ACTIVE TRANSPORT JOURNEY PLANNER METHODOLOGY

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ABSTRACT

This research endeavours to define and develop a methodology based on 'multi-objective linear programming' and 'multi criteria analysis', to rank all the admissible transport options from home to the university based on total disutility during the journey. It aims to assist individual traveller with multi-objective to make smart choice in route and mode selection process. The objectives in the case study were identified as personal energy expenditure, travel time, travel cost, CO_2 emission and energy resource consumption regarding sustainability concerns.

An active transport journey planner was developed in the Excel to allow user to set their constraints for most objectives and give their weightings, respectively. The recommended transport solution (the least disutility one) and ranking of other transport options along with their detailed objective-related information will be delivered in the end. Initial result shows that the developed methodology could be applied in selecting smart transport solution based on user's multi-objective preferences. In addition, transport option incorporating more cycling and walking has the higher probability to deliver as the smart solution to user if social, environmental concerns were taken into account beyond economic issues.

***Key Words**:* Active transport; Journey planner; Individual transport planning; Multi criteria analysis; Multi-objective linear programming; Sustainability

1. INTRODUCTION

1.1 Problem Statement

As in many industrialized nations, the level of physical activity among Australians is insufficient. It is demonstrated that in 2004-05, 70% of Australians aged 15 years and over were classified as sedentary or having low exercise levels. (ABS 2006) There is consistent epidemiological evidence that demonstrates the role that physical activity plays as a major modified risk factor in the reduction of mortality and morbidity from many chronic diseases. These diseases include cardiovascular disease, several cancers, Type 2 diabetes, mental health and the risk of falls and injuries in the elderly. (USHHS 1996, Stephenson *et al*.2000, Armstrong *et al*.2000)

Expert groups, focusing primarily on the outcome of all-cause mortality, have concluded that the minimum physical activity recommendation for the adult population is 30 minutes of moderately vigorous physical activity on most days of the week. (USHHS1996) In recent years the focus of physical activity research has moved away from vigorous physical activity to moderate-intensity activities such as walking or cycling for transport. This has resulted from the epidemiological evidence that regular moderate-intensity activity can provide similar health benefits as vigorous activity. (USHHS 1996, Blair *et al*. 1996, Pate *et al*. 1995) This move is reflected in the National Physical Activity Guidelines that recommend that adults accumulate, on most days, 30 mins or more of moderate-intensity physical activity that can be accumulated in bouts of approximately 10-15mins. (USHHS 1996, Pate *et al*. 1995, ADHA 1998)

Although there has been a slight increase in the use of walking, cycling or public transport over the past 10 years, in March 2006, three-quarters (75%) of adults living in capital cities travelled to their usual place of work or study using private motor vehicles as their main form of transport. (ABS 2008) As Woodcock indicted, 'fossil-fuel energy use in transport leads to many adverse effects, including climate change, physical inactivity, urban air pollution, energy insecurity, and environmental degradation…' (Woodcock, Banister, Edwards, Prentice & Roberts 2007)

The term '**active transport**' relates to '*physical activity undertaken as a means of transport. This includes travel by foot, bicycle and other non-motorized vehicles. Use of public transport is also included in the definition as it often involves some walking or cycling to pick-up and from drop-off points. Active transport does not include walking, cycling or other physical activity that is undertaken for recreation*.' (NPHP 2001) So increases in active transport are likely to have significant direct health benefits. Indirect health benefits may also accrue from reduced environmental pollution and increased community cohesion through increasing physical activity and use of public transport or by walking or cycling.

A report on the ROMANSE project, which provides real-time information, stated that the greatest potential impact on travel behaviour was the provision of "pre-trip in-home information". (Powell 1993) In many capital cities, people can use online transport planning system to acquire public transport information about timetables, services, fares and ticketing, such as 'metlink' (see metlinkmelbourne.com.au) in Melbourne. In terms of the emerging and expanding theoretical and empirical research and study in active transport area, these systems are not adequate for people's improving requirements any more. There is a need to design an improved transport planning system involving active transport options as well as advanced multi objective function for people to easily select their travelling preferences as well as involving more active transport for daily travel from home to the workplace to potentially change people's travel behaviour toward a sustainable future.

1.2 Literature Review

1.2.1 Current Functions and Limitations on Existing Journey Planner

Existing journey planners (see theaa.com or thetrainline.com) typically concentrate on one form of transport, providing information on mileage and directions, or number of stages and the time each will take. Transport Direct (see transportdirect.gov.uk), a national journey planning service, extends this across routes combining all forms of transport including bus, train, air and car. In Australia, there are also several journey planners available for users in main cities, such as 'metlink' in Melbourne (see metlinkmelbourne.com.au), '131500 Transport Infoline' in Sydney, (see 131500.info/realtime/newjourney.asp), 'TRANSLink' (see jp.transinfo.qld.gov.au) in Brisbane, 'Transperth' in Perth (see transperth.wa.gov.au), and 'Adelaide Metro' in Adelaide (see adelaidemetro.biz/planner.php). Their simple functions include providing users with transport information based on start/end location and departing/arriving time. In advanced function, user can choose their preferences for transport mode, trip and other special requirements, such as fewest changes, only use services with wheelchair accessible vehicles, etc. Although the existing journey planners provide schedule and duration information effectively, realistic transport decisions involve constraints, such as weather, safety, fitness and environmental concerns. To address the lack of constraint expression, this research extends the existing journey planner concept to allow users to choose between available routes based on their multi-objective preferences and priorities on transport concerns.

1.2.2 Methods Available to Tackle the Limitations

Decisions on the daily transport planning involve multi-objective. All multi-objective decision problems can be represented in J-dimensional space. Discrete decision problems involve a finite set of alternatives. The problem addressed in discrete evaluation methods is to judge the attractiveness of alternatives on the basis of two elements: (Janssen 1992)

1) The consequences of the alternatives in terms of the decision criteria. Consider i (i=1,2,…,I) alternatives and j (j=1,2,…, J) decision criteria. Let x_{ji} denote the effect of alternative I according to criterion j. The matrix **X** of size J*I includes all information on the performance of the alternatives.
2) The priorities assigned to the decision criteria are denoted in terms of weights w_j (j=1, 2, … , J) which are contained in the weight vector **w**.

Discrete evaluation methods differ with respect to the elements in X and w. The available methods include the Weighted Summation method, the Multiattribute Utility Model, the Ideal Point method and finally the Electre method. These methods require quantitative information on the scores of the criteria as well as on priorities. The elements of an evaluation method are the decision rule (DR), the set (X) of alternatives (x), and the set of rules (f_1, f_2, …, f_j) by which the value of each attributes is evaluated for a given alternative x. An evaluation method can be then written as: DR $\{f_1(x), f_2(x), \dots, f_j(x)\}$, ($x \varepsilon X$) (Janssen 1992) Weighted summation is a simple and often used evaluation method. An appraisal score is calculated for each alternative by first multiplying each value by its appropriate weight followed by summing of the weighted scores for all criteria.

In the past 50 years, LP has been applied extensively to industrial problems. Even though the applications are diverse, all LP problems have four properties in common. First, problems seek to maximize or minimize an objective. Second, Constraints limit the degree to which the objective can be obtained. Third, there must be alternatives available. Fourth, Mathematical relationships are linear. (Render, Stair & Hanna 2006)

In the case study, it is assumed that the traveller wants to minimize the total disutility regarding multi-objective requirements during the journey.

The objective function can be written as **Min** $\sum_{r=1}^{N}(R_r \times DU_r)$ **,** R_r stands for the route option r. if route option r is selected, R_r =1; otherwise R_r =0. r stands for the route option number, where ε

R [1,2,…,N]; R is the set of route options, and N is the total number of route options. DU_r is the total disutility in route option r.

Constraints can be expressed as $0 \leq O_{min} \leq O_r \leq O_{max}$. Where O_r is the set of objectives achieved in route option r; O_{min}, O_{max} are the minimum or maximum value of constraints for set of objectives in route option r, respectively.

All feasible transport options selected through the multi-objective linear programming could further be evaluated by multi-criteria analysis using weighted summation to rank feasible transport options based on each option's total disutility during the journey. The least total disutility transport option will be delivered as the recommended solution.

2. CASE STUDY

The case study is demonstrated according to the procedure of systems approach which is illustrated in Figure1.

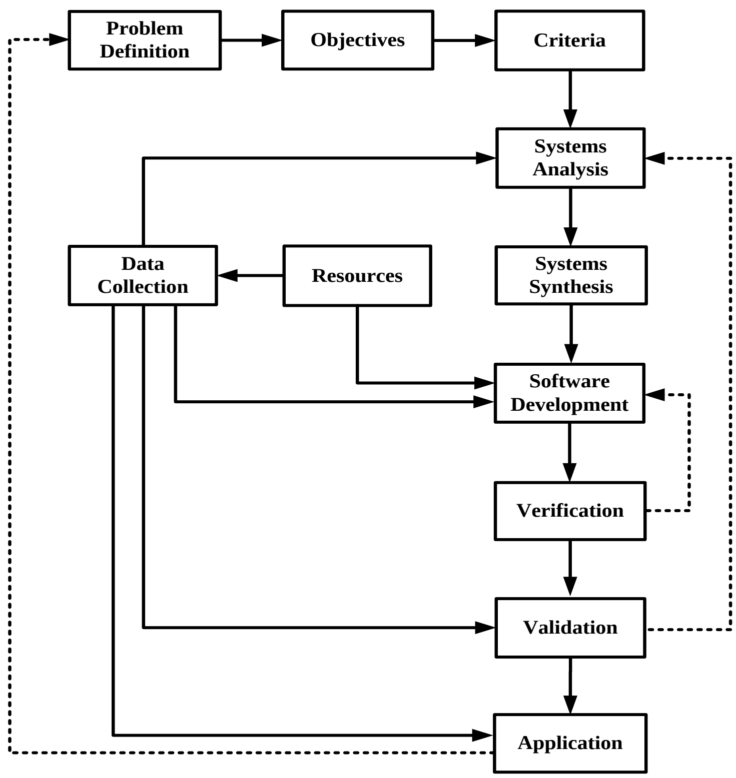


Figure1. *Systems Approach (Render, Stair & Hanna 2006)*

2.1 Aim

This case study aims to apply the methods of 'multi-objective linear programming' and 'multi-criteria analysis' to define and develop a methodology to assist individual traveller to select smart transport route and mode among admissible transport options and highlight the trade-offs among multi-objective in terms of health, economic, social and environment benefits from home to the university.

2.2 Scope

a) Geographic & temporal

Daily transport from a residence home (296 Hope Street, Brunswick West, VIC, 3055) arriving at workplace (University of Melbourne Gate 10, Grattan Street) no later than 9 am.

b) Organizational

6 reasonable travel routes which consist of active transport option and hybrid travel modes. And 7 available modes include train, tram, bus, car, motorcycle, bicycle and walk which can adequately represent the reality.

c) Functional

Select and rank all feasible transport options and highlight the best one in terms of multi-objective based on user's preferences.

2.3 Problem Definition

Rank the reasonable travel options from home to the university involving active transport solution and highlight the best one in terms of multi-objective including personal energy expenditure, travel time, travel cost, CO_2 emission and energy resource consumption based on user's preferences.

Hypothesis:

- All the travel modes (train, tram, bus, car, motorcycle, bicycle & walk) are available for selected travel routes at all times before 9am.
- No waiting time to, from and during the travel.
- No correlations among multi-objectives.

2.4 Objectives and Criteria

There are five objectives in this case study including personal energy expenditure, travel time, travel cost, CO_2 emission and energy resource consumption associated with social, health, economic and environmental benefits. Normally, for these objectives, their corresponding criteria are presented in table1.

Table1. *Objectives and corresponding criteria in case study*

Sustainability	**Objective**	**Criteria (Unit)**
Social(Health)	Personal Energy Expenditure	kJ
Economic	Travel Time	hr
	Travel Cost	$
Environmental	CO_2 Emission	g
	Energy Resource Consumption	MJ

2.5 Systems Analysis and Synthesis

Research methods applied in the case study include:

- Multi-objective linear programming
- Multi Criteria Analysis: Weighted Summation

There are five steps in the multi-criteria analysis which is illustrated in Figure2:

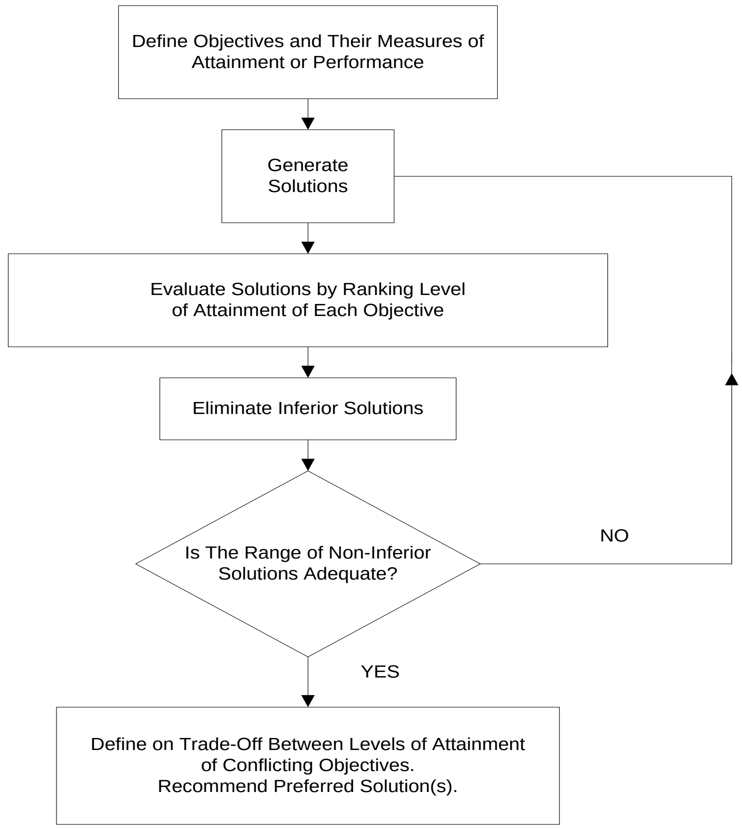


Figure2. *Basic Steps in Multi-objective Planning (O'Brien, Thornley & Atkins 1976)*

In this case study, journey planner evaluates and ranks alternatives based on each option's total disutility. In disutility analysis a function is assessed for each criterion separately in terms of each specific characteristic. As presented in Table2, personal energy expenditure is in inverse proportion to disutility, which means the less energy you spent during the journey, the more disutility it incurs. Whereas, the other four objectives, travel time, travel cost, CO_2 Emission and energy resource consumption, are in direct proportion to disutility, which means the less travel time it take, the less disutility it leads and so on. Meanwhile, the value of each criterion can be generated from the objective-related parameter based on distance. As shown in Table2.

Table2. *Relationship of objective and disutility, Generation of value for each criterion*

Sustainability	**Objective**	**Disutility (DU)**	**Criteria (Unit)**
Social(Health)	Personal Energy Expenditure (EE)	Inverse proportion (i.e.$EE\downarrow \rightarrow DU_{EE}\uparrow$)	kJ = kJ/person/km * km
Economic	Travel Time (TT)	Direct proportion (i.e.$TT\downarrow \rightarrow DU_{TT}\downarrow$)	hr =hr/person/km * km
	Travel Cost (TC)	Direct proportion (i.e.$TC\downarrow \rightarrow DU_{TC}\downarrow$)	$ =$/person/km * km
Environmental	CO_2 Emission (CE)	Direct proportion (i.e. $CE\downarrow \rightarrow DU_{CE}\downarrow$)	g =g/person/km * km
	Energy Resource Consumption (EC)	Direct proportion (i.e.$EC\downarrow \rightarrow DU_{EC}\downarrow$)	MJ =MJ/person/km * km

2.6 Resources and Data Collection

2.6.1 Generate Solutions

Based on the investigation of the public transport information and consultation of the traveller within the scope of case study, six transport solutions involving active transport options are generated. The corresponding transport modes for each route are presented in Figure3 according to their sequence during the journey from home to the university.

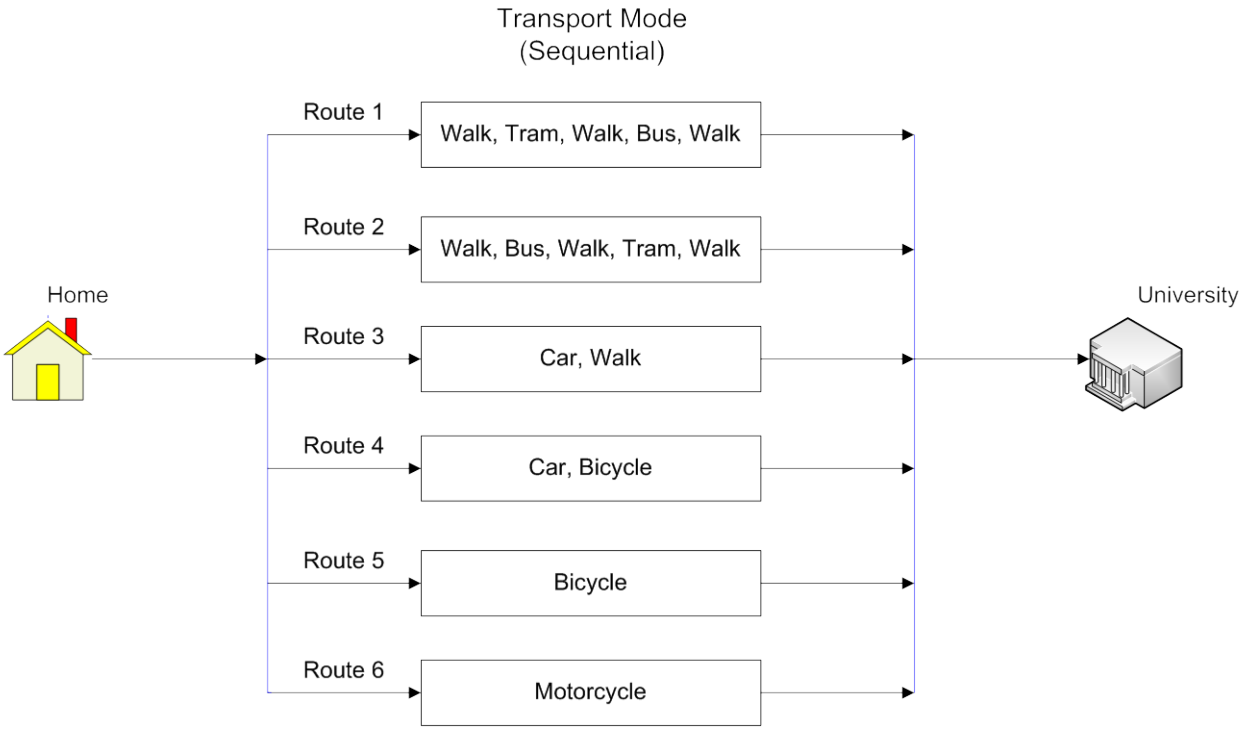


Figure3. *Generated route and mode options from home to the university*

2.6.2 Generate Variables

Travelled distance (unit: km) by each transport mode m in route option r is indicated as $X_{m,r}$, which is the key variable in the multi-objective linear programming objective function. It means the travel distance by travel mode m in route option r. For each transport route, the distance travelled by each mode is generated in table 3.

Table3. *Transport distance allocated to each mode for each route*

<table>
<tr><th>Route</th><th>Start</th><th colspan="5">Trip Description</th><th>End</th></tr>
<tr><td>1</td><td rowspan="6">Home</td><td>Walk(0.28km)</td><td>Tram (4.8km)</td><td>Walk(0.28km)</td><td>Bus(1.25km)</td><td>Walk(0.44km)</td><td rowspan="6">University</td></tr>
<tr><td>2</td><td>Walk(0.33km)</td><td>Bus (5.83km)</td><td>Walk(0.17km)</td><td>Tram(3.47km)</td><td>Walk(0.33km)</td></tr>
<tr><td>3</td><td colspan="4">Car (6.2km)</td><td>Walk (0.05km)</td></tr>
<tr><td>4</td><td colspan="2">Car (2.8km)</td><td colspan="3">Bicycle (3.24km)</td></tr>
<tr><td>5</td><td colspan="5">Bicycle (6.16km)</td></tr>
<tr><td>6</td><td colspan="5">Motorcycle (6.20km)</td></tr>
</table>

2.6.3 Generate parameters

The parameter for each objective is presented in table 4. The value of parameter for each objective please refers to Appendix II.

Table4. *Parameter for each objective*

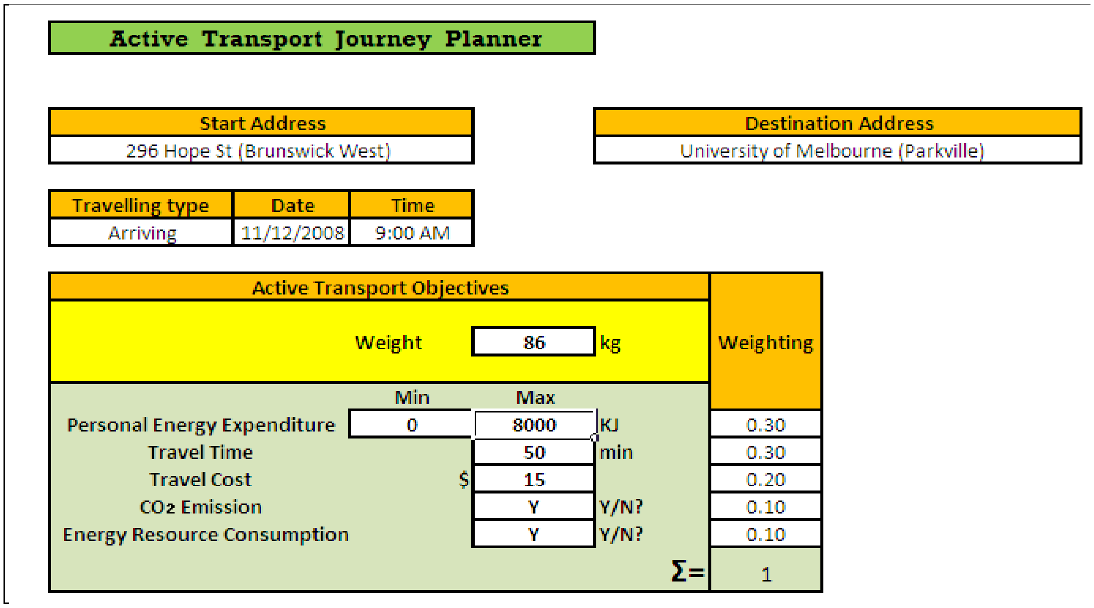
Objective	Criteria	Parameter	Unit
Personal Energy Expenditure	kJ	How many kilojoules a person spends by each travel mode;	kJ/person/km
Travel Time	hr	How long a person spends by each travel mode;	hr/person/km
Travel Cost	$	How much money a person spends by each travel mode;	$/person/km
CO_2 Emission	g	How many grams a person produces by each travel mode;	g/person/km
Energy Resource Consumption	MJ	How many mega joules a person spends by each trave mode.	MJ/person/km

2.7 Model Development

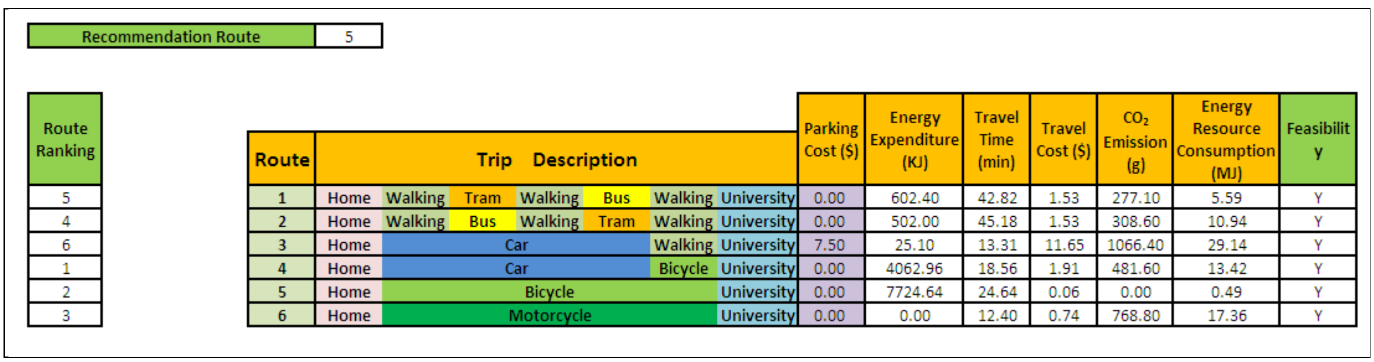
2.7.1 Model Interface

As demonstrated in Graph1, user can enter information and requirements for most objectives through Active Transport Journey Planner input interface, such as personal weight which is used for calculating energy expenditure during the journey,86kg; expected achieved minimum or maximum value of personal energy expenditure, 0~8000kJ; expected travel time, 50 mins, travel cost, $15. Since user may not have a clear idea of the amount of CO_2 and energy resource consumption expected to save, here user can select taking this two elements into account or not. All the information and requirements will be calculated within the model as well as set as the constraints to select the feasible transport options and to eliminate the infeasible ones.

Then, the feasible transport solutions will be evaluated based on the user's allocated weighting for each objective. The final rank of all feasible options will be delivered according to their total disutility. The least disutility one will be delivered as the recommended transport solution in the end. In addition, the rank of all feasible options and detailed objective-related information will also be presented through user output interface, which is shown in Graph 2.



Graph1. *User Input Interface*



Recommendation Route	5

Route Ranking	Route	Trip Description							Parking Cost ($)	Energy Expenditure (KJ)	Travel Time (min)	Travel Cost ($)	CO_2 Emission (g)	Energy Resource Consumption (MJ)	Feasibility
5	1	Home	Walking	Tram	Walking	Bus	Walking	University	0.00	602.40	42.82	1.53	277.10	5.59	Y
4	2	Home	Walking	Bus	Walking	Tram	Walking	University	0.00	502.00	45.18	1.53	308.60	10.94	Y
6	3	Home	Car				Walking	University	7.50	25.10	13.31	11.65	1066.40	29.14	Y
1	4	Home	Car				Bicycle	University	0.00	4062.96	18.56	1.91	481.60	13.42	Y
2	5	Home	Bicycle					University	0.00	7724.64	24.64	0.06	0.00	0.49	Y
3	6	Home	Motorcycle					University	0.00	0.00	12.40	0.74	768.80	17.36	Y

Graph2. *User Output Interface*

2.7.2 Model Function

In the case study, it is assumed that all the transport options are feasible regarding to the user's multi-objective requirements. The value of each objective for six transport options is shown in Table5.

Table5. *Value of each objective for transport options*

Objective	Route 1	Route 2	Route 3	Route 4	Route 5	Route 6
Personal Energy Expenditure (kJ)	602.40	502.00	25.10	4062.96	7724.64	0.00
Travel Time (hr)	0.71	0.75	0.22	0.31	0.41	0.21
Travel Cost ($)	1.53	1.53	11.65	1.91	0.06	0.74
CO_2 Emission (g)	277.10	308.60	1066.40	481.60	0.00	768.80
Energy Resource Consumption (MJ)	5.59	10.94	29.14	13.42	0.49	17.36

During the normalization procedure, the measure of the performance of alternatives is modified to be comparable, thus ensuring the applicability of preference or disutility aggregation under consideration for all criteria. Table6 shows the value of weighted summation using interval standardization and quantitative weights. Weighted summation requires quantitative information on values and weightings. Only the relative values of this information are used in the evaluation. The method provides a complete ranking and information on the relative differences between alternatives. The standardization process please refer to Appendix I.

Table6. *Standardized value of each objective for transport options*

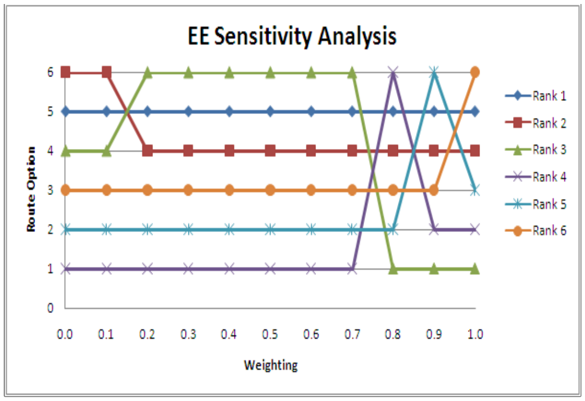
Objective	**Route 1**	**Route 2**	**Route 3**	**Route 4**	**Route 5**	**Route 6**	**Weight**
Personal Energy Expenditure (kJ)	0.923	0.936	0.996	0.474	0.000	1.000	0.3
Travel Time (hr)	0.899	1.000	0.031	0.208	0.414	0.000	0.3
Travel Cost ($)	0.180	0.180	1.000	0.159	0.000	0.059	0.2
CO_2 Emission (g)	0.260	0.289	1.000	0.452	0.000	0.721	0.1
Energy Resource Consumption (MJ)	0.178	0.365	1.000	0.451	0.000	0.589	0.1
Total	0.626	0.682	0.708	0.327	0.124	0.443	1.0

2.8 Research Results

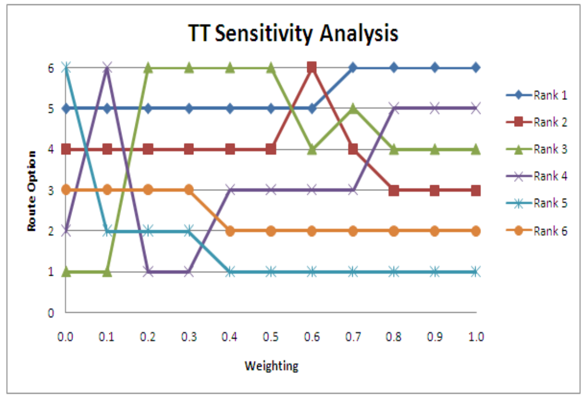
According to the user expected attainments and weightings allocated to each objective described above in model interface, it can be seen from Graph2 the Active Transport Journey Planner delivers the route 5, cycling from home to the university is the best solution, following by route 4, 6, 1, 2, 3; with around 7725kJ energy expenditure, 25 minutes, 0.06 dollars, no CO_2 emission and 0.49 MJ energy resource consumption which is only caused in the bicycle manufacturing stage.

3. SENSITIVITY ANALYSIS

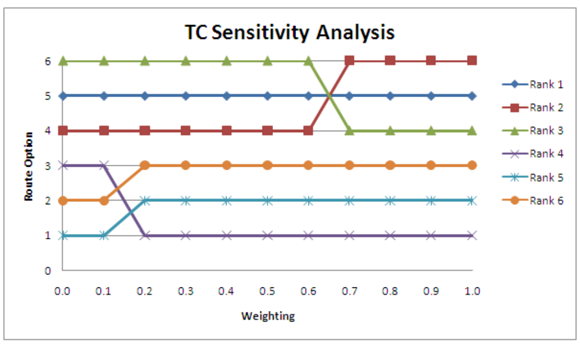
The consistency of results delivered from several evaluation approaches can be reviewed using a sensitivity analysis, which aims at investigating the influence of modified input data on the calculated results and testing the stability of an obtained compromise solution. In principle, all parameters can or should be subject to sensitivity analysis, but usually only criterion weights are treated. Graph3 demonstrates the results vary as the principle parameter: personal energy expenditure, travel time, travel cost, CO_2 Emission and energy resource consumption change from 0.1-1.0, respectively, using distribution sensitivity analysis.



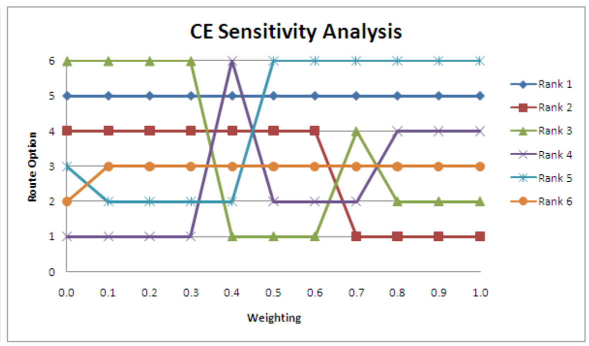
(1) Personal Energy Expenditure



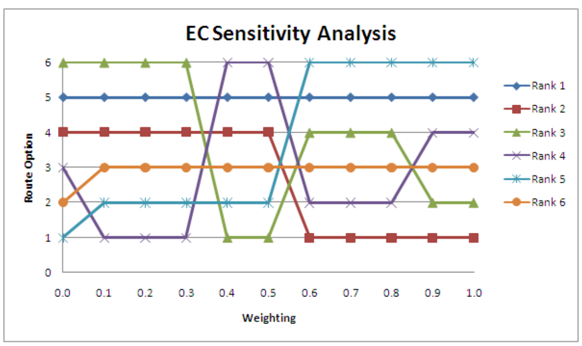
(2) Travel Time



(3) Travel Cost



(4) CO_2 Emission



(5)Energy Resource Consumption

Graph3. *Sensitivity analysis changing the weighting of each objective (distribution sensitivity analysis)*

4. DISCUSSION

From the sensitivity analysis, it can be seen that the energy resource consumption is most sensitive objective, as all transport mode except walk are involved, either for manufacturing or operating stage. Other objective such as personal energy expenditure only exists for cycle and walk. So transport option incorporating more cycling and walking has the higher probability to deliver as the smart solution to user if social, environmental concerns were taken into account beyond economic issues.

Further research is needed to extend and test this model in order to take other objectives, such as weather, safety and other objectives into account through survey or stakeholder workshop. In addition, the value of parameter for each objective in further research should involve the time and space consideration for its wider and more flexible update and utilization.

5. CONCLUSION

Initial result shows that the developed methodology could be applied in selecting best transport solution based on individual user's multi-objective preferences and weightings. In addition, transport option incorporating more cycling and walking has the higher probability to deliver as the best solution to user if social, environmental concerns were taken into account beyond economic issues.

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Appendix I: Objective Function

Objective Function

$$\mathbf{Min}\ \sum_{\boldsymbol{r=1}}^{\boldsymbol{N}}(\mathrm{R_r} \times \mathrm{DU_r})$$

$$= \mathbf{Min} \sum_{\boldsymbol{r=1}}^{\boldsymbol{N}} [\mathrm{R}_r \times \sum_{o}^{O} \omega_o \, \mathrm{DU'}_{o,r}]$$

$$= \mathbf{Min} \sum_{\boldsymbol{r=1}}^{\boldsymbol{N}} \{\mathrm{R}_r \times \{\sum_{o}^{O} \{\omega_o [(\mathrm{DU}_{o,r} - \mathrm{Min}_r \{\mathrm{DU}_{o,r}\}) / (\mathrm{Max}_r \{\mathrm{DU}_{o,r}\} - \mathrm{Min}_r \{\mathrm{DU}_{o,r}\})]\}\}\}$$

$$\mathrm{DU'}_{o,r} = \begin{cases} \mathrm{DU'}_{o,r} = (\mathrm{DU}_{o,r} - \mathrm{Min}_r \{\mathrm{DU}_{o,r}\}) / (\mathrm{Max}_r \{\mathrm{DU}_{o,r}\} - \mathrm{Min}_r \{\mathrm{DU}_{o,r}\}), \text{ if o is a cost objective;} \\ 1 - \mathrm{U'}_{o,r} = 1 - [(\mathrm{U}_{o,r} - \mathrm{Min}_r \{\mathrm{U}_{o,r}\}) / (\mathrm{Max}_r \{\mathrm{U}_{o,r}\} - \mathrm{Min}_r \{\mathrm{U}_{o,r}\})], \text{ if o is a benefit objective.} \end{cases}$$

Where $\mathrm{DU}_{o,r}$ or $\mathrm{U}_{o,r} = \sum_{m=1}^{M} a_{o,m,r} \lambda_{m,r} X_{m,r}$, for either cost or benefit objective.

Constraints

$$0 \leq O_{min} \leq O_r \leq O_{max}$$

Where, O_r is the set of objectives achieved in route option r;

O_{min}, O_{max} are the minimum or maximum value of constraints for set of objectives in route option r, respectively.

Decision Variables

- R_r: Route option r;

$$\begin{cases} R_r = 1, \text{ if route option r is selected;} \\ R_r = 0, \text{ otherwise.} \end{cases}$$

- r: Route option number, r ε R [1,2,…,N]; where R is the set of route options, and N is the total number of route options;
- $X_{m,r}$: Travelled distance by travel mode m in route option r; (km)

Parameters

- ω_o: Weighting of objective o;
- m: Travel mode number; m ε M[1,2,…,7], where M is the set of travel modes, and M is the total number of travel mode options; ***In the case study****, 7 travel modes totally, i.e.1-train, 2-tram, 3-bus, 4-car, 5- motorcycle, 6- bicycle, 7- walk;*
- $\lambda_{m,r}$: Availability of travel mode m in route option r;

$\begin{cases} \lambda_{m,r} = 1, \text{ if travel mode m is available in route option r;} \\ \lambda_{m,r} = 0, \text{ otherwise.} \end{cases}$

- $a_{o,m,r}$: Disutility (for cost objective) or utility (for benefit objective) conversion factor with regard to the extent of objective o achieved by travel mode m per person per km in route option r;

Terminology

- $Min_r\{DU_{o,r}\}$: Minimum value of disutility with regard to cost objective o in route options;
- $Max_r\{DU_{o,r}\}$: Maximum value of disutility with regard to cost objective o in route options;
- DU_r: Total value of disutility in route option r;
- $DU_{o,r}$: Value of disutility with regard to cost objective o in route option r;
- $DU'_{o,r}$: **Standardised** value of disutility with regard to cost objective o in route option r;
- $Min_r\{U_{o,r}\}$: Minimum value of utility with regard to benefit objective o in route options;
- $Max_r\{U_{o,r}\}$: Maximum value of utility with regard to benefit objective o in route options;
- U_r: Total value of utility in route option r;
- $U_{o,r}$: Value of utility with regard to benefit objective o in route option r;
- $U'_{o,r}$: **Standardised** value of utility with regard to benefit objective o in route option r;
- o: Objective, either cost objective or benefit objective; ***in the case study***, *where o ε O [EE, TT, TC, CE, EC]* ;
- O: Set of objectives;

Standardisation

Objective scores are generally mutually incompatible since most of the measurement units are different. Therefore, there is a need to transform costs and benefits for each objective for each mode option into one (dimensionless) unit.

Extreme Value

$$DU'_{o,r} \begin{cases} DU'_{o,r} = (DU_{o,r} - Min_r\{DU_{o,r}\}) / (Max_r\{DU_{o,r}\} - Min_r\{DU_{o,r}\}), \text{ if o is a cost objective;} \\ 1 - U'_{o,r} = 1 - [(U_{o,r} - Min_r\{U_{o,r}\}) / (Max_r\{U_{o,r}\} - Min_r\{U_{o,r}\})], \text{ if o is a benefit objective;} \end{cases}$$

$DU'_{o,r}$ or $U'_{o,r}$ indicates relative position on interval between the lowest & highest values.

Appendix II: Case Study Reference Table

I. Personal Energy Expenditure Table

Weight		50 kg	68 kg	77 kg	86 kg	91 kg	100 kg
Velocity		Personal energy expenditure（kJ/hr/person）					
m=6 Bicycle	15-16 (km/hr)	577	786	890	991	1045	1150
	21 (km/hr)	920	1254	1421	1588	1672	1839
m=7 Walk	3.3 (km/hr)	276	376	426	477	502	552
	4.8 (km/hr)	368	502	568	635	669	736

(Source: Bauman 2004)

Note:

EE: Personal energy expenditure of travel mode m based on weight index w (kg) and velocity index v (km/hr); (kJ/hr)

V: Velocity of alternative v of travel mode m; (km/hr)

Parameter of personal energy expenditure = EE /V; (**kJ**/person/km)

II. Travel Velocity Table

		Travel Velocity（km/hr）						
Travel Mode		Train	Tram	Bus	Car	Motorcycle	Bicycle	Walk
Velocity	Slow	60[*]	16[**]	25[***]	45[***]	30[****]	15[*****]	3.3[*****]
	Fast	60[*]	16[**]	35[***]	50[***]	50[****]	21[*****]	4.8[*****]

(Source: [*]: Data from Melbourne Connex Train website (Connex 2008), [**]: Data from Melbourne Yarra Tram website (Yarra Tram 2008), [***]: (Tranter 2004); [****]: consultation form traveller Asif within case study scope (Zaman 2008); [*****]: (Bauman 2004))

Parameter of travel time= 1/ V (**hr**/person/km)

III. Travel Cost Table

Travel Mode	Train	Tram	Bus	Car	Motorcycle	Bicycle	Walk
Travel Cost ($/person/km)	1.53[*] ($/trip)	1.53[*] ($/trip)	1.53[*] ($/trip)	0.67[**] ($/km)	0.12[***] ($/km)	0.01[* *] ($/km)	0

(Source: [*]: data from the calculation based on the assumption that traveller use yearly Metcard($1117) take public transport for return between home and workplace on weekdays in scope($1117/(2*5) (Metlink 2008)); [**]: (ABS 2008); [***]: consultation form traveller Asif within case study scope (Zaman 2008))

IV. CO_2 Emission Table

Travel Mode	Train	Tram	Bus	Car	Motorcycle	Bicycle	Walk
CO_2 Emission (g/person/km)	14	52	22	172	124	0	0

(Source: ABS 2003)

V. Energy Resource Consumption Table

Travel Mode	Train	Tram	Bus	Car	Motorcycle	Bicycle	Walk
Energy Resource Consumption (MJ/person/km)	0.2	0.8	1.4	4.7	2.8	0.08	0

(Source: ABS 2006)