A Binary Logit Model to Integrate Economic, Environmental and Social Factors for Formulating and Prioritising Transport Policies [1]

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Abstract: Transport is recognised as one of the important parts of human life. One of the core issues of this study is to develop a model that assesses individuals' responses to transport policies using revealed and stated preference data. The dependent variable of this model is the choice of a residential location in regional Western Australia under different transport situations with regard to various prices of fuel, property, etc., pollution situations and other factors. The model will be used to determine the weights of economic, environmental and social factors in formulating transport policies.

A universal choice set, which contains various decision scenarios with respect to those economic, environmental and social factors, will be developed for a binary logit model to estimate the reactions of individuals, in which marginal effects are the marginal changes in the expected probability of choices. Another important part of the logit model, the property of independence from irrelevant alternatives (IIA), is also analysed. In this study, eight attributes are classified as three subsets: economic, environmental and social subsets. The IIA test is applied here to check the correlation between error terms of alternatives in different subsets. The attributes of alternative choice items are combined to create profiles and the respondents are asked whether they would choose a residential location under a particular transport policy. A mail-out survey titled "Region Policy Response Survey 2006" is used to get people's responses to the transport policies in nine regions of Western Australia. Meanwhile, this model also analyses individuals' socio-demographic factors such as income etc.

1 Introduction

Transport is recognised as one of the most important components in human life. The core issue of this study is to develop a model that would quantify individual responses to transport policies.

The problem in bringing all policy considerations into any formal evaluation is to find satisfactory weights. Multi-Criteria Analysis usually attempts to do this by seeking community opinions on which to base priority weights for all factors (Nijkamp et al 1990). However, the resulting weighted sum of criterion scores for each project may be difficult to turn into practical policy if the government is not satisfied that its concerns have been fully represented. Currently, the determination of weights has been based on what-if scenario analysis approach through Goal Programming (Taplin et al 1995) or arbitrary assignment as in multi-criteria analysis. Whether or not these weights reflect community preferences needs thorough research.

In this study, a choice model is developed to measure people's maximisation of their utility. The objective is to estimate individual choices under different levels of predictors reflected by different attributes. As discussed by D'Arcier et al (1998), a 'Behavioural Response Choice Set' (BRCS) is organised that 'all the behavioural responses the individual can imagine in order to cope with any changes in his or her environment'. It covers a broader range of alternatives than conventional choice set as defined by transport planners and model developers. In this study, economic, environmental and social aspects will be integrated into

[1] *I would like to acknowledge the help of Dr Min Qiu and Professor John Taplin who generously provided advices.*

the BRCS to probe individual responses to situation changes with respect to residential location transport policies.

2 The model

2.1 A binary logit model

A universal choice set {Yes, No} will be developed in this study for the binary logit model to estimate individuals' residential choice in terms of transport policy changes. Utility functions and choice probabilities for both sets of data are discussed as equation (1) and (2):

$$U_{iq} = V_{iq} + \varepsilon_{iq} \tag{1}$$

where, *i* is one alternative, referring to 'Yes' or 'No' for individual *q*.

U_{iq} is the utility of alternative *i* to individual *q*

V_{iq} is the observed utility component

ε_{iq} is the unobserved component

It is important to point out that V_{iq} is a function and is assumed to be non-random, while ε_{iq} may also be a function, but it is random from the observational perspective of the analyst. Randomness arises because the analyst cannot peep into the head of each individual and fully observe the set of influencing factors (referring to quantified economic, environmental and social factors in this study) (Louviere et al 2000). As specified by Ben-Akiva and Lerman (1985), V_{iq} can be thought of as the means of U_{iq}. The system component of utility can be identified; the parameters can be estimated from an appropriately designed experimental study. Individual preferences are revealed by the choices made in choice experiments. In the binary choice model the probability of an individual of choosing 'Yes' is expressed as:

$$\begin{aligned} P(Yes) &= P(U_{Yes} > U_{No}) \\ &= P(V_{Yes} + \varepsilon_{Yes} > V_{No} + \varepsilon_{No}) \\ &= P(V_{Yes} - V_{No} > \varepsilon_{No} - \varepsilon_{Yes}) \end{aligned} \tag{2}$$

As discussed by Ben-Akiva and Lerman (1985), the specification of binary choice model considers only the difference of random components $(\varepsilon_{No} - \varepsilon_{Yes})$ instead of each single element separately. They also stated that there is no real difference between shifting the mean of the random component of one alternative and shifting the systematic component by the same amount, which implies that as long as one can add a constant to the systematic component, the means of random components can be defined as equal to any constant without loss of generality. The most convenient assumption is that all the random components have zero means. Using the binary logit model, one can estimate the probability of choosing 'Yes', which can be expressed as:

$$P(Yes \mid Yes, No) = \frac{e^{V_{Yes}}}{e^{V_{Yes}} + e^{V_{No}}} \tag{3}$$

Similarly, the probability of choosing 'No' can be expressed as:

$$P(No \mid Yes, No) = \frac{e^{V_{No}}}{e^{V_{Yes}} + e^{V_{No}}} \tag{4}$$

The systematic (observed) component, V_{Yes}, is assumed to be homogeneous across the population in terms of relative importance of those attributes enclosed in V_{Yes}. This component is also assumed to be a linear and additive function of the attributes which determine the utility of the alternative 'Yes'. This can be expressed as:

$$V_{Yes} = \sum_i \beta_i X_i + \sum_q \alpha_q Z_q \tag{5}$$

where β_i is a vector with respect to *i* attribute vectors, X_i

α_q is a vector regarding to *q* individual characteristics, Z_q

Analysts have control over the attribute vectors by designing them to satisfy the properties of interest; but in a random sample they have no control over individual characteristics, which is Z_q in equation (5).

The logit model is derived from the assumption that the error terms of alternatives in utility functions are independent and identically Gumbel distributed. These models were first introduced in the context of binary choice models, where the logistic distribution is used to derive the probability. An important property of the multinomial logit model is IIA property. In word, IIA property states that the *ratio of the choice probabilities of any pair of alternatives is independent of the presence or absence of any other alternative in a choice set*. A particularly important behaviour implication of IIA is that all pairs of alternatives are equally similar or dissimilar. This restriction enables analysts to add a new alternative or delete an existing alternative without having to re-estimate the model (Ben-Akiva and Lerman 1985). For the set of attributes that are not observed, this amounts to assuming that all the information in the random component is identical in quantity and relationship between pairs of alternatives are hence across all alternatives. Later stage of this study will focus on the analysis of this IIA property in the choice model.

2.2 Combining RP and SP data

"Revealed choices" are decisions made by respondents in response to their actual behaviour; "Stated choices" are decisions made in hypothetical experiments in which there may be no real choices, or any "real" consequences of making a choice (Adamowicz et al 1997). Despite the potential lack of realism in such situations, random utility theory suggests that consumers should try to maximize their utility. Whether choice processes are the same in real and hypothetical situations is an empirical issue, even if there is now a growing body of evidence to suggest that choice process can be very similar in both types of situations (Louviere and Swait 1996). The implications of differing characteristics of RP and SP data are summarised in Table 1.

Both RP and SP can be modelled by a random utility model with the discrete choice method. Choice studies use either RP or SP or both, each having its own characteristics. In the situation when no or limited data are available, SP creates new information. Morikawa (1994) and others (Louviere et al 2000, Ben-Akiva and Morikawa 1990a, 1990b, Cherchi and Ortuzar 2002) recommended an approach which uses RP and SP data jointly to exploit their advantages and overcome their limitations. The process of pooling RP and SP data and estimating a model from the pooled data is called 'data enrichment' (Louviere et al 2000) and the purpose of data enrichment is to produce a model which can be used to forecast real future market scenarios.

Equation (6) to (9) show the functions of utility and probability in the choice model.

$$U_{iq}^{RP} = V_{iq}^{RP} + \varepsilon_{iq}^{RP} \tag{6}$$

Table 1: Differing characteristics of RP data and SP data and characteristics of combined RP and SP estimated method

	RP data	**SP data**
Preference	Choice behaviour in an actual market which is related with individuals' actual behaviour	Preference statement for hypothetical scenarios, not guaranteeing to be harmonious with actual behaviour
Alternatives	Actual alternatives, excluding non-observable alternatives	Generated alternatives, which can elicit preference for non-existing alternatives
Attributes	May include measurement errors; correlated attributes; limited ranges	No measurement errors; multicollinearity can be avoided; can extend ranges
Number of responses	Difficult to obtain multiple response from an individual	Repetitive questioning is easily implemented
Response format	Preference indicators available are "choices"	Preference indicators have various formats (e.g., choose one, ranking, rating, matching)
	Combined RP and SP estimation method	
Key features	1. Efficiency: joint estimation of preference parameters from all the available data; 2. Bias correction: explicit response models for SP data that include both preference and bias parameters; and 3. Identification: estimation of trade-offs among attributes and the effects of new services that are not identifiable from RP data.	

Source: Ben-Akiva et al 1991.

$$P_q^{RP}(i) = \frac{e^{V_{iq}^{RP}}}{\sum_j e^{V_{iq}^{RP}}} \tag{7}$$

$$U_{iq}^{SP} = V_{iq}^{SP} + \varepsilon_{iq}^{SP} \tag{8}$$

$$P_q^{SP}(i) = \frac{e^{\mu V_{iq}^{SP}}}{\sum_j e^{\mu V_{iq}^{SP}}} \tag{9}$$

Where, U_{iq} is utility of alternative *i* to individual *q*

V_{iq} is systematic component of U_{iq}

ε_{iq} is random component of U_{iq}

$P_q(i)$ is probability of individual *q* choosing alternative *i*

The superscript RP or SP indicates the data type.

The scale factor μ in equation (9) establishes a relationship between random terms of each data set, which is essentially the ratio of standard deviations of ε^{RP} and ε^{SP}, as shown in equation (10):

$$Var(\varepsilon^{RP}) = \mu^2 Var(\varepsilon^{SP}) \tag{10}$$

Therefore, now ε^{RP} and $\mu\varepsilon^{SP}$ conform to the independent and identically distributed (IID) assumption. The scale factor μ along with other parameters can be estimated by Maximum Likelihood methods. A number of studies have reported that a combined RP/SP model produces more efficient estimates, such as studies including Adamowicz et al (1997), Boxall et al (2003), Ben-Akiva et al (1991), Ortuzar and Iacobelli (1998), Hensher et al (2005) and many others.

2.3 Regional transport policy reaction model

The principle of this study is individual reactions to transport policies which can affect people's residential choices in regional Western Australia; the dependent variable is the choice of residential location under various transport situations with regard to pricing factors, pollution considerations and other factors, as shown in equation (11).

$$U_{iq} = \beta_1 X_{ie,q} + \beta_2 X_{ien,q} + \beta_3 X_{is,q} + \varepsilon_{iq} \tag{11}$$

There are nine regions in Western Australia.[2] In the case of individual *q* living in a region making location choice *i*, U_{iq} stands for the modelled values of utilities derived from choice *i* for individual *q*. X_e, X_{en}, X_s are the values of the relevant vectors of attributes (economic, environmental and social) to influence transport policy. β_1, β_2, β_3 are parameters reflecting the attributes' relative weights which are unknown to individual *i* and to be estimated.

Environmental factors are one of the most important elements in transport sustainability. People's measured evaluation of environmental goods is essential as "the absence of such data is arguably a significant obstruction to environmentally sensitive decision-making" (Pearman 1994, p.229). SP methods are particularly useful in estimating environmental aspects because they allow us "to establish values for those environmental goods which, because they are not directly traded in conventional markets and do not have immediately available monetary values to form the basis of inputs to financial, cost-benefit and similar forms of policy appraisal" (Pearman 1994, p.229) either in the traditional four-stage transportation planning model or the cost benefit analysis in evaluating transportation infrastructural projects. To evaluate the environmental factors, only SP data can be collected, for economic and social factors, combined RP and SP data will be collected.

2.4 Weighting

In equation (11), β_1, β_2, β_3 are parameters reflecting attribute weights "unknown" to individual *q* and to be estimated in some way. X_e, X_{en}, X_s may be the transforms of measurable quantities; for instance, logarithms will give a multiplicative form (Fowkes and Wardman 1988, pp.27-44). This research will also apply relevant theories of discrete choice to these issues. (Ben-Akiva and Lerman 1985, pp.253-275). Within each region, individual weights will be averaged for aggregation and get W_{1e}, W_{2e}, … W_{9e} as weights of economic, W_{1en}, W_{2en}, … W_{9en} of environmental and W_{1s}, W_{2s}, … W_{9s} of social factors in transport decision-making. Furthermore, this research will do the weighting by different sizes of population, so that the weights for the whole of Western Australia can be calculated by equations in (12).

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[2] *For details, see http://www.mainroads.wa.gov.au/NR/mrwa/run/start.asp.*

$$W_e = \frac{W_{1e}P_1 + W_{2e}P_2 + ... + W_{9e}P_9}{P_1 + P_2 + ... + P_9}$$
$$W_{en} = \frac{W_{1en}P_1 + W_{2en}P_2 + ... + W_{9en}P_9}{P_1 + P_2 + ... + P_9} \quad (12)$$
$$W_s = \frac{W_{1s}P_1 + W_{2s}P_2 + ... + W_{9s}P_9}{P_1 + P_2 + ... + P_9}$$

In the equations above, W_e, W_{en}, W_s are weights of three factors calculated for all Western Australia. In this way, the research will combine the individual's preferences into the community's collective preference to determine the relative weights attached to social, economic, and environment factors to achieve a sustainable transport policy.

Besides the size of population of each region, this research might also consider such things as size of the region, contribution of economy, etc., in weighting as different weighting systems/ schemes. Different weighting schemes will be compared/analysed in the context of Arrow's work.

3 Experimental design

The questionnaire or survey instrument design is an important step that will impact on the quality of the survey results. Main elements that need to be determined for the survey instrument design are: the alternatives, the attributes and levels of attributes, the experimental design, and presentation of choice tasks. Carson et al (1994) suggest that through experience, the average number of attributes included in questionnaires is about seven. A designed experiment is a way of manipulating attributes and their levels to allow rigorous testing of certain hypotheses of situation (Louviere et al 2000). The experimental design method has been widely used in many fields of study.

An experimental design may be classified as fully or fractionally factorial. A full factorial design enumerates all possible combinations of attribute levels. Although this design ensures that all effects of the attributes are captured, it is only practical when a small number of attributes and levels are of interest. As the number of attributes or the levels of attributes increase, the number of choice sets also increases dramatically. Consider 6 attributes with 3 levels each, the full factorial design will end up with 216 (6^3) choice sets. A fractional factorial design can be used to minimise the number of combinations by selecting particular subset or sample of complete factorials so that particular effects of interest can be estimated as efficiently as possible. Fractional factorial designs involve a fraction of the full factorials and allow the estimation of at least all main effects. They can be designed to retain the orthogonality of the full factorial in which there is zero correlation between attributes. Two-way or higher order interactions can also be estimated but again this might increase the number of choice sets in the design leading to an increase in task complexity.

3.1 Attributes

In this study seven policy measures (attributes) were identified. Two of these attributes had 2 levels of value and the others had 3 levels. Therefore, if we consider a complete factorial design the total number of combinations would be 972 ($= 3^5 \times 2^2$) profiles, which would be difficult to collect from respondents. Fractional factorial designs involve a fraction of the full factorials and allow the estimation of at least all main effects and some interactions between variables. Attributes to be considered in this survey are for people in nine regions of Western Australia. Table 2 shows the attributes and their assigned levels for the decision process.

Table 2: Attributes and their levels used for decision process

Attributes	Levels of attributes	Units
Petrol price	$1.40, $1.50, $1.60	Per litre for travelling within a region
Property price	$250,000, $350,000, $450,000	Per residential property
Travel cost	Less than $1, $1-$1.5, More than $1.5	Per kilometre of individuals' trip cost from a region to Perth
Number of heavy vehicles passing respondents' residential location	Equals to or more than 5, less than 5	Heavy vehicles per day
Incremental freight cost per ton to a changed location	$4, $5, $6	Extra freight charge per added 100 kilometres to the business most frequent dealt with
Places of interests in the region	Yes, No	
Job opportunities that a region can provide relative to the current region	More, Same as current region, Fewer	

3.1.1 Petrol price

Petrol price is highly concerned by people in regional areas who use vehicles to work, to send children to schools, to visit friends, to go shopping, and so on. The changes of fuel price may be one of very important factors in people's response of choosing residential location. Here the petrol only refers to unleaded petrol; diesel and gas will move similarly, so they will be transferred to unleaded petrol price to make the result more consistent and reliable. Figure 1 shows the average prices of petrol in regional Western Australia.

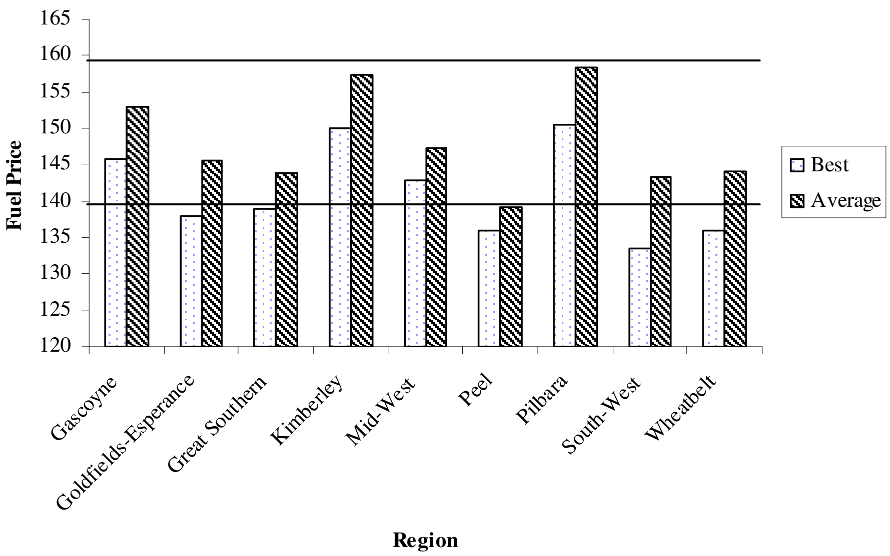

Figure 1: Regional Western Australia best vs. average petrol prices (unleaded fuel)

Note: Best prices available from 6am Thursday 13 July 2006.
Source: http://www.fuelwatch.wa.gov.au/.

3.1.2 Property price

Property price in terms of distance from busy transport (roads, railway and airport) facilities is a charge imposed on one of environmental considerations (including air and noise quality). To those who live in the town, the price is assumed to be higher if the location is farther away from heavily polluted and lower otherwise. Therefore, property price will be considered to vary with environmental factors in this survey. Given three levels of distance from the busy traffic area, there are three property price levels posed for this attribute.

3.1.3 Travel cost

Travel cost per kilometre from a region to metropolitan area (e.g., Perth city), for business, visiting friends or education propose and so on. Travel includes car, bus or aircraft. Lower travel cost will also attract tourists from metropolitan area. Therefore, change of travel cost can be considered as an economic attribute in this study. There are three levels to be planned in this attribute.

3.1.4 Number of heavy vehicles passing respondents' residential location

Number of heavy vehicles passing individual's residential location per day is considered an environmental and safety problem. This factor is of great concern to parents who have children and worry about their safety. It will be divided into two levels: equal to or fewer than 5, more than 5 heavy vehicles. Pictures of heavy vehicles will be provided together with the survey form to give respondents a visual impression.

3.1.5 Incremental freight cost per ton to a changed location

Agriculture is Western Australia's second major export industry. The State's vast area provides soils and climates suited to a variety of agricultural production from open range grazing and broad acre cereal cropping to irrigated pastures and horticulture, orchards and vineyards, which cause demand for road freight services.[3] Changes of freight expense per extra distance unit (referring to per tonne per 100 kilometres) are faced by both freight users and freight suppliers. In this study, freight suppliers are businesses that provide freight transport services. It is a significant economic factor. This variable will be expressed together with a dummy variable, which indicated whether an individual has a business requiring or relating to transport. As shown in Figure 2, Australian Road Transport Federation (ARTF) / Transport Workers' Union (TWU) of Australia: Recommended minimum interstate owner or driver rates based on minimum load of 23 tonnes, the rates applicable from 1 May 2006. With 100 kilometre's increment, there will be $4-$6 more freight cost.

3.1.6 Places of interests in the region

Many individuals think highly of their places of interests. Whether there are places of interests (e.g., public parks, beauty spot, etc.) will be concerned as a significant environmental factor in individuals' responses in choosing their residential locations. It can be at two levels: "YES" or "NO".

3.1.7 Job opportunities that a region can provide relative to the current region

There are a range of employment opportunities available in regional Western Australia. Various kinds of information are provided to support regional areas attract people with the skills they need (Government of Western Australia). In interview, job opportunities were considered as an important social factor for residents living in a region. It can be indicated at three levels: "More job opportunities", "Same as current region" or "Fewer job opportunities" that a regions can provide.

The attributes above are combined together to create profiles and respondents were asked whether they would change the residential location with the stated attributes under the transport policy. The choice response is binary, 'Yes' or 'No'. Using fractional factorial

[3] For details, see http://www.about-australia.com/facts/western-australia/.

designs involve a fraction of the full factorials and allow the estimation of at least all main effects and some interactions between variables.

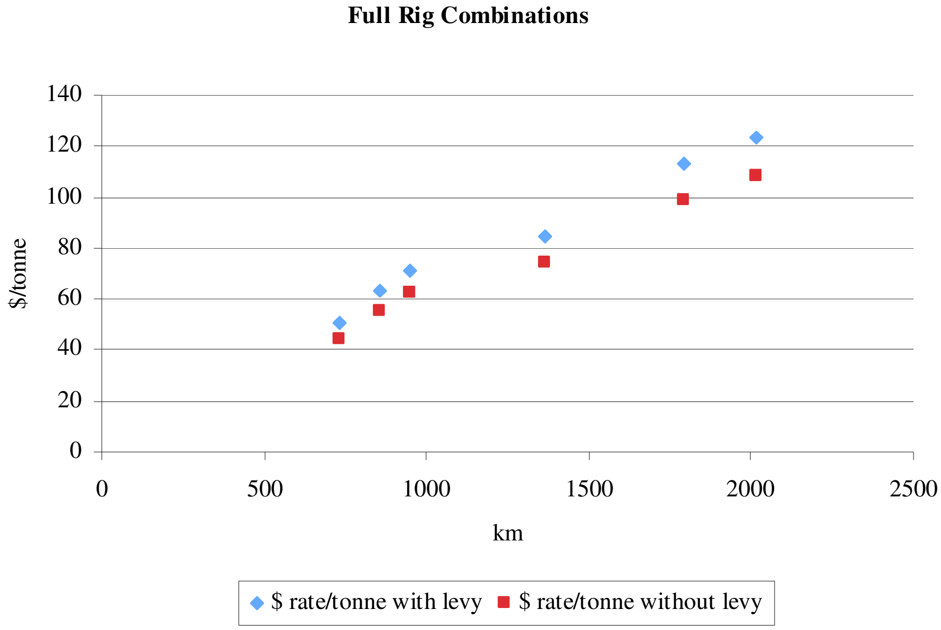

Figure 2: Recommended minimum interstate owner/driver rates

Source: Australian Road Transport Federation (ARTF) / Transport Workers' Union (TWU) of Australia: Recommended minimum interstate owner or driver rates based on minimum load of 23 tonnes, the rates applicable from 1 May 2006.

Note:
1. A fuel levy of 14.43% (full rig) and 15.57% (tow operators) has been applied to the standard scheduled rates.
2. The fuel levy will be reviewed quarterly and must be read in conjunction with the revised ARTF/TWU Interstate Owner/Driver Agreement.

3.2 Socio-demographic factors

Socio-demographic factors of the respondents are important. Individuals with higher income will respond differently from those with lower income. A useful grouping for further analysis is higher income and lower income groups. These two groups have contrasting views of the SP/RP scenarios. The social-demographic factors are integrated into the choice model of this study.

4 Sample framework and mail-out survey

Ideally, the analyst would like to have survey data of the entire population relevant for their research that could be used to address every question. However, it is only in censuses where participation is complete that there is even such a possibility. Censuses are prohibitively expensive, and the feasible amount of detail that can be collected is usually small (Kennickell 2005).

4.1 Sample framework

Kish (1965) and Särndal et al (1992) indicated that sample based estimates are treated as realizations of random variables arising from some process in the relevant population. In the purest version of the former work, random sampling without explicit model assumptions is shown to guarantee for a broad class of estimators (such as the mean) that if estimates are made repeatedly from many identically structured samples, the average of all estimates converges to the true value. In addition, this approach gives a way of characterizing the probability conditional on the sampling process that the true value might actually be within an interval some distance from the estimate given by a particular sample. The sampling error increases as the sample size decreases (Stopher and Meyburg 1979).

The sample frame defines the universe of respondents from which a finite sample is drawn to collect data. The objective of the study often influences the sample frame. As the objective of the study is to assess the reaction of regional residents under the transport policy, the sample frame should be all households who live in regional WA. A final sample size of 400 is convenient for the purpose of this study. It was expected that the response rate would be about 20% in the case of a mail survey. Keeping this rate in mind, a sample size of 2000 households was selected from 545,185 persons in regional Western Australia. According to Louviere et al (2000) this sample size is within the size range of a sample for simple random sampling.

4.2 A mail-out survey

In this study, a mail-out survey called "Regional Transport Policy Survey 2006" is planned to get 2000 households' responses in nine regions of Western Australia. Sampling was by random selection of numbers listed in the CD-ROM of "2004 - Australia Residential and Business". The distribution of these surveys will be determined by the proportion of each region to the whole population of regional Western Australia, as shown in Figure 3. The detailed survey distribution is indicated in Table 3. Respondents are asked whether or not they would change their residential locations under various scenarios.

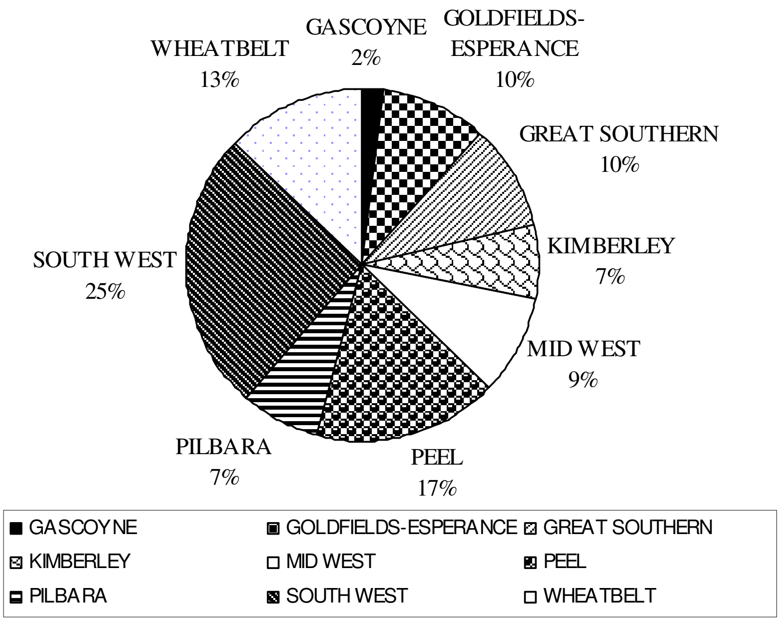

Figure 3: Population distribution of regional Western Australia

5 Conclusions

Completion of the questionnaire is considered evidence of consent to participate in the study. While this article analyses the survey design, later stage will focus on the data collection and the data analysis to assess individuals' responses in considering their region's transport policies.

By investigating satisfactory weights to bring all policy considerations into any formal evaluation, this research will advance the application of discrete choice modeling to transport policy decision-making. Furthermore, it will contribute to achieving the strategic sustainability visions, and be applicable to evaluation and resource allocation for planning and transport programs, including growth and preservation.

Table 3: Estimated resident population of regional Western Australia 2005

Regions in Western Australia	Population in 2005	Number of Surveys
GASCOYNE	9,854	100*
GOLDFIELDS-ESPERANCE	53,661	197
GREAT SOUTHERN	53,738	197
KIMBERLEY	35,748	131
MID WEST	50,071	184
PEEL	91,853	337
PILBARA	39,282	144
SOUTH WEST	140,846	517
WHEATBELT	70,132	257
REGIONAL WA	**545,185**	**2,064**

Note: *According to Gascoyne population, the number of surveys to be mailed out should be 36, which will be increased to 100 considering the validity of response rate.

Source: Australian Bureau of Statistics.

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