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## Travel Behaviour under Fuel Constraint Study: TACA SIM

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### ABSTRACT:

Future oil availability and cost has been discussed recently in international agency and government reports. Transportation is the fastest-growing and largest user of oil. Future personal transportation will continue to be fuelled by oil. However, as the oil price rises the transport systems will be affected. Alternative energy sources (such as solar, wind, biofuel) are not available to economically replace traditional fossil fuels. Travel demand management (TDM) is a key approach to transport and land use planning. It provides a feasible solution to the problems relating to uncertainty of fuel supply, and offers many alternative ways of mitigating environmental problems. However, integration of TDM to transport planning requires understanding of people's travel behaviour. We propose a game-based survey tool, Travel Activity Constraint Adaptation Simulation (TACA Sim<sup>®</sup>) that simulates a situation with high fuel prices and captures the data of "normal" travel behaviour and behaviour changes. The tool additionally provides feedback information based on the concept that all human beings have the responsibility to inform themselves and evaluate their past and current actions for future planning. TACA Sim collects not only travel behaviour data, but also provides the travel behaviour information and adaptation risk for self-evaluation in order to help individuals realise sustainable lifestyles.

**KEYWORDS:** High price; Travel behaviour; Travel adaptability; Transport survey; Demand response

### 1. INTRODUCTION

Growing uncertainty in fuel supply is a concern for governments, and other stakeholders. An uncertain future supply would bring about high fuel prices<sup>1</sup>. The issue has been discussed recently in several international government reports as it has many impacts on all sectors of the economy. Several reports have shown that large amounts of petroleum are consumed by transportation [1,2,3]. A rising oil demand reflects increasing transport demand, especially road transport. For example, a recent New Zealand travel survey [4] indicates that kilometres travelled by cars, vans, utility vehicles (utes), and SUVs has increased by approximately 2% per year since 1990 while *New Zealand's Energy Outlook to 2030* [2] reported an increase of energy use in transport during the same period.

Future energy demands can be reduced to only two options: increasing supply or decreasing the demand for energy, and the latter implies Demand Side Management (DSM). Considering the limited amount of the remaining fossil fuels [5,6] and the extreme long-term hazards associated with nuclear energy [7], it is clear that in the future all energy may come from renewable sources. However, renewable energy sources (such as solar, wind, biofuel) may not produce enough energy to substitute economically and environmentally for traditional fossil fuels [8,9]. The other option for meeting future demand would be through DSM. DSM was used when the energy crisis of the 1970s suggested that some of the most

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<sup>1</sup> at time of writing fuel supply and fuel price are major international issues.

convenient fossil fuel energy reserves, such as crude oil, were made scarce through the OPEC oil embargo.

Constrained supply results in high fuel prices and constrained mobility. High price is one of the factors that influences travel behaviour [10,11]. Travel adaptability normally occurs when a person's mobility is restricted or threatened with elimination [12]. In the short term, people would be expected to modify their travel behaviour by travel mode shifting, destination change, and curtailing trips to mitigate the impacts of the threat. However, travel behaviour change depends on the “*essentiality*” of the trips, and is classed by the impact on people's wellbeing

“*Essentiality*” is a new term to measure the importance of the trip to a household's wellbeing. Dantas et. al [13], classify trips into three levels of essentiality; Optional, Necessary, and Essential. Changing behaviour and losing accessibility are tied to different scales of costs and other negative effects. Therefore, the impact is divided into three levels:

- *Low impact* occurs if an optional trip is curtailed.
- *Medium impact* is generated if a necessary trip cannot be made.
- *High impact* happens if an essential trip cannot be made so that impact to the individual's wellbeing may occur.

Many new technologies such as Global Positioning Systems (GPS) and a web-based survey have been employed to obtain high feature travel demand data and have improved understanding of travel behaviour [14,15,16]. However, evidence of how high fuel price affects human travel behaviour remains obscure. Therefore, further technologies and approaches need to be focused on predicting of travel demand and adaptability.

Policy makers and transport planners increasingly need to better understand people's travel behaviour change. Providing feedback information to the travellers is an effective way to encourage greater demand savings for current and future travels. Travel Demand Management (TDM) has been introduced as an approach to achieve an efficient transport system by conducting a multiplicity of strategies that affects travel behaviour. Similar to the DSM, the TDM strategy seeks to address the transport demand side through initiatives that improve travel efficiency, influence travel behaviour and reduce the need for travel. One of the important strategies is a provision of effective information that plays a crucial role in supporting individual demand optimisation measures [17].

We propose a novel survey method that aims to understand individual normal travel behaviour and adaptability, and deliver information as feedback to the participant. TACA Sim [18] is implemented in order to quantify travel behaviour and adaptability to high fuel prices. TACA Sim does not only collect travel demand and adaptability data but also provides feedback on individual travel information that may trigger participants to consider their current travel alternatives and improve their travel patterns.

## **2. TRANSPORTATION AND DEMAND RESPONSE**

One category of TDM that can be applied in personal transport is a provision of information that would increase traveller's awareness of energy use and the impacts of peak oil and high fuel prices on individual travel activity. People's behaviour change with improved use of technologies plays a key role in energy saving. The short-term behaviour change of consumer in responding to external indicators is known as a demand response. However, the behaviour change requires a comprehensive information dissemination method that can influence individual energy use behaviour. We propose that through feedback

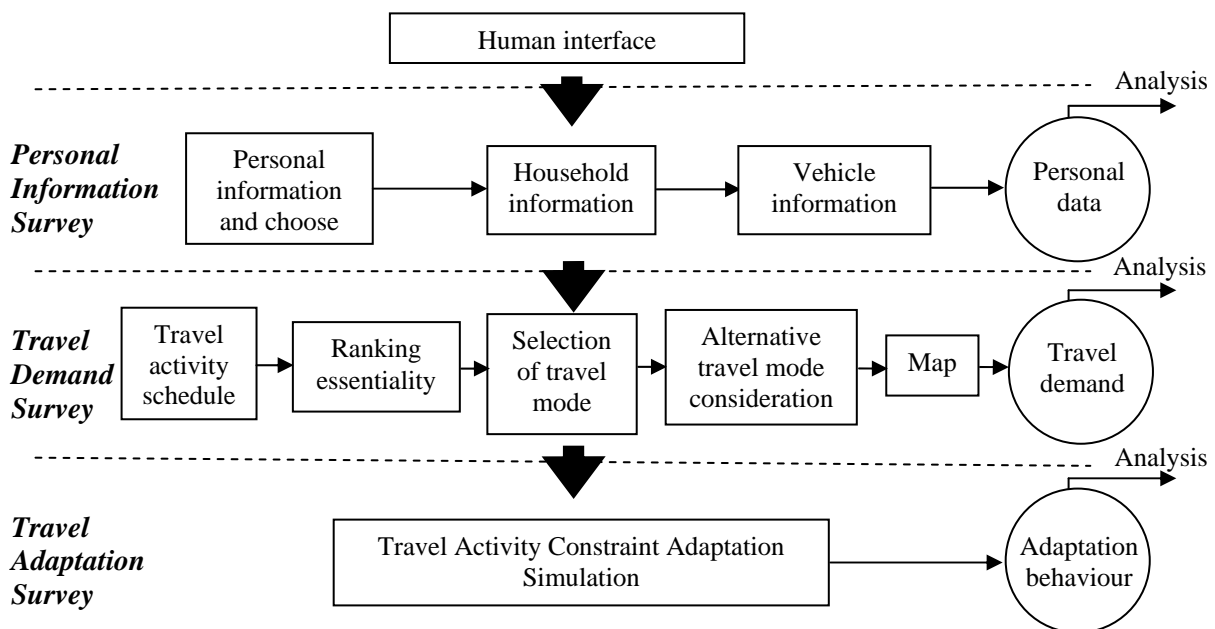
information to the participants, a short-term modification of people’s behaviour can be achieved effectively. High fuel prices may slow down the growth in personal travel. It is therefore important to provide effective information that will enhance behaviour change as an adaption strategy. As we show later in this paper, the travel behaviour of a person that participated in the trial of TACA Sim changed her travel behaviour after receiving feedback information on her daily travel activity.

### 3. TACA SIM SURVEY

TACA Sim has been designed not only for recording travel behaviour and decision-making of individual adaptability but also for providing travel information to encourage the participants consider their current travel behaviour and alternatives. It works as a conventional travel demand survey with a role-playing scheme to record a person’s travel pattern and decision on changes according to high fuel prices. Moreover, it provides feedback scenes at the end of the survey that present several scores as behaviour indicators for an individual self-evaluation.

#### 3.1. Obtaining travel demand and adaptability data

The TACA Sim helps to simplify the travel demand survey-conducting process. A personal diary-schedule activities and a familiar city map to navigate in TACA Sim capture people’s normal experiences associated with their daily travel. Questions and feedback scenes designed in TACA Sim are based on the concept that “all human beings have the responsibility to inform themselves and evaluate their past and current actions in order to plan for the future” [19]. The design of TACA Sim is divided into three survey levels: (1) Personal information survey, (2) Travel demand survey, and (3) Travel Adaptation survey as can be seen in Figure 1.



**Figure 1:** Three main levels of TACA Sim

At the first level, TACA Sim collects personal information relatively quick and in an engaging way as general role-play game by having the participant choose a virtual character and tick appropriate boxes. The second level is a simple travel demand survey, but TACA Sim engages the participant’s interest by familiar visual cues and selections. Daily travel

activities are entered into a day-planner according to the time schedule which should be more familiar to people than the normal trip purpose diary used in paper surveys. The participant fills in their activities, origin, departure and arrival time on each day as shown in Figure 2, then clicks on the mode button to continue with trip route and modal questions.

Now please fill in your travel activities on Monday.  
 (Please include "returning home" as an activity.)

	Activity	Origin	Time (24 hr)		Mode
			Depart Hour Minute	Arrive Hour Minute	
1.)	work	home	9 00	9 20	Mode
2.)	home	work	17 00	17 20	Mode
3.)					Mode
4.)					Mode
5.)					Mode
6.)					Mode
7.)					Mode
8.)					Mode

Where did you go? From where did you start your trip? What time did you leave the origin? What time did you arrive at destination? How did you get there?

Mon Tue Wed Thu Fri Sat Sun

After finish each activity, press "mode" button.

Back SAVE QUIT Same pattern as yesterday Next

**Figure 2:** Travel Activity Diary

Subsequently, the trip essentiality is measured by asking the participants to rank the impact for each of their activities if they were not able to make that trip. The travel mode is asked in this scene. If "car (vehicle driver or vehicle passenger)" is selected, the participant is asked about the details of the vehicle (e.g. engine size, make of vehicle, and type of vehicle) that is normally used and the numbers of passengers in the vehicle. The purpose of each travel activity is obtained by tick box selection. After the purpose selection, participants further indicate any alternative travel modes they may have for each activity. For example, the participant who usually travels to work by driving car might consider the public bus as an alternative. The selection of no alternatives for fuel-using trip will be counted as a travel activity risk.

The participant points and clicks on a familiar map of the city to indicate the real locations of their homes, and destinations such as work, school, shopping. Figure 3 shows a study area (Christchurch) map scene. The participant fills in the address of origin and destination. They can also move a small car icon by the mouse and follow their usual travel routes. The map will generate the travel distance automatically. When the participants complete their travel schedule for a whole week, the feedback scene of the travel demand survey will be displayed in this level.



Figure 3: Study area map scene

The third level is designed to use the full role-playing environment. The roles of the participant are to make the key decisions about their travel activities and adapt themselves to the situation of high fuel prices. The TACA Sim game integrates the simulation of three fuel-price intervals starting from the actual fuel price of \$2.04 NZD per litre (New Zealand Dollar) at the time of the survey, then increases to \$6.05 NZD in the second week, and \$10.05 NZD in the third week in order to capture the decision of the pattern change of trips. Figure 4 presents a full role-play in room scene at the adaptation survey level.



**Figure 4:** A room screen with interface panel in adaptation survey level

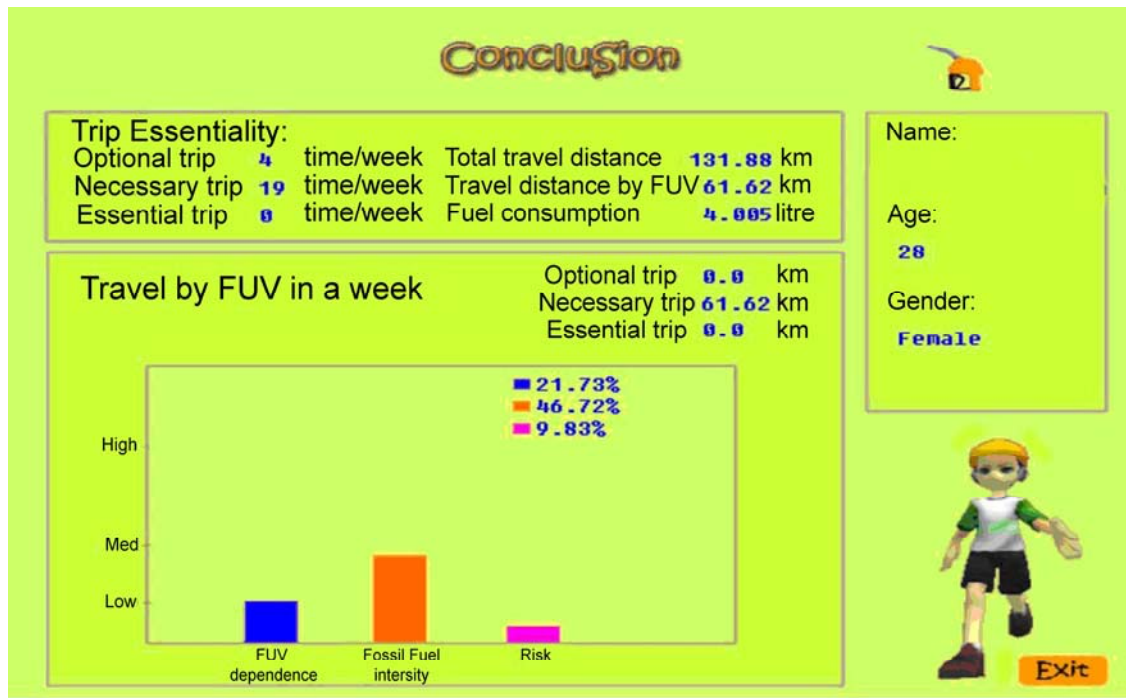
The participants are signalled to make choices on their activity participations by pop-up questions. The questions are asked on the trip purpose and their willingness to retain their normal activities. The participants are offered the options to make a decision on changing mode, changing destination, curtailing activities, and participating activity at home. Based on decision-making, the participants try to balance their travel behaviour indicators and activity participation scores displayed on the control panel. An interaction with “Telephone” provides functionality for purchasing fuel. In addition, if the participant’s car is too low on fuel to continue, the fuel-purchasing scene pops up automatically. Participants are required to play through a whole week (Monday to Sunday). At the end of the scenario, the adaptation feedback scene will be presented.

### 3.2. Providing travel information in feedback scenes

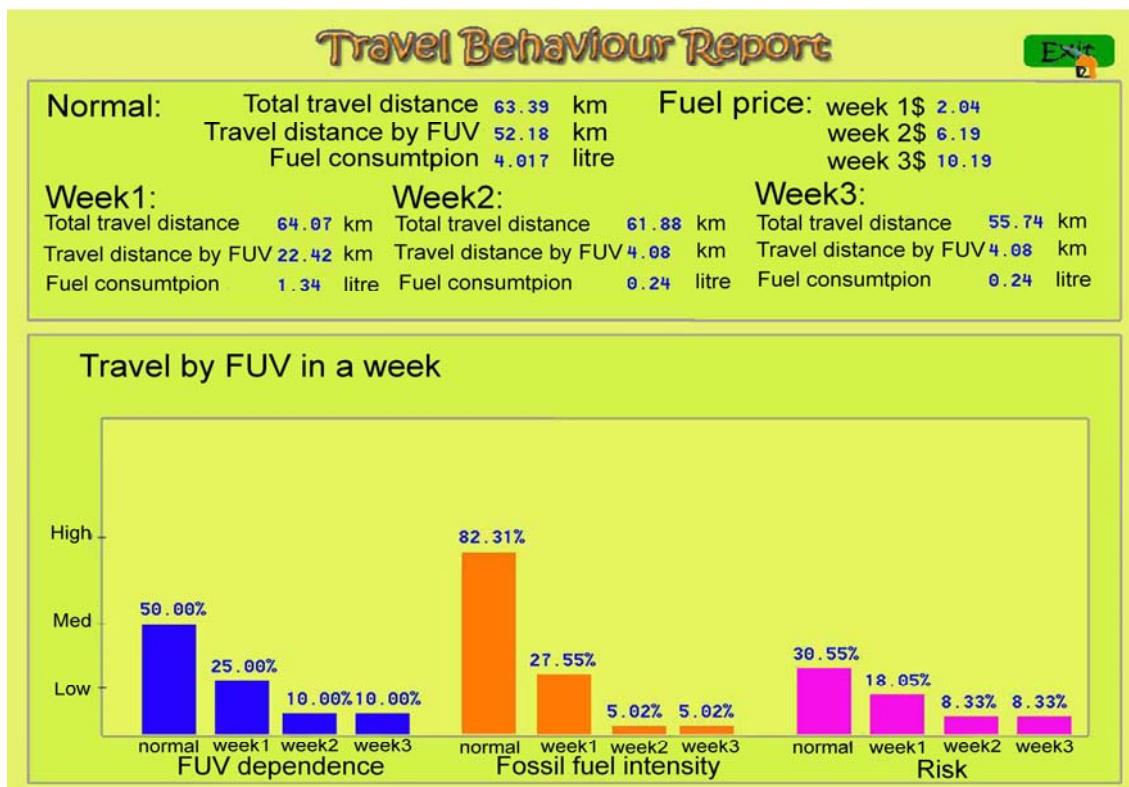
The feedback scene gives several “scores” for the person’s travel behaviour, e.g. total travel distance, distance travelled by a fuel-using vehicle (FUV), fuel consumption, numbers of optional trips, numbers of necessary trips, and numbers of essential trips in a week. The tool additionally calculates the indicators of the travel demand behaviour:

- FUV dependence
- Fossil fuel intensity (or carbon footprint)
- Adaptability risk

These measures will be correlated to the decisions of participants’ behaviour change in the last stage when high fuel prices are simulated. The feedback scenes are shown in Figure 5.



(a)



(b)

**Figure 5:** (a) An example of a feedback-scene at the end of the travel demand survey level.  
 (b) An example of a feedback-scene at the adaptation survey level.

*FUV dependence* is calculated by taking the trip numbers travelled by an FUV in a week, divided by total number of trips. For example, a person uses his bike to go 2 km to work every day for 5 days (total 20 km in a week), drives to the shops 5 km from home and



drives to play golf at a course 25 km from home on weekend. In a week, this person makes totally 14 trips (10 trips by bike and 4 trips by car). In this example, the person's FUV dependence for trips would be  $(4/14) \times 100 = 28.57\%$ .

*Fossil fuel intensity* takes into account the fuel efficiency of the modes used for weekly trips. The fossil fuel intensity is defined as the ratio of fuel use for all trips to fuel use if all the trips have been made with FUV. Obviously, if a person only rides a bike, his fuel intensity would be zero. On the other hand, if he only ever drives a car, his fuel intensity would be definitely 100 percent. The person from the example above drives a car 60 km from the total travel 80 km in a week with the fuel consumption rate 8 litres per 100 km (0.08l/km). This person would have  $(60 \times 0.08 / 80 \times 0.08) \times 100 = 75\%$  fuel intensity.

*Adaptability risk* is a measure of the trips that inevitably require fuel. In the mode selection, people were asked if they had ever taken any other mode when they chose a personal vehicle choice. A person who takes all essential trips travelled by the personal vehicle, and who has never taken any other mode has the highest risk. The adaptability risk is calculated by the percentage of numbers of alternatives deducted from numbers of FUV trips, weighted by essentiality score (1 for optional trip; 3 for necessary trip; 5 for essential trip). For example, a person conducts totally 20 trips (including return trips) in a week. Four trips are optional (total 4 points), ten trips are necessary (total 30 points), and the rests are essential (total 30 points). All trips would be totally 64 points. Out of these 20 trips, ten trips are travelled by car. Two of car trips are optional (total 2 points). Four car trips are necessary (total 12 points) and another four car trips are essential (total 20 points). Total points are 34. If this person has decided to shift two of the optional trips (total 2 points), two of the necessary trips (total 6 points), and two of the essential trips (10 points) from car to bike, the total points of alternatives are 18. Therefore, this person's risk would be  $((34-18)/64) \times 100 = 25\%$ .

## 4. RESULTS AND ANALYSIS

### 4.1. Travel demand and adaptability data

Ten participants volunteered to play TACA Sim in a trail stage, up to the point of both feedback scenes. The average time for completion of the travel demand survey level was 40 minutes, while the adaptation survey level took approximately 20 minutes. The participants included postgraduate students, academic staff, and technical staff at the University of Canterbury as well as several other people.

The travel demand data and travel behaviour indicators for an example of student participants are shown in Table 1.

**Table 1:** (a) Weekly travel demand data sample. (b) Modal split data. (c) Behaviour indicator results for the first participant trial of TACA Sim.

(a)

Occupation	Residential location	Total travel distance (km)	Travel distance by FUV (km)	Total essentiality (time/week)			Essentiality of trips by FUV (time/week)			Alternatives (time/week)		
				Opt	Nec	Ess	Opt	Nec	Ess	Opt	Nec	Ess
Student	Riccarton	77.5	61.0	1	4	12	1	3	4	1	3	4

(b)

		Mode					
FUV driver	FUV passenger	Bus	Bicycle	E-Bike	Walk	Skates	Other
0	8	0	0	0	9	0	0

(c)

Fuel consumption (litre)	FUV dependence (%)	Fuel intensity (%)	Risk (%)
3.176	47.05	78.71	0

From the Table 1(a), the Student B travelled a total of 77.5 km in a week, 61 km was travelled by car. Nine short trips (less than 2 km) were walking from home to university. The student's residential area is approximately 2 km from university which is walk-able and bike-able. The student travelled more kilometres by car than walking. This student does not own or drive a vehicle, but Table 1(c) shows her fuel intensity and FUV dependence are very high. She travelled as a car passenger and shared half of fuel intensity for all car trips. The results also show that this student will share rides only for non-work purposes, i.e., go shopping, and social. However, all trips can be shifted from car to another mode. Therefore, this student does not have any risk on her current travel pattern.

Table 2 shows the results of travel pattern changes over two weeks of fuel price rise. On the first week, TACA Sim begins with the actual fuel price (\$2.04 NZD) at the time of the survey. A professor made one optional and four necessary trips as a car driver with total distance 22.42 km. Twelve trips were travelled by bicycle and two trips by bus. When the price rose to \$6.05 per liter, the professor reduced three more of the driving car trips and started to work from home. A car trip was shifted to carpooling mode. However, the numbers of car trips remained the same in the third week when the price rose to \$10.05 per liter. Therefore, this person has 8.3% of adaptation risk at the fuel price \$6-\$10 per liter as reported in Table 2(c).

**Table 2:** Travel behaviour over three weeks (a) Travel demand data. (b) Modal split data. (c) Behaviour indicator results for a participant.

(a)

Person	Travel distance by FUV (km) as driver			Essentiality of trips by FUV (time/week) as driver								
				Week1			Week2			Week3		
	W1	W2	W3	Opt	Nec	Ess	Opt	Nec	Ess	Opt	Nec	Ess
Professor	22.42	4.08	4.08	1	4	0	0	2	0	0	2	0

(b)

Week1							Week2							Week3								
Mode						Work at home	Mode						Work at home	Mode						Work at home		
FUV driver	FUV passenger	Bus	Bicycle	Walk	Other		FUV driver	FUV passenger	Bus	Bicycle	Walk	EffCar		EffScooter	FUV driver	FUV passenger	Bus	Bicycle	Walk		EffCar	EffScooter
5	1	2	12	0	0	0	2	2	2	12	0	0	0	2	2	2	0	12	0	0	0	4

(c)

Fuel consumption (l)			FUV dependence (%)			Fuel intensity (%)			Risk (%)		
W1	W2	W3	W1	W2	W3	W1	W2	W3	W1	W2	W3
1.34	0.24	0.24	25	10	10	27.55	5.02	5.02	18.05	8.33	8.33

W1: week1, W2: week2, W3: week3

Opt: Optional trip; Nec: Necessary trip; Ess: Essential trip

EffCar: Efficient car; EffScooter: Efficient scooter

**Note:** Ride sharing and public transport are not included in fuel consumption, FUV dependence, fuel intensity and risk in this table.

## 4.2. Responses to information provided in TACA Sim

The trial participants made a decision to change or maintain their modes and activities after the feedback scene at the end of the second level was provided. They were interviewed after completing all the levels. The participants realised their current travel behaviour such as fuel consumption, FUV dependence, fossil fuel intensity and adaptability risk with some surprise from the feedback scene. For example, Student A, who has several trips for the purpose of delivering his kids to/from school thought about the alternatives to reduce his car trips after he was exposed to the simulated high fuel prices. He decided to change from car to bus when the price was approximately \$3 per litre. Student B was a car passenger for all fuel-using vehicle trips, and she did not seem to consider that her friend might decide not to drive the car, leaving her at risk.

Table 3 shows the behaviour change results according to the individual information provided in the feedback scene of a UC professor. The person had considered herself to be a “sustainable traveller” since she uses a bicycle every day to get to work. The person was quite surprised at how far she actually drove to access several recreational activities. The person continued the game in the third level and reduced the car trip. She tried to take the bus and increased bicycle trip for her activities in order to get an improved score.

**Table 3:** Travel behaviour before and after receiving information from a feedback scene (a) Travel demand data. (b) Modal split data. (c) Behaviour indicator results for a participant on trial of TACA Sim (Ride sharing is not taken into account for the indicator calculations in this table.).

(a)

Person	Travel distance by FUV (km)		Essentiality of trips by FUV (time/week)					
	Normal	W1	Normal			Week1		
			Opt	Nec	Ess	Opt	Nec	Ess
Professor	52.18	22.42	4	6	0	1	4	0

(b)

Mode													
FUV driver		FUV passenger		Bus		Bicycle		Walk		EffVeh		Work at home	
Normal	W1	Normal	W1	Normal	W1	Normal	W1	Normal	W1	Normal	W1	Normal	W1
10	5	0	1	0	2	10	12	0	0	0	0	0	2

(c)

Fuel consumption (l)		FUV dependence (%)		Fuel intensity (%)		Risk (%)	
Normal	W1	Normal	W1	Normal	W1	Normal	W1
4.017	1.34	50	25	82.31	27.55	30.55	18.05

Normal: Normal travel behaviour; W1: First week after feedback scene  
 Opt: Optional trip; Nec: Necessary trip; Ess: Essential trip  
 EffVeh: Efficient vehicle

## 5. FUTURE WORK

The TACA Sim tool will be deployed at the University of Canterbury for a random sample of participants in October 2008. The surveys will coincide with a paper travel demand survey which is done at the university every 4 years. The use of an immersive virtual reality computer game as a travel demand survey tool will be verified by comparing the paper survey results to the TACA Sim results. A further, more comprehensive study is proposed which will survey samples of university academic staff, students, and general staff. This should give information about differences in travel demand behaviour between people of different income levels who all participate in the same activity and travel using the same transport network. Because the tool is low-cost and relatively fast, we are also planning to conduct random surveys of these sample groups over the course of a year in order to track travel behaviour change as fuel prices rise. This data can be used to verify that the choices indicated in the role-playing level 3 of TACA Sim reflect real choices.

## 6. CONCLUSIONS

The feedback and information provided in TACA Sim did not aim to force people's behaviour change. It may be useful for their decisions about reducing fuel consumption. This travel demand survey method will provide more understanding about travel behaviour changes. The application of TDM would be greatly improved with better understanding. Fuel constraints have an impact on the individual's access to the activities. People will make decisions about mode change or curtailing their trips depending on the impact to their wellbeing. Travel behaviour and adaptability data are important to transport engineering and government to propose their demand management policies. TACA Sim has been carefully designed with the perspective of the participant in mind in order to obtain and assess their travel behaviour. The software is engaging, simple and fun, with a feedback score at the end. The TACA Sim has been developed with a sufficient scope to immerse participants in a situation with high fuel prices. The software then lets people evaluate their own options and choices and make decisions about what changes they will make. These changes are recorded in a database for further analysis. An early trial of the prototype software shows that the given information encourages the participants to consider their necessity of using car and the alternatives. The adaptability behaviour for travel demand will be assessed for the first time using the full range of the software platform.

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