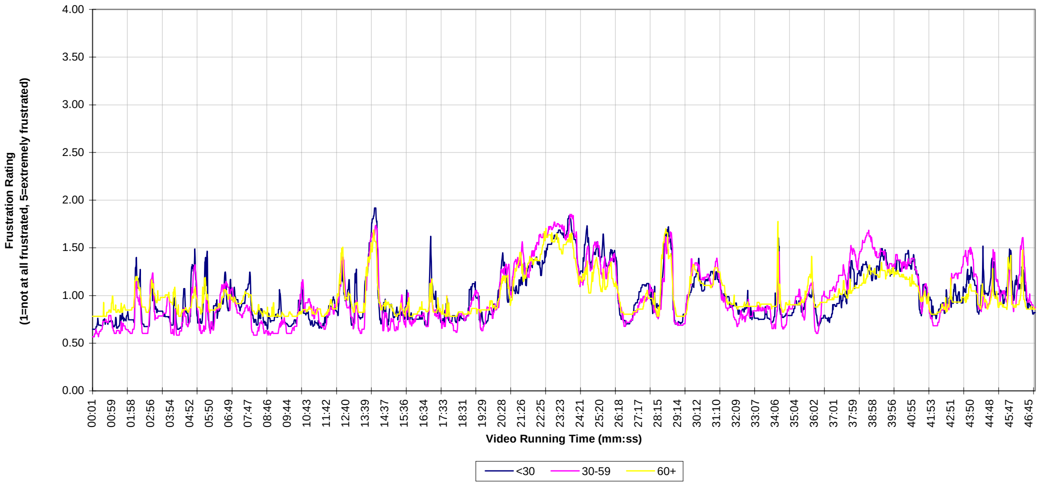


Figure 4: Mean Normalised Frustration Rating vs time

Figure 4(a)

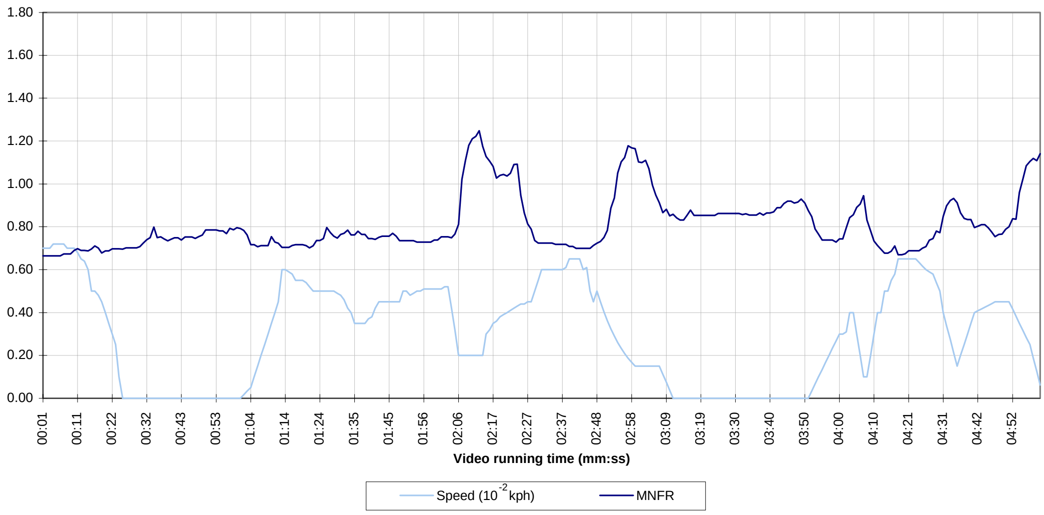


Figure 4(b)

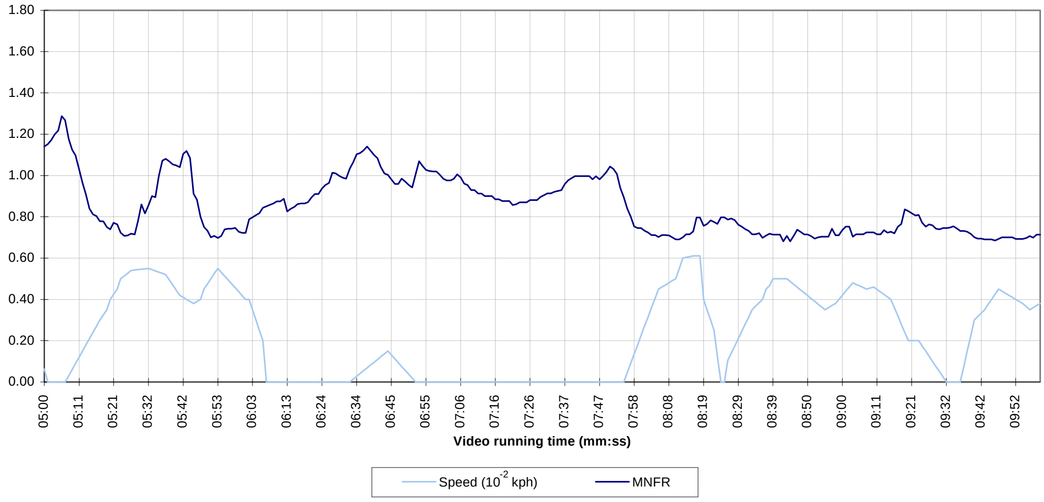


Figure 4(c)

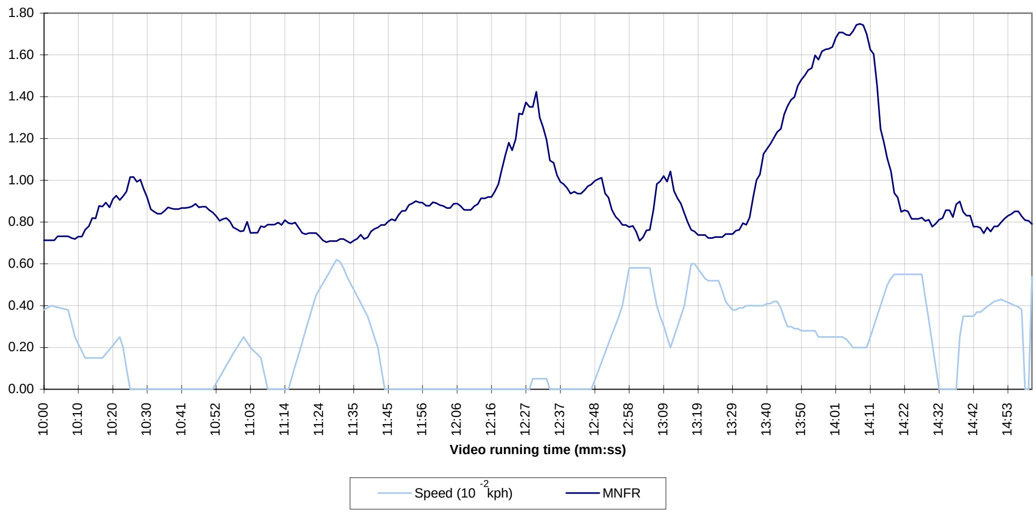


Figure 4(d)

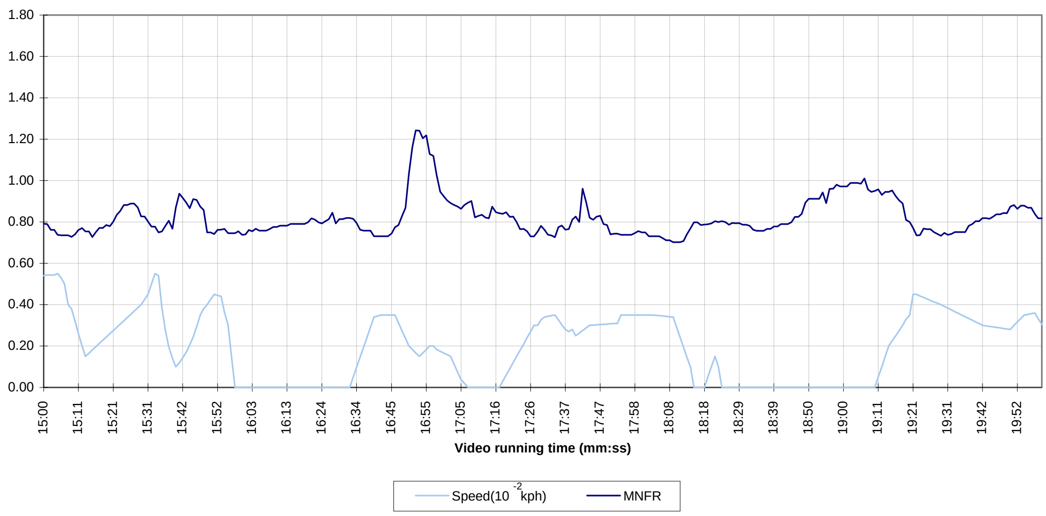


Figure 4(e)

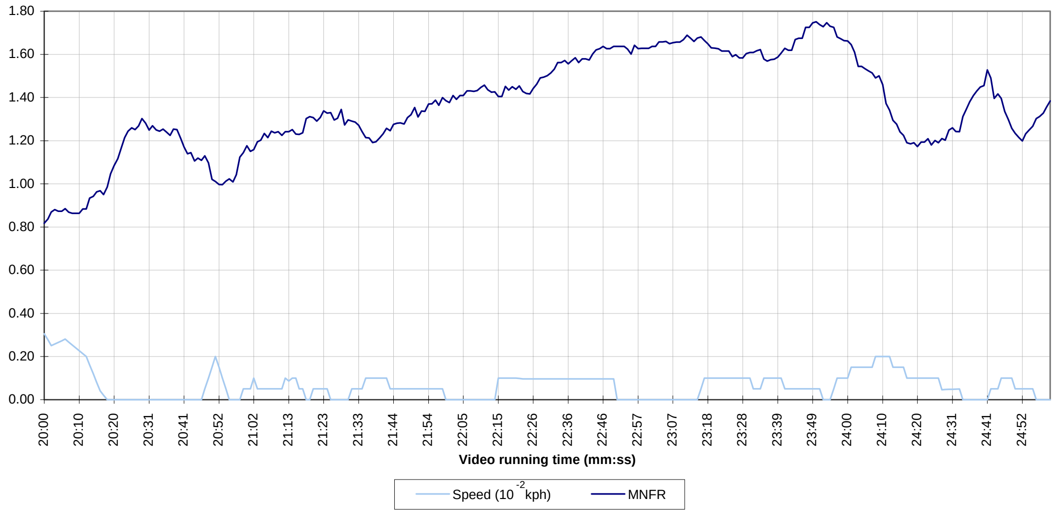


Figure 4(f)

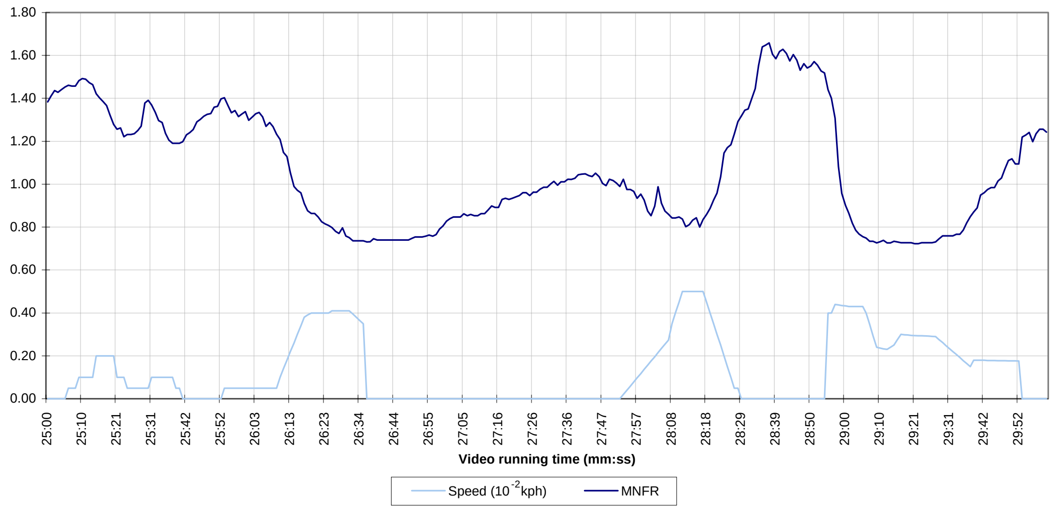


Figure 4(g)

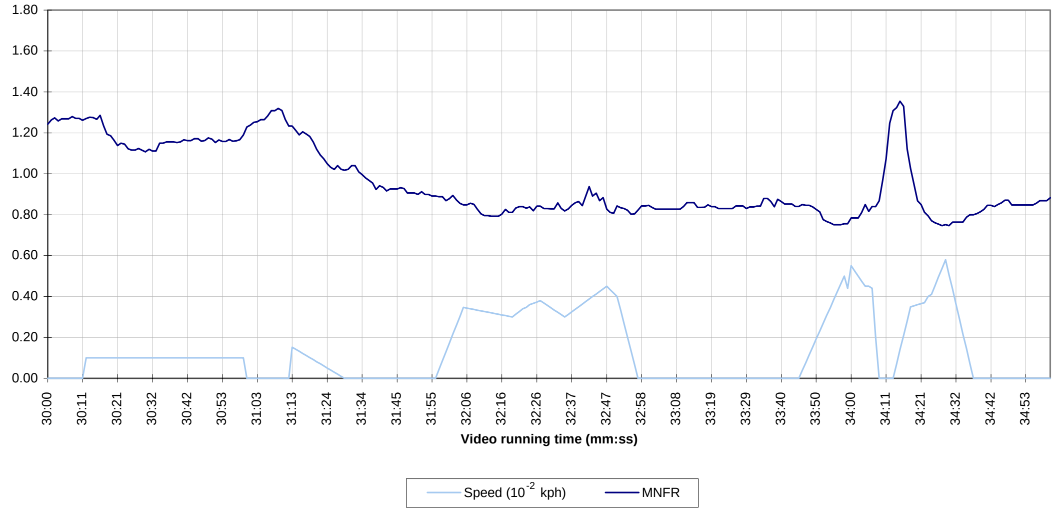


Figure 4(h)

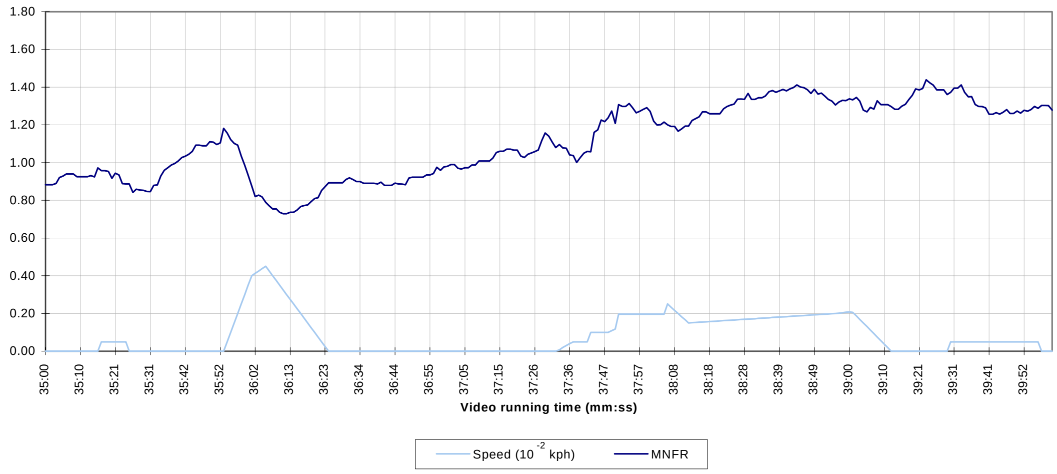
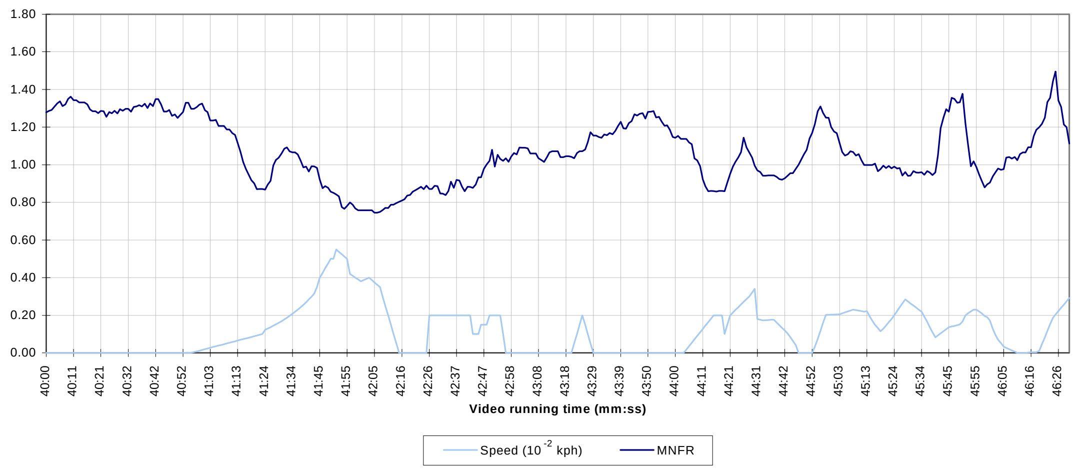


Figure 4(i)



3.2 Analysis of Responses to Individual Incidents.

The individual incidents were grouped according to type. From the video tape, the duration of the incident was determined by observing when the incident began to develop, and determining when the incident was clearly over, usually when the vehicle began to pick up speed. The speed trace superimposed on Figures 4(a) to (i) assisted in this process. From the response records, the peak MNFR during the incident and the MNFR over the whole incident were determined. A basic measure of the impact of each incident was obtained by multiplying the duration of the incident by the average MNFR during the incident. A more sophisticated measure of impact is developed in Section 3.3. The results of this initial analysis are presented in Table 2 grouped by type of incident, and summarised in Table 3.

Table 2
Calculation of Impact by event type

Event Type	Start	Finish	Cause	Duration (s)	Average MNFR	Impact (s)
FLC	2:55	3:01	parked car, wait for traffic to clear	6	1.01	6.06
(parked car)	19:38	19:42	parked car	4	0.80	3.20
	28:29	28:54	parked car, wait for traffic to clear	23	1.54	35.42
	37:38	37:47	parked car, wait for tram to pass	9	1.11	12.21
	45:38	45:45	double parked truck	7	1.12	7.84
FLC (other)	14:45	14:49	lane closure due to construction	4	0.77	3.08
	15:38	15:42	turning vehicle	4	0.86	3.44
	25:53	26:10	truck turning right at lights	17	1.31	22.28
	34:18	34:23	car turning right at lights	5	0.96	4.80
	41:26	41:42	3 flc in a row- parked cars and cars turning right	16	1.02	16.32

Slow travel	02:04	02;24	caught behind a bus	20	1.06	21.20
	04:52	05:10	banked up traffic through intersection	18	1.10	19.80
	04:32	04:40	banked up traffic	8	0.88	7.04
	13:41	14:10	caught behind a construction vehicle	29	1.54	44.66
	20:14	20:29	banked up traffic through intersection	15	1.18	17.70
	20:48	25:39	heavy congestion	290	1.41	410.13
	29:34	31:28	congestion	114	1.15	131.10
	37:48	39:56	caught behind a tram	128	1.31	167.68

Event Type	Start	Finish	Cause		Duration (s)	Average MNFR	Impact (s)
Stops	0:25	0:01	traffic light		35	0.75	26.34
	3:11	3:51	traffic light		40	0.87	34.77
	6:07	7:55	traffic light	(2 cycles)	108	0.96	164.42
	8:24	8:25	traffic light		1	0.80	0.80
	9:32	9:36	traffic light		4	0.69	2.76
	11:08	11:15	traffic light		7	0.79	5.55
	11:44	12:47	traffic light	(wait to turn right)	63	0.99	62.18
	15:58	16:32	traffic lights		34	0.78	26.68
	18:15	19:10	traffic lights		55	0.85	46.97
	26:36	27:41	traffic lights		75	0.89	78.29
	32:57	33:45	traffic lights		48	0.84	40.40
	34:37	35:53	traffic lights	(wait to turn right)	76	0.93	103.71
	36:24	37:32	traffic lights		68	0.97	66.02
	42:15	42:25	traffic lights		10	0.85	8.50
Stops (congested flow)	20:30	20:47	traffic lights	congested flow	17	1.21	20.52
	25:40	25:52	traffic lights	congested flow	12	1.29	15.50
	31:29	31:56	traffic lights	congested flow	27	0.94	25.48
	39:57	40:57	traffic lights	congested flow	60	1.30	78.16
Stops (pedestrian crossings)	10:25	10:51	signalised pedestrian crossing		26	0.89	23.14
	17:07	17:17	signalised pedestrian crossing		10	0.85	8.48
	42:56	44:03	signalised pedestrian crossing	(2 cycles)	67	1.13	75.71
'Other' events	04:03	4:08	stopped behind a turning vehicle		5	0.89	4.45
	05:32	5:44	car cutting in front, then slowing to turn left		13	1.02	13.26
	09:11	9:23	stopped behind a turning vehicle		12	0.77	9.24
	10:08	10:20	stopped behind a turning vehicle		12	0.81	9.72
	13:05	13:11	stopped behind a turning vehicle		6	0.98	5.88
	14:32	14:37	stopped behind a turning vehicle		5	0.84	4.20
	15:12	15:26	stopped behind a turning vehicle at green light		14	0.80	11.20
	16:46	16:53	truck turning across traffic stream		7	0.99	6.93
	17:40	17:44	car cutting in front from parking spot		4	0.88	3.52
	24:40	24:41	car cutting in front from parking spot, pedestrian crossing in front		1*	1.49	1.49
	27:59	28:04	pedestrian jaywalking, delaying turn		5	0.91	4.55
	32:37	32:45	stopped behind a turning truck		8	0.88	7.04
	34:05	34:12	car in front doing 3-point turn		7	0.98	6.86
	44:19	44:25	car cutting in front b/c of parked car, no indicator		6	0.93	5.58
	44:47	44:51	car in front suddenly deciding to park		4	1.14	4.56
	44:58	44:59	wide truck, taking up two lanes		1*	1.25	1.25
	45:07	45:18	stopped behind a turning vehicle		11	1.02	11.22
	45:46	45:47	pedestrian jaywalking, delaying manoeuvre		1*	1.36	1.36
	46:11	46:18	stopped behind a right turning car and parked car		7	1.09	7.63

* These three events of very short duration have been treated as outliers in the following analysis. Refer to figure 10.

Table 3
Summary of MNFRs by event type

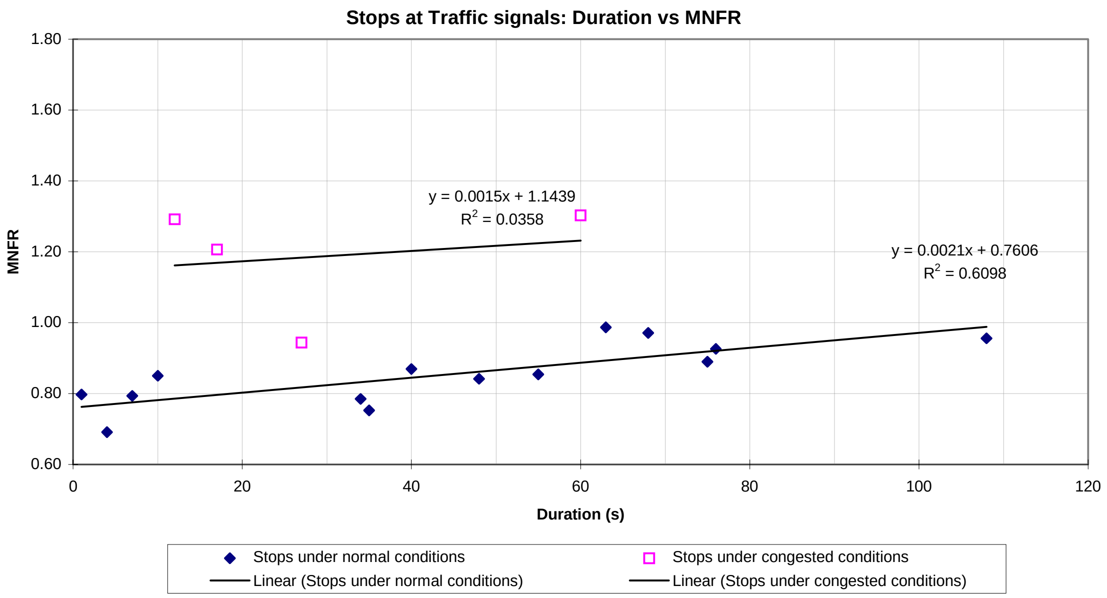
Event Type	MNFR
Uneventful travel	0.81
Traffic lights (not in congested flow)	0.85
Ped Xings	0.96
FLC (other)	0.98
Other	1.00
FLC (due to parked cars)	1.12
Traffic lights (in congested flow)	1.19
Slow travel	1.20

The average baseline MNFR for uneventful travel was 0.81, equivalent to a 'Not at all frustrating' rating on the scale. The various event classes identified from the tape elicited MNFRs which varied considerably. Traffic lights in uncongested flow elicited slightly higher MNFRs (0.85), pedestrian crossings slightly higher MNFRs again (0.96), followed by forced lane changes due to circumstances other than parked cars (0.98), other events (1.00), forced lane changes due to parked cars (1.12), traffic signals in congested flow (1.19) and slow travel (1.20).

Plotting the MNFR for each incident against the time over which the incident lasted indicated that the MNFR generally increased with the time over which the incident lasted, and that the data were generally well described by a linear regression equation. The relationships obtained are shown in Figures 5-10 below.

Figure 5 — Stops at traffic signals

Duration vs MNFR



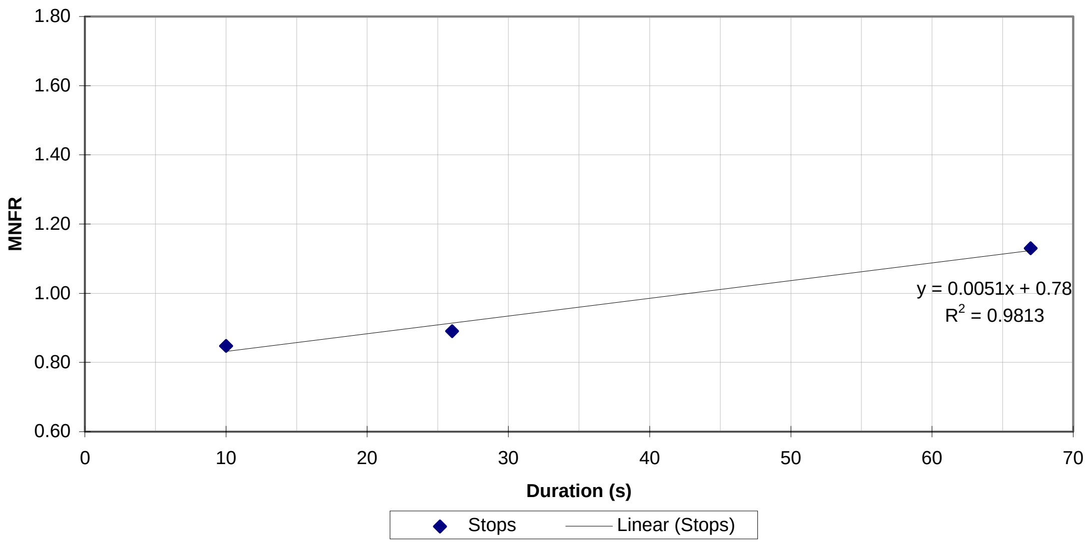
The MNFR for stops at traffic signals is plotted against duration in Figure 5. Regression analysis was carried out to describe the relationship between MNFR and duration. Observation of the results suggested that ratings under congested conditions were generally considerably higher than ratings for less congested conditions. It was therefore decided that it was appropriate to treat the results as two different types of situation and to determine the regression line for each separately. In this context, a stop in congested situations refers to a stop made during a period of slow travel due to congestion. The distinction here is that drivers forced to travel slowly due to congestion tend to already be frustrated. Having to stop at a red light may not only be a further annoyance but most drivers feel that they would not have been caught at the light had they been travelling in uncongested conditions.

The R-square statistic associated with the regression equation for uncongested conditions is not particularly high in this case (0.6098), and slightly better results were obtained with a polynomial fit (R2= 0.6117). However, for all the other variables examined in this fashion, a linear regression gave an adequate fit which was not improved by polynomial regression. It was therefore decided to stick with linear regression in the interests of consistency.

The point of origin for the regression line (0.76) is close to the MNFR for uneventful travel. MNFR increases rather slowly with increasing delay, with a 10 second delay increasing MNFR by just over 0.02 points, and 48 second delay required to cause a 0.10 shift in MNFR.

The regression line for stops under congested conditions has a similar slope to the line for uncongested conditions, but a considerably higher intercept. This suggests that any stop is particularly frustrating under congested conditions but, as was the case with uncongested conditions, the level of frustration increases quite gradually with the amount of time stopped. The increase in frustration due to stopping would appear to be approximately 0.34 points, equivalent to being delayed for almost three minutes under uncongested conditions. Note however that the fit of the regression line is very poor under congested conditions (R^2 = 0.0358).

Figure 6 — Stops at signalised pedestrian crossings. Duration vs MNFR



The regression of MNFR against duration for stops at signalised pedestrian crossings shown in Fig. 6 provided an excellent fit to the data (R^2= 0.9813). Note, however, that there only three data points. Again, the intercept (0.78) was very close to the value for uneventful travel. Delay at pedestrian crossings resulted in MNFR increasing 2.5 times faster than was the case at intersection signals, with a 10 second delay resulting in a 0.05 increase in MNFR, and a delay of 20 seconds being required to cause an increase of 0.10 points in MNFR.

Figure 7 — Slow travel. Duration vs MNFR

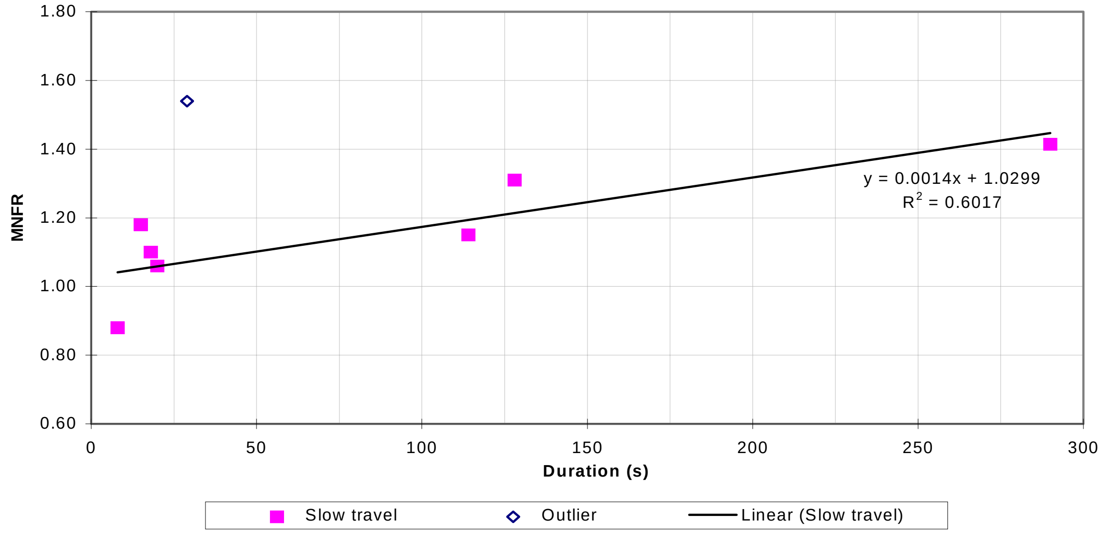


Figure 7 shows the regression of MNFR against duration for slow travel. Incidences of slow travel were caused by things such as congestion and being caught behind slow vehicles such as trams, trucks and buses. The fit of the regression line is not particularly good ($R^2 = 0.6017$). The data were re-examined to determine whether any basis for establishing a relationship between mean MNFR and speed or change in speed could be discerned, but none was apparent. In this case, the intercept is 1.03, which suggests that any amount of slow travel will increase MNFR by 0.2 points. The slope is relatively gentle, so that 10 seconds travel at slow speeds would increase the MNFR by a further 0.01 points.

Figure 8 — Forced lane changes due to parked cars

Duration vs MNFR

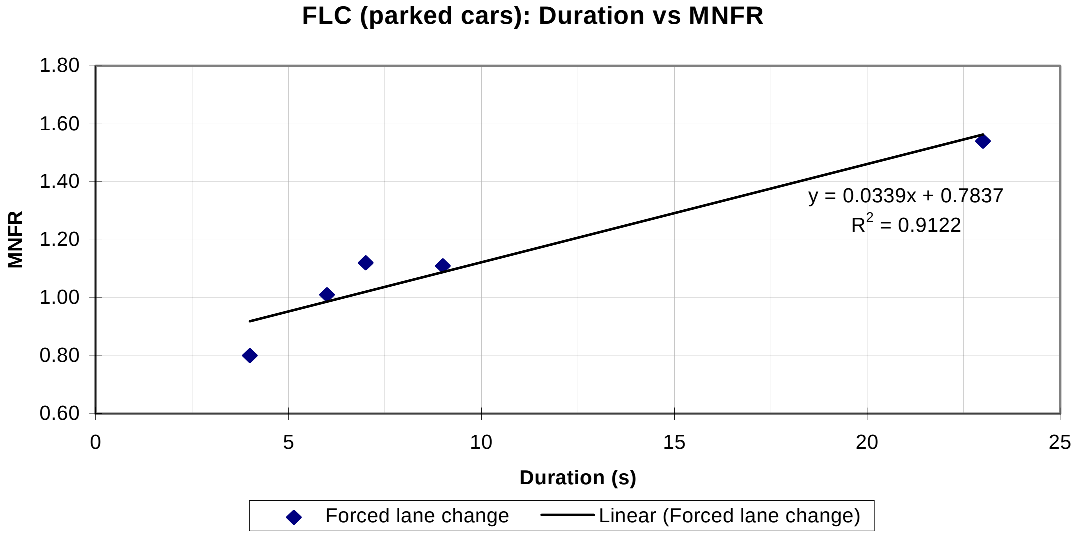
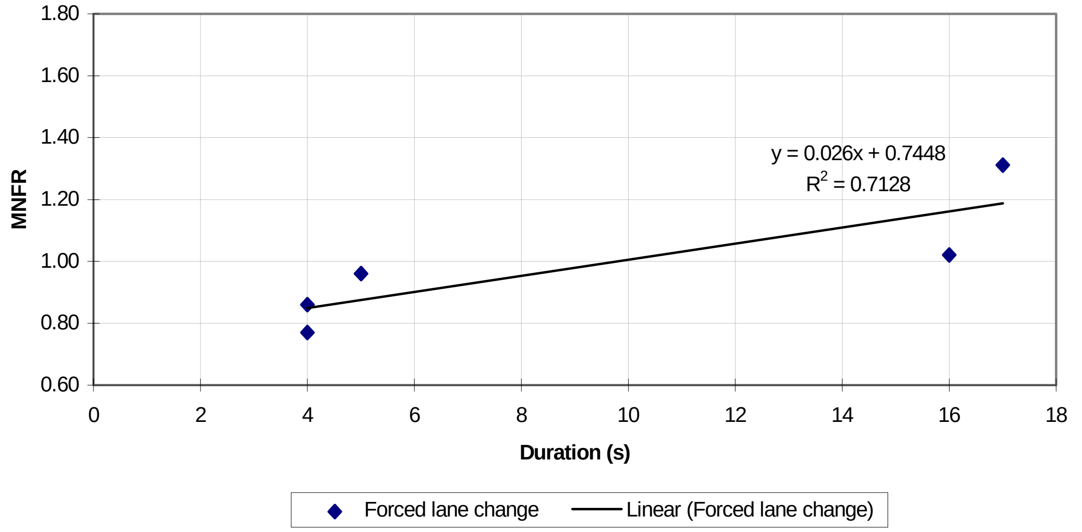


Figure 8 shows the regression of MNFR against duration for forced lane changes due to parked cars. This regression shows a good fit to the data (R-squared = 0.9122), with the intercept close to the average value for MNFR for uneventful travel (0.78). The slope of the regression line is relatively steep in this case, with a 10 second delay resulting in a 0.34 increase in MNFR, and a delay of just 3 seconds being required to cause in increase of 0.10 points in MNFR.

Figure 9 — Forced lane changes (other)

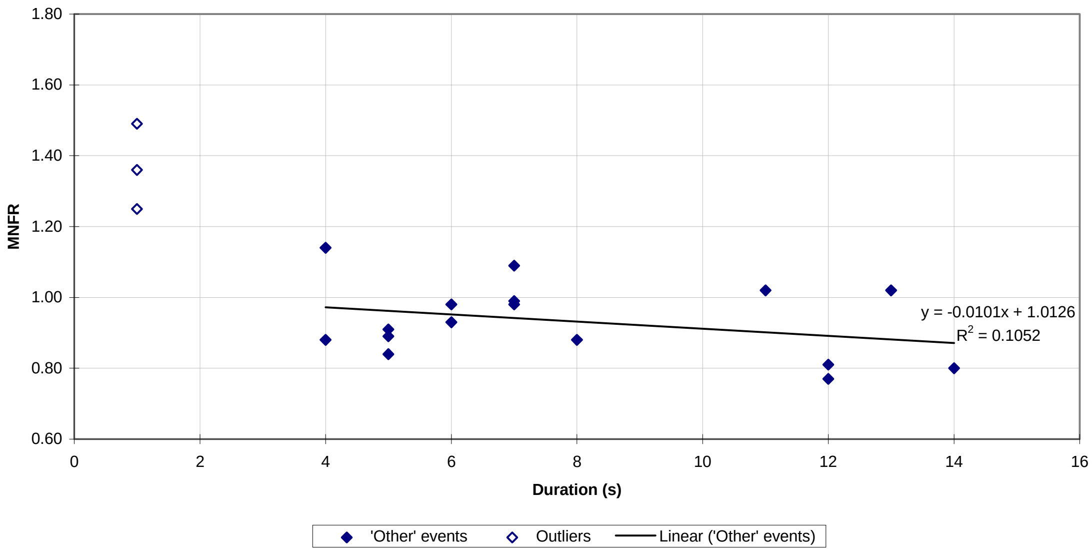
Duration vs MNFR



The regression of MNFR against duration for other types of forced lane changes is shown in Figure 9. The fit (R square = 0.7128) is weaker than was the case for the forced lane changes due to parked cars, the intercept further from the MNFR for uneventful travel (0.74), and the slope of the line not quite so steep, though still steep in comparison to 'other' types of events. A 10 second delay will result in an increase in MNFR of 0.26, and a delay of 4 seconds required to cause an increase of 0.10 points in MNFR.

Figure 10 — 'Other' events

Duration vs MNFR



Regression of MNFR against duration for the ‘other’ events proved more problematical, and has necessitated some manipulation of the data to achieve readily interpretable results. Near the top left hand corner of Figure 10 are the plots for three events of short duration which attracted very high ratings. These events were: a pedestrian stepping out in front of the survey vehicle and delaying a turning movement, a wide truck preventing overtaking, and a utility executing a three-point turn in front of the survey vehicle. These events have been treated as outliers and excluded from the analysis. The regression line appears to intercept the x-axis at value of just over 1.0, and to have a negative slope. This negative slope is problematical, as it makes little sense to expect events to become less frustrating the longer they last. The most satisfactory explanation is probably that these ‘other’ events constitute a very diverse range of happenings and that the MNFR for each incident is more a reflection of the nature of the incident than its duration. Note, too, that the fit for this line in noticeably poorer than the regression lines for the other types of incident (R^2 =0.1227).

3.3 Implications for modelling

These results suggest that two rather simple models may provide an adequate description of the relationship between traffic incidents and MNFR.

(a) For most of the variables examined, the linear regression is an adequate description of the relationship between MNFR and the duration of the incident. In addition, the intercept from the regression equation lies close to the MNFR for uneventful travel. It is therefore proposed that an appropriate term for each incident can be derived from the slope multiplied by the duration, ie

Term describing the incident = slope × duration.

This term is equivalent to the average increase in frustration above the baseline level for uneventful travel for a particular type of incident.

It would also be appropriate to weight each incident for the length of time over which it lasted to produce an estimate of the impact of the incident, ie

Impact = slope × duration × duration, ie

Impact = slope × duration^2

Thus each incident would be represented by a term calculated from the constant (ie slope) characteristic of each type of incident and the square of the duration of the incident.

(b) A slightly different approach is called for in the case of stops at traffic signals under congested conditions and the case of slow travel, where it will be recalled these events produced regression equations with intercepts some points higher than was the case for the other events. In both cases it is necessary to add the difference in the intercept to the duration x slope term, before multiplying by the duration to determine the overall impact.

This does not apply in the case of the ‘other’ incidents where there was a negative slope and an intercept of 1.02. It is proposed to treat ‘other’ incidents by simply allocating a score of 0.2 when the incident occurs. This is equivalent to adding the difference between the intercept of the regression line and the MNFR for uneventful travel, and disregarding the length of time over which the incident lasted.

The possible terms for modelling are set out in Table 4. While the terms listed in the table are a possible basis for modelling driver reactions to traffic conditions, two issues remain to be resolved from further examination of the data. These are the point at which traffic becomes sufficiently congested to warrant treatment of stops as Stops under congested conditions', and the point at which travel speed has been reduced sufficiently to warrant treatment as slow travel.

Table 4 — Possible terms for modelling equations based on outcomes of rating experiment

Type of event	Term estimating the impact	R^2 statistic for regression equation
Stop at intersection signal	$0.0021T_e^2$	0.61
Stop at intersection signal (under congested conditions)	$T_e(0.3 + 0.0013\ T_e)$	0.04
Stop at pedestrian operated signals	$0.005\ T_e^{\ 2}$	0.98
Slow travel	$T_e(0.2 + 0.0014\ T_e)$	0.60
Forced lane change - parked cars	$0.034\ T_e^{\ 2}$	0.91
Forced lane change - other	$0.026\ T_e^{\ 2}$	0.71
Other events	$0.20\ T_e$	0.12

T_e = duration of the incident in seconds.

With the benefit of more data, it may be possible to develop a more refined approach to both issues, which perhaps substitutes for the single constant a range of constants which reflect the degree of congestion or, in the case of slow travel, the absolute speed or the amount by which travel speed is reduced. In the meantime, it would appear that the regression equations developed in the present study are sufficient to begin building and validating models of the relationship between driver frustration and traffic conditions, with the exception of two types of incident which are better represented by a unitary score rather than a score which is related to the duration of the incident.

4. Discussion

The video footage and rating procedure appeared to have a degree of face validity in as much as they were effective in engaging participants' attention and emotions in response to the traffic situations. Incidental observation of participants' behaviour in the study suggested a range of responses, from people who were completely engrossed in the task and indicating high levels of emotion to people who were less engrossed, but nonetheless still responded continuously to the changing situations.

One of the limitations of this technique is that the participants are not themselves in charge of the 'vehicle', and are therefore judging how frustrating they find someone else's driving. It may have been particularly annoying to some participants that more was not done to avoid situations such as forced lane changes, and this may be expressed in higher frustration ratings than would be the case with their own driving.

The three groups of respondents were highly consistent in the responses they gave to the different situations, with the line showing the mean frustration rating for each group having peaks and troughs which coincided with the peaks and troughs in the lines for the other groups. The lines, were, however, clearly separated, indicating that the groups differed in the degree of frustration experienced. Once the scores were normalised by dividing the score for each second by the overall average for the session, individually for each participant, the differences between the groups disappeared and the pattern appeared very consistent across all groups.

The growth in frustration over time was examined by taking the mean normalised frustration rating (MNFR) for each incident, then plotting it against the duration of the incident. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the MNFR level for uneventful travel.

The results of the ratings study were not as had been anticipated, and do not agree well with currently-held priorities in traffic management.

Respondents were relatively indifferent to routine stops at traffic signals, and showed relatively little frustration even after fairly long delays. There was no suggestion of an exponential increase in frustration as delay increased, at least over the range of values covered in the study, which included several delays of over 1 minute, and one of almost two minutes which lasted through two signal cycles. Frustration ratings at pedestrian-operated signals increased at 2.5 times that rate. Perhaps the delays imposed upon drivers after the pedestrians had completed their crossing contributed to this.

The picture with slow travel is rather more complicated. There is a marked dislike of being forced to travel slowly, but the frustration increases over time at about the same rate as it does for time stopped at traffic signals.

Forced lane changes are very much disliked, and the dislike appears to be directly proportional to the time spent delayed. Delays due to forced lane changes arising from parked cars increase at approximately 26 times the rate for time delayed at intersection signals, and delays due to forced lane changes caused by other factors result in a 20 fold increase over the rate time delay at intersections.

A different approach is called for with ‘other’ events, as the slope of the regression line was negative and the fit of the regression line poor. It was therefore decided to adopt an approach of adding a constant amount for each incident, and multiplying that by the duration to determine impact.

It must be acknowledged that the investigation relies on eliciting frustration ratings in an artificial situation, and that the frustration ratings may therefore not be representative of the frustration experienced in real life situations. It was not possible to include either physical elements such as road roughness or the extra steering effort required with narrow lanes, or more long term aspects of the situation, such as trip predictability, ie how much longer than expected does it take to complete a familiar trip.

The data themselves have features which both challenge and support the validity of the exercise. The principal challenge is that the overall frustration ratings seem rather low, given that a 13 km trip took 46 minutes to complete and average speeds on the link sections were generally well below the speed limit. Two observations must be set against this. First, that much of the delay was due to predictable delays arising from features of the traffic system, to which participants gave low frustration ratings and second, that a high degree of consensus was evident in the timing of frustrating events in Figure 1.

Appendix 1 — Sequential listing of incidents shown on video tape for the test session

Start (mm:ss)	Finish (mm:ss)	Event Type	Cause	Duration (mm:ss)
00:25	01:00	Stop	traffic light	00:35
02:04	02:24	Slow Travel	bus	00:20
02:55	03:01	FLC	parked car, wait for traffic to clear	00:06
03:11	03:51	Stop	traffic light	00:40
04:03	04:08	other	stopped behind a turning vehicle	00:05
04:32	04:40	Slow Travel	banked up traffic	00:08
04:52	05:10	Slow Travel	traffic banked up through intersection	00:18
05:32	05:44	other	car cutting in front, then slowing to turn left	00:12
06:07	07:55	Stop	traffic light (2 cycles)	01:48
08:24	08:25	Stop	traffic light	00:01
09:11	09:23	other	stopped behind a turning vehicle	00:12
09:32	09:36	Stop	traffic light	00:04
10:08	10:20	other	stopped behind a turning vehicle	00:12
10:25	10:51	Stop	Signalised Pedestrian Crossing	00:26
11:08	11:15	Stop	traffic light	00:07
11:44	12:47	Stop	traffic light wait to turn right	01:03
13:05	13:11	other	stopped behind a turning vehicle	00:06
13:41	14:10	Slow Travel	stopped behind a construction vehicle	00:29
14:32	14:37	other	stopped behind a turning vehicle	00:05
14:45	14:49	FLC	lane closure due to construction	00:04
15:12	15:26	other	stopped behind a turning vehicle at green light	00:14
15:38	15:42	FLC	turning vehicle	00:04
15:58	16:32	Stop	traffic lights	00:34
16:46	16:53	other	truck turning across traffic stream	00:07
17:07	17:17	Stop	Signalised Pedestrian Crossing	00:10
17:40	17:44	other	car cutting in front from parking spot	00:04
18:15	19:10	Stop	traffic lights	00:55
19:38	19:42	FLC	parked car	00:04
20:14	20:29	Slow travel	traffic banked up through intersection	00:15
20:30	20:47	Stop	traffic lights Congested flow	00:17
20:48	25:38	Slow Travel	heavy congestion	04:50
24:40	24:41	other	car cutting in front from parking spot, pedestrian crossing in front	00:01
25:40	25:52	Stop	traffic lights Congested flow	00:12
25:53	26:10	FLC	truck turning right at lights, parked car on departure side of intersection	00:17
26:36	27:51	Stop	traffic lights	01:15
27:59	28:04	other	pedestrian jaywalking, delaying turn	00:05
28:29	28:52	FLC	parked car, wait for traffic to clear	00:23
29:34	31:28	Slow Travel	congestion, banked up traffic	01:54
31:29	31:56	Stop	traffic lights Congested flow	00:27
32:37	32:45	other	stopped behind a turning truck	00:08
32:57	33:45	Stop	traffic lights	00:48
34:05	34:12	other	car in front doing 3-point turn	00:07
34:18	34:23	FLC	car turning right at lights	00:05
34:37	35:53	Stop	traffic lights wait to turn right	01:16
36:24	37:32	Stop	traffic lights	01:08

Appendix 1 — Sequential listing of incidents shown on video tape for the test session (contd)

Start (mm:ss)	Finish (mm:ss)	Event Type	Cause	Duration (mm:ss)
37:38	37:47	FLC	parked car, wait for tram to pass	00:09
37:48	39:56	Slow Travel	stopped behind tram	02:08
39:57	40:57	Stop	traffic lights Congested flow	01:00
41:26	41:42	FLC	3 flc in a row- parked cars and cars turning right	00:16
42:15	42:25	Stop	traffic lights	00:10
42:56	44:03	Stop	Signalised Pedestrian Crossing (2 cycles)	01:07
44:19	44:25	other	car cutting in front b/c of parked car, no indicator	00:06
44:47	44:51	other	car in front suddenly deciding to park	00:04
44:58	44:59	other	wide truck, taking up two lanes	00:01
45:07	45:18	other	stopped behind a turning vehicle	00:11
45:38	45:45	FLC	double parked truck	00:07
45:46	45:47	other	pedestrian jaywalking, delaying manoeuvre	00:01
46:11	46:18	other	stopped behind a right turning car and parked car on the left	00:07

Section 3

Development of a Traffic Frustration Index

By
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Contents

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Thanuja Gunatillake contributed towards additional data analyses on frustration ratings reported in this paper.

Executive Summary

This is the third report under the ARRB TR research project RC 7111 "*Traffic Management Performance Measures*" funded by AUSTROADS (Project NRUM 9805). This report discusses the development of a Traffic Frustration Index based on further analysis of the results of the work to date. The first project report RC 7111-1 (Gunatillake and Cairney 1998) presented a literature review on the subject.

The second report RC 7111-2 (Cairney and Gunatillake 1999) described a laboratory study to determine driver responses (from 'Extremely Frustrating' to 'Not at all Frustrating') to a range of potentially frustrating traffic events. 60 subjects were surveyed individually, and categorised by age into three groups. It was found that, although the three groups differed in the degree of frustration, the rating patterns were similar.

The frustration ratings for each participant were normalised by taking the average of the participant's ratings over the whole session and then dividing each rating throughout the session by that average. The normalised ratings were then averaged for each group. The resulting average normalised ratings for the three groups were found to be virtually identical. These normalised ratings were then averaged across groups to produce mean normalised frustration ratings (MNFR) which formed the basis for the main analysis. The mean normalised frustration rating (MNFR) will be referred to as the *frustration rating* (symbol R) in this report. Seven traffic event groups and an "uneventful travel" group were defined. The frustration ratings for individual events were plotted against the event duration for seven traffic event groups. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the frustration rating level for uneventful travel.

Further analysis of the relationship between frustration rating and event duration is given in *Section 2.* Data used to derive the results given in this report differ from the previous report to some extent. Firstly, the results given in this report are clearly qualified as relevant to a particular road class (undivided road with a speed limit of 60 km/h). Secondly, uneventful travel segments with an average speed less than 30 km/h are now qualified as slow travel. The analysis results indicate that simpler grouping of traffic events (four event types rather than seven) is feasible. The effect of speed change parameters on frustration rating is analysed using the energy factor (E) and equivalent stop value (ESV) parameters. Regression results indicate that the effects of speed change manoeuvres as measured in this study cannot be related to the frustration rating. Therefore, the relationships based on event duration are recommended for practical use.

Section 3 introduces a Traffic Frustration Index (TFI) based on the use of the frustration ratings for different traffic event groups. A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described. A level of service (LOS) table is given defining LOS in relation to a selected traffic quality index.

Concluding remarks are presented in *Section 4.* It is recommended that the proposed practical procedure including the simplified event type grouping system described in this report should be tried and refined in the validation of the proposed Traffic Frustration Index. For this purpose, each event type should be defined clearly, including the method to identify the start and end of each event type.

Notations

d	Average delay per unit distance (excess travel time with reference to a the zero-flow travel time) per vehicle (seconds per km); this does not include d_m $d = t - t_o$
d_m	Minimum (average) delay experienced by a vehicle at near-zero flow conditions (seconds per km) $d_m = sum\ (d_{mj}) / L_t$
d_{mj}	Minimum (average) delay at jth interruption point (seconds)
E	Energy factor associated with the acceleration or deceleration part of a speed change cycle: the change in kinetic energy per mass per unit distance during a speed change manoeuvre (m/s^2) $E = 0.5\ (v_i^2 - v_f^2)/L_s$ if $v_i > v_f$ (deceleration) $= 0.5\ (v_f^2 - v_i^2)/L_s$ if $v_f > v_i$ (acceleration)
E_f	Energy factor for a full stop-start cycle (m/s^2) $E_f = 0.5\ v_c^2/L_f$
ESV	Equivalent stop value of a deceleration-acceleration (speed change) cycle in terms of a major stop-start cycle ($0 \le ESV \le 1.0$) ESV for driver frustration modelling: $ESV = (v_i^2 - v_f^2) / v_c^2$ if $v_i > v_f$ (deceleration) $= (v_f^2 - v_i^2) / v_c^2$ if $v_f > v_i$ (acceleration) ESV for general traffic analysis purposes: $ESV = E / E_f$ (where E is based on the acceleration part of the speed-change manoeuvre)
f_b	Speed ratio for uneventful travel $f_b = v_b/v_f$
f_n	Speed ratio for speed at capacity $f_n = v_n/v_f$
f_o	Speed ratio for speed zero-flow speed $f_o = v_o/v_f$
L_a	Distance traveled during the acceleration part of a speed change cycle (m)
L_b	Total distance traveled during the uneventful travel segments of a trip (km)
L_f	Distance traveled during the acceleration part of a full stop-start cycle (m)
L_i	Distance travelled during each (*ith*) traffic event or uneventful travel (m)
L_s	Distance traveled during the acceleration or deceleration part of a speed change cycle (m)
L_t	Total travel distance including all events and uneventful travel (km)

p_L	Lower limit of the frustration impact ratio or travel time ratio (a selected constant)
p_R	Frustration impact ratio: the ratio of frustration impact rate at the uneventful trip (base) level to the frustration impact rate for a trip $p_R = R_{bT} / R_T$
p_U	Upper limit of the frustration impact ratio $p_U = R_{bT} / R_{T(at\ t=tb)} = R_b\ t_b / [(R_o + s_t\ t_b)\ t_b] = R_b / (R_o + s_t\ t_b)$
R	Frustration rating (mean normalised frustration rating, MNFR) $R = R_o + s_t\ T$
R_b	Frustration rating for uneventful trip (base level)
R_{bT}	Frustration impact rate (per unit distance) at the uneventful trip (base) level $R_{bT} = R_b\ t_b = R_b\ T_b / L_b$
R_o	Frustration rating for an event of very short duration (intercept of the linear function representing the frustration rating – event duration relationship; intercept in similar relationships between frustration rating and energy factor or equivalent stop value)
R_T	Frustration impact rate for the total trip $R_T = R_b\ t_b + \mathit{sum}\ (R_i\ T_i) / (L_t - L_b)$
s_e	The rate of increase in frustration rating with increased energy factor (E) or equivalent stop value (ESV) (slope of the linear function representing the relationships between frustration rating and energy factor or equivalent stop value)
s_t	The rate of increase in frustration rating with increased event duration (slope of the linear function representing the frustration rating - event duration relationship)
t	Average travel time per unit distance for interrupted and uninterrupted traffic, including the effect of delays due to interrupted conditions (seconds per km)
t_b	Travel time per unit distance for the uneventful travel segments of a trip (seconds per km) $t_b = T_b / L_b = 3600 / v_b$
t_f	Free-flow travel time per unit distance, including the effect of minimum delays at traffic interruption points (seconds per km) $t_f = 3600 / v_f$
t_o	Zero-flow travel time per unit distance, including the effect of minimum delays at traffic interruption points (seconds per km) $t_o = t_f + d_m = 3600 / v_o$
T	Duration of an event (seconds)
T_b	Total travel time for the uneventful travel segments of a trip (seconds)
T_i	Duration of each (*ith*) traffic event or uneventful travel (seconds)
T_t	Total trip time (seconds) $T_t = T_b + \mathit{sum}\ (T_i)$

v	Speed (km/h or m/s)
v_b	Average speed for the uneventful travel segments of a trip (km/h)
v_c	Cruise speed (km/h)
v_i	Initial speed during a speed change manoeuvre (m/s)
v_f	1. Free-flow travel speed (km/h) $v_f = 3600 / t_f$ 2. Final speed during a speed change manoeuvre (m/s)
v_n	Speed at capacity (km/h)
v_o	Zero-flow travel speed (km/h) $v_o = 3600 / t_o$
v_t	Average speed for the total trip (km/h) $v_t = 3600\ L_t / T_t$

1. Introduction

This is the third report under the ARRB TR research project RC 7111 "*Traffic Management Performance Measures*" funded by AUSTROADS (Project NRUM 9805). This report discusses the development of a *Traffic Frustration Index* based on further analysis of the results of the work to date.

The first project report RC 7111-1 (Gunatillake and Cairney 1998) presented a literature review on the subject.

The second report RC 7111-2 (Cairney and Gunatillake 1999) described a laboratory study to determine drivers' responses to a range of potentially frustrating traffic situations. The design of the study was based on experience gained from an earlier pilot study. The specific aims of the study were to determine how individuals responded to a range of driving situations by having them make continuous ratings as they viewed a video tape of a drive through traffic.

The video tape was prepared by taping from a camera mounted on a tripod situated in front of the front passenger seat in a large sedan car. Most of the driving was done along undivided primary and secondary arterials (speed limits 70 and 60 km/h, rspectively). All roads were in the Eastern inner suburbs of Melbourne. The taping was done in peak and non-peak times so that a range of traffic conditions was recorded. The tapes were edited to produce a practice segment lasting approximately 7 minutes, and the main tape which lasted 46 minutes. The incidents incorporated in the tape were stopping at intersection signals, stopping at pedestrian signals, slow travel, forced lane change (due to parked vehicle and other reasons), and various other events.

Participants viewed the television monitor and were provided with a small response dial which they could adjust continuously between two extremes labelled 'Extremely Frustrating' and 'Not at all Frustrating'. Participants viewed the tape individually, and adjusted the knob on the dial to reflect the level of frustration they felt with the traffic situation. The position of the knob was sampled once a second, and the results stored in the computer. Five positions of the knob could be distinguished.

60 subjects were surveyed, and categorised by age into three groups (<30, 30-59, 60+). It was found that, although the three groups differed in the degree of frustration, the rating patterns were similar. The frustration ratings for each participant were normalised by taking the average of the participant's ratings over the whole session and then dividing each rating throughout the session by that average. This has the effect of removing the differences between individuals but retaining the differences between events. The normalised ratings were then averaged for each group, and the average normalised ratings for the three groups were found to be virtually identical. These normalised ratings were then averaged across groups to produce mean normalised frustration ratings (MNFR) which formed the basis for the main analysis.

Seven traffic event groups and an "uneventful travel" group were defined. The mean normalised frustration ratings (MNFR) for individual events were plotted against the event duration for seven traffic event groups. In all cases but two, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the MNFR level for uneventful travel.
The mean normalised frustration rating (MNFR) will be referred to as the *frustration rating* (symbol R) in this report.

Further analysis of the relationship between frustration rating and event duration is given in *Section 2*. Data used to derive the results given in this report differ from the previous report to some extent. Firstly, the results given in this report are clearly qualified as relevant to a particular road class (undivided road with a speed limit of 60 km/h). Secondly, uneventful travel segments with an average speed less than 30 km/h are now qualified as slow travel. The analysis results indicate that simpler grouping of traffic events (four event types rather than seven) is feasible. The effect of speed change parameters on frustration rating is analysed using the energy factor (E) and equivalent stop value (ESV) parameters. Regression results indicate that the effects of speed change manoeuvres as measured in this study cannot be related to the frustration rating. Therefore, the relationships based on event duration are recommended for practical use.

Section 3 introduces a Traffic Frustration Index (TFI) based on the use of the frustration ratings for different traffic event groups. A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described. A level of service (LOS) table is given defining LOS in relation to a selected traffic quality index.

Concluding remarks are presented in *Section 5*.

2. Further Analysis

This section presents a summary and further analysis of the results from the previous project report RC 7111-2 (Cairney and Gunatillake 1999), as well as the results of analyses of the effect of speed change parameters on frustration rating using the energy factor (E) and equivalent stop value (ESV) parameters.

2.1 Frustration Rating vs Event Duration

In the previous project report RC 7111-2 (Cairney and Gunatillake 1999), seven traffic event groups (event types 1 to 7) and an "uneventful travel" group (event type 1) were defined and linear regression equations relating the frustration rating (MNFR, or R) to the event duration (T) were derived for each event group. The linear relationship is expressed as:

$$R = R_o + s_t T \qquad (2.1.1)$$

where

R_o = frustration rating for an event of very short duration
s_t = the rate of increase in frustration rating with increased event duration
T = duration of the event (seconds).

Data Changes and New Results

The results were analysed in more detail and some changes were introduced due to problems encountered in developing the Traffic Frustration Index (*Section 3*).

(i) The travel conditions in the driver response study involved driving on two different classes of road. At the start of the trip, there was a short section on a divided road with a speed limit of 80 km/h, followed by driving on undivided roads with a speed limit of 60 km/h. The latter represented most data used in the study, and it was decided to eliminate the data belonging to the initial section. Thus, the results given in this report are clearly qualified as relevant to a particular road class (undivided road with a speed limit of 60 km/h).

(ii) *Uneventful travel* segments (Event type 1) with an average speed less than 30 km/h (half the speed limit) are now qualified as *slow travel* (Event type 5).

As a result of the above changes:

(i) the frustration rating for uneventful travel is no longer dependent on the average speed in the uneventful travel segment,

(ii) the range of frustration ratings for uneventful travel is reduced to a more acceptable level (from 0.68 to 1.10 to 0.70 to 0.93), and

(iii) the average value of frustration rating for uneventful travel, to be used as the base frustration level, is R_b = 0.79 (0.81 in the previous report).

The linear regression results changed as a result of the above changes to data. As in the previous report, it was found that, for four of seven event groups (event types 2, 4, 6, 7), the intercept of the regression line was close to the frustration rating for uneventful travel (R_b = 0.79). In view of this, revised regression equations are obtained by setting the intercept to this value ($R_o = R_b$ = 0.79). The resulting relationships are close to the free regression results.

Table 2.1.1 gives the revised regression results for all event groups, as well as the average frustration rating (R_a), the range of frustration ratings, average event duration obtained from *Equation (2.1.1)* setting $R = R_a$, i.e. $T_a = (R_a – R_o) / s_t$, and the range of event durations.

The average speed for uneventful travel is v_b = 37.7 km/h, and the corresponding travel time per unit distance is t_b = 95.5 s/km (for the data used in the previous report, v_b = 33.7 km/h, t_b = 106.7 s/km). The average speed for uneventful travel is considerably less than the speed limit (60 km/h). However, the low value of v_b is mainly due to editing of the tape to minimise long periods of cruise conditions.

Simplification of Event Type Groups
Further analyses of frustration rating – event duration relationships were carried out with a view to simplifying event groupings. It appears that the following simplifications are feasible:

(i) combine stops at traffic signals (non-congested) and pedestrian signals (2+4),
(ii) combine stops at traffic signals during travel in congested environment with the slow travel group (3+5), and
(iii) combine all forced lane change events together (6+7).

The regression results for the simplified event groupings are summarised in *Table 2.1.2*. which also includes the regression results for all events (1 to 7) combined together.

Table 2.1.3 presents the recommended event type groupings using new event type numbers (0 to 9) with the corresponding event type numbers used in the previous report (as in *Table 2.1.2*). Event type number 0 is used for uneventful travel, and numbers 4 to 8 are reserved for additional event groups. Event type 10 represents the general function for the road facility (obtained using all events 1 to 9 together).

Figures 2.1.1 to 2.1.4 show the regression results for event types with simplified groupings 1, 2 and 3 (previously 2+4, 3+5 and 6+7), and all events together (event type 10).

Table 2.1.1
Frustration rating – event duration relationships for eight event types

Event type	Description	Frustration rating $R = R_o + s_t T$		Average frustration rating	Range of frustration ratings	Average event duration (s)	Range of event durations (s)	
		R_o	s_t	R_a	R_i	T_a	T_i	$R_o - R_b$
1	Uneventful travel	0.79	0	0.79	0.70 - 0.93	-	14 - 44	0
2	Stops at traffic signals (non-congested conditions)	0.79	0.0017	0.86	0.69 - 0.99	41.2	1 - 108	0
3	Stops at traffic signals (congested conditions)	1.14	0.0015	1.19	0.94 - 1.30	33.3	12 - 60	0.35
4	Stops at pedestrian signals	0.79	0.0049	0.96	0.85 - 1.13	34.7	10 - 67	0
5	Slow travel	0.89	0.0020	1.01	0.74 - 1.54	60.0	8 - 290	0.10
6	Forced lane change due to parked cars	0.79	0.0333	1.14	0.80 - 1.54	10.5	4 - 23	0
7	Forced lane change due to other factors	0.79	0.0226	0.98	0.77 - 1.31	8.4	4 - 17	0
8	Other events	1.01	0	1.01	0.77 - 1.49	-	1 - 14	0.22

T_a is a calculated value: $T_a = (R_a – R_o) / s_t$

Table 2.1.2
Frustration rating – event duration relationships for simplified event groups

Event type	Description	Frustration rating $R = R_o + s_t T$		Average frustration rating	Range of frustration ratings	Average event duration (s)	Range of event durations (s)	
		R_o	s_t	R_a	R_i	T_a	T_i	$R_o - R_b$
1	Uneventful travel	0.79	0	0.79	0.70 - 0.93	-	14 - 44	0
2+4	Stops at intersection and pedestrian signals (non-congested conditions)	0.79	0.0021	0.88	0.69 - 1.13	42.9	1 -108	0
3+5	Slow travel including stops at traffic signals (congested conditions)	0.95	0.0017	1.04	0.74 - 1.54	52.9	8 - 290	0.16
6+7	Forced lane change	0.79	0.0282	1.05	0.77 - 1.54	9.2	4 - 23	0
8	Other events	1.01	0	1.01	0.77 - 1.49	-	1 - 14	0.22
2 to 7	All event types (uneventful travel not included)	0.91	0.0018	0.99	0.69 - 1.54	44.4	1 - 290	0.12

T_a is a calculated value: $T_a = (R_a – R_o) / s_t$

Table 2.1.3
Recommended event type grouping

Event type	Event type in previous report	Description	Frustration rating $R = R_o + s_t T$	
			R_o	s_t
0	1	Uneventful travel	0.79	0
1	2+4	Stops at intersection and pedestrian signals (non-congested conditions)	0.79	0.0021
2	3+5	Slow travel including stops at traffic signals (congested conditions)	0.95	0.0017
3	6+7	Forced lane change	0.79	0.0282
(4-8)	-	(reserved for additional event types)		
9	8	Other events	1.01	0
10	2 to 7	All event types (1 to 9) (uneventful travel not included)	0.91	0.0018

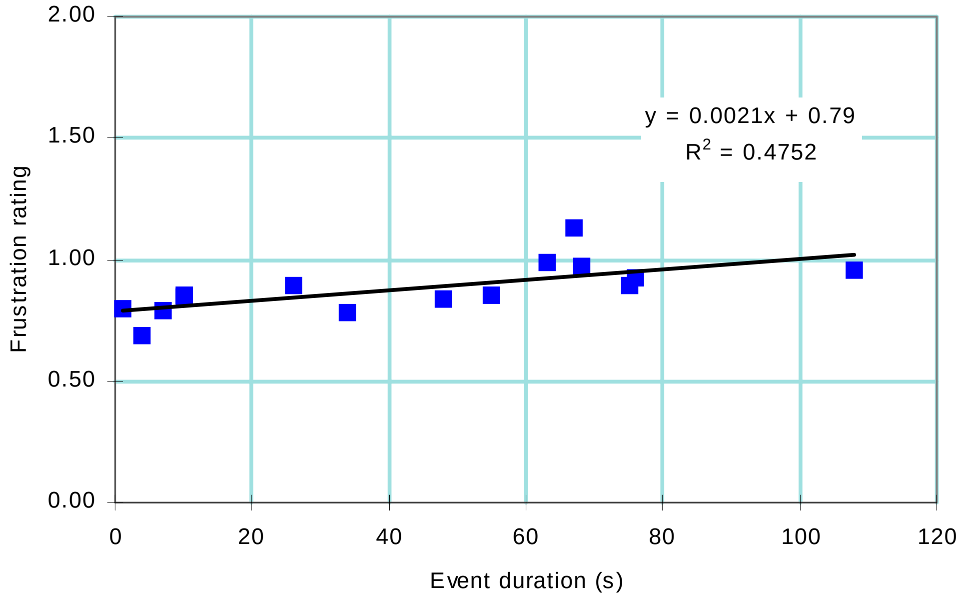

Figure 2.1.1 — Frustration rating as a function of event duration for stops at traffic signals under non-congested driving conditions: Event type 1 (previously 2+4)

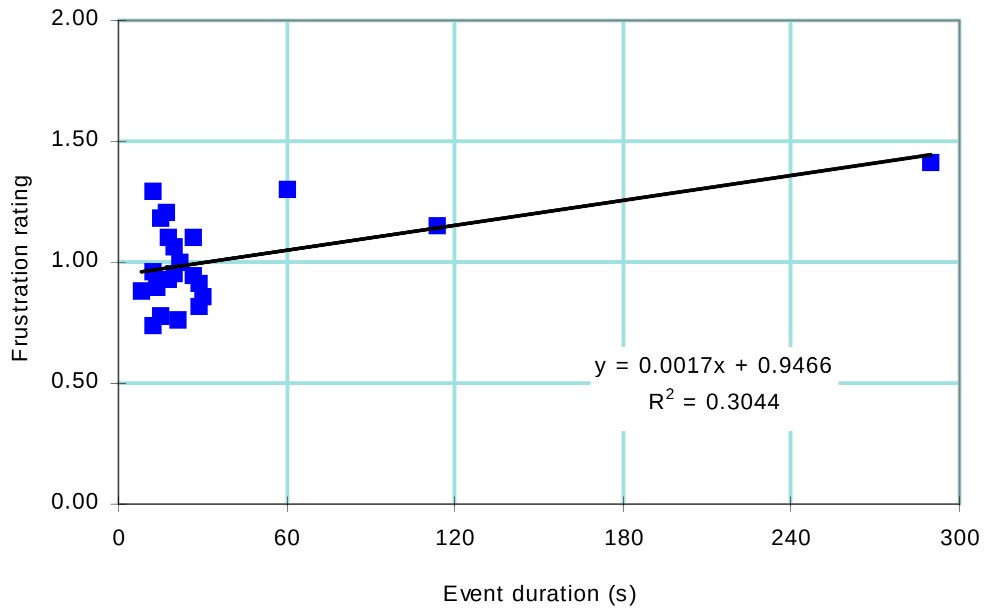

Figure 2.1.2 — Frustration rating as a function of event duration for slow travel including stops at signals under congested driving conditions: Event type 2 (previously 3+5)

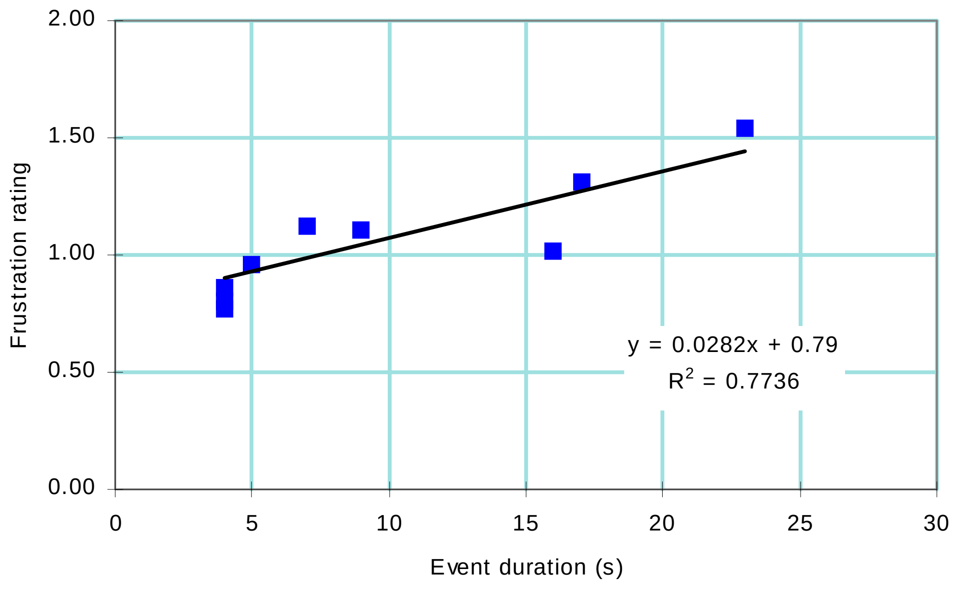

Figure 2.1.3 — Frustration rating as a function of event duration for all forced lane change events: Event type 3 (previously 6+7)

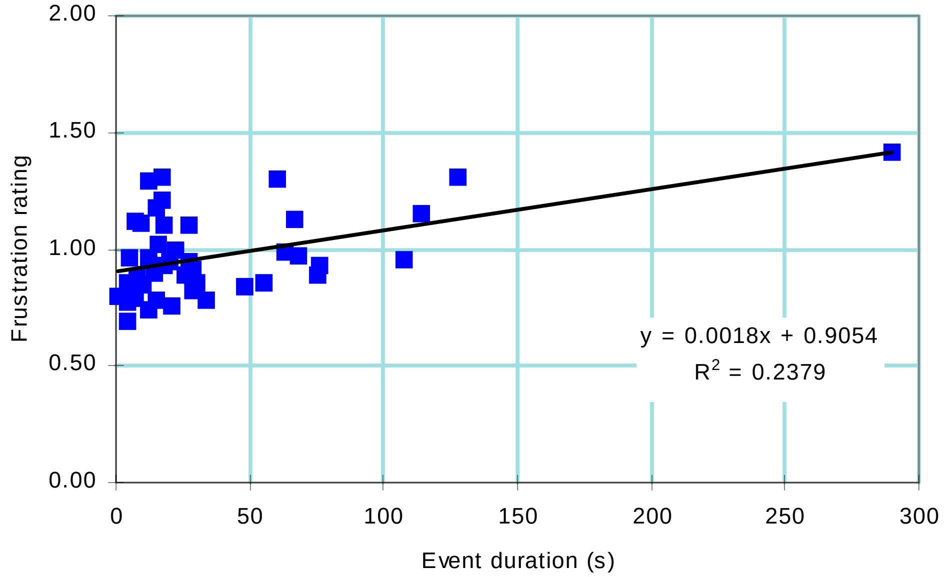

Figure 2.1.4 – Frustration rating as a function of event duration for all events: Event type 10 (previously 2 to 7)

2.2 Frustration Rating vs Speed Change Effects

An analysis of the relationship between parameters representing the effect of speed change manoeuvres and the frustration rating was carried out.
It is emphasised that, during the filming of traffic conditions, it was not possible to obtain simultaneous speed-time measurements using an instrumented car. Instead, the speeds were recorded manually during the trip, including speeds at the start and end of each traffic event. As a result, the analysis presented here is not very precise. A sample sequence of second-by second frustration rating and speed profile is shown in *Figure 2.2.1*.

Two parameters were used in the analysis:

(i) energy factor (E), and
(ii) equivalent stop value (ESV).

These are associated with a speed change manoeuvre, and applied to the acceleration or deceleration part of the cycle as relevant to various traffic events.

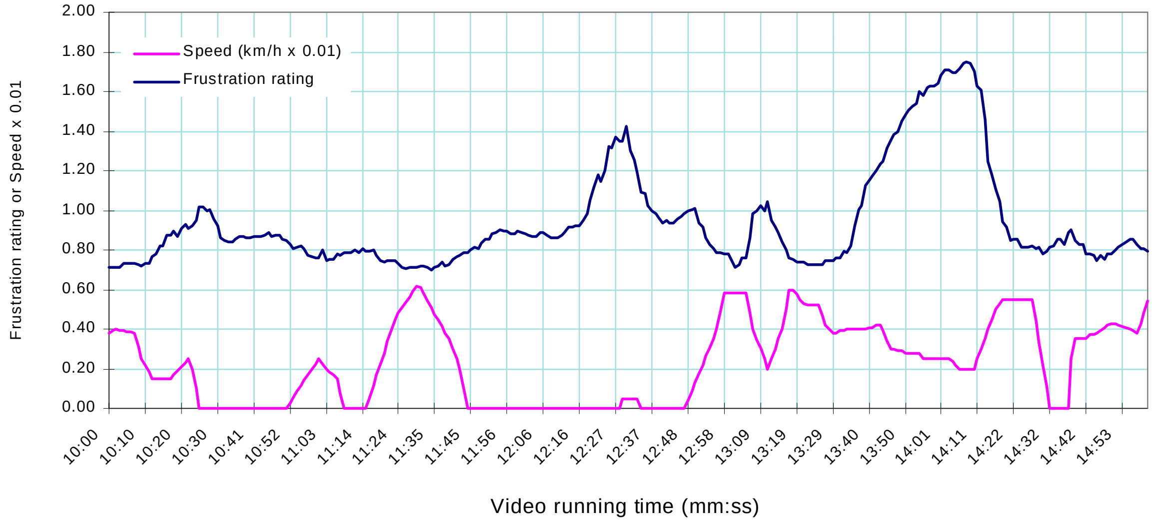

Figure 2.2.1 – Frustration rating and speed profiles (a sample sequence)

Energy Factor
The energy factor is the change in kinetic energy per mass per unit distance during a speed change manoeuvre:

$$E = 0.5\,(v_i^2 - v_f^2) / L_s \qquad \textit{if } v_i > v_f \textit{ (deceleration)} \qquad (2.2.1)$$
$$\;\; = 0.5\,(v_f^2 - v_i^2) / L_s \qquad \textit{if } v_f > v_i \textit{ (acceleration)}$$

Where

E = energy factor (in joules per kilogram-metre, or m/s^2)
v_i = initial speed during a speed change manoeuvre (m/s)
v_f = final speed during a speed change manoeuvre (m/s)
L_s = distance traveled during the acceleration or deceleration (m).

Driver frustration response to most events that involved a speed change cycle was observed to occur during the deceleration part of the cycle ($v_i > v_f$). The acceleration manoeuvre ($v_f > v_i$) was relevant for some events, particularly forced lane change events. As a result, *Equation (2.2.1)* is formulated in such a way that the resulting energy factor is always a positive value.

The energy factor is based on the E_k parameter used in fuel consumption and emission models (Bowyer, Akçelik and Biggs 1985). Parameters E and E_k are essentially the same except that E_k is negative for deceleration manoeuvres and positive for acceleration manoeuvres.

The sum of positive kinetic energy changes during a trip or trip segment (E_{k+}) used in Bowyer, Akçelik and Biggs (1985) is related to the PKE (positive kinetic energy) parameter used in fuel consumption and emission models (Akçelik 1983) through $E_{k+} = 0.5$ PKE.

Equivalent Stop Value
The equivalent stop value (ESV) is a concept used in the SIDRA software package (Akçelik and Besley 1999) to determine effective stop rates at traffic facilities. Currently, SIDRA calculates the equivalent stop value as the ratio of delay experienced during a speed-change cycle to the delay during a full stop-start cycle.

As an alternative method for general traffic analysis purposes, ESV can be determined as the ratio of the energy factor for a speed-change cycle to the energy factor for a full stop-start cycle:

$$ESV = E / E_f \quad \textit{subject to } ESV \le 1.0 \tag{2.2.2}$$
$$E = 0.5\,(v_f^2 - v_i^2) / L_a \tag{2.2.3}$$
$$E_f = 0.5\, v_c^2 / L_f \tag{2.2.4}$$

where

ESV = equivalent stop value
E = energy factor calculated using the acceleration part of a speed change cycle (m/s^2)
E_f = energy factor for a full stop-start cycle (m/s^2)
v_c = cruise speed (m/s)
L_a = distance traveled during the acceleration part of a speed change cycle (m)
L_f = distance traveled during the acceleration part of a full stop-start cycle (m).

It is seen that the ESV formulation given above uses the acceleration part of the speed-change cycle. In modelling applications using average acceleration rates as in SIDRA, $v_f \le v_c$ and $L_a \le L_f$. Therefore, ESV ≤ 1.0 would be satisfied. In analysing the survey results, there are difficulties in applying this method since:

(a) v_c can be chosen as the speed limit, but the selected v_c value can exceed the initial or final speed in some individual speed change cycles (for the survey data used in this study, v_c = 60 km/h was used), and
(b) acceleration distance may vary for individual speed change cycles, and $L_a > L_f$ may result.

As a result, $L_a > L_f$ may result for some speed change cycles. To avoid these difficulties, a modified formula was used for the purpose of driver frustration modelling:

$$ESV = (v_i^2 - v_f^2) / v_c^2 \quad \textit{if } v_i > v_f \textit{ (deceleration)} \tag{2.2.5}$$
$$= (v_f^2 - v_i^2) / v_c^2 \quad \textit{if } v_f > v_i \textit{ (acceleration)}$$
$$\textit{subject to } ESV \le 1.0$$

where
v_i = initial speed during a speed change manoeuvre (m/s)
v_f = final speed during a speed change manoeuvre (m/s)
v_c = cruise speed (m/s).

Frustration Rating Model
The frustration rating was then related to parameters E and ESV using linear regression models:

$$R = R_o + s_e\, E \tag{2.2.6}$$
$$R = R_o + s_e\, ESV \tag{2.2.7}$$

where

R_o = frustration rating for E = 0 or ESV = 0 (i.e. for no speed change, $v_f = v_i$)
s_e = the rate of increase in frustration rating with increased E or ESV value
E = energy factor (m/s^2) from *Equation (2.2.1)*
ESV = equivalent stop value from *Equation (2.2.5).*

Regression analyses for individual event groups as defined in *Table 2.1.1* and the simplified groupings and all events types together (2 to 8) as defined in *Table 2.1.2* were carried out to determine parameters R_o and s_e in *Equations (2.2.6) and (2.2.7).*

Figures 2.2.2 and 2.2.3 show frustration rating as a function of E and ESV, respectively, for all event groups (2 to 8). Similar results were obtained for individual event types and various event groupings. The R-E relationships had slopes close to zero, and R-ESV relationships indicated negative but weak correlations.

These results indicate that the effects of speed change manoeuvres as measured in this study cannot be related to the frustration rating. Therefore the relationships based on event duration only (discussed in *Section 2.1*) will be used.

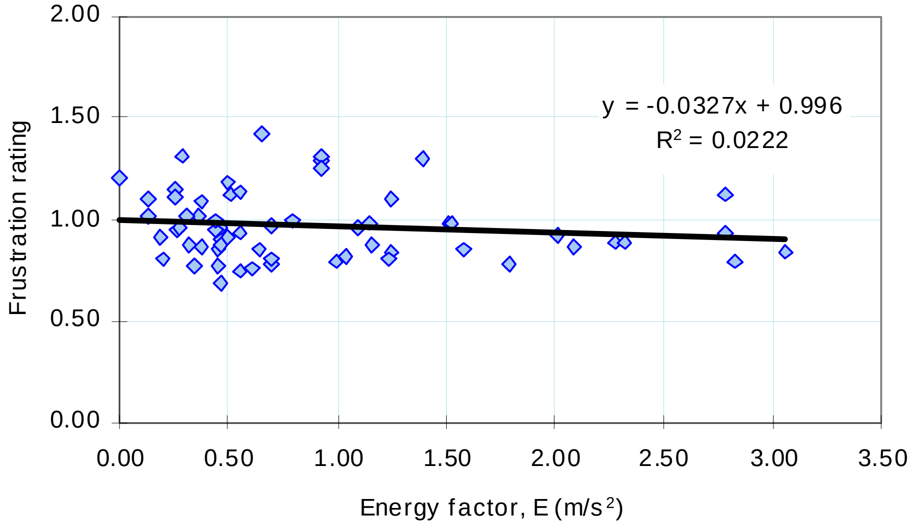

Figure 2.2.2 — Frustration rating as a function of energy factor (E) for all events (Event types 2 to 8)

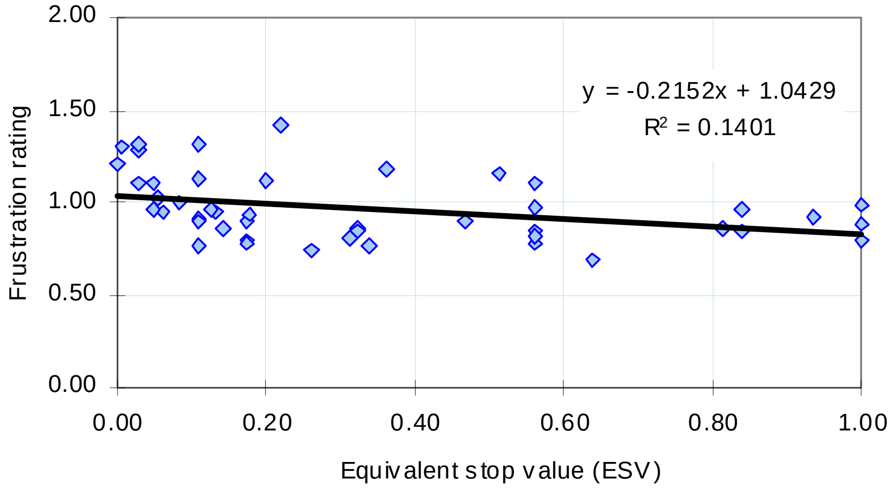

Figure 2.2.3 — Frustration rating as a function of equivalent stop value (ESV) for all events (Event types 2 to 8)

3. Traffic Frustration Index

This section presents a Traffic Frustration Index (TFI) based on the use of the frustration ratings (R) for different traffic event types. Levels of Service based on TFI are also described.

3.1 Traffic Frustration Index

For use with the practical procedure described in Section 3.2, the Traffic Frustration Index (TFI) is defined as follows:

$$TFI = 10\,(p_R - p_L) / (p_U - p_L) \quad \textit{for } p_R > p_L \qquad (3.1.1)$$
$$= 0 \quad \textit{for } p_R \le p_L$$

where

$$p_R = \textit{min}\,(p_U, R_{bT} / R_T) \qquad (3.1.2)$$
$$R_{bT} = R_b\, t_b \qquad (3.1.3)$$
$$R_T = R_{bT} + \textit{sum}\,(R_i\, T_i) / (L_t - L_b) \quad \textit{for } L_t > L_b \qquad (3.1.4)$$
$$= R_{bT} \quad \textit{for } L_t = L_b$$
$$R_i = R_o + s_t\, T_i \qquad (3.1.5)$$
$$t_b = T_b / L_b \qquad (3.1.6)$$
$$p_U = R_b / [(R_o + s_t\, t_b)_{\text{for event type 10}}] \qquad (3.1.7)$$

where

p_R = frustration impact ratio: the ratio of frustration impact rate for uneventful travel to the frustration impact rate for the total trip
p_U = upper limit of the frustration impact ratio calculated as the ratio of frustration rate for uneventful travel to the frustration rating for event type 10 (*Table 2.1.3*) obtained setting $T = t_b$
p_L = lower limit of the frustration impact ratio (a selected constant; range: 0 to 0.3, default: 0; must be less than p_U)
R_{bT} = frustration impact rate (per unit distance) at the uneventful trip (base) level
R_T = frustration impact rate (per unit distance) for the total trip
R_b = frustration rating for uneventful travel
R_i = frustration rating for *ith* event (R_o and s_t depends on the event type as in *Equation (2.1.1)*; see *Table 2.1.3*)
t_b = travel time per unit distance for the uneventful travel segments of the trip (seconds per km)
T_b = total travel time for the uneventful travel segments of the trip (seconds)
L_b = total distance traveled during the uneventful travel segments of the trip (km)
T_i = duration of *ith* event (seconds)
L_t = total travel distance including all events and uneventful travel (km).

The frustration impact rate (R_T) is calculated on a per km basis, i.e. it is the impact rate per unit distance.

This represents both the *frustration levels* and the *intensity* of traffic events that cause frustration.

The basis of the TFI formulation given in *Equation (3.1.1)* is shown in *Figure 3.1.1*.

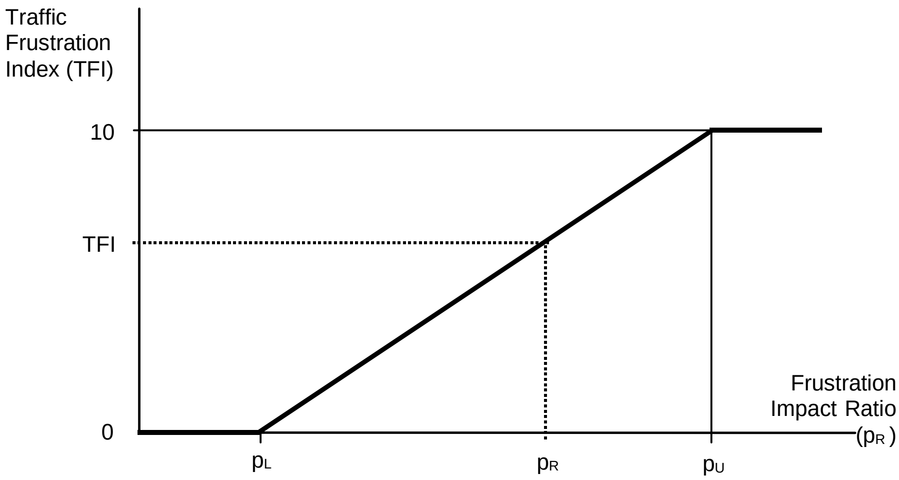

Figure 3.1.1 – The basis of Traffic Frustration Index (TFI) formulation

The total distance traveled during the uneventful travel segments of the trip, and the corresponding travel time, are calculated from:

$$L_b = \textit{sum}\ (L_i)_{\text{for event type 0}} \qquad (3.1.8)$$
$$T_b = \textit{sum}\ (T_i)_{\text{for event type 0}} \qquad (3.1.9)$$

where $(L_i)_{\text{for event type 0}}$ is the distance traveled during the *ith* uneventful travel segment, and $(T_i)_{\text{for event type 0}}$ is the corresponding travel time.

The average speed, v_b (km/h) and the travel time per unit distance, t_b (s/km) for the uneventful travel segments of the trip are given by:

$$v_b = 3600\ L_b / T_b \qquad \textit{for } T_b > 0 \qquad (3.1.10)$$
$$= 0.8\ v_f \qquad \textit{for } T_b = 0$$
$$t_b = 3600 / v_b = T_b / L_b \qquad (3.1.11)$$

where
L_b = total distance traveled during the uneventful travel segments of the trip (km)
T_b = total travel time for the uneventful travel segments of the trip (seconds)
v_f = free fow speed (km/h).

The condition $T_b = 0$ may occur if there was no uneventful travel segment during the trip. In this case, 80 per cent of the free-flow speed (speed limit) is used.

Total travel time for the trip, T_t (seconds) is given by

$$T_t = T_b + \textit{sum}\ (T_i)_{\text{for event types 0 to 9}} \qquad (3.1.12)$$

where

T_b = total travel time for the uneventful travel segments of the trip (km)
T_i = duration of *ith* event (seconds) for all event types (0 to 9)

The average speed for the total trip is given by:

$$v_t = 3600\, L_t / T_t \qquad (3.1.13)$$

where

L_t = total travel distance including all events and uneventful travel (km)
T_t = total travel time for the trip (seconds).

The use of the travel time per unit distance for the uneventful travel segments of the trip (t_b) as the base travel condition in TFI simplifies the method in relation to the data collected during the survey (see *Section 3.2*). An alternative is to use the zero-flow travel time (t_o), or the free-flow travel time (t_f) instead of t_b.

The zero-flow travel time (t_o) is experienced under near-zero travel demand conditions (very light traffic):

$$t_o = t_f + d_m \qquad (3.1.14)$$

where

t_f = free-flow travel time per unit distance (t_f in s/km)= 3600 /v_f where v_f is the free-flow speed in km/h (approximately the speed limit)
d_m = minimum delay per unit distance (s/km) experienced at interruption points along the facility:

$$d_m = \Sigma d_{mj} / L_t \qquad (3.1.15)$$

where

d_{mj} = minimum delay (s) at *jth* interruption point
L_t = total travel distance along the facility (km).

A simple method is to use:

$$d_m = n\, d_{mj} \qquad (3.1.16)$$

where

d_{mj} = an average value of d_{mj} per interruption point for the road class
n = the number of interruption points per km for the road class.

The *zero-flow travel speed* (v_o) in km/h is given by:

$$v_o = 3600 / t_o \qquad (3.1.17)$$

The *zero-flow speed ratio* is defined as:

$$f_o = v_o / v_f \qquad (3.1.18)$$

The *travel delay per unit distance* (d) is calculated as the difference between the travel time (t) for a trip and the zero-flow travel time:

$$d = t - t_o \qquad (3.1.19)$$

Note that this delay excludes the minimum delay per unit distance (d_m) which is included in t_o.

Levels of Sevice

Various levels of service (LOS) can be defined in relation to a selected traffic quality index. Alternative methods can be developed for determining a travel quality index. The Traffic Frustration Index (TFI) described in *Section 3* provides such a travel quality index measure.

Table 3.1.1 presents an interim set of LOS criteria. Appropriate values of the criteria used in this table to define different LOS grades need to be developed using results from field data. The values given in *Table 3.1.1* have been chosen considering their implications for the degree of saturation, speed and travel delay values for each LOS grade.

Table 3.1.1
Level-of-service definitions based on a travel quality index

Level of Service	Traffic Quality Index *
Good	7 < Index ≤ 10
Fair	5 < Index ≤ 7
Poor	3 < Index ≤ 5
Very poor	0 ≤ Index ≤ 3

3.2 Practical Procedure

A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described below. The use of the recommended event type grouping given in *Table 2.1.3* is assumed.

Input Data
Collect the following input data by driving along the traffic facility and recording the start and end points of each traffic event:

- Event type number (1 to 9) for each traffic event encountered, or event type number = 0 for uneventful travel segments.
- Start and end times of each event and each uneventful travel segment. This will be used to determine the duration of each event and each uneventful travel segment, T_i (seconds). It will also be useful for determining the travel distance, L_i (m) for each event.
- If speed is being recorded manually, record the speed at the start and end of each speed cycle (initial and final speeds, v_i, v_f) and the cruise speed (v_c) for near-constant speed segments. Alternatively record the instantaneous speed at regular short intervals (Δt), e.g. second by second ($\Delta t = 1$ s) using an instrumented car.
- Distance travelled for each uneventful travel segment, L_i (m). With instrumented car surveys, distance for each event can be determined as:

$$L_i = sum\ (v\ \Delta t) \qquad (3.2.1)$$

where v is the instantaneous speed (m/s), Δt is the time interval used in the survey (s), and summation is for the duration of the event.

In the case of speeds recorded manually, approximate distance can be calculated from:

$$L_i = 0.5\,(v_i + v_f)\,T_i \qquad (3.2.2)$$

Where

v_i = initial speed (m/s)
v_f = final speed (m/s)
T_i = duration of the event or the uneventful travel segment.

- Total travel distance, L_t (km). This can be calculated by summing distances travelled during each event and uneventful travel segments, L_t = *sum* (L_i) for all events.
- Also record the *speed limit* and other characteristics of the traffic facility to determine the *road class*, and other conditions affecting travel (weather, etc).

The speed limit may be used as the free flow speed, v_f (km/h) for the traffic facility. Using this speed, the free-flow travel time per unit distance, t_f (s/km) can be calculated from

$$t_f = 3600 / v_f \qquad (3.2.3)$$

Calculated Parameters

Enter the input data into the TFI application spreadsheet to obtain the TFI value and the corresponding level of service (LOS). The following parameters will be calculated by the application:

- Total distance for uneventful travel, L_b (km)
- Total time for uneventful travel, T_b (km)
- Average speed for uneventful travel, v_b (km/h)
- Travel time per unit distance for uneventful travel, t_b (s/km)
- Total travel time for the trip, T_t (s)
- Average speed for the total trip, v_t (km/h)
- Frustration impact rate for uneventful travel, R_{bT}
- Total frustration impact for event types 1 to 9, *sum* (R_iT_i)
- Total travel distance for event types 1 to 9, (L_t - L_b) (km)
- Frustration impact rate for the total trip, R_T
- Frustration impact ratio, p_R
- Upper limit of frustration impact ratio, p_U
- Free-flow travel time per unit distance, t_f (s/km)
- Traffic Frustration Index (TFI)
- Level of Service (LOS)

An Example

As an example for the application of the procedure to determine TFI and LOS, *Figures 3.2.2 and 3.2.3* present the input data and analysis results for the trip as seen by drivers who participated in the frustration rating study. In the study, speeds were recorded frequently, and travel distances were calculated using *Equation (3.2.2)* for each section for which recorded speeds were available (i.e. this is more detailed than using the initial and final speeds for each uneventful travel segment).

The Traffic Frustration Index value for this example is seen to be very low (TFI = 2.6) and LOS determined as "Very poor". This may be a result of biased representation of travel conditions due to editing of the video tape to minimise long periods of cruise conditions. For example, if the total travel distance is specified as L_t = 20 km instead of 12.527 km, TFI = 4.5 and LOS = "Poor" is obtained (this assumes that the t_b value is not affected).

INPUT

Road class		Divided road
Speed limit (km/h)	v_f =	60
Total travel distance (km)	L_t =	12.527

Event	Event type	Duration	Uneventful travel distance	Uneventful travel time	Frustration rating	Frustration impact
	(0 to 9)	T_i (s)	(m)	(s)	R_i	R_i T_i
Slow travel	2	8			0.96	7.7
Slow travel	2	18			0.98	17.7
Uneventful travel	0	23	217.2	23	0.79	18.2
Other	9	13			1.01	13.1
Uneventful travel	0	21	245.0	21	0.79	16.6
Stop at signals	1	108			1.02	109.8
Uneventful travel	0	27	292.5	27	0.79	21.3
Stop at signals	1	1			0.79	0.8
Uneventful travel	0	44	488.9	44	0.79	34.8
Other	9	12			1.01	12.1
Stop at signals	1	4			0.80	3.2
Uneventful travel	0	30	300.0	30	0.79	23.7
Other	9	12			1.01	12.1
Stop at signals	1	26			0.84	22.0
Slow travel	2	15			0.98	14.6
Stop at signals	1	7			0.80	5.6
Uneventful travel	0	27	292.5	27	0.79	21.3
Stop at signals	2	63			1.06	66.6
Uneventful travel	0	16	168.9	16	0.79	12.6
Other	9	6			1.01	6.1
Uneventful travel	0	28	342.2	28	0.79	22.1
Slow travel	2	29			1.00	29.0
Uneventful travel	0	20	244.4	20	0.79	15.8
Other	9	5			1.01	5.1
Forced lane change	3	4			0.90	3.6
Uneventful travel	0	21	256.7	21	0.79	16.6
Other	9	14			1.01	14.1
Forced lane change	3	4			0.90	3.6
Uneventful travel	0	14	128.3	14	0.79	11.1
Stop at signals	1	34			0.86	29.3
Slow travel	2	12			0.97	11.6
Other	9	7			1.01	7.1
Slow travel	2	12			0.97	11.6
Stop at signals	1	10			0.81	8.1
Slow travel	2	21			0.99	20.7
Other	9	4			1.01	4.0
Uneventful travel	0	29	249.7	29	0.79	22.9

Figure 3.2.2(a) – Traffic frustration index (TFI) and level of service (LOS) determined for the trip used in driver frustration survey: An example of INPUT DATA – section 1

Stop at signals	1	55			0.91	49.8
Uneventful travel	0	16	177.8	16	0.79	12.6
Forced lane change	3	4			0.90	3.6
Slow travel	2	30			1.00	30.0
Slow travel	2	15			0.98	14.6
Stop at signals	2	17			0.98	16.6
Slow travel	2	290			1.44	418.5
Other	9	1			1.01	1.0
Stop at signals	2	12			0.97	11.6
Forced lane change	3	17			1.27	21.6
Uneventful travel	0	24	240.0	24	0.79	19.0
Stop at signals	1	75			0.95	71.1
Other	9	5			1.01	5.1
Uneventful travel	0	23	217.2	23	0.79	18.2
Forced lane change	3	23			1.44	33.1
Uneventful travel	0	38	337.8	38	0.79	30.0
Slow travel	2	114			1.14	130.4
Stop at signals	2	27			1.00	26.9
Uneventful travel	0	39	325.0	39	0.79	30.8
Other	9	8			1.01	8.1
Stop at signals	1	48			0.89	42.8
Uneventful travel	0	18	165.0	18	0.79	14.2
Other	9	7			1.01	7.1
Uneventful travel	0	18	185.0	18	0.79	14.2
Forced lane change	3	5			0.93	4.7
Stop at signals	1	76			0.95	72.2
Slow travel	2	29			1.00	29.0
Stop at signals	1	68			0.93	63.4
Forced lane change	3	9			1.04	9.4
Slow travel	2	128			1.17	149.5
Stop at signals	1	60			0.92	55.0
Slow travel	2	27			1.00	26.9
Forced lane change	3	16			1.24	19.9
Uneventful travel	0	31	327.2	31	0.79	24.5
Stop at signals	1	10			0.81	8.1
Slow travel	2	29			1.00	29.0
Stop at signals	1	67			0.93	62.4
Slow travel	2	14			0.97	13.6
Other	9	6			1.01	6.1
Slow travel	2	20			0.98	19.7
Other	9	4			1.01	4.0
Other	9	1			1.01	1.0
Other	9	11			1.01	11.1
Slow travel	2	18			0.98	17.7
Forced lane change	3	7			0.99	6.9
Other	9	1			1.01	1.0
Slow travel	2	22			0.99	21.7
Other	9	7			1.01	7.1
	Total =	**2339**	**5201**	**507**		**2370.8**

**Figure 3.2.2(b) — Traffic frustration index (TFI) and level of service (LOS) determined for the trip used in driver frustration survey:
An example of INPUT DATA – section 2**

ANALYSIS RESULTS

10 = best 0 = worst

Traffic Frustration Index (TFI) =	**2.6**	<< (0 to 10)
Level of service (LOS) =	**Very poor**	

Total travel distance (km)	L_t =	12.53
Total distance for uneventful travel (km)	L_b =	5.20
Total time for uneventful travel (s)	T_b =	507
Average speed for uneventful travel (km/h)	v_b =	36.9
Travel time per unit dist. for uneventful travel (s/km)	t_b =	97.5
Total travel time for the trip (s)	T_t =	2339
Average speed for the total trip (km/h)	v_t =	19.3
Frustration rating for uneventful travel	R_b =	0.79
Frustration impact rate for uneventful travel	R_{bT} =	77.0
Total frustration impact for event types 1 to 9	*sum* $(R_i T_i)$ =	2370.8
Total travel distance for event types 1 to 9 (km)	$L_t - L_b$ =	7.3
Frustration impact rate for the total trip	R_T =	400.6
Frustration impact ratio	p_R =	0.19
Upper limit of frustration impact ratio	p_U =	0.73
Lower limit of frustration impact ratio	p_L =	0.00
Free-flow speed (s/km)	v_f =	60.0
Free-flow travel time per unit distance (s/km)	t_f =	60.0

Figure 3.2.3 — Traffic Frustration Index (TFI) and level of service (LOS) determined for the trip used in driver frustration survey: An example of ANALYSIS RESULTS

4. Concluding Remarks

Further analysis of the relationship between frustration rating and event duration indicated that simpler event type groupings are feasible. The speed change parameters (energy factor, E and equivalent stop value, ESV) could not be related to the frustration rating. Therefore, the relationships based on event duration are recommended for practical use.

A Traffic Frustration Index (TFI) based on the use of the frustration ratings for different traffic event groups is proposed. A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described. A level of service (LOS) table is given defining LOS in relation to a selected traffic quality index. The next stage of the current project is a validation study to apply the detailed Traffic Frustration Index method given in *Section 3*.

It is recommended that the proposed practical procedure including the simplified event type grouping system described in this report should be tried and refined in the validation of the proposed Traffic Frustration Index. For this purpose, each event type should be defined clearly, including the method to identify the start and end of each event type.

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Section 4

Application and Validation of the Traffic Frustration Index

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Contents

Executive Summary

Introduction and study design

The present report forms the final phase of the ARRB TR research project RC 7111 "*Traffic Management Performance Measures*" funded by AUSTROADS (Project NRUM 9805).

This investigation set out to discover whether a Traffic Frustration Index which quantified the events which contributed to driver frustration would be a useful supplement to measures such as traffic speed and flow in identifying priorities for traffic management interventions and assessing the outcomes of such interventions.

The project proceeded by four main stages:

- A literature review.
- A laboratory experiment to quantify situations which drivers regarded as frustrating.
- The development of a Traffic Frustration Index (TFI) model to incorporate the different types of frustrating event and relate them to travel speed.
- Evaluation of the model by applying it to a number of different routes at different times of day and comparing the TFI to user ratings of traffic conditions on these roads at these times.

The present report is concerned with the last of these steps. Since it is the final report in the series, this Executive Summary describes the whole study. A separate report for each of the four stages has been provided to the client.

Literature review

The literature showed growing recognition of the need to incorporate human factors into the measure of travel flow quality. However, these factors tended to be assumed on the basis of traffic speed and density rather than measured directly. Modellers such as Greenshields (1957) and Guerin (1958) both agree that driver discomfort is caused by restriction to manoeuvre or travel at a desired speed. Greenshields (1957) index was based on frequency and magnitude of speed changes and Guerin's (1958) on the speed distribution of vehicles on the roadway. Neither model measured how much discomfort was caused by each event and whether certain events created more discomfort than others. Other literature explored the human reaction to congestion. Dommerholt et al (1988) conducted experiments with test persons to assess the overtaking behaviour of drivers under varying levels of congestion. Mohktarian and Raney (1997) proved that socio-demographic variables such as gender and family status provided an indication of an individual's tolerance to congestion. Matthews et al (1998) concluded that drivers recently subjected to a major life stressor were more susceptible to accidents. An individual's tendency towards aggression, dislike and alertness was shown to affect their perceptions of the traffic environment and predict what coping strategies they would adopt (ie selecting alternate routes or transport, moving).

Research to date has concentrated more on differences in individual reactions rather than differences in traffic situations. Modellers are still faced with the issue of incorporating the human element into an overall performance measure of travel flow. The main problem faced by modellers lies in deciding what aspects of the human response to traffic situations (eg comfort, effort, stress etc) are the most relevant and the lack of established methods to directly measure the human reactions to traffic. The literature points to a need for modellers to identify what best determines quality of travel flow, to quantify these measurements of the human reaction and to incorporate them into an overall flow index.

Laboratory study of driver frustration ratings

Method and Procedure

A video tape of traffic incidents was prepared using a camera mounted on a tripod situated in front of the front passenger seat in a large sedan car. Most of the driving was done along undivided primary and secondary arterials, the type of road where a traffic index is likely to find the greatest application. All roads were in the eastern inner suburbs of Melbourne. The taping was done in peak and non-peak times so that a range of traffic conditions was recorded.

The tapes were then edited to produce a practice segment lasting approximately 7 minutes, and the main tape which lasted 46 minutes. The incidents incorporated in the tape are:

Type of incident	**Number**
Stop-intersection signals	18
Stop- pedestrian-operated signals	3
Slow travel	8
Forced lane change-due to parked vehicle	5
Forced lane change-other	5
Other	19

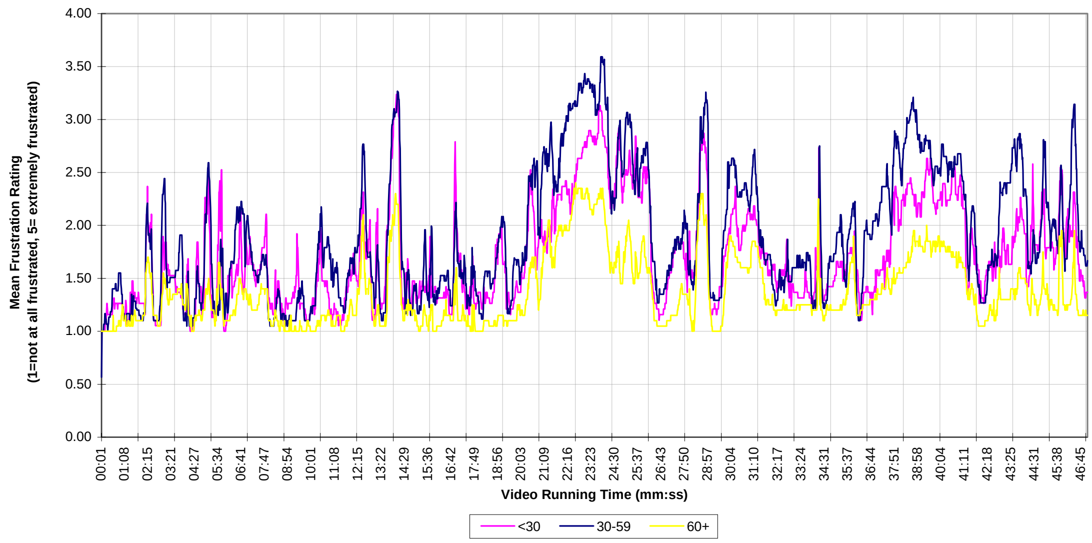
Participants viewed the television monitor and were provided with a small response dial which they could adjust continuously between two extremes labelled 'Extremely Frustrating' and 'Not at all Frustrating'. Participants viewed the tape individually, and adjusted the knob on the dial to reflect the level of frustration they felt with the traffic situation. The position of the knob was sampled once a second, and the results stored in the computer. Five positions of the knob could be distinguished.

Three groups of twenty participants, aged 18-29, 30-59, and 60 and over, took part in the study.

Results and conclusions

The video footage and rating procedure used in the study appeared to provide a valid means of engaging the participants' emotions and perceptions in relation to traffic situations. The three groups of respondents were highly consistent in the responses they gave to the different situations, although there were differences in the level of frustration expressed by the three groups (see Figure 1). Once the scores were normalised by dividing the score for each second by the overall average for the session, individually for each participant, the differences between the groups disappeared and the pattern appeared very consistent across all groups.

Figure 1 — Mean frustration rating by age group vs time



The growth in frustration over time was examined by taking *the mean normalised frustration rating* (MNFR) for each incident, then plotting it against the duration of the incident. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the MNFR level for uneventful travel.

The results of the ratings study were not as had been anticipated, and do not agree well with currently-held priorities in traffic management. The main features of the responses to different types of incident are:

- Respondents were relatively indifferent to routine stops at traffic signals, and showed relatively little frustration even after fairly long delays. This result was particularly surprising.
- The picture with slow travel is rather more complicated. There is a marked dislike of being forced to travel slowly, but the frustration increases over time at about the same rate as it does for time stopped at traffic signals.
- Forced lane changes are very much disliked, and the dislike appears to be directly proportional to the time spent delayed. Delays due to forced lane changes arising from parked cars increase driver frustration at approximately 26 times the rate for time delayed at intersection signals, and delays due to forced lane changes caused by other factors result in a 20 fold increase over the rate for time delayed at intersections.
- For 'other' events, the slope of the regression line was negative and the fit of the regression line poor. It was therefore decided that the most appropriate approach to modelling this type of event would be to add a constant amount for each incident, and multiply that by the duration to determine impact.

The results of this investigation suggest that relatively simple models may adequately predict the relationship between traffic conditions and driver frustration. The implications of the regression results for modelling the relationship between frustration and traffic conditions are discussed.

Developing the Traffic Frustration Index

Seven traffic event groups and an "uneventful travel" group were defined. The frustration ratings for individual events were plotted against the event duration for seven traffic event groups. In all cases but one, a linear regression gave a reasonable or good fit to the data, with most lines passing through the x-axis close to the frustration rating level for uneventful travel.

Data used to derive the results given in this report differ from the previous report to some extent. Firstly, the results given in this report are clearly qualified as relevant to a particular road class (undivided road with a speed limit of 60 km/h). Secondly, uneventful travel segments with an average speed less than 30 km/h are now qualified as slow travel. The analysis results indicate that simpler grouping of traffic events (four event types rather than seven) is feasible. The effect of speed change parameters on frustration rating is analysed using the energy factor (E) and equivalent stop value (ESV) parameters. Regression results indicate that the effects of speed change manoeuvres as measured in this study cannot be related to the frustration rating. Therefore, the relationships based on event duration are recommended for practical use.

A Traffic Frustration Index (TFI) is developed based on the use of the frustration ratings for different traffic event types. The numerical values of the Traffic Frustration Index can be directly translated into a level of service (LOS) using tables defined in the report. A simplified outline of the steps involved in calculating the TFI for a given traffic facility is presented in the highlighted section below.

It is recommended that the proposed practical procedure including the simplified event type grouping system described in this report should be tried and refined in the validation of the proposed Traffic Frustration Index. For this purpose, each event type should be defined clearly, including the method to identify the start and end of each event type.

Practical Procedure

A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described below. The use of the recommended event type grouping is assumed.

Input Data

Collect the following input data by driving along the traffic facility and recording the start and end points of each traffic event:

- Event type number (1 to 9) for each traffic event encountered, or event type number = 0 for uneventful travel segments.
- Start and end times of each event and each uneventful travel segment. This will be used to determine the duration of each event and each uneventful travel segment, T_i (seconds). It will also be useful for determining the travel distance, L_i (m) for each event.
- If speed is being recorded manually, record the speed at the start and end of each speed cycle (initial and final speeds, v_i, v_f) and the cruise speed (v_c) for near-constant speed segments. Alternatively record the instantaneous speed at regular short intervals (Δt), e.g. second by second ($\Delta t = 1$ s) using an instrumented car.
- Distance travelled for each uneventful travel segment, L_i (m). With instrumented car surveys, distance for each event can be determined as:

  $$L_i = \textit{sum}\,(v\,\Delta t) \qquad (3.2.1)$$

  where v is the instantaneous speed (m/s), Δt is the time interval used in the survey (s), and summation is for the duration of the event.

In the case of speeds recorded manually, approximate distance can be calculated from:

$$L_i = 0.5\,(v_i + v_f)\,T_i \qquad (3.2.2)$$

Where

v_i = initial speed (m/s)

v_f = final speed (m/s)

T_i = duration of the event or the uneventful travel segment.

- Total travel distance, L_t (km). This can be calculated by summing distances travelled during each event and uneventful travel segments, L_t = *sum* (L_i) for all events.
- Also record the *speed limit* and other characteristics of the traffic facility to determine the *road class*, and other conditions affecting travel (weather, etc). The speed limit may be used as the free flow speed, v_f (km/h) for the traffic facility. Using this speed, the free-flow travel time per unit distance, t_f (s/km) can be calculated from

$$t_f = 3600 / v_f \qquad (3.2.3)$$

Calculated Parameters

Enter the input data into the TFI application spreadsheet to obtain the TFI value and the corresponding level of service (LOS). The following parameters will be calculated by the application:

- Total distance for uneventful travel, L_b (km)
- Total time for uneventful travel, T_b (km)
- Average speed for uneventful travel, v_b (km/h)
- Travel time per unit distance for uneventful travel, t_b (s/km)
- Total travel time for the trip, T_t (s)
- Average speed for the total trip, v_t (km/h)
- Frustration impact rate for uneventful travel, R_{bT}
- Total frustration impact for event types 1 to 9, *sum* (R_iT_i)
- Total travel distance for event types 1 to 9, (L_t - L_b) (km)
- Frustration impact rate for the total trip, R_T
- Frustration impact ratio, p_R
- Upper limit of frustration impact ratio, p_U
- Free-flow travel time per unit distance, t_f (s/km)
- Traffic Frustration Index (TFI)
- Level of Service (LOS)

Applying and Validating the Traffic Flow Index

Application of the TFI

Measurements were made in both directions on seven road sections during morning peak, the mid-day period between peaks, and the evening peak. All roads were close to the VicRoads Head Office in Kew, Melbourne where persons who made the ratings of travel conditions worked. Measurements taken included the time and distance for the trip (from which uneventful travel was calculated), and the occurrence and duration of a number of traffic events.

Obtaining User Ratings

Staff working in VicRoads Head Office were asked to identify any roads which they used frequently at nominated times of day (morning peak, the mid-day period, and evening peak), and to rate the quality of travel only for trips with which they were familiar. For this survey, the approach to the respondents was made via e-mail, and respondents replied via the same medium. TFI was plotted against user ratings, each individual combination of road, direction of road and time of day constituting a data point in the plot.

Findings

The principal findings of the investigation are:

(viii) The Traffic Frustration Index provided a clear differentiation between the different routes used in the study.

(ix) Differentiation by time of day was less clear. This may have been due to taking measurements during school holidays, which possibly resulted in less traffic in peak times than would normally occur.

(x) There was a moderately good correlation between user ratings of how well the roads performed and TFI, with a correlation of - 0.56.

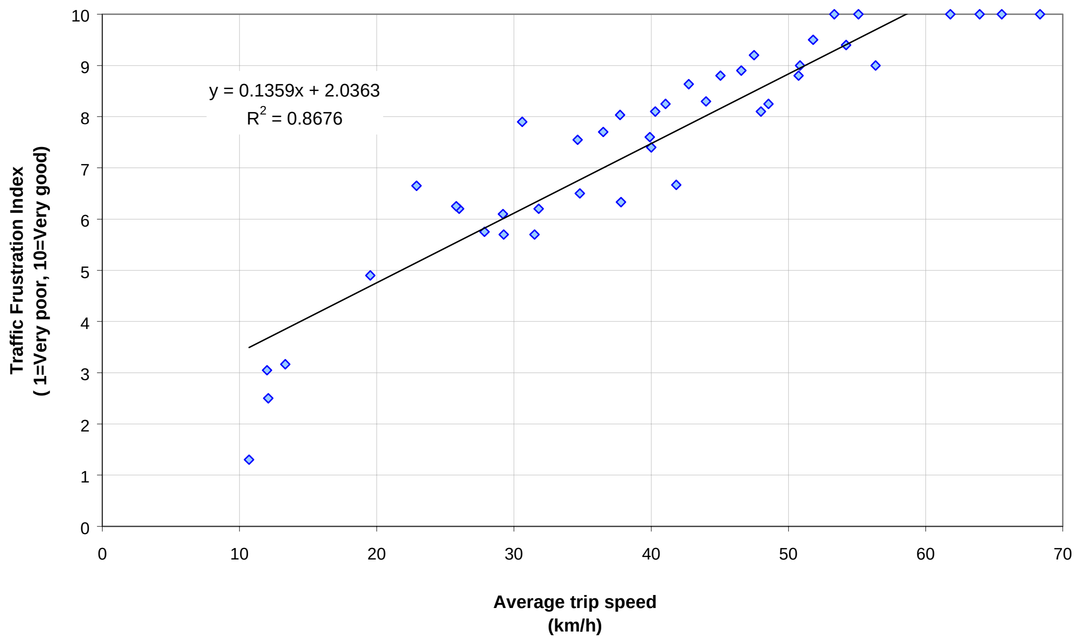
(xi) This correlation was higher for less frequent users than for frequent users (- 0.63 compared with - 0.47).

(xii) The correlation was also higher for travel during the day than for travel at peak times (- 0.81 compared with 0.38 for morning peak and 0.68 for evening peak).

(xiii) The fact that the traffic measurements were taken during a school holiday period may explain the relatively low correlations between TFI and user ratings especially in the morning peak. School holidays would tend to result in lower traffic flows (hence better TFIs) than normal, while the road users may have been basing their judgements on a memory of average weekday conditions acquired over a long period of time.

(xiv) There was a very close correlation between travel speed and TFI (0.96).

Figure 2 — TFI vs Average travel speed (modelled by linear trendline)



Overall Conclusions

(vi) The process of developing the TFI, particularly the rating study, indicated the consistency of reactions across a broad cross-section of drivers to different traffic situations. Although there were differences between the groups in the intensity of their frustration ratings, there was strong agreement about which events caused frustration and the point at which the situation started to become frustrating. This approach could be used in assessments of future traffic management initiatives in the future.

(vii) The investigation aimed to discover whether it was worth qualifying traffic speed as a measure of traffic performance by developing a method for quantifying events which frustrate drivers. Although it was demonstrated that different types of events have different impacts on driver frustration, the aggregate of these events correlates closely with travel speed and appears to add little if anything to the prediction of driver satisfaction. In view of this, it is difficult to justify the additional expense and complication of collecting travel time information.

(viii) The TFI does however provide a mechanism to calibrate travel speed in terms of user satisfaction in a manner which does not simply depend on the arbitrary allocation of different satisfaction values to different speeds. This has been calibrated for undivided urban roads in the present investigation. It may be worth establishing similar values for other classes of road as part of future work.

(ix) Further work is required to test the validity and usefulness of the TFI. This includes comparison with data collected out of school holidays, and a desk exercise to estimate the impact of various traffic engineering measures on TFI and average speed.

(x) Further development of the model could include its extension to divided roads and the inclusion of roundabouts.

1. Introduction

The notion of ‘quality of travel’ has traditionally been quantified by measures such as average travel speed. However, transport modellers are becoming increasingly aware that a measure of quality calls for not only objective measurements of the numerical parameters that define the flow, but also subjective responses to travel conditions based on road users’ perceptions. Driver comfort, frustration and stress are all relevant issues in the discussion of quality of travel. The literature suggests that modellers find difficulty in quantifying such factors and in determining what weighting they should be given in the development of a general ‘travel quality’ indicator. In formulating standard measures of the quality of traffic flow, the general tendency of modellers to date has been to simply assume that certain parameters of traffic flow are valid indicators of the travelling public’s annoyance or dissatisfaction, and to combine these parameters in some intuitive fashion. A preferable approach would be to investigate which parameters of traffic flow actually relate to driver annoyance or dissatisfaction, and to find some way of combining these factors in order to give each a weighting that reflects the extent to which they relate to annoyance and dissatisfaction.

The present investigation aims to achieve this by:

(i) reviewing previous work in the field.

(ii) determining how drivers respond to delays, slow travel, forced lane changes, and other frustrating events which are likely to be encountered in the course of driving in urban environments.

(iii) developing an index which describes quality of travel and gives appropriate weighting to different types of events, based on the investigation of driver responses and other previous research.

(iv) applying this index to typical travel situations.

(v) validating the traffic flow index by comparing the index for certain trips at certain times against driver assessment of travel quality.

The first three stages have already been reported (Gunatillake and Cairney 1999, Cairney and Gunatillake 1999 and Akçelik 1999). The present final report describes the last two stages, the application of the traffic flow index to actual travel situations, and the validation of the traffic flow index against driver assessments of travel quality. It also presents a simplified model developed from a laboratory study of driver frustration ratings in response to different traffic situations, and constitutes the final report in the series arising from this project.

2. Traffic Frustration Index and Levels of Service

Development of a *Traffic Frustration Index* (TFI) based on the use of *frustration ratings* for different traffic event types was discussed in Akçelik (1999). The method, which has been slightly simplified, is summarised in this section. The level of service definitions based on TFI have been modified and level of service definitions based on average travel speed have been introduced.

2.1 Frustration Ratings

Based on a laboratory study to determine drivers’ responses to a range of potentially frustrating traffic situations (Cairney and Gunatillake 1999), an "uneventful travel" group (event type 0) and ten traffic event groups (event types 1 to 10) were defined as summarised in *Table 2.1*. Linear regression equations relating the frustration rating to the event duration were derived for event types 0, 1 to 3, 9 and 10. Event types 4 to 8 are reserved for future use, and event type 10 incorporates all current event types (1 to 3 and 9).

The linear relationship between the frustration rating and the event duration is expressed as:

$$R = R_o + s_t\,T \qquad (2.1)$$

where

R = frustration rating for an event of duration T seconds,
R_o = frustration rating for an event of very short duration
s_t = the rate of increase in frustration rating with increased event duration
T = duration of the event (seconds).

The regression results for the event types are summarised in *Table 2.1*. The regression results are based on driver frustration ratings of conditions of driving on undivided roads with a speed limit of 60 km/h. Uneventful travel segments (Event type 0) represent conditions with an average travel speed above 30 km/h and no event of type 1, 3 or 9. Segments with no event of type 1, 3 or 9 but with an average travel speed below 30 km/h are qualified as *slow travel* (Event type 2).

Table 2.1
Event types for frustration ratings

Event type	Description	Frustration rating $R = R_o + s_t\,T$	
		R_o	s_t
0	Uneventful travel	0.79	0
1	Stops at intersection and pedestrian signals (non-congested conditions)	0.79	0.0021
2	Slow travel including stops at traffic signals (congested conditions)	0.95	0.0017
3	Forced lane change	0.79	0.0282
(4-8)	(reserved for additional event types)		
9	Other events	1.01	0
10	All event types (1 to 9) (uneventful travel not included)	0.91	0.0018

2.2 Traffic Frustration Index

For use with the practical procedure described in *Section 2.3*, the Traffic Frustration Index (TFI) is defined as follows:

$$TFI = 10\,(p_R - p_L) / (p_U - p_L) \quad \text{for } p_R > p_L \qquad (2.2)$$
$$= 0 \quad \text{for } p_R \le p_L$$

where

$$p_R = \min\,(p_U,\ R_{bT} / R_T) \qquad (2.3)$$
$$R_{bT} = R_b\, t_b \qquad (2.4)$$
$$R_T = \Sigma\,(R_i\, T_i) / L_t \qquad (2.5)$$
$$t_b = T_b / L_b \qquad (2.6)$$
$$T_b = \Sigma\,(T_i)_{\text{for event type 0}} \qquad (2.7)$$
$$L_b = \Sigma\,(L_i)_{\text{for event type 0}} \qquad (2.8)$$
$$L_t = \Sigma\,(L_i)_{\text{for event types 0 to 9}} \qquad (2.9)$$

p_R = frustration impact ratio: the ratio of frustration impact rate for uneventful travel (R_{bT}) to the frustration impact rate for the total trip (R_T)

p_L = lower limit of the frustration impact ratio (a selected constant; range: 0 to 0.3, default: 0; must be less than p_U)

p_U = upper limit of the frustration impact ratio (a selected constant; range: 0.7 to 1.0, default: 1.0; must be larger than p_L)

R_{bT} = frustration impact rate (per unit distance) at the uneventful trip (base) level

R_T = frustration impact rate (per unit distance) for the total trip; summation ($R_i\, T_i$) is for all event types (0 to 9) including uneventful travel

R_b = frustration rating for uneventful travel (R_b = 0.79 in *Table 2.1*)

R_i = frustration rating for *ith* event calculated from *Equation (2.1)* using the parameters given in *Table 2.1*

T_i = duration of *ith* event (seconds)

t_b = travel time per unit distance for the uneventful travel segments of the trip (seconds per km)

T_b = total travel time for the uneventful travel segments of the trip (seconds); $(T_i)_{\text{for event type 0}}$ is the travel time for the *ith* uneventful travel segment

L_b = total distance traveled during the uneventful travel segments of the trip (km); $(L_i)_{\text{for event type 0}}$ is the distance traveled during the *ith* uneventful travel segment

L_t = total travel distance for all event types (0 to 9) including uneventful travel (km); $(L_i)_{\text{for event types 0 to 9}}$ is the distance traveled during the *ith* travel segment.

The *frustration impact rate* (R_T) is calculated on a per km basis, i.e. it is the impact rate per unit distance. This represents both the *frustration levels* and the *intensity* of traffic events that cause frustration. The basis of the TFI formulation given in *Equation (2.2)* is shown in *Figure 2.1*.

A simpler form of *Equation (2.2)* is obtained by setting the lower and upper limits of the frustration impact ratio to the default values $p_L = 0$ and $p_U = 1.0$:

$$\begin{aligned} TFI &= 10\, p_R \\ &= 10\, R_{bT} / R_T \end{aligned} \qquad (2.10)$$

The lower limit of the frustration impact ratio (p_L) can be increased and the upper limit (p_U) can be decreased in order to adjust the sensitivity of the TFI function. *Figure 2.2* compares the Traffic Frustration Index (TFI) functions using ($p_L = 0$, $p_U = 1.0$) (broken line) and ($p_L > 0$, $p_U < 1.0$). It is seen that the effect of increased p_L is to reduce the TFI value for a given frustration impact ratio (p_R). Similarly, the effect of reduced p_U is to increase the TFI value for a given frustration impact ratio (p_R).

The results in *Section 3.5* are based on the use of the TFI function with $p_L = 0$ and $p_U = 1.0$.

Figure 2.1 - The basis of Traffic Frustration Index (TFI) formulation

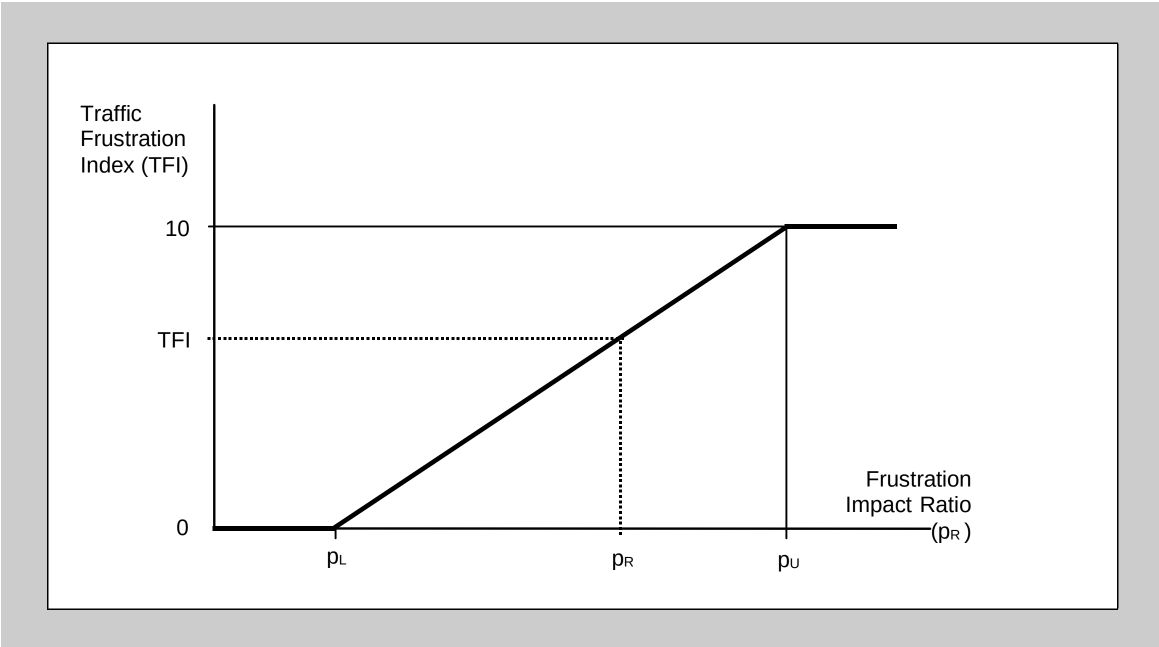
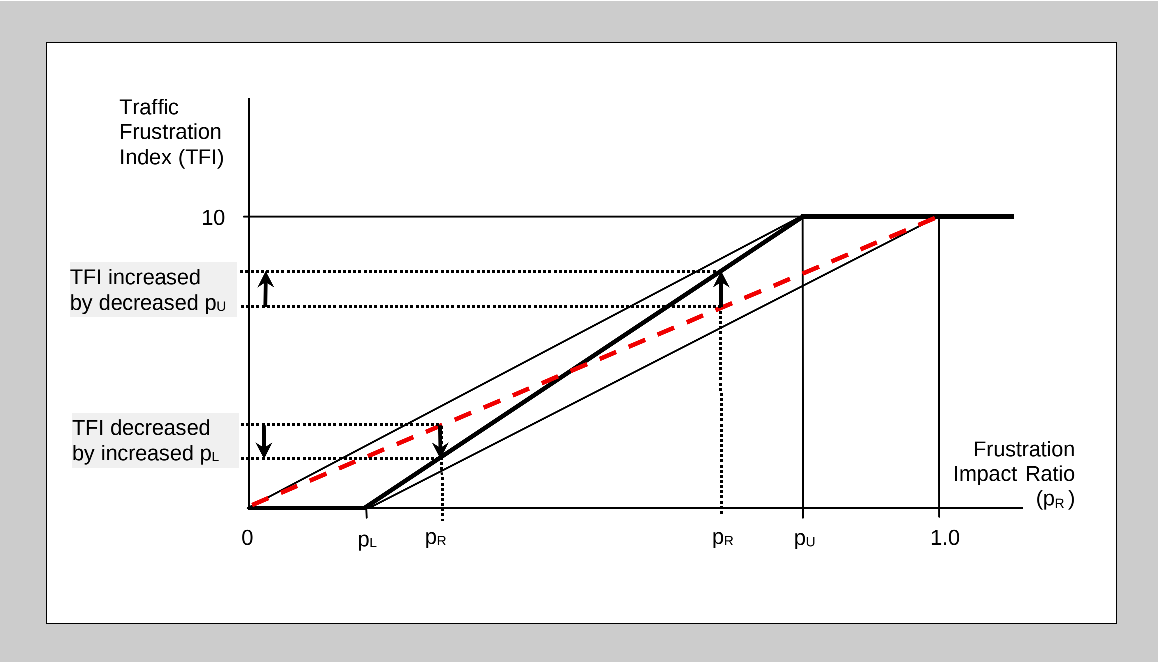


Figure 2.2 - Comparison of the Traffic Frustration Index (TFI) functions using (p_L = 0, p_U = 1.0) (broken line) and (p_L > 0, p_U < 1.0)



The average speed, v_b (km/h) for the uneventful travel segments of the trip is given by:

$$v_b = 3600 / t_b = L_b / T_b \quad \textit{for } T_b > 0$$
$$ = 0.8\, v_f \quad \textit{for } T_b = 0 \qquad (2.11)$$

where t_b, L_b and T_b are as in *Equations 2.6 to 2.8*, and v_f is the free-flow speed (km/h).

The condition $T_b = 0$ may occur if there was no uneventful travel segment during the trip. In this case, 80 per cent of the free-flow speed (speed limit) is used.

The average speed for the total trip is given by:

$$v_t = 3600\, L_t / T_t \qquad (2.12)$$

where

L_t is given by *Equation 2.9*, and T_t is the total travel time for the trip (seconds) given by:

$$T_t = \Sigma\, (T_i)_{\text{for event types 0 to 9}} \qquad (2.13)$$

where

T_i = duration of *ith* event (seconds); $(T_i)_{\text{for event types 0 to 9}}$ is the travel time for the *ith* travel segment, and summation is for all event types (0 to 9) including uneventful travel.

The use of the travel time per unit distance for the uneventful travel segments of the trip (t_b) as the base travel condition in TFI simplifies the method in relation to the data collected during the survey (see *Section 2.3*). An alternative is to use 80 per cent of the free-flow travel time (t_f) as implied by *Equation 2.11*, or the zero-flow travel time (t_o), instead of t_b.

The zero-flow travel time (t_o) is experienced under near-zero travel demand conditions (very light traffic):

$$t_o = t_f + d_m \quad (2.14)$$

where

t_f = free-flow travel time per unit distance (s/km) given by:

$$t_f = 3600 / v_f \quad (2.15)$$

v_f = free-flow speed in km/h (approximately the speed limit)

d_m = minimum delay per unit distance (s/km) experienced at interruption points along the facility:

$$d_m = \Sigma\, d_{mj} / L_t \quad (2.16)$$

where

d_{mj} = minimum delay (s) at *jth* interruption point

L_t = total travel distance along the facility (km).

A simple method is to use:

$$d_m = n\, d_{mj} \quad (2.17)$$

where

d_{mj} = an average value of d_{mj} per interruption point for the road class

n = the number of interruption points per km for the road class.

The *zero-flow travel speed* (v_o) in km/h is given by:

$$v_o = 3600 / t_o \quad (2.18)$$

2.3 Levels of Service

Various levels of service (LOS) can be defined in relation to a selected traffic quality index. Alternative methods can be developed for determining a travel quality index. The Traffic Frustration Index (TFI) described in *Section 2.2* provides such a travel quality index measure. *Table 2.3* presents the LOS definitions based on the Traffic Frustration Index. The values given in *Table 2.3* have been chosen considering their implications for the degree of saturation and speed values for each LOS grade.

Table 2.4 presents an alternative method for defining levels of service. This is based on the use of average travel speed similar to the method used in the US Highway Capacity Manual (HCM), Chapter 11 (TRB 1998). The speed criteria given in *Table 2.4* are close to those given in the HCM for Arterial Class II (roads with free-flow speed in the range 55 to 70 km/h).

Table 2.3
Level-of-service definitions based on the Traffic Frustration Index (TFI)

Level of Service	Traffic Frustration Index
Very Good	$8.5 < TFI \leq 10$
Good	$7 < TFI \leq 8.5$
Acceptable	$5 < TFI \leq 7$
Poor	$3 < TFI \leq 5$
Very Poor	$0 \leq TFI \leq 3$

Table 2.4
Level-of-service definitions based on average travel speed (v_t)

Level of Service	Average travel speed (km/h)
Very Good	$50 < v_t \leq 60$
Good	$40 < v_t \leq 50$
Acceptable	$30 < v_t \leq 40$
Poor	$20 < v_t \leq 30$
Very Poor	$0 \leq v_t \leq 20$

2.4 Practical Procedure

A practical procedure to measure the Traffic Frustration Index (TFI) for a traffic facility is described below. This is based on the use of event type grouping given in *Table 2.1*.

Input Data

Collect the following input data by driving along the traffic facility.

- Record the event type number (1 to 9) for each traffic event encountered, or event type number = 0 for uneventful travel segments.
- Record the start and end times of each event and each uneventful travel segment. This will be used to determine the duration of each event and each uneventful travel segment, T_i (seconds). It will also be useful for determining the travel distance, L_i (m) for each event.
- If speed is being recorded manually, record the speed at the start and end of each speed cycle (initial and final speeds, v_i, v_f), and the cruise speed (v_c) for near-constant speed segments. Alternatively record the instantaneous speed at regular short intervals (Δt), e.g. second by second ($\Delta t = 1$ s) using an instrumented car.

- Record the distance travelled for each uneventful travel segment, L_i (m). With instrumented car surveys, distance for each event can be determined as:

  $$L_i = \Sigma (v \Delta t) \qquad (2.19)$$

  where v is the instantaneous speed (m/s), Δt is the time interval used in the survey (s), and summation is for the duration of the event.

  In the case of speeds recorded manually, approximate distance can be calculated from:

  $$L_i = 0.5 (v_i + v_f) T_i \qquad (2.20)$$

  where

  v_i = initial speed (m/s)

  v_f = final speed (m/s)

  T_i = duration of the event or the uneventful travel segment.

- Record the total travel distance, L_t (km). This can be calculated by summing distances travelled during each event and uneventful travel segments, $L_t = \Sigma (L_i)$ for all events.
- Also record the *speed limit* and other characteristics of the traffic facility to determine the *road class*, and other conditions affecting travel (weather, etc). The speed limit may be used as the free flow speed, v_f (km/h) for the traffic facility. Using this speed, the free-flow travel time per unit distance, t_f (s/km) can be calculated from *Equation 2.15*.

Calculated Parameters

Enter the input data into the TFI application spreadsheet to obtain the TFI and average travel speed values and the corresponding levels of service (LOS). The following parameters are calculated by the application:

- Traffic Frustration Index (TFI)
- Level of Service (LOS) based on TFI
- Level of Service (LOS) based on average travel speed, v_t
- Total travel distance, L_t (km)
- Total distance for uneventful travel, L_b (km)
- Total time for uneventful travel, T_b (km)
- Average speed for uneventful travel, v_b (km/h)
- Travel time per unit distance for uneventful travel, t_b (s/km)
- Total travel time for the trip, T_t (s)
- Average speed for the total trip, v_t (km/h)
- Frustration impact rate for uneventful travel, R_{bT}
- Total frustration impact for event types 1 to 9, $\Sigma (R_i T_i)$
- Total travel distance for event types 1 to 9, $(L_t - L_b)$ (km)
- Frustration impact rate for the total trip, R_T
- Frustration impact ratio, p_R
- Upper limit of frustration impact ratio, p_U
- Free-flow travel time per unit distance, t_f (s/km)

An example of the application of the above procedure to determine TFI and LOS is presented in the *Appendix.*

3. Application of traffic flow index to actual travel situations

3.1 Purpose

The purpose of this part of the research is to assess how the Traffic Flow Index developed in the previous stages of the research relates to actual traffic conditions. Issues of interest are:

- Does the index discriminate between different routes where traffic conditions are obviously different?
- Does the index discriminate between traffic conditions on the same route at different times of day in a way which reflects differences in demand levels?
- Do the routes measured cover the range of scores available, and are scores evenly distributed along the range?

3.2 Method

In seeking to validate the Traffic Frustration Index (TFI) formulated in the previous stage of this project, the following experimental procedure (based on *Section 2.4*) was employed.

The model developed calculates the TFI for any given trip, based on the occurrence and duration of the 'events' encountered and also on basic parameters such as travel time. The current model uses five basic event types:

Event type 1: Stops at traffic lights
Event type 2: Slow travel
Event type 3: Forced lane changes
Event type 9: Other events
Event type 0: Uneventful travel

For events of type 1,2,3 and 9 the model requires input of occurrence and duration. For events of type 0, the model requires input of occurrence, duration and the distance travelled in that period. This is effectively a measure of the average speed during uneventful travel.

A special survey vehicle was used to measure these parameters on all the trips included in the investigation. The late model Toyota sedan was equipped with satellite connection and a Global Positioning System (GPS). The position of the vehicle in terms of latitude and longitude was time stamped (local time) and recorded at intervals of 5 seconds. This satellite data was supplemented by in-vehicle records of odometer reading and fuel consumption. All satellite and in-vehicle information was stored in a data logger which was downloaded to a laptop at the end of each session. All information was stored in the data logger until downloaded, regardless of how many times the car was turned off and on.

Once downloaded, the data was transferred to an Excel format. Local time, latitude, longitude and odometer reading were presented in simple column format. Speed was not recorded by the vehicle, but could easily be calculated using the difference in odometer readings and time stamp. Although speed was not required as an input to the TFI model, it proved useful to pinpoint the duration of stops at traffic lights where the average speed equalled 0 km/h and to identify sections of slow travel where average speeds were equal to or less than 30km/h (applicable to roads with 60 km/h speed limits only).

The data recorded by the survey vehicle was used to work out the duration of stops at traffic lights and slow travel and to calculate the distance travelled during uneventful segments. The occurrence and duration of other event types was recorded manually.

3.3 Route selection

The TFI index was validated against seven routes, for trips in both directions. All routes are urban arterials, with a speed limit of 60 km/h. The routes selected are shown in *Table 3.1*.

The trips were selected so as to be close to VicRoads' Head Office, since the TFI scores were to be compared later with user ratings made by VicRoads staff *(see Section 4)*. Routes were selected which gave access to different parts of the metropolitan area, and which would be likely to be used by VicRoads staff for travel to and from work, or for work-related travel during the day.

Table 3.1
Routes surveyed in validation study

Route	
Barkers Road	From Denmark St to Burke Rd
High Street	From Old Post Office to Harp Rd
Victoria Street	From Hoddle St to Burnley Rd
Studley Park Rd	From Yarra Blvd to Kew Junction
Power Street	From Barkers Rd to Riversdale Rd
Princess Street	From Chandler Hwy to Kew Junction
Cotham Rd	From Old Post Office to Burke Rd

Surveys were conducted on Tuesday, 6 July and Wednesday, 7 July. Each trip was made during the following three periods, representing different traffic flow conditions during the day:

AM Peak: 7:00 AM - 9:00 AM

Midday: 10:00 AM - 4:00 PM

PM Peak: 4:00 PM - 6:00 PM

The TFI calculated for a given trip is based on the occurrence and duration of the events which are encountered. To some extent, the TFI may be affected by individual driving style. For example, a defensive driving style may minimise the duration of events such as forced lane changes through early detection or avoiding them altogether through anticipatory lane changing. Similarly, a very passive driving style may result in longer delays and greater frustration than the average driver would experience. In the current study the same driver was employed for all trips and was instructed to stay in the middle lane and travel at the prevailing speed of traffic. The TFI for each trip may therefore be considered a rating applicable to the average driver.

3.4 Data Collection

A proforma was prepared for each trip, with details of route, direction and time of day specified. The surveyor sat in the passenger seat of the vehicle with a clipboard and two stop watches. The time on the watches was synchronised with standard local time (as used by the vehicle's recording system). One watch was simply used to note down the time at which each trip started and finished and also the time at which each event occurred. The other watch was set on the timer and used to time the duration of each event.

Only events of type 1,2,3 and 9 were recorded in this way. Uneventful travel (type 0) was defined as the periods in between other events. At the start of each event, the local time was noted and the timer started. At the end of the event, the timer was stopped and the duration noted. The time at which the event finished was calculated later as the start time plus duration. The longitude and latitude of the start and finish of each route was also noted through the course of the surveys.

The distance travelled during events of type 0 (uneventful travel) was calculated as the difference in odometer readings at the end and start of each uneventful segment.

For each trip, the information gathered through manual records and through the vehicle's recording systems was tabulated in the following format (*see Figure 3.1*), and the data input into the TFI model to calculate the Traffic frustration Index.

Figure 3.1 — Sample of survey results for use in TFI calculations

ROUTE: Victoria St
DIRECTION: Eastbound
TIME: MIDDAY
DATE: 6 July, 1999

Local Time	Event Type	Event Duration	Duration of uneventful segments	Total Distance travelled (m)	Distance during uneventful travel (m)
16:26:58	2	0:01:23			
16:27:06	1	0:00:08			
16:27:36	0	0:00:30	0:00:30		238
16:27:42	9	0:00:06			
16:28:25	0	0:00:43	0:00:43		331
16:29:01	1	0:00:36			
16:29:47	0	0:00:46	0:00:46		425
16:29:58	1	0:00:11			
16:30:28	0	0:00:30	0:00:30		303
TOTAL		0:04:53	0:02:29	1640	1297

3.5 Results

Table 3.2 lists the TFI calculated for each trip, along with the Level of Service for the trip (see *Table 2.3* for the relation between Level of Service and TFI). TFI values have been averaged over the two survey dates.

It can be seen from *Table 3.2* that the TFI provides clear differentiation between different trips. For example, Studley Park Road provides a "Very Good" level of service in both directions at all times of day, while Victoria Street never has a TFI better than the equivalent of "Acceptable" and has a "Poor" level of service for much of the time. Other trips lie between these extremes. The index would appear to discriminate less between trips at different times of day, with most trips differing by only one scale point across the day.

Table 3.2
TFI scores for validation surveys

Route	Direction	Time	TFI	Level of Service based on TFI
Barkers Road	Eastbound	AM Peak	9.0	Very Good
		Mid-day	8.3	Good
		PM Peak	7.4	Good
	Westbound	AM Peak	8.8	Very Good
		Mid-day	9.4	Very Good
		PM Peak	8.1	Good
Cotham Rd	Eastbound	AM Peak	5.7	Acceptable
		Mid-day	6.7	Acceptable
		PM Peak	7.6	Good
	Westbound	AM Peak	7.9	Good
		Mid-day	8.8	Very Good
		PM Peak	7.6	Good
High Street	Eastbound	AM Peak	9.2	Very Good
		Mid-day	8.6	Very Good
		PM Peak	9.0	Very Good
	Westbound	AM Peak	1.3	Very Poor
		Mid-day	6.3	Acceptable
		PM Peak	8.3	Good
Power Street	Northbound	AM Peak	8.1	Good
		Mid-day	8.0	Good
		PM Peak	5.7	Acceptable
	Southbound	AM Peak	6.5	Acceptable
		Mid-day	5.8	Acceptable
		PM Peak	6.3	Acceptable
Princess Street	Northbound	AM Peak	9.5	Very Good
		Mid-day	8.9	Very Good
		PM Peak	8.3	Good
	Southbound	AM Peak	6.1	Acceptable
		Mid-day	6.2	Acceptable
		PM Peak	7.7	Good
Studley Park Rd	Eastbound	AM Peak	10.0	Very Good
		Mid-day	10.0	Very Good
		PM Peak	10.0	Very Good
	Westbound	AM Peak	10.0	Very Good
		Mid-day	10.0	Very Good
		PM Peak	10.0	Very Good
Victoria Street	Eastbound	AM Peak	6.2	Acceptable
		Mid-day	4.9	Poor
		PM Peak	6.7	Acceptable
	Westbound	AM Peak	2.5	Very Poor
		Mid-day	3.2	Poor
		PM Peak	3.1	Poor

4. Road user ratings of traffic route performance

4.1 Purpose

The purpose of this part of the investigation was to obtain driver ratings of a number of different traffic routes at different times of day in order to compare them with Traffic Flow Index scores for the same routes at the same times of day.

4.2 Method

The innovative step was taken of using an e-mail survey to collect road user ratings of traffic route performance.

VicRoads staff working at VicRoads Head Office in Kew, Melbourne were contacted by e-mail. The e-mail message consisted of a covering letter from a senior manager in the Traffic and Road Use Management group inviting staff to participate, and a questionnaire which could be filled in via keyboard and screen in a few minutes and returned to the project team by e-mail

The questionnaire required the respondent to consider travel in either direction along seven sections of arterial roads close to VicRoads Head Office. It was anticipated that some staff would use these roads for commuting or for work-related travel during the day, and travel along each section at different times of day. The 42 combinations generated by this process corresponded to the sections at different times of day for which Traffic Flow Indices were obtained in the manner described in *Sections 3.2 to 3.4.*

Respondents were asked to rate any section/direction/time combination along which they travelled as a driver, motorcyclist, car or bus passenger, or cyclist on most working days as “1”, and any section /direction/time combination along which they travelled less often but at least once a month as “2”. Only trips which were rated as ‘1’ or ‘2’ for frequency of travel were then rated for travel quality.

Respondents were provided with a 5-point rating scale, with statements describing the extreme categories at each end of the scale to guide their ratings (these guiding statements are referred to as “anchors” in the literature on rating scales).

1 Very Good - *Freely flowing traffic with hardly any conflicting vehicle movements, equivalent to the least stressful travel you normally encounter.*

2 Good

3 Just acceptable

4 Poor

5 Very Poor - *Congested traffic with conflicting vehicle movements, equivalent to the most stressful travel you normally encounter.*

4.3 Results

A total of 199 VicRoads staff replied to the e-mail survey. A summary of their ratings of each route is presented in *Table 4.1*.

Of those who replied to the survey:

- 70% were male
- 41% were aged 40-49, with a total of 69% aged over 40
- 86% said that for the journeys rated, they were usually the driver

Table 4.1
Summary of email surveys
Average travel quality ratings for each trip

Route	Time Period	*n*	Average Travel Quality Rating	Description
Barkers Road, Denmark St to Burke Rd,	AM Peak	*16*	3	Acceptable
Travelling East (away from City)	Mid-day	*27*	2	Good
	PM Peak	*71*	3	Acceptable
Barkers Road, Burke Rd to Denmark St,	AM Peak	*56*	3	Acceptable
Travelling West (towards the City)	Mid-day	*24*	2	Good
	PM Peak	*18*	2	Good
High Street, Old Post Office to Harp Rd	AM Peak	*9*	3	Acceptable
Travelling East (away from City)	Mid-day	*5*	2	Good
	PM Peak	*42*	2	Good
High Street, Harp Rd to Old Post Office	AM Peak	*40*	3	Acceptable
Travelling West (towards the City)	Mid-day	*4*	3	Acceptable
	PM Peak	*4*	3	Acceptable
Victoria Street, Hoddle St to Burnley Rd	AM Peak	*10*	3	Acceptable
Travelling East (away from City)	Mid-day	*14*	4	Poor
	PM Peak	*13*	4	Poor
Victoria Street, Burnley Rd to Hoddle St	AM Peak	*12*	4	Poor
Travelling West (towards the City)	Mid-day	*16*	4	Poor
	PM Peak	*19*	4	Poor
Studley Park Rd, Yarra Blvd to Kew Junction	AM Peak	*14*	2	Good
Travelling East (away from City)	Mid-day	*7*	2	Good
	PM Peak	*9*	2	Good
Studley Park Rd, Kew Junction to Yarra Blvd	AM Peak	*4*	3	Acceptable
Travelling West (towards the City)	Mid-day	*9*	2	Good
	PM Peak	*21*	2	Good
Power Street, Barkers Rd to Riversdale Rd	AM Peak	*15*	4	Poor
Travelling South	Mid-day	*21*	2	Good
	PM Peak	*34*	3	Acceptable
Power Street, Riversdale Rd to Barkers Rd	AM Peak	*29*	3	Acceptable
Travelling North	Mid-day	*20*	3	Acceptable
	PM Peak	*15*	4	Poor
Princess Street, Chandler Hwy to Kew Junction	AM Peak	*70*	4	Poor
Travelling South	Mid-day	*26*	2	Good
	PM Peak	*19*	3	Acceptable
Princess Street, Kew Junction to Chandler Hwy	AM Peak	*21*	4	Poor
Travelling North	Mid-day	*30*	2	Good
	PM Peak	*74*	4	Poor
Cotham Rd, Old Post Office to Burke Rd	AM Peak	*6*	2	Good
Travelling East (away from City)	Mid-day	*6*	2	Good
	PM Peak	*22*	2	Good
Cotham Rd, Burke Rd to Old Post Office	AM Peak	*19*	3	Acceptable
Travelling West (towards the City)	Mid-day	*7*	2	Good
	PM Peak	*4*	2	Good

5. Comparison of TFI Scores with User Ratings

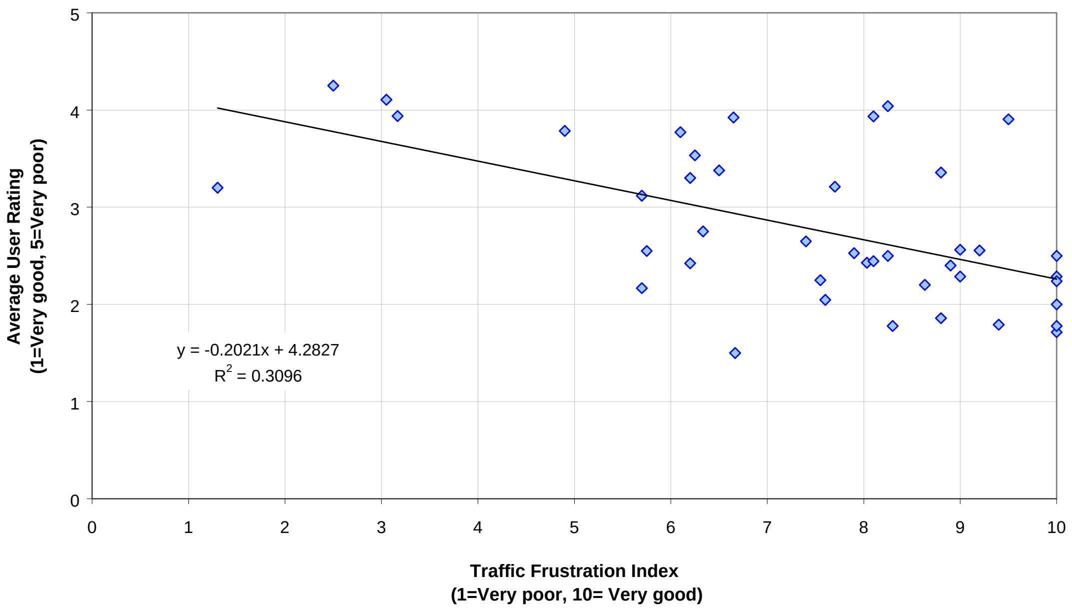
5.1 Purpose

In validating the TFI model, it is important to assess whether the TFI calculated for a given trip actually reflects the real life situation as perceived by drivers. The purpose of the surveys conducted amongst staff at VicRoads, Kew was to capture the opinions of road users who are familiar with the traffic conditions on the routes tested. Comparison of these ratings with the calculated TFIs provides a means of testing how accurately the Index models user perceptions of trip stress.

5.2 TFI vs Average Ratings

Figure 5.1 plots average user ratings against the TFI calculated for each trip. Note that TFI ranges from 1 to10 where 1 corresponds to Very poor conditions and 10 corresponds to Very good conditions. The user ratings range only from 1 to 5, where 1 corresponds to Very good conditions and 5 reflects Very poor conditions.

Figure 5.1 — TFI vs Average User Rating



The correlation coefficient between TFI and average rating is - 0.56. While a negative relationship is expected (since TFI increases as the average rating decreases), the relationship between the two variables is moderate with a some degree of scatter. *Figure 5.1* does indicate however, that despite a large number of trips scoring TFIs in the 'Very Good' range of 8.5 to 10, user ratings did not exceed 1.5 or 'Good'. This suggests that according to the user, the TFI tended to overrate the quality of the trips. Only trips which scored a TFI of 5.5 or more were considered 'Acceptable' by the user. Trips which were rated by users as being of a Very poor to Acceptable standard (3 to 5) yielded TFI values ranging from 1 to 10.

5.2.1 Frequent users and Occasional users

The questionnaire separates the ratings of users who make the specified trips frequently from users who only make the trips occasionally. The results presented above are the average ratings for all users. *Figures 5.2(a) and 5.2 (b)* separate the two classes of users in plots of TFI vs average user rating. *Figure 5.2(a)* indicates that the ratings of frequent users covers a broader range of values between the two extremes of 'Very poor' and 'Very good'. Occasional users *(see Figure 5.2(b))* tend to be more conservative in their judgements, avoiding ratings at the extreme ends of the scale. These users may be hesitant to offer ratings as strong as 'Very good' or 'Very poor' when they only have a limited experience of the traffic conditions encountered. Frequent users may feel more confident to pass stronger judgements when they have better idea of the daily conditions.

The actual relationship between TFI and average user ratings is stronger with occasional users, with a correlation coefficient of - 0.63 compared with - 0.47 for frequent users. It may be that the more conservative judgements of the occasional users matched the conditions encountered during the validation surveys more closely.

Figure 5. 2(a) — TFI vs average user ratings for frequent users

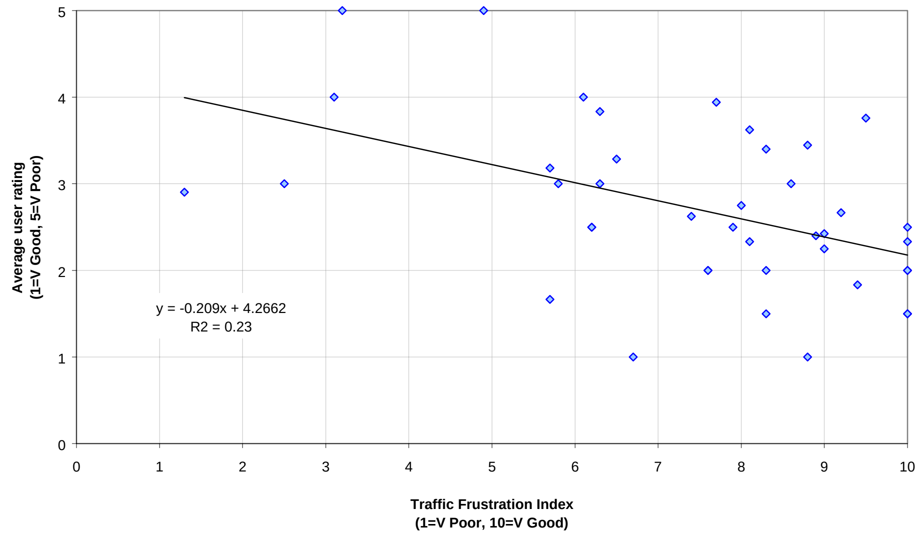
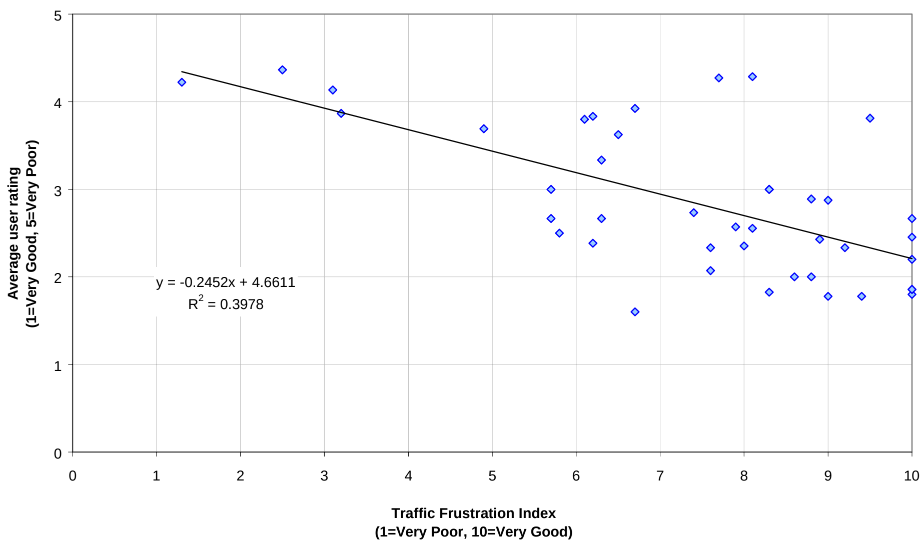


Figure 5. 2(b) — TFI vs average user ratings for occasional users



5.2.2 Variation of TFI–User Rating relationship by time of day

Figures 5.3 to 5.5 plot TFI vs average user ratings for trips made during specific periods (ie AM peak, Midday and PM peak).

Figure 5.3 — TFI vs Average rating for trips made during the AM peak period

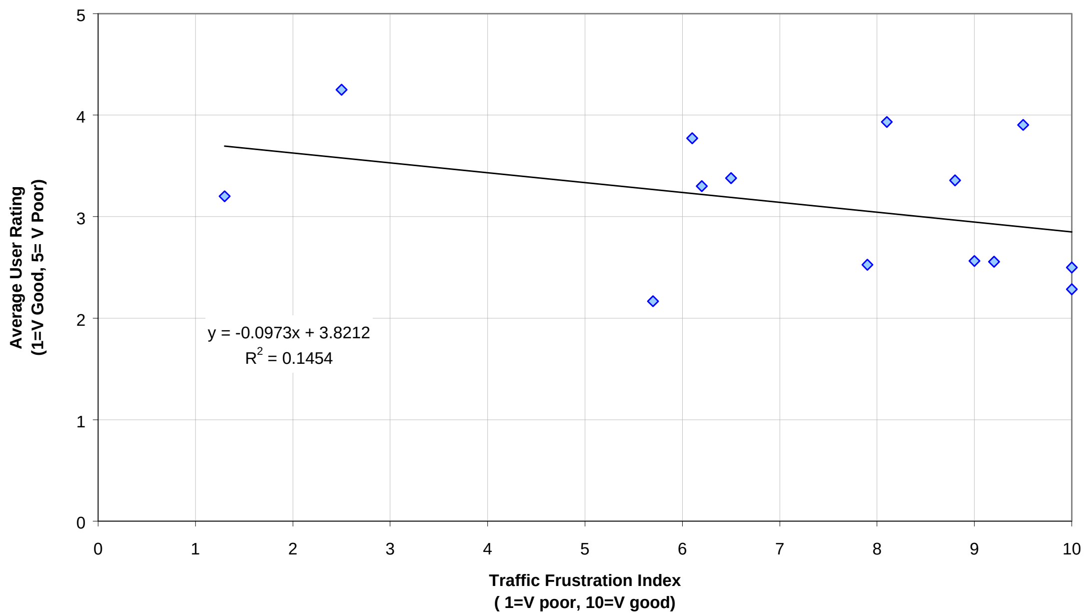


Figure 5.4 — TFI vs Average User Rating for trips made in the Midday period

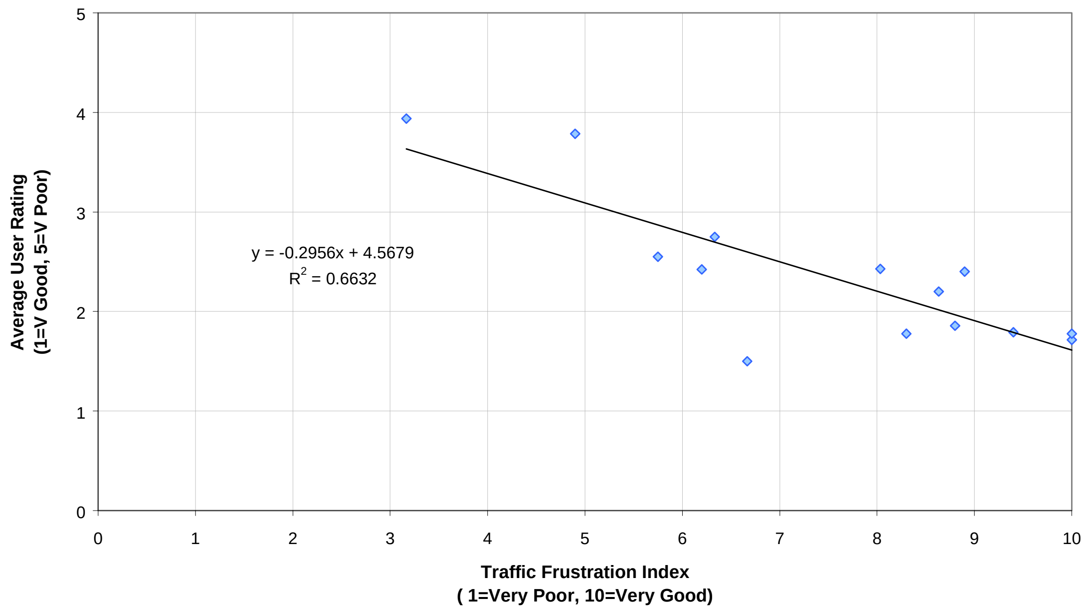


Figure 5.5 — TFI vs Average user rating for trips made during the PM peak period

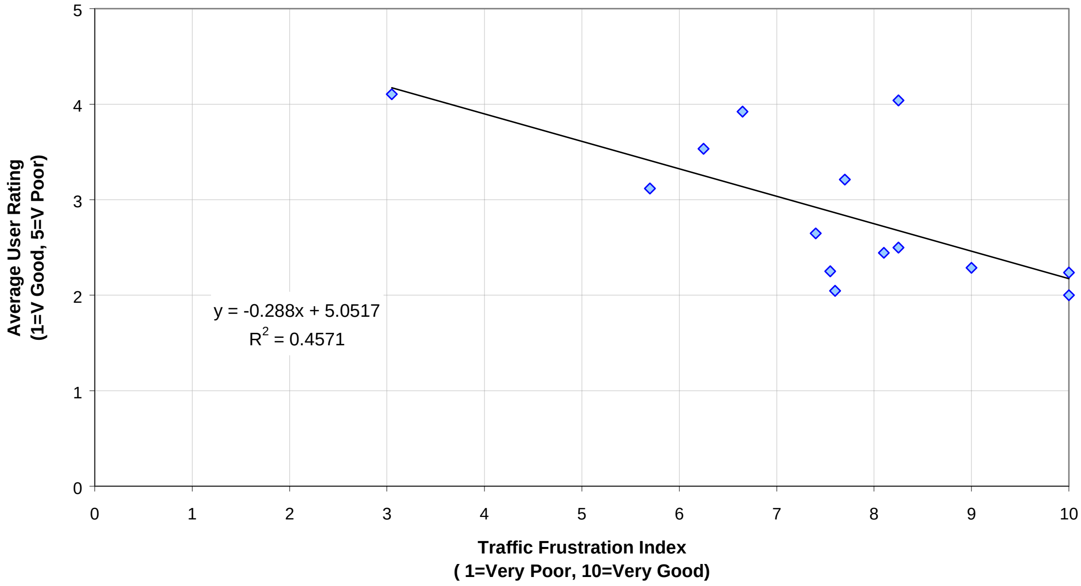


Figure 5.3 indicates a poor relationship between the TFI and average user rating during the AM peak, with a correlation coefficient of only - 0.38. However, the correlation coefficient between the two variables in the midday period is - 0.81 Figure 5.4), and - 0.67 in the PM peak(Figure 5.5). Thus, there is a significant variation in the strength of the relationship across the day.

During the AM peak *(Figure 5.3)*, all user ratings fall within the 'Poor' to 'Acceptable' range. No trips achieved a rating of Good or Very Good despite TFI scores ranging up to 10. *Figure 5.4* shows that during the midday period, users considered trips to be of a slightly higher quality with ratings ranging up to 1.5 or 'Good'. However, the TFI tended to overrate the quality of the trips. Where the TFI rated a trip in the 'Very Good' range, the user only rated it as 'Good'. During the PM peak *(Figure 5.5)*, the relationship between TFI and user rating was slightly weaker than during the midday period but stronger than during the am peak. A TFI rating of 10 yielded a rating of 2 or 'Good' by the user. In the PM peak, a trip required a TFI score of at least 7.5 to be considered 'Acceptable' by the user.

5.3 Discussion

There is a significantly large proportion of trips with high TFI values which suggests that on the days surveyed, flow along all routes was of a fairly high standard. It is important to note that the validation surveys were conducted during school holidays. Three large schools are located within the survey area: Xavier College, Methodist Ladies College and Carey Baptist Grammar. The absence of traffic generated by these schools may explain the high standard of traffic flow captured by the TFI model and the poor relationship of these TFI scores to the ratings provided by regular users of the roads.

The tendency for the TFI to overrate the quality of the trips relative to user ratings suggests that overall, trip quality improved during school holidays, and this may explain, at least in part, the relatively poor correlation between TFI and user ratings.

While the TFI scores calculated correspond to specific trips at specific times of the day, it seems reasonable to regard the user ratings as general impressions of the quality of travel over specified periods in the day, gained from several repetitions of the journey under "normal' conditions

Due to the general hours of operation, schools are most likely to affect traffic in the am peak and in the late afternoon, and to have less impact during the middle of the day. During the period in which measurements were taken, it therefore seems likely that travel flow conditions were better than normal, but the VicRoads staff judgements were based on an impression of traffic flow which was averaged over normal weekday conditions. This may explain the weakness of the relationship between TFI and user ratings for trips made in the am peak *(Figure 5.3)* and pm peak *(Figure 5.4),* and the relatively high correlation between TFI and ratings in the middle of the day (*Figure 5.5).*

It also seems likely that school traffic affects certain routes more than others, and that there may be considerable variation in traffic conditions within the time periods specified (ie AM peak, midday, PM peak), even from one half hour to the next. However, it was beyond the scope of the study to explore the effects of school traffic any further.

Another complicating factor is that drivers may have different expectations in regard to travel quality in peak and off peak periods, despite the clear labelling and anchoring of the rating scales. What might be rated as ‘Good’ in the AM peak may be rated as ‘Poor’ in a midday period. Essentially, the traffic conditions under which the validation trips were made did not adequately match those of the trips rated by users.

6. Comparison of Index Scores with other parameters

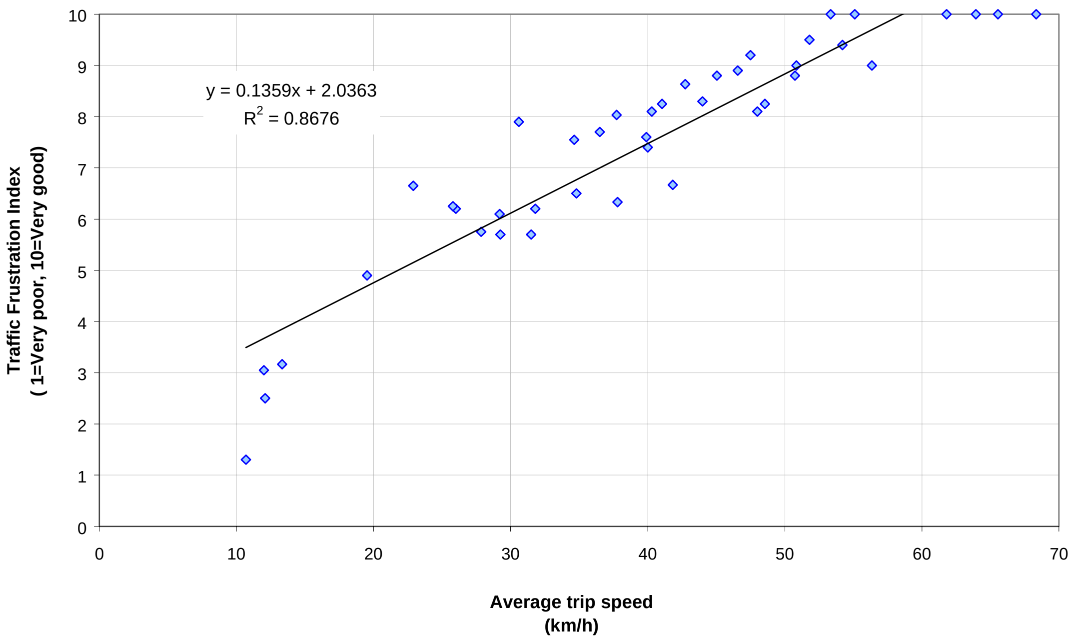
6.1 Purpose

The level of detail required by the TFI model and the concept of modelling driver frustration far exceeds most existing travel quality models which are based on simple trip parameters such as average travel speed. By testing the relationship of the TFI to these basic trip parameters, it becomes apparent whether or not the Frustration Index provides a more discerning classification of travel quality than these simpler models.

6.2 TFI vs Average trip speed

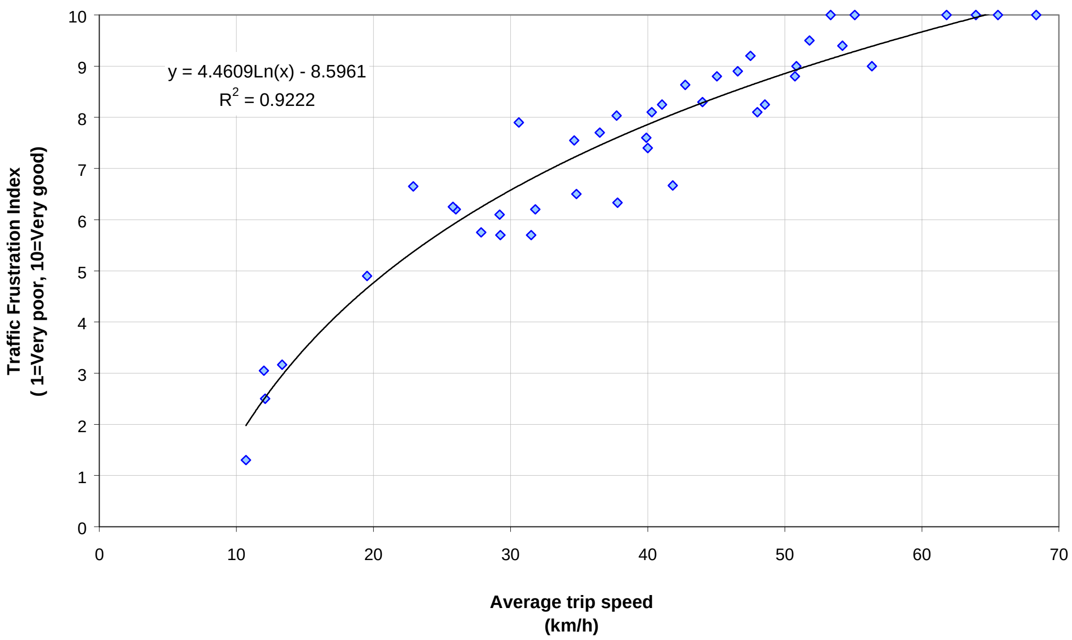
There is a strong positive correlation of 0.93 between TFI and average trip speed. As trip speed increases, TFI also increases, reaching its maximum of 10 at speeds of 60 km/h and greater *(see Figure 6.1(a))*. The strength of the relationship as indicated by the linear trendline suggests that a level of service based on driver frustration could also be based on average trip speed alone.

Figure 6.1(a) - TFI vs Average travel speed (modelled by linear trendline)



The relationship between TFI and average trip speed is modelled more closely by a logarithmic trendline as seen in *Figure 6.1(b).*

Figure 6.1 (b) — TFI vs Average travel speed (modelled by logarithmic trendline)



It is a debateable point whether drivers in general have expectations primarily about average travel speed from moment to moment, or about the length of time a trip of a given length will take. The data in Figures 6.1 (a) and 6.1(b) have been replotted in Figures 6.1 (c) and 6.1 (d) respectively against minutes per kilometre travelled rather than speed to explore whether produces a better fit to the data.

Figure 6.1(c) — TFI vs Average travel speed (modelled by linear **trendline)**

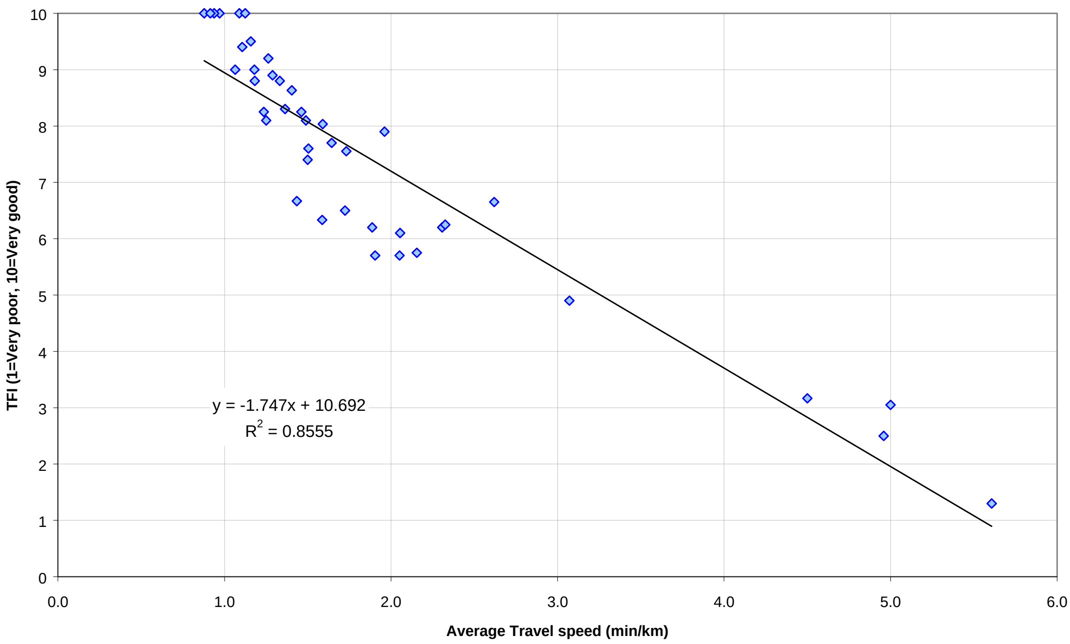
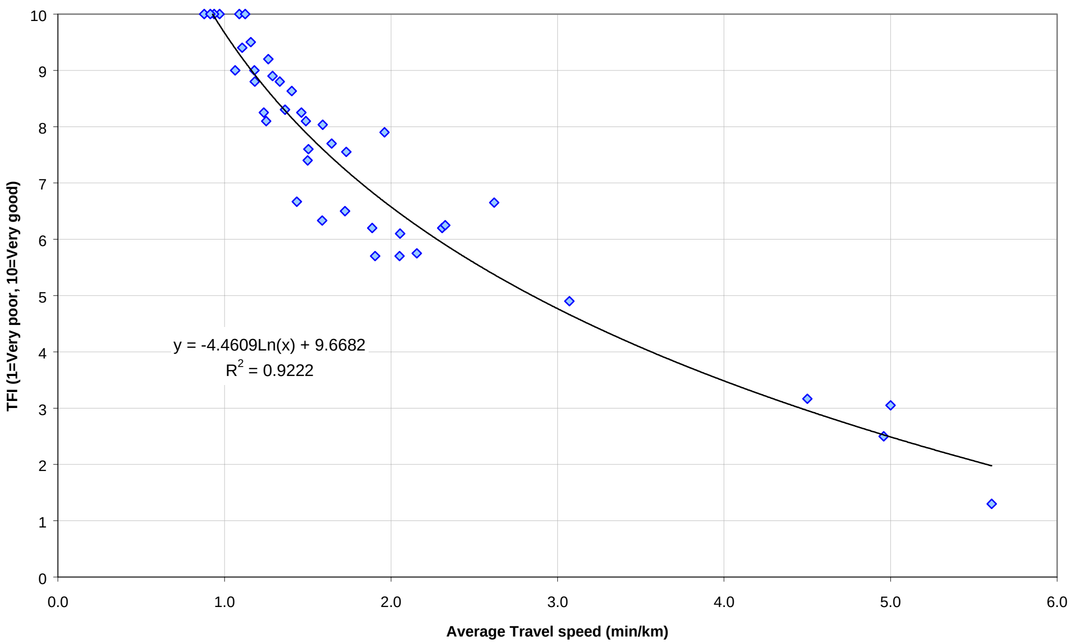


Figure 6.1(d) — TFI vs Average travel speed (modelled by logarithmic trendline)

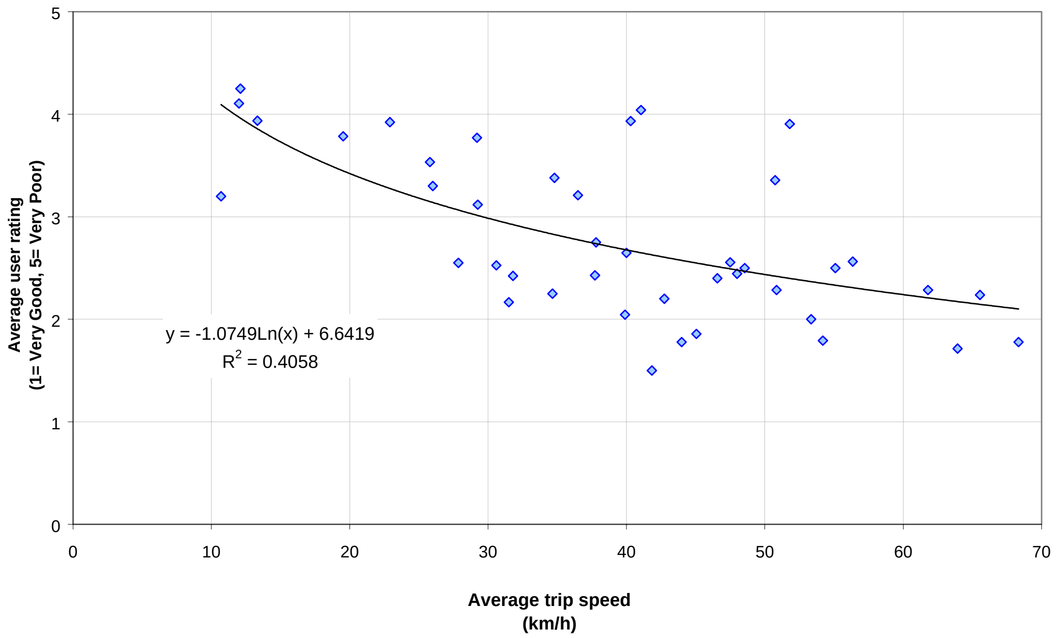


Inspection of the graphs and r-square values indicates that there is little difference in the goodness of fit. It should however be noted that one effect of plotting TFI against minutes per kilometre travel is to concentrate results into the 1.0 to 2.0 minutes category, equivalent to 60-30 km/h. Thus although plotting TFI against minutes per kilometre travel may accord more closely with some drivers' perceptions of the situation, it does not produce better agreement between the speed measure and TFI.

6.3 Average user ratings vs trip speed

The correlation coefficient of the relationship between average travel speed and user rating is - 0.63. It is not as strong as the relationship between TFI and average speed, and was not substantially improved by fitting a curve in place of a straight line (*see Figure 6.2).*

Figure 6.2 — User rating vs average trip speed



6.4 Relationships between levels of service

A comparison of levels of service based on TFI values (see *Table 2.3*) and average user ratings is shown in *Figure 6.3*. Similarly, a comparison of levels of service based on average travel speeds (see *Table 2.4*) and average user ratings is shown in *Figure 6. 4)*. These figures confirm the findings in *Section 5* based on direct comparison of TFI values and average travel speeds with average user ratings.

Figure 6.3 — Level of Service based on TFI vs average user rating

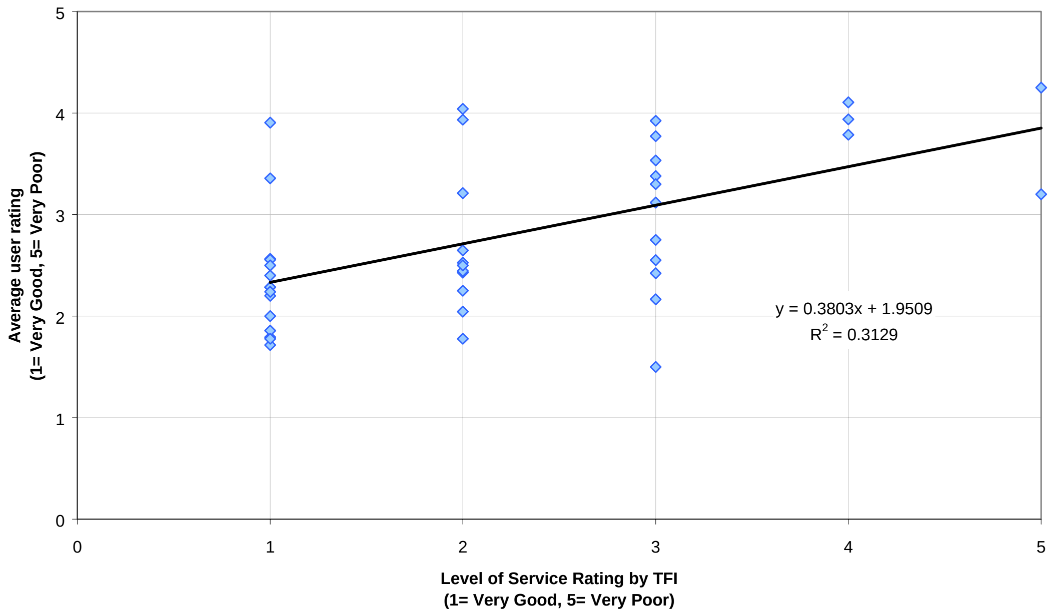
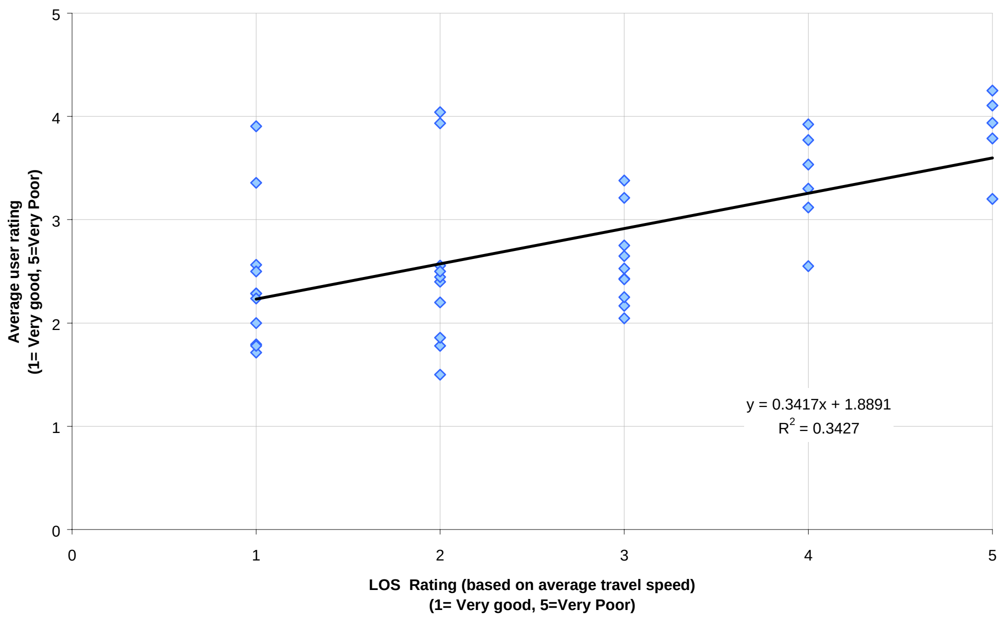


Figure 6.4 - Level of Service based on average travel speed vs average user rating



6.5 Discussion

The close correlation of TFI to speed raises a critical issue for the future of the TFI, and that is, if the TFI is so closely related to average travel speed, is it worth persisting with the development of an index if it can be predicted satisfactorily by a parameter which is much simpler to measure?

Although the argument for relying solely on speed as a measure of user satisfaction is appealing on grounds of simplicity, there are reasons for being cautious about reverting to such a simple measure.

First, as the laboratory study of driver frustration ratings showed, it is not delay or travel speed itself which is annoying so much as unexpected interruptions to travel flow (Cairney and Gunatillake 1999). However, conditions which result in high average travel speeds tend to be associated with few unexpected interruptions to traffic flow, and conditions which result in low traffic speeds are associated with many such interruptions. While getting rid of unexpected reductions in travel flow should always result in higher speeds, not all actions which increase travel speeds are aimed at reducing these events. For example, reducing the time stopped at traffic signals will increase trip speed but, as the laboratory experiment demonstrated, is likely to have little effect on user frustration.

Second, it should be borne in mind that traffic speed does not predict user satisfaction ratings any better than does the TFI. The relationship shown in *Figure 6.2* suggests a correlation of - 0.63, which is better than the correlation between user ratings and TFI taken as a whole (- 0.56, *see Figure 5.1*), but considerably less than the correlation between user ratings and TFI for ratings collected in the middle of the day (- 0.81), the ratings thought to be least affected by changes in traffic flow due to school holidays.

Thus, both traffic speed and TFI miss some elements of whatever it is that determines user satisfaction. As pointed out in *Section 5*, there are some concerns regarding the TFI measurements due to the collection of data during a school holiday period. This may have resulted in high TFI scores, while the ratings with which they were compared were based on a memory of trips made under normal (ie more highly congested) conditions. This argument applies to the correlation of user ratings both with TFI and with speed.

It must be recognised that any index which is used must be practical, ie the data must be readily measurable, must be intuitively obvious, and must not require complex calculation procedures. While it is recognised that it is extremely difficult and complex to develop measures which incorporate user assessments of conditions in this way, there are risks in developing abstract models which are not calibrated against road user perceptions of the system's performance. Those risks are principally that the abstract model will focus on the wrong parameters and that consequently investments will be made in improvements to the road system which do not result in any perceived difference to the performance of the traffic system.

If the approach of developing a TFI along the lines suggested in the present paper is deemed worthwhile, there would seem to be three research issues which would be worth pursuing. these are:

1. Other road features, such as divided roads and roundabouts. This would require further laboratory studies similar to the one described in RC7111/2 to determine basic reactions to these situations.

2. Other road users and other driving environments, for example investigating response to traffic conditions in Metropolitan CBDs, outer suburbs, and provincial centres using representatives from the appropriate driving population.

3. The relationship between TFI and road crashes. In one sense, this might not be particularly helpful as high TFI scores and high crash numbers are likely to be correlated, and found on congested part of the network, in much the way that TFI and speed are related, so that there may be no causal link. On the other hand, perhaps particular crash patterns could be indicative of high TFI scores, so that routine crash recording could be used as a diagnostic tool. This approach might be particularly beneficial in terms of combining the benefits of reduced TFI with crash reduction benefits. In this way it may be possible to justify some remedial actions which would yield insufficiently high benefit cost ratios if only TFI reductions or crash reductions were considered in isolation.

7. Findings and conclusions

7.1 Findings

In summary, the following are the main findings of this part of the study.

(i) The Traffic Flow Index provided a clear differentiation between the different routes used in the study.

(ii) Differentiation by time of day was less clear. This may have been due to taking measurements during school holidays, which possibly resulted in less traffic in peak times than would normally occur.

(iii) There was a moderately good correlation between user ratings of how well the roads performed and TFI, with a correlation of - 0.56.

(iv) This correlation was higher for less frequent users than for frequent users (- 0.63 compared with - 0.47).

(v) The correlation was also higher for travel during the day than for travel at peak times (- 0.81 compared with 0.38 for morning peak and 0.68 for evening peak).

(vi) The fact that the traffic measurements were taken during a school holiday period may explain the relatively low correlations between TFI and user ratings especially in the morning peak. School holidays would tend to result in lower traffic flows (hence better TFIs) than normal, while the road users may have been basing their judgements on a memory of average weekday conditions acquired over a long period of time.

(vii) There was a very close correlation between travel speed and TFI (0.96).

(viii) The correlation between travel speed and user ratings was only slightly higher than the correlation between user ratings and TFI, and less than the correlation between these two variables for travel during the day.

7.2 Conclusions

Based on the earlier parts of the study as well as the work reported in the present document, the main conclusions are:

(i) The process of developing the TFI, particularly the rating study, indicated the consistency of reactions across a broad cross-section of drivers to different traffic situations. Although there were differences between the groups in the intensity of their frustration ratings, there was strong agreement about which events caused frustration and the point at which the situation started to become frustrating. This approach could be used in assessments of future traffic management initiatives in the future.

(ii) The investigation aimed to discover whether it was worth qualifying traffic speed as a measure of traffic performance by developing a method for quantifying events which frustrate drivers.

Although it was demonstrated that different types of events have different impacts on driver frustration, the aggregate of these events correlates closely with travel speed and appears to little if anything to the prediction of driver satisfaction. In view of this, it is difficult to justify the additional expense and complication of collecting travel time information.

(iii) The TFI does however provide a mechanism to calibrate travel speed in terms of user satisfaction in a manner which does not simple depend on the arbitrary allocation of different satisfaction values to different speeds. This has been calibrated for undivided urban roads in the present investigation. It may be worth establishing similar values for other classes of road as part of future work.

(iv) Further work is required to test the validity and usefulness of the TFI. This includes comparison with data collected out of school holidays, and a desk exercise to estimate the impact of various traffic engineering measures on TFI and average speed.

(v) Further development of the model could include its extension to divided roads and the inclusion of roundabouts, to other driving environments and their driver populations, and to the relationship between TFI and crash occurrence.

(vi) Any index which is adopted must be practical, ie the data must be readily measurable, must be intuitively obvious, and must not require complex calculation procedures.

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Appendix

An example of the application of the TFI model

As an example for the application of the procedure to determine TFI and LOS, *Figures A.1 and A.2* present the input data and analysis results for the trip used in the frustration rating study (Cairney and Gunatillake 1999). In the study, speeds were recorded frequently, and travel distances were calculated using *Equation (2.20)* for each section for which recorded speeds were available (i.e. this is more detailed than using the initial and final speeds for each uneventful travel segment).

The Traffic Frustration Index value for this example is TFI = 3.9 and the corresponding LOS is "Poor" (*see Table 2.3*). The average travel speed is calculated as v_t = 19.2 km/h, and the level of service on this basis is determined as "Very Poor" (*see Table 2.4*).

To show the sensitivity of the TFI and LOS values to the total travel distance, the uneventful travel distance for the trip shown in *Figures A.1 and A.2* is increased from L_b = 5.20 km to L_b = 15.2 km, i.e. adding 10 km of uneventful travel. As a result, the total travel distance is increased to L_t = 22.53 km. The uneventful travel time is increased from t_b = 507 s to t_b = 1482 so that the average travel speed for uneventful travel is kept constant, v_b = 36.9 km/h. These changes result in LOS = "Acceptable" (instead of "Poor") corresponding to TFI = 5.3 (instead of 3.9). The average travel speed is increased from v_t = 19.2 km/h to v_t = 24.4 km/h and the level of service on this basis becomes "Poor" (instead of "Very Poor").

Figure A.1(a) - An example of INPUT DATA for determining the Traffic Frustration Index and level of service for the trip used in driver frustration survey (section 1)

INPUT

Road class		Divided road
Speed limit (km/h)	v_f =	60
Total travel distance (km)	L_t =	12.527

Event	Event type	Duration	Uneventful travel distance	Uneventful travel time	Frustration rating	Frustration impact
	(0 to 9)	T_i (s)	(m)	(s)	R_i	$R_i T_i$
Slow travel	2	8			0.96	7.7
Slow travel	2	18			0.98	17.7
Uneventful travel	0	23	217.2	23	0.79	18.2
Other events	9	13			1.01	13.1
Uneventful travel	0	21	245.0	21	0.79	16.6
Stops at signals	1	108			1.02	109.8
Uneventful travel	0	27	292.5	27	0.79	21.3
Stops at signals	1	1			0.79	0.8
Uneventful travel	0	44	488.9	44	0.79	34.8
Other events	9	12			1.01	12.1
Stops at signals	1	4			0.80	3.2
Uneventful travel	0	30	300.0	30	0.79	23.7
Other events	9	12			1.01	12.1
Stops at signals	1	26			0.84	22.0
Slow travel	2	15			0.98	14.6
Stops at signals	1	7			0.80	5.6
Uneventful travel	0	27	292.5	27	0.79	21.3
Slow travel	2	63			1.06	66.6
Uneventful travel	0	16	168.9	16	0.79	12.6
Other events	9	6			1.01	6.1
Uneventful travel	0	28	342.2	28	0.79	22.1
Slow travel	2	29			1.00	29.0
Uneventful travel	0	20	244.4	20	0.79	15.8
Other events	9	5			1.01	5.1
Forced lane change	3	4			0.90	3.6
Uneventful travel	0	21	256.7	21	0.79	16.6
Other events	9	14			1.01	14.1
Forced lane change	3	4			0.90	3.6
Uneventful travel	0	14	128.3	14	0.79	11.1
Stops at signals	1	34			0.86	29.3
Slow travel	2	12			0.97	11.6
Other events	9	7			1.01	7.1
Slow travel	2	12			0.97	11.6
Stops at signals	1	10			0.81	8.1
Slow travel	2	21			0.99	20.7
Other events	9	4			1.01	4.0
Uneventful travel	0	29	249.7	29	0.79	22.9
Stops at signals	1	63			0.92	58.1
Uneventful travel	0	16	177.8	16	0.79	12.6
Forced lane change	3	4			0.90	3.6

Figure A.1(b) — An example of INPUT DATA for determining the Traffic Frustration Index and level of service for the trip used in driver frustration survey (section 2)

Slow travel	2	30			1.00	30.0
Slow travel	2	15			0.98	14.6
Slow travel	2	17			0.98	16.6
Slow travel	2	290			1.44	418.5
Other events	9	1			1.01	1.0
Slow travel	2	12			1.14	130.4
Forced lane change	3	17			1.27	21.6
Uneventful travel	0	24	240.0	24	0.79	19.0
Stops at signals	1	75			0.95	71.1
Other events	9	5			1.01	5.1
Uneventful travel	0	23	217.2	23	0.79	18.2
Forced lane change	3	23			1.44	33.1
Uneventful travel	0	38	337.8	38	0.79	30.0
Slow travel	2	114			1.14	130.4
Slow travel	2	27			1.00	26.9
Uneventful travel	0	39	325.0	39	0.79	30.8
Other events	9	8			1.01	8.1
Stops at signals	1	48			0.89	42.8
Uneventful travel	0	18	165.0	18	0.79	14.2
Other events	9	7			1.01	7.1
Uneventful travel	0	18	185.0	18	0.79	14.2
Forced lane change	3	5			0.93	4.7
Stops at signals	1	76			0.95	72.2
Slow travel	2	29			1.00	29.0
Stops at signals	1	68			0.93	63.4
Forced lane change	3	9			1.04	9.4
Slow travel	2	128			1.17	149.5
Stops at signals	1	60			0.92	55.0
Slow travel	2	27			1.00	26.9
Forced lane change	3	16			1.24	19.9
Uneventful travel	0	31	327.2	31	0.79	24.5
Stops at signals	1	10			0.81	8.1
Slow travel	2	29			1.00	29.0
Stops at signals	1	67			0.93	62.4
Slow travel	2	14			0.97	13.6
Other events	9	6			1.01	6.1
Slow travel	2	20			0.98	19.7
Other events	9	4			1.01	4.0
Other events	9	1			1.01	1.0
Other events	9	11			1.01	11.1
Slow travel	2	18			0.98	17.7
Forced lane change	3	7			0.99	6.9
Other events	9	1			1.01	1.0
Slow travel	2	22			0.99	21.7
Other events	9	7			1.01	7.1
	Total =	**2347**	**5201**	**507**		**2497.8**

Figure A.2 — Traffic Frustration Index and level of service determined for the trip used in driver frustration survey: ANALYSIS RESULTS

ANALYSIS RESULTS

Traffic Frustration Index (TFI): 10 = best, 0 = worst	3.9	
Level of service based on TFI	Poor	
Level of service based on average speed (v_t)	Very Poor	
Total travel distance (km)	L_t =	12.53
Total distance for uneventful travel (km)	L_b =	5.20
Total time for uneventful travel (s)	T_b =	507
Average speed for uneventful travel (km/h)	v_b =	36.9
Travel time per unit dist. for uneventful travel (s/km)	t_b =	97.5
Total travel time for the trip (s)	T_t =	2347
Average speed for the total trip (km/h)	v_t =	19.2
Frustration rating for uneventful travel	R_b =	0.79
Frustration impact rate for uneventful travel	R_{bT} =	77.0
Total frustration impact for event types 0 to 9	*sum* $(R_i T_i)$ =	2497.8
Total travel distance for event types 1 to 9 (km)	$L_t - L_b$ =	7.33
Frustration impact rate for the total trip	R_T =	199.4
Frustration impact ratio	p_R =	0.39
Upper limit of frustration impact ratio	p_U =	1.00
Lower limit of frustration impact ratio	p_L =	0.00
Free-flow speed (s/km)	v_f =	60.0
Free-flow travel time per unit distance (s/km)	t_f =	60.0

INFORMATION RETRIEVAL

Austroads (2000), **Traffic Management Performance – Development of a Traffic Frustration Index**, Sydney A4, 116pp, AP-160/00

KEYWORDS:

Driver frustration, Traffic Frustration Index, travel quality, speed, satisfaction, user ratings, flow.

ABSTRACT:

This report examines whether a Traffic Frustration Index, which quantifies the events which contribute to driver frustration, would be a useful supplement to measures such as traffic speed and flow in identifying priorities for traffic management interventions and assessing the outcomes of such interventions.

The report, covering the four stages of the project, documents the results of a literature review, a laboratory experiment to quantify situations which drivers regard as frustrating, the development of a Traffic Frustration Index model of different types of frustrating events and an evaluation of the model through its application to a number of traffic routes.

The project determined that there was a very close correlation between the Traffic Frustration Index and travel speed and good correlation between user ratings on how well certain roads performed and the Traffic Frustration Index.

Although it was demonstrated that different types of traffic events have different impacts on driver frustration, the aggregate of these events correlates closely with traffic speed and adds little to the prediction of overall driver satisfaction.