LAND USE/TRANSPORT SCENARIO ASSESSMENT MODEL: OPTIMIZATION ALGORITHMS AND PREFERENCE FUNCTIONS, ACCESSIBILITY AND GREEN-HOUSE GAS TRADE-OFFS

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ABSTRACT

The context for our theoretical research into novel evaluation models for land use and transport scenarios is the move towards a carbon economy. To deliver sustainable transport in the future, and to achieve the greenhouse gas emission targets, the research challenge is to reform the current analytical tools that are used by practitioners to evaluate the benefits and costs of a transport investment scheme to ensure carbon emissions can be captured and accounted for in an appropriate and credible manner. Visioning future scenarios and backcasting is one such promising tool. The model quantifies performance measures or metrics of such scenarios. For urban regions there are trade-offs amongst economic, social and environmental criteria and a holistic assessment framework (Doust and Black, 2009) is extended by combining: a mathematical model to minimize the total amount of travel in distance in the region considering the preference function of journey-to-work travel by applying the optimal commuting assignment problem; the calibration of commuter preference functions for cities of varying size and stages of economic development; and the formulation of visual sustainability metrics based on the concept of a sustainability goal in "environmental sustainability – accessibility space" that estimates greenhouse gas emissions by private transport.

Keywords: Land use and transport, sustainability framework, assessment model, commuting preference function, optimum commuting assignment

INTRODUCTION

Traditionally in Australia strategic land use, transport and environmental planning have been matters of State and Territory Governments, but now each will have capital city strategic plans by 2012 that meet national criteria for transport, housing, urban development and sustainability because from 1 January 2012, the Commonwealth Government will link future infrastructure funding to States and Territories meeting these criteria. State and Territory planning systems will be independently assessed by the Council of Australian Governments (COAG) Reform Council in this major microeconomic reform agreed by Governments at a COAG meeting in December, 2009. Capital city strategic plans are needed to lift economic productivity, respond to climate change and ensure the nation is geared up for 35 million people by 2049. Against a backdrop of integrated strategic planning, each jurisdiction should address nationally significant policy issues including: population growth and demographic change; productivity and global competitiveness; climate change mitigation and adaptation; efficient development and use of existing and new infrastructure and other public assets; connectivity of people to jobs and businesses to markets; social inclusion; and health, liveability, and community wellbeing. The criteria require better transport planning to tackle urban congestion, and new urban development to be better linked to transport, jobs and services (www.minister.infrastructure.gov.au/aa/releases/2009/December/aa523_2009.htm, accessed 10th December, 2009).

The breadth of issues our world now finds itself facing and the shift in values and aspirations in communities around the world is challenging the way we plan. It has been common place in many cities for planning to be for continuation of past trends. Transport planning, for example, often involves a process of estimating future demand based on recent past trends. This results in the continuation of the status quo to transport supply, urban form and other policy instruments. The uncertainty associated with change can present a risk with this approach. However, the risk associated with not changing planning approaches could equally lead to uncharted risks. Issues such as climate change, rapidly increasing population and urbanization, and resource limitations are requiring future scenarios to be envisaged that are trend breaking. In recent years “one approach to developing trend breaking futures is to use visioning and backcasting as a form of scenario building” (Hickman and Bannister, 2009). Visioning and backcasting are being applied to engage communities to help define what these future scenarios should be. Similarly, agencies such as the Asian Development Bank prefer planning capable of defining trend breaking future scenarios where they are needed.

Evidence-based, scenario planning is required to make the funding case for infrastructure to support the preferred direction of urban development. Given the raft of inter-related policies it is clear that options for future urban spatial form and density by mid-century, journey to work travel, and the transport infrastructure to support this will require quantitative analysis of current data and forecasts. New, innovative tools and approaches are needed to enhance the aim of sustainability. There is a substantial body of more recent research (for example, Guers and Van Wee, 2000; Hickman and Banister, 2009) that suggestion visioning and backcasting as an appropriate tool. Backcasting, which is not a novel tool (see, Hojer and Mattsson, 2000; and Westerman and Black, 1983), is especially appropriate today where current trends are leading towards an unfavorable long-term state. One of the most interesting methodological procedures to be followed in "backcasting" starts from a "desirable" long-term future scenario, followed by the identification of a set of mutually reinforcing policies or actions required to make it viable, and enable it to happen. This approach of visioning and backcasting was taken in a recent London Study by Vibat (http://www.vibat.org/vibat_ldn/index.shtml, accessed 19th Jan 2010). The desirable future is defined through visioning with stakeholders and the use of criteria which can be quantified and have environmental significance. Taking into account the current trends, the policies or actions to be undertaken will then lead society to achieve this more desirable situation.

This paper is not about specifying those desirable long-term future scenarios, say for Australian cities, although such visions have been partially constructed in the past by the Australian Institute of Urban Studies (Simons and Black, 1992) and by the Federal Government's Ecologically Sustainable Development (ESD) Transport Working Group, as conveniently summarized under goals and objectives and solutions by Black (1996). However, an important connection needs to make between visioning, backcasting techniques and the need for evidence-based scenario planning. Our proposed land-use and transport assessment model is designed to provide a methodology that begins to build this connection. Our model is based on strands of previously unconnected research already reported in the scientific literature, such as journey to work behavioral travel preference functions (Black, et al, 1993; Cheung and Black, 2008), and the optimal commuting assignment problem with embedded preference functions (Masuya, et al, in press).

The paper is structured into five sections. Firstly, the overall structure of the model is laid out showing the connection to visioning and backcasting and how it provides the evidence basis for the scenarios being considered. A particular advantage of this approach is the strategic scan of the scenarios. This section discusses in outline the rationale for connecting pieces of previously unconnected research: a sustainability framework with metrics for economic, social and environmental sustainability with the inclusion of journey to work preference functions, and the optimal commuting assignment problem to construct one of the many possible future scenarios. The second section explains the context of the urban sustainability framework in providing the evidence basis for the scenario planning. Having set the model picture the paper discusses in more detail the sustainability assessment methods that are brought together for characterizing the performance of each scenario. These are whether or not commuters in the aggregate travel shorter or longer distances, residential accessibility to employment and carbon dioxide emissions from transport (including the embodied energy consumption in road construction). The paper then sets out the equations for the model of optimal commuting assignment as a method for indicating the optimal scenario. The conclusions suggest areas for further research, including empirical testing in a case study city and the need for shared information on different cities to form scenario typologies.

LAND USE/TRANSPORT SCENARIO ASSESSMENT MODEL

Our model provides a methodology that informs the visioning and backcasting process with simple visualizations to give the evidence basis to the scenarios being assessed. The structure of our model is shown in Figure 1. If we have a present situation with any city of the world (the "now") there are really two possibilities as far as data on land use, transport and travel: data rich; or data poor (for example, the case of many cities in the developing world). The "base case" in Figure 1 assumes a case study area where there are rich data sets. In this latter city, let us follow through the steps for visioning and backcasting. A group of stakeholders are involved in a visioning study for that city and will almost certainly derive information (typologies) about desirable futures from experience in other "data rich" cities of the world. Visioning will lead to various future scenarios. Backcasting will help formulate a sequence of policy packages or actions to achieve the most desirable future.

The logic underpinning our model is that strategic scans of the performance of each scenario are necessary to help to choose the most desirable future (including an optimization as one of the potential scenarios. Our sustainability framework (see next section) provides the metrics for such an assessment of the best scenario, as shown on the right hand side of the flow diagram in Figure 1. It should be noted that in the case of a data poor case study city resort must be made to typologies of relevant cities where such information is available to assist in the formulation of appropriate scenarios for that particular city. Again, the metrics that we propose can be applied too in this situation. The significance of this approach is that it becomes a valuable tool for stakeholders and their consultants in developing countries where international agencies such as the World Bank and the Asian Development Bank are attempting to forge strategies to make developing cities more sustainable.

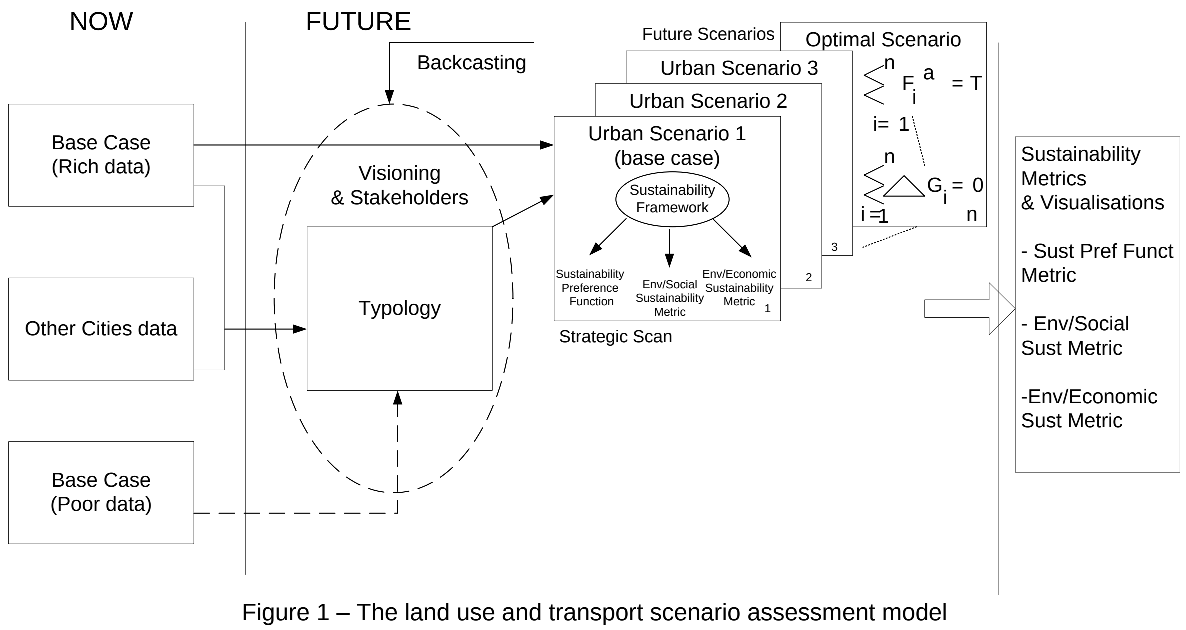

Figure 1 – The land use and transport scenario assessment model

The sustainability framework embedded in Figure 1 enables the proposed land-use and transport scenario assessment model to generate logical sustainability assessment metrics and optimization algorithms that include accessibility and green house gas trade-offs. These are described in the following sections, but the main features are:

- Preference functions to capture zonal travel behavior;
- Triple bottom line assessment of the optimum pattern of urban development and travel (journey to work mean trip lengths as a key sustainability indicator);
- The assessment includes accessibility to employment from residential zones (social equity), accessibility to labor from employment zones (economic efficiency) and carbon dioxide emissions from the road network; and
- A land-use optimization process using these travel preference functions to constrain commuting travel patterns to match the observed behavior.

The model is built on the use of sustainability assessment metrics for gauging how the urban system, policy packages and resulting urban dynamics perform. Two independent research areas have contributed these metrics. Our model has developed the use of sustainability metrics that are able to characterize the sustainability performance of existing and future scenarios. The metrics selected are the sustainability preference functions, together with environmental/social equity and environmental/economic efficiency sustainability metrics developed through prior research. Both of these are set in the sustainability framework discussed in the next section and reflect the behavioral responses of the community to the urban system and the other drivers. It can be appreciated from Figure 1 that the same can be developed for each other scenario under consideration.

The work on “preference functions” has given a metric that reflects the community urban dynamic choices and degree of difference these choices make to the expected trip patterns. The second research work area has produced sustainability metrics based on accessibility and environmental measures such as greenhouse gas emissions. This type of metric enables both the collective and internal transport-related sustainability performance to be assessed for the city. A novel feature is its approach to understanding paired sustainability pillar performance, namely environmental/social equity and environmental/economic efficiency, in addition to performance for individual sustainability pillars.

The relationship between the physical urban system, other drivers, the community response and sustainability outcomes are defined with the aid of the traditional building-blocks of the transport planning and urban planning methodologies that have been maturing over many years of practice. These computer-based methodologies have been recently set into a sustainability framework that has further enhanced a systems approach to understanding sustainability outcomes. The detail of the sustainability framework is shown in Figure 2 and discussed in the next section.

The third area of research we are bringing into this model is that of optimal commuting assignment. Using the preference function metrics as inputs and constraints in the system, the work on optimal commuting assignment allows us to define an additional optimum scenario, which is albeit theoretical but one which provides the ultimate benchmark for the various metrics. Thus, optimization provides a useful best option as a reference scenario in the mix of scenarios under consideration. The sustainability metrics provide simple visualizations based on a robust sustainability framework. When applied to each of the urban scenarios under consideration they generate a consistent, and well-founded, basis for making a choice between scenarios.

Assumptions may be changed and included in the assessment model. For example, the zonal preference functions may take on steeper or shallow gradients to reflect trends towards a more minimization behavior or a more maximization before, respectively, to reflect mobility assumptions (such as higher petrol prices or road pricing scenarios). Future modal splits for the journey to work may be assumed or modeled as a function of urban density and car ownership, using, for example in the case of metropolitan Sydney, the regression techniques developed by Suthayana and Black (2001).

There are two levels of application of this model in providing an evidence basis to the proposed and optimal scenarios. Each scenario, present and future can be subject to detailed study and modeling of the interactions between the Urban System, policy package, free-market influences and community responses to generate the preference functions and sustainability metrics. This can be a robust, but time consuming and costly, exercise that still requires sizeable assumptions on both the characteristics and responses in trend breaking scenarios. A second level of application is to use the modeling to provide strategic scans of scenario performance. The proposition here is to use the collective relationship experience between known preference functions, sustainability metrics and the urban system/policy package characteristics that drive them. Using these relationships to provide expected performance ranges for different urban system and policy package typologies, proposed scenarios can be analyzed more simply. While downstream detailed assessment may still be required, this initial assessment could be sufficient enable a high level of confidence in the scenario selection and lower the risk of making the wrong scenario choice.

THE URBAN SUSTAINABILITY FRAMEWORK

A key to sustainability in cities is that three pillars of environmental sustainability (stewardship), social equity and economic efficiency work together (United Nations, 2002). Sustainable performance requires all three pillars to achieve complementary outcomes rather than competing outcomes. Urban form, transportation and interactions with communities, is central to the question of sustainability in cities. Understanding of interactions between urban form, transportation and community are essential for meaningful interpretation of performance of the three pillars of sustainability. A challenge for researchers is to provide methodology that is not only objective but able to be simply and meaningfully understood, and used, by the community and governments. Our integrated model is a response to this challenge.

The "Urban System" is the physical aspect of the framework shown in Figure 2, consisting of the "Urban Form" and "Transportation" elements which define the spatial configuration of the city. Intentional changes to the "Urban System" can be viewed as strategic instruments that enable governments to have some levers to shape how the city functions. Response of the community to the "Urban System" produces interactions that result in selection of location of residence and workplace, industry and trips and so on. These interactions that have a time dimension are collectively known as "Urban Dynamics". The resulting "Urban Dynamics" outcomes generate the sustainability performance in terms of the three pillars included as elements in Figure 2. Each pillar has a feedback to the "Urban Dynamics" and consequently to the "Urban System" (indicated by the double headed arrows in Figure 2).

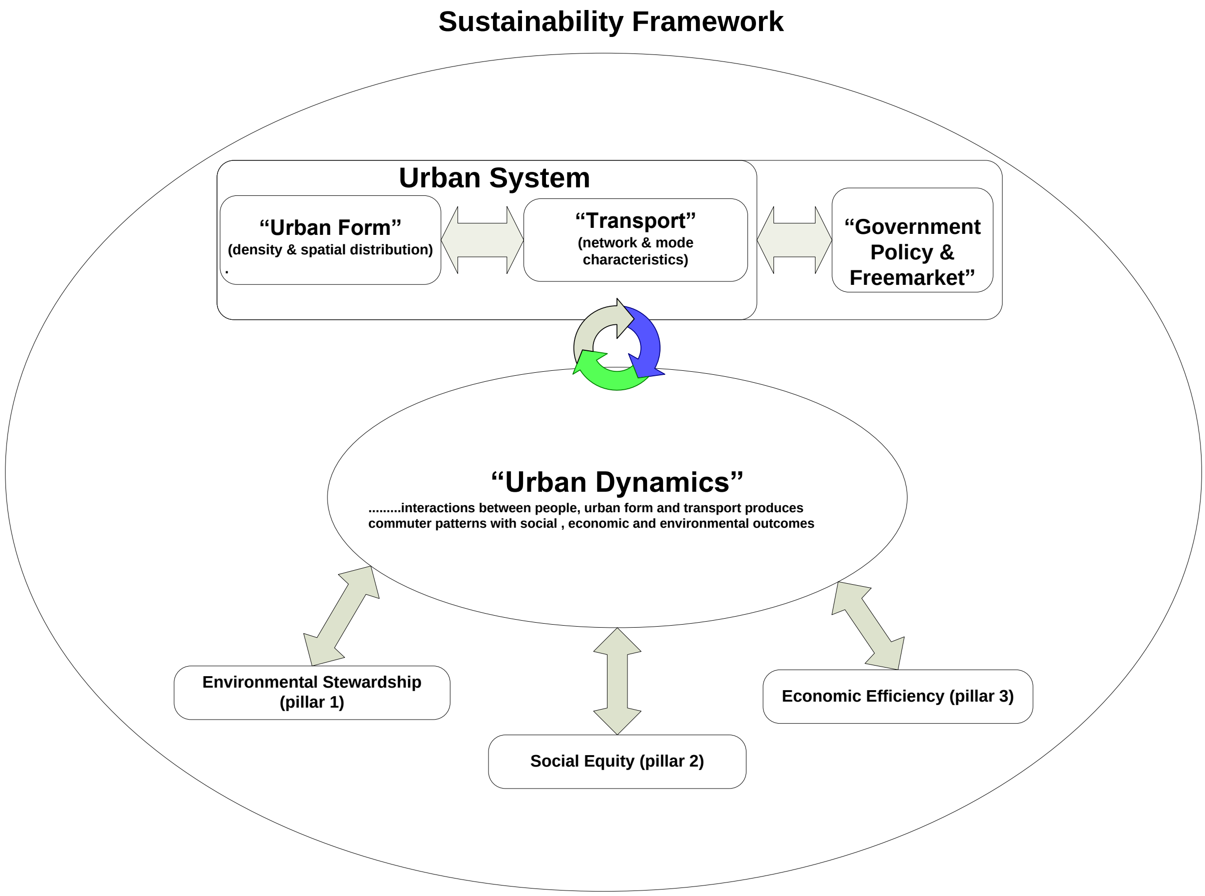

Figure 2 – The Urban "Sustainability Framework"

(Source: Doust, 2008, Figure 4.1, p. 136)

Other strategic instruments that influence the Urban Dynamics are the non asset policies such as pricing, parking restrictions and tax deduction incentives. These types of instruments can form part of the policy packages developed through the backcasting process. Underpinning this framework, methods based on the traditional Transportation Planning Models (TPM) and Integrated Land Use Transportation Models (ILUTM) and methodologies remain the strongest building blocks for a quantitative methodology for assessing the sustainability of cities, coupled with GIS visualization.

A particular strength of using the sustainability framework and the metrics discussed in the next sections is that they are derived from data sets that have been commonly used by planners for many years. These are commonplace amongst transport and city planning departments. With these inputs and the assistance of readily available GIS-Transportation software, all of the urban dynamics and sustainability metrics are able to be derived. The sustainability framework enables the holistic picture of sustainability to be maintained during the assessment process. With this analytical basis all the visualizations used in our model have traceability back through the algorithms to the source inputs. This is a particular strength when checking results, making scenarios changes and applying different planning instruments. We now describe in more functional detail each of the metrics starting with the preference functions.

SUSTAINABILITY PREFERENCE FUNCTION METRICS

In the long term, we need to model the change in travel behavior induced by the policy packages that might have emerged during the backcasting process. We can do this by changes in the shape of preference functions. The intervening opportunities model assumes that trip making is not explicitly related to distance, nor to travel time but to the relative accessibility of opportunities for satisfying the objective of the trip. Stouffer's theory, developed in the 1940s, was made into an operational transport model by Ruiter (1969) who gives a detailed mathematical exposition, together with calibration procedures. One of the first comprehensive land-use and transportation studies of the 1950s, the Chicago Area Transportation Study (CATS), applied this model for trip distribution estimation and forecasts. A general notation for the intervening opportunities model is shown below:

$$T_{ij} = T_{i}.(e^{-LT} - e^{-LT(T + Tj)})$$

Where,

T_{ij} = estimate of the number of journey to work trips from zone i to j

T = trip destination opportunities closer to zone i than those in zone j

T_i = trip end opportunities in zone i

T_j = trip end opportunities in zone j

L = probability that any destination opportunity will be chosen

Conceptually, the raw preference function that we refer to in this paper is simply the inverse of Stouffer's intervening opportunities theory that relates the proportion of migrants or travelers continuing given reaching various proportions of the opportunities reached. More technically correct, this is the L-factor parameter in the intervening opportunities model of trip distribution (Ruiter, 1969). In transport analysis, a preference function is an aggregate of the travel behavioral response by a zonal grouping given a particular opportunity surface surrounding those travelers. To improve curve fitting of the preference function (or the L-factor line) for modeling purposes, the shape of the observed preference function can be transformed as a linear-natural logarithm function, as a quadratic function, or as a power function.

The estimation of the shape of the zonal preference functions requires data for the zonal number of resident workers, the zonal number of job opportunities, the origin-destination pattern of traffic, and the inter-zonal transport impedance matrix (distance, travel time, or generalized cost). Typically, such information may be extracted from the Census journey to work (JTW) data. Preference functions can be constructed from the residential zone where the opportunity surface is access to jobs, or from the employment zone where the opportunity surface is access to spatial labor markets. For example, the estimation of the raw preference function in a residential location is set out in the following five steps. (1) Destination zones are ranked in order of increasing distance from the origin zone. (2) The cumulative number of jobs is calculated at increasing distance from the origin zone, and these are expressed as a proportion of the metropolitan total. (3) From the OD data, the numbers of jobs with destinations at increasing distance from the origin zone are set out. (4) The OD flows are expressed as a proportion by destination of the total zonal trip productions. (5) Finally, the proportions of the raw data are plotted as a graph (Figure 3).

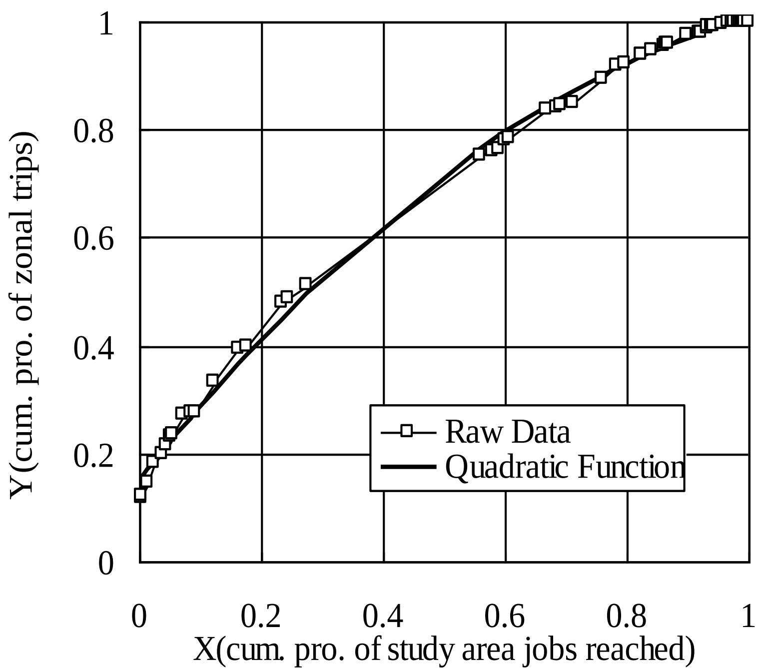

Figure 3 – Example of raw preference function and curve fitting

To illustrate the shape of these preference functions we draw on previously published research. We note that for inner, middle and outer areas across Australian cities there are marked differences in the slopes of these preference functions. Using Australian Bureau of Statistics 2001 Census Journey to

Work (JTW) origin-destination trip matrix datasets for Sydney and Canberra, and distance matrices based on strategic network models, the shapes of the preference function for selected inner, middle and outer areas for Sydney and Canberra are shown in Figure 4.

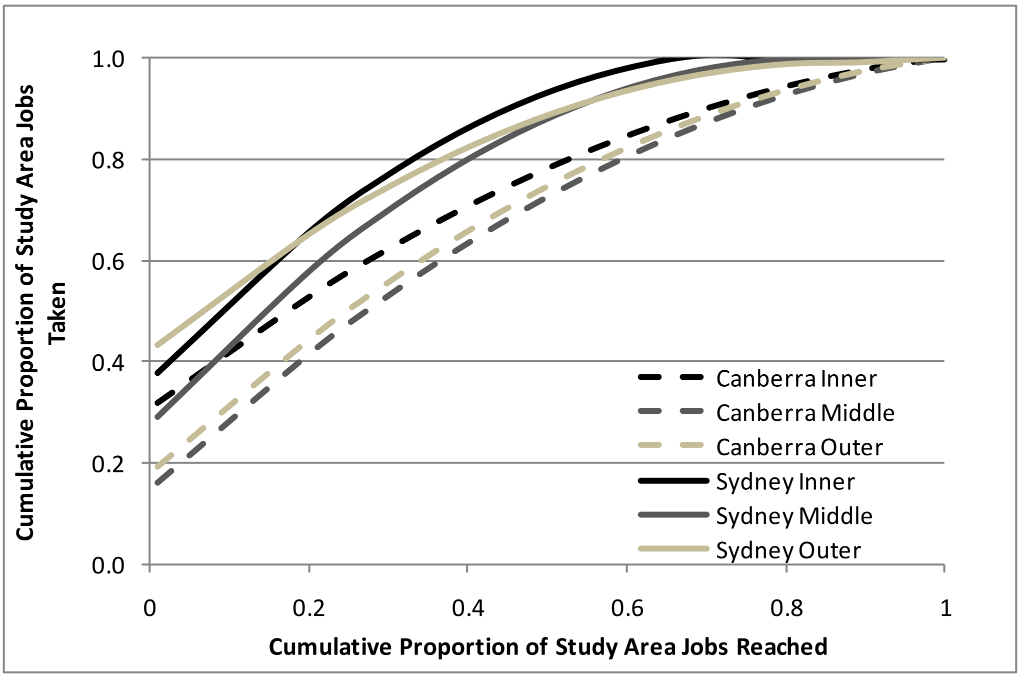

Figure 4 – Residential Preference Functions for Sydney and Canberra Areas

Overall, the Sydney Inner areas (which consists of the CBD, North Sydney and South Sydney in this case study) represent the best distance minimization characteristics. It shows that nearly 40% of the workforce takes up job opportunities located in its own local governmental area, and almost all the workforce take up work opportunities when 60% of all jobs are reached. The Sydney Outer areas (e.g. Blacktown, Penrith, Campbelltown and Liverpool) also present good distance minimization characteristics, with slightly more than 40% of the workforce take up job opportunities locally. This is not surprising as these outer suburbs are employment centers themselves. Its function follows a similar shape compared to the Sydney Inner function but with a relatively higher number of workforce seeking longer commutes.

It is interesting to observe that the Sydney Middle areas (e.g. Parramatta, Ryde, Randwick and Leichhardt) are less sustainable compared to the inner and outer areas of Sydney. A possible explanation is that these areas are usually situated between the Sydney CBD and outer centers and their workforce have options to commute either way, but make longer commuting journeys.

Unlike Sydney, which has medium to high-density polycentric employment centres, Canberra's employment opportunities are located in a more scattered manner across a low density landscape punctuated by much open space as befits a garden city with the distinct towns connected by excellent roads. Canberra commuters are predominantly car travelers. These characteristics are reflected in the preference function plots as they are less sustainable (i.e. distance maximization) when compared to their Sydney equivalences. Interestingly, and like the Sydney case study, the inner areas of Canberra presents a better distance minimization preference function compared to its middle and outer areas. This is followed by the outer suburbs and lastly, middle suburbs.

The above preference function case study illustrates how different areas within a city perform in terms of sustainable journey-to-work travel. The size of the city, its transport system and technology, distribution of residential and employment centers and many other factors influence the commuting patterns and the shape of their preference functions (see, for example, Masuya and Black, 2007). For instance, a high density polycentric city such as Sydney encourages a higher level of sustainable travel (i.e. distance minimization) compared to a more dispersed and low-density city like Canberra. High density inner city areas present a higher level of sustainable travel compared to middle and outer areas. Early research has confirmed the role of transport system technology and performance in the shape of these preference functions observed in any city (Black, et al, 1993). For Shanghai in 1985, where walking, and cycling once were the dominant modes for the journey to work in a very high density city, preference functions had steep gradients. Sapporo, Japan, on the other hand, had an excellent road system and an efficient subway network and its preference functions had a much more pronounced shallow gradient.

It is also important to understand the changes to the shape of the preference functions over time (i.e. whether the city is becoming more or less sustainable in terms of its travel pattern), which requires time series datasets, (as reported in Black, et al, 1993). Preference function analyzes of datasets from other cities across the world will be valuable in order to establish robust preference function metrics, especially for scenario building and assessment in data poor case study areas.

ENVIRONMENTAL/SOCIAL/ECONOMIC SUSTAINABILITY METRICS

The sustainability metric methodology of the model is designed to estimate the triple bottom line metrics of economic, social and environmental performance of residential and workplace locations and associated travel (Doust and Black, 2009) of those desirable long-term scenarios. The methodology could be applied to track the economic, social and environmental trajectories of land-use and transport system scenario and the actions anticipated from policy packages developed from the backcasting.

In modeling this system, accessibility to land-use activities (as operationalized by the Hansen model of potential accessibility – see, Black, 1977; Black, 1981, Chapter 1), is an approach that brings the sustainability performance of the three pillars together, providing a mechanism to visualize the complementary performance in addition to the individual performance of the three pillars of sustainability.

An ideal planning goal for sustainable urban development is to have high accessibility with a low environmental footprint. A city's sustainability performance in relation to this goal can be analytically quantified and simply visualized in plots on what we call the "environmental sustainability-accessibility space" (Figure 5).

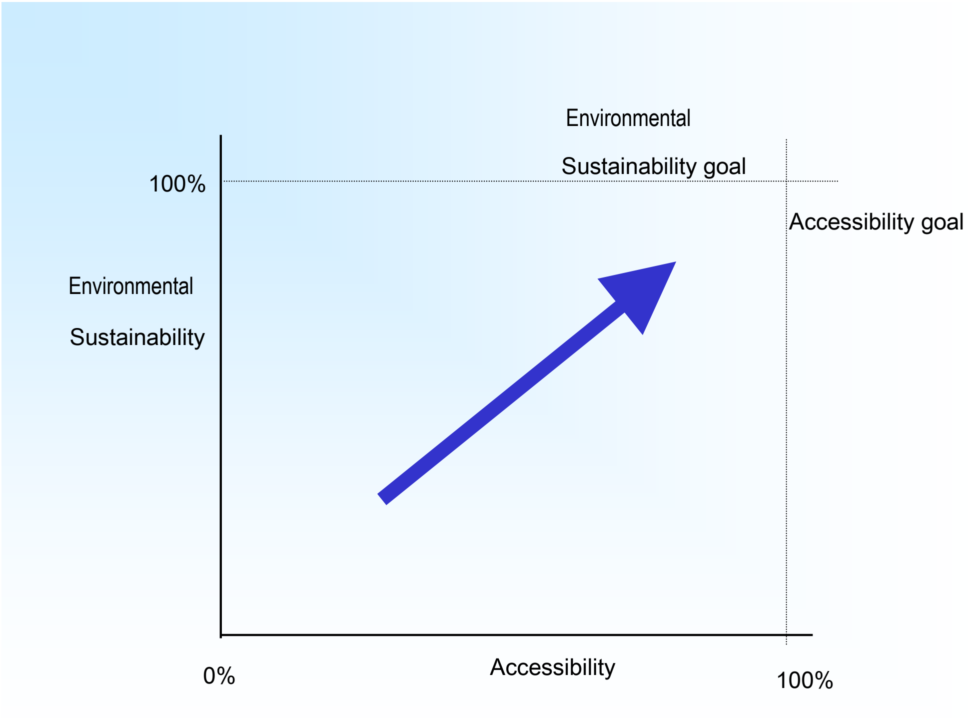

Figure 5 – Environmental Sustainability - Accessibility Space

(Source: Doust, 2008, Figure 4.2, p.138)

This figure refers to "Sustainability" as meaning environmental sustainability (stewardship) and "Accessibility" as meaning accessibility of workers to places of employment, shopping schools and, so on, or, alternatively, meaning accessibility of employment to workers – the spatial labor market. For either type of accessibility (worker or employment, for example), the figure shows that the environmental sustainability performance on the ordinate can be plotted with the corresponding accessibility performance on the abscissa for any pair of land-use zones where interaction takes place. The concept enables both a quantifiable measure and a visual representation of the mutual performance. A goal or target for environmental sustainability and accessibility is also able to be applied and visually represented in the same space. The 100% goal position may vary depending on the relative weighting or priority of the two pillars.

The two dimensional environmental sustainability-accessibility space has a parallel to the geographical information system (GIS) for geographic space. In geographic space, spatial disaggregation enables a visual appreciation, for example, of land-use distribution. In the environmental sustainability-accessibility space, the spatial disaggregation enables a visual appreciation of the sustainability performance distribution. For example, the sustainability distribution for land-use zone pairs in a city. The environmental sustainability measure adopted is the inverse urban CO_2-e measure. Units are (grams of $CO_2)^{-1}$.

Existing building block methods (Hansen measures of potential accessibility) for measuring accessibility from residential original zones to places of employment and accessibility from places of employment to labor markets provided the foundation to ensure quantifiable and traceability in the metrics. Accessibility to jobs is one measure of social equity. Accessibility to the labor force for an industry is a measure of economic efficiency. Environmental sustainability can be defined with many different measures, but to illustrate the general approach a CO_2 equivalent (CO_2-e) was adopted that includes both energy embodied in transportation construction and maintenance, and in the energy consumed in making the journey by automobile. The steps are shown in Figure 6 to develop the metrics with authentic data that would be readily available in metropolitan regions of the world. An example of its application to Sydney can be found in Doust and Black (2009).

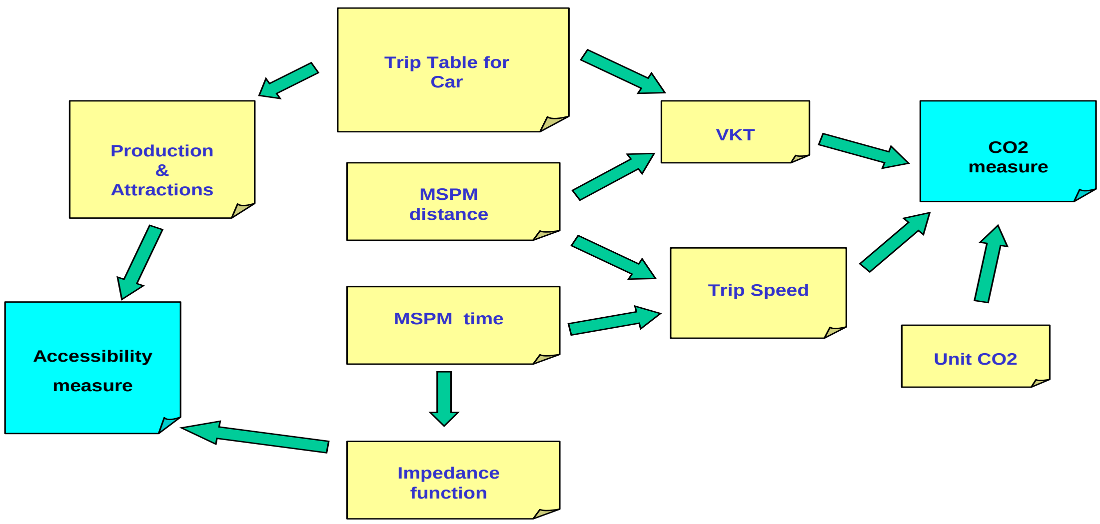

Figure 6 – Flow Diagram for Accessibility Measures and Environmental Sustainability Measures Estimations for Road Based Carbon Dioxide Emissions

(Source: Doust, 2008, Figure 4.7, p. 154)

FORMULATION OF OPTIMAL COMMUTING ASSIGNMENT SCENARIO

Finally, we show how an optimal scenario might be constructed to provide a reference point for other plausible scenarios. We have formulated a mathematical model to minimize the total amount of travel in distance in the city considering the preference function of journey-to-work travel by applying the optimal commuting assignment problem. The model is formulated

as a non-linear mathematical problem that includes the quadratic models of the travel preference functions. The minimization problem is subject to the land-use constraints being satisfied that the number of work trips generated by each residential zone equals the number of resident workers living there, and that the number of work trips attracted to each employment zone equals the number of jobs located there. An additional constraint is that inter-zonal trip flows are non-negative.

The raw zonal preference functions are derived from data for the zonal number of resident workers, the zonal number of job opportunities, the origin-destination pattern of traffic (OD traffic pattern), and the inter-zonal distances. Quadratic functions are then fitted to these zonal preference functions. The variation of job opportunities by re-locating employment makes the ratio of number of jobs (ug^{a}_{i}). As a result, the ratio of number of journey-to-work trips from zone i to k-th zone in zone i is changed from f^{a}_{ik} to f^{b}_{ik} by the change in ug^{a}_{ik} from ug^{b}_{ik} as shown in Figure 7.

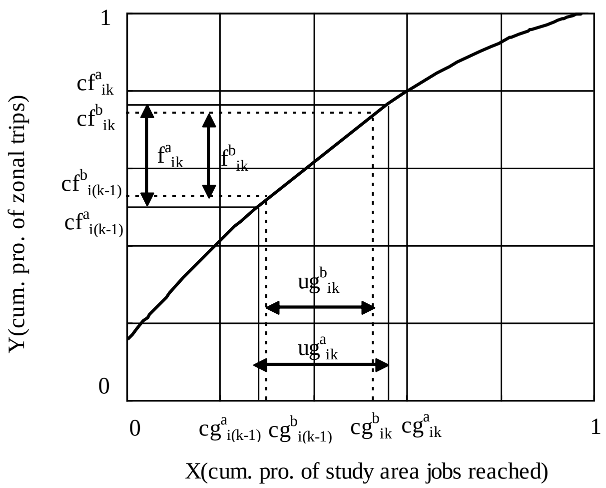

Figure 7 – Ratio of number of journey-to-work trips after re-location of employment

Traffic generated from residential land uses and traffic attracted to employment zones forms the journey-to-work patterns in urban areas and contributes the most to person kilometers of travel. The journey-to-work trip length depends on the urban structure with its distinctive land-use pattern (spatial distribution of residential and employment zones) and the travel behavior of these commuters. The mathematical model is formulated to minimize the least possible overall amount of travel in distance in the city considering the preference function of commuters in their journey-to-work travel by applying the optimal commuting assignment problem. This minimization model is formulated as a non-linear mathematical problem that includes the quadratic models of the preference functions (Equations (1) – (17), below).

$\sum_{i=1}^{n} F_i^a = T$		(1)
$F_i^a = F_i^b + \Delta F_i$	$(i = 1,\cdots,n)$	(2)
ΔF_i : *free variable*	$(i = 1,\cdots,n)$	(3)
$\sum_{i=1}^{n} \Delta F_i = 0$		(4)
$\Delta F_i^L \le \Delta F_i \le \Delta F_i^U$	$(i = 1,\cdots,n)$	(5)
$\sum_{i=1}^{n} G_i^a = T$		(6)
$G_i^a = G_i^b + \Delta G_i$	$(i = 1,\cdots,n)$	(7)
ΔG_i : *free variable*	$(i = 1,\cdots,n)$	(8)
$\sum_{i=1}^{n} \Delta G_i = 0$		(9)
$\Delta G_i^L \le \Delta G_i \le \Delta G_i^U$	$(i = 1,\cdots,n)$	(10)
$ug_i^a = G_i^a / T$	$(i = 1,\cdots,n)$	(11)
$cg_{ik}^a = cg_{i(k-1)}^a + ug_{ik}^a$	$(i = 1,\cdots,n)\ (k = 1,\cdots,n)$	(12)
$cf_{i(k-1)}^a = a_i {cg_{i(k-1)}^a}^2 + b_i cg_{i(k-1)}^a + c_i$	$(i = 1,\cdots,n)\ (k = 1,\cdots,n)$	(13)
$cf_{ik}^a = a_i {cg_{ik}^a}^2 + b_i cg_{ik}^a + c_i$	$(i = 1,\cdots,n)\ (k = 1,\cdots,n)$	(14)
$f_{ik}^a = cf_{ik}^a - cf_{i(k-1)}^a$	$(i = 1,\cdots,n)\ (k = 1,\cdots,n)$	(15)
$X_{ik}^a = F_i^a \cdot f_{ik}^a$		(16)
$\sum_{i=1}^{n}\sum_{k=1}^{n} X_{ik}^a d_{ik}$: *min*		(17)

Where

F_i^b, F_i^a :	number of resident workers living in zone i before and after implementation of re-location of residence respectively
ΔF_i :	variation of number of workers in zone i (free variable)
T :	total number of trips
$\Delta F_i^L, \Delta F_i^U$:	lower and upper limit of number of variation of workers in zone i respectively
G_i^b, G_i^a :	number of jobs located in zone i before and after implementation of re-location of employment respectively
ΔG_i :	variation of number of jobs in zone i (free variable)
$\Delta G_i^L, \Delta G_i^U$:	lower and upper limit of variation of number of jobs in zone i respectively
ug_i^a :	ratio of number of jobs in zone i after implementation of re-location of employment
ug_{ik}^a, cg_{ik}^a :	ratio and cumulative ratio of number of jobs of k-th zone in zone i

	after implementation of re-location of employment respectively
$cf^{a}_{i(k-1)}, cf^{a}_{ik}$:	cumulative ratio of k-th and (k-1)-th zone in zone i based on regression coefficient and regression constant of quadratic function respectively
f^{a}_{ik} :	ratio of number of journey-to-work trips from zone i to k-th zone in zone i after implementation of re-location of employment
X^{a}_{ik} :	number of journey-to-work trips from zone i to k-th zone in zone i after implementation of re-location of employment
d_{ik} :	distance from zone i to k
a_i, b_i, c_i :	regression coefficient and regression constant of preference function in zone i respectively

Equations (1) and (6) refer to the land-use constraints being satisfied that the sum of the number of resident workers living or jobs located in each zones equals the total number of jobs. Equations (2) and (7) represent the relationships between the number of resident workers living or jobs located in each zones before and after implementation of re-location of employment. Equations (4) and (9) also represent the constraint with respect to the sum of the variations of number of resident workers or jobs in each zone. Equations (11) and (12) refer to the ratio, and cumulative ratio, of the number of jobs after implementation of re-location of employment in each OD pair. Equations (13) - (16) also refer to the number of journey-to-work trips after the implementation of re-location of employment including the quadratic models of the preference functions. The number of jobs and the number of journey-to-work trips can be calculated as a problem of minimizing the total amount of travel in terms of distance in Eqn. (17) under Eqn. (1) - (16) as the constraint equations.

CONCLUSIONS

There is renewed interest amongst researchers in visioning that helps create future scenarios and backcasting to help devise policies and actions to achieve more sustainable cities and transport. The logic underpinning our land-use and transport assessment model (Figure 1) is that strategic scans of the performance of each scenario is needed to help choose the most desirable future (including optimization as one of the potential scenarios). Our sustainability framework (Figure 2) enables the metrics for such an assessment of the best scenario, as shown on the right hand side of the flow diagram in Figure 1. They include: a preference function that represents spatial characteristics of the journey from home to work based on the intervening opportunity model; accessibility properties of the urban system; and greenhouse gas emissions related to road transport. All of these metrics have been subject to empirical investigations in various cities of Australasia, as published in peer review papers.

In the case of data poor case study cities, and the application of the proposed assessment model, resort must be made to typologies of relevant cities where such information is available to assist in the formulation of appropriate scenarios for that particular city. Again, the metrics that we propose can be applied too in this situation. The significance of this approach is that it becomes a valuable tool for stakeholders and their consultants in developing countries where international agencies offering aid money for transport infrastructure are attempting to forge policies and strategies to make developing cities more sustainable. A promising area for future research, and one that would benefit from international collaboration much along the lines of the APEC-TR project funded by the Eastern Asia Society for Transportation Studies (Alpkokin, et al, 2008) would be the building of case studies to form the typologies shown in Figure 1. The comparison of journey to work preference functions based on both cross sectional and time series data would be an important start.

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