Visual Sustainability Metrics : A Community Discussion And Decision Making Tool.

Ken.Doust[1], John Black[2]
[1] University of NSW, Sydney, NSW, Australia & also Senior Consultant WS Atkins International, Sydney, NSW, Australia
[2] Emeritus Professor, University of NSW, Sydney, NSW, Australia

1 Introduction

Sustainability has become a fundamental expectation in our societies today. The experience of cities under stress with loss in environmental quality, liveability and numerous inequities has given communities an imperative to do things better and strive for values and a future vision that has collectively become known as sustainability. The reality of climate change we now face is imposing an overarching new timeframe for sustainability action.

Community and governments alike know the need for sustainability in our cities, however, how to measure sustainability performance remains a fundamental difficulty. This paper discusses assessment of sustainability in relation to transport within cities and offers some practical methods for engaging communities and other decision makers.

2 A Sustainability Context for Cities

To begin, it is useful to quickly visit the collective view on what sustainability is. The principal meaning of sustainability was identified in the three pillars of sustainable development in ground breaking work by the United Nations in the last decades of the 20th century. The pillars of environmental sustainability (or stewardship), social equity and economic efficiency are identified as embracing all aspects of sustainability (World Commission, 1987).

A key to sustainability in cities has been identified as all three pillars of environmental sustainability (stewardship), social equity and economic efficiency working together. Therefore an effective sustainability performance requires all three pillars to achieve complementary outcomes rather than simply individual outcomes. A most significant influencer of sustainability is the urban form, the transport characteristics and the interactions between these and the communities they support. Outcomes of these urban dynamics shape the sustainability performance of a city, which in turn can feedback to reshape the urban dynamics. Furthermore, the outcomes of these urban dynamics can feedback to affect the characteristics of the urban form and transport elements themselves.

Community involvement in shaping sustainability strategy is often through participation in visioning and goals setting. However, when it comes to the question of which scenario should be selected, there is little scope for community to confidently help shape the choice. Without quantifiable assessment methods, the connection between scenarios and sustainability outcomes are extremely subjective to the point where little benefit may come from public discussion. Improving the visibility of these connections for community and decision makers alike would increase the opportunity for better choices.

The key challenge is to add a holistic assessment framework, methodologies to better understand urban dynamics, the drivers that produce sustainability performance and to objectively measure the performance of all three pillars of sustainability. A particular challenge is to not only fill the sustainability assessment methodology gap, but to provide methodologies and tools that are able to be simply and meaningfully understood.

3 Visual Metrics in a Sustainability Framework

In a new approach to sustainability analysis (Doust, 2008), a sustainability framework is formulated to bring not only the three pillars of sustainability together, but also a holistic consideration of the urban system, the urban dynamics and the resulting sustainability performance. Figure 1.1 summarises the framework, showing the interconnection between the urban system elements, the urban dynamics and identifying the three pillars of sustainability. This framework lays out the frame points for ensuring that the systems elements and interactions that drive the sustainability performance of the city are visible and measured.

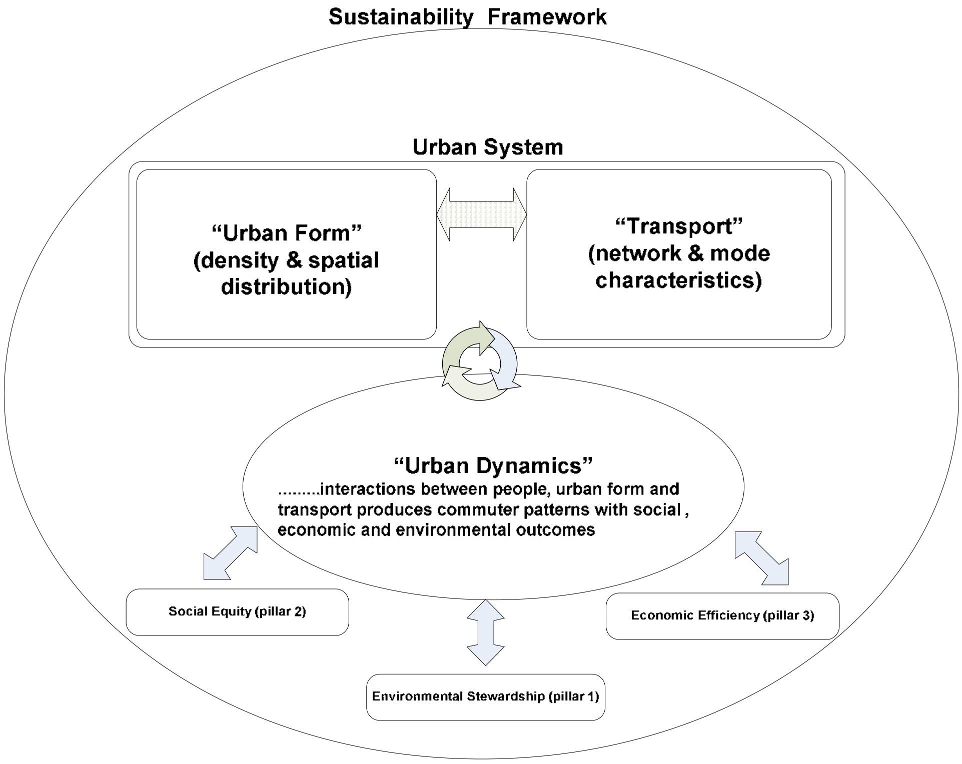


Figure 1.1 The urban "sustainability framework"

The "Urban System" is the physical aspect of the framework, consisting of the "Urban Form" and "Transport" elements which define the structural configuration of the city. Interaction between these two elements shows their interdependencies. "Urban Form" is characterised by density and spatial distribution of land-use. "Transport" on the other hand is characterised by the transport network spatial layout and the specific mode characteristics.

The system function is to provide for the needs of the community (including industry). 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 are collectively known as "Urban Dynamics". It is an iterative process as indicated by the circular arrow having feedback effect between each element. The resulting “Urban Dynamics” outcomes generate the sustainability performance in terms of the three pillars included as elements in Figure 1.1. Each pillar has a feedback to the “Urban Dynamics” and consequently the “Urban System”. This is indicated by the double headed arrows in the figure.

Existing visualisation methods using GIS and graphical displays illustrate the value of visual metrics in communicating urban dynamic outcomes and sustainability performance. Visualisation using GIS techniques is proving to be effective in displaying complex information in a simple but meaningful way as illustrated in Figure1.2.

Sydney, a global city with a history of planning policies since 1948 and a long running series of journey to work data sets was selected to case study test these techniques. Trips to and from work account for a significant proportion of the transport pressures on sustainability in cities and as such is a good subject for illustrating techniques in sustainability assessment.

Having developed a picture of the urban dynamics in the Sydney case study, sustainability metrics, using visualisations in “environmental sustainability – accessibility space” of a metric indicating the accessibility to jobs for workers from their place of residence were generated. Visualisations for measures of environmental sustainability and economic efficiency focused accessibility (the first and third pillars of sustainability) were also produced.

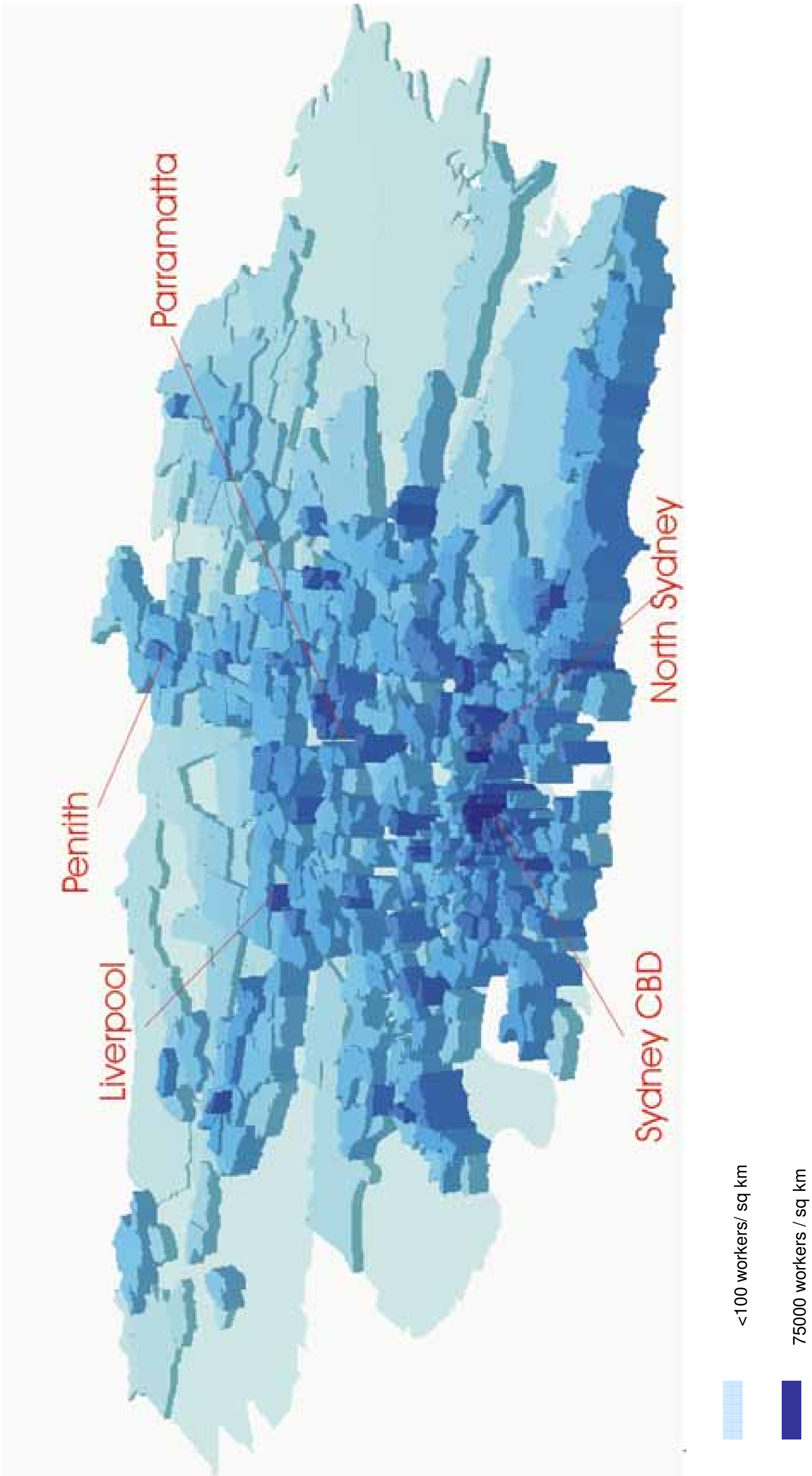


Figure 1.2 1981 to 2001 change in employment density

4 Visual Metrics of Sustainability Performance

Visualisation of metrics using GIS and graphical displays has been identified as a key approach in communication of urban dynamic outcomes and sustainability performance in a simple, meaningful way.

An approach to visual sustainability metrics has been developed based on the concept of a sustainability goal in “environmental sustainability – accessibility space”. Figure 1.3 illustrates this spatial concept and the idealised performance goal. A city’s sustainability performance in relation to the goal can be analytically quantified and simply visualised in plots for assessing the three pillars of sustainability in cities.

The environmental sustainability measure (Pillar1) can be formulated from many different parameters (e.g. traffic noise generated, ecological stress, particulate emissions, resource usage). For illustrative purposes a measure based on known fuel consumption of vehicles (see Cosgrove, 2003, p342) with speed was used to calculate CO_2-e footprints for motor vehicles. Detailed operational methods were developed (Doust, 2008, Chap 4) and applied to generate a quantifiable measure. Accessibility has been identified as a useful measure in social and economic aspects of sustainability (see Expert Group on the Urban Environment, 1996; Warren Centre for Advanced Engineering, 2003; Kachi, *et al.*, 2005; Kachi, *et al.,* 2007). Accessibility measures were derived (Doust, 2008, Chap 4) for each travel zone pair. Separate operational methods were developed to generate worker and employer focussed accessibility measures. These are measures that are relatable to social equity (Pillar 2) and economic efficiency (Pillar 3) respectively.

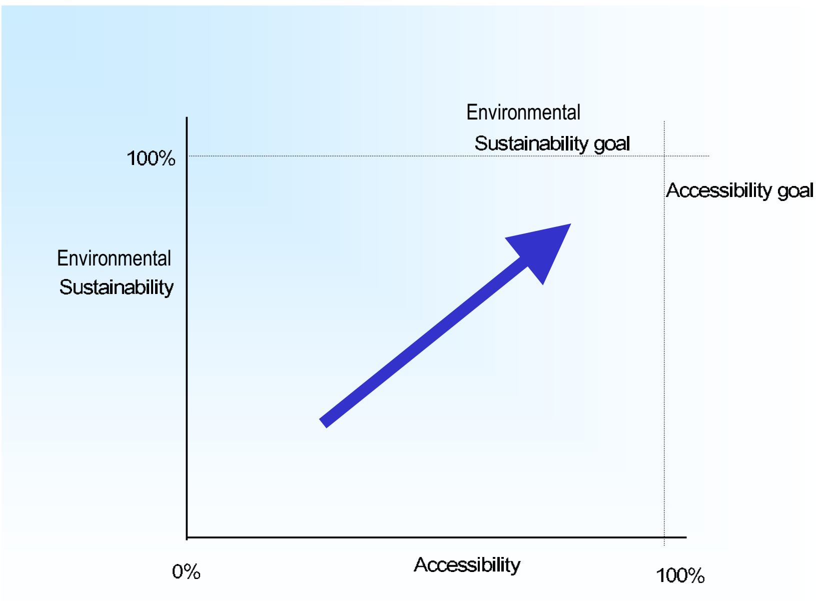
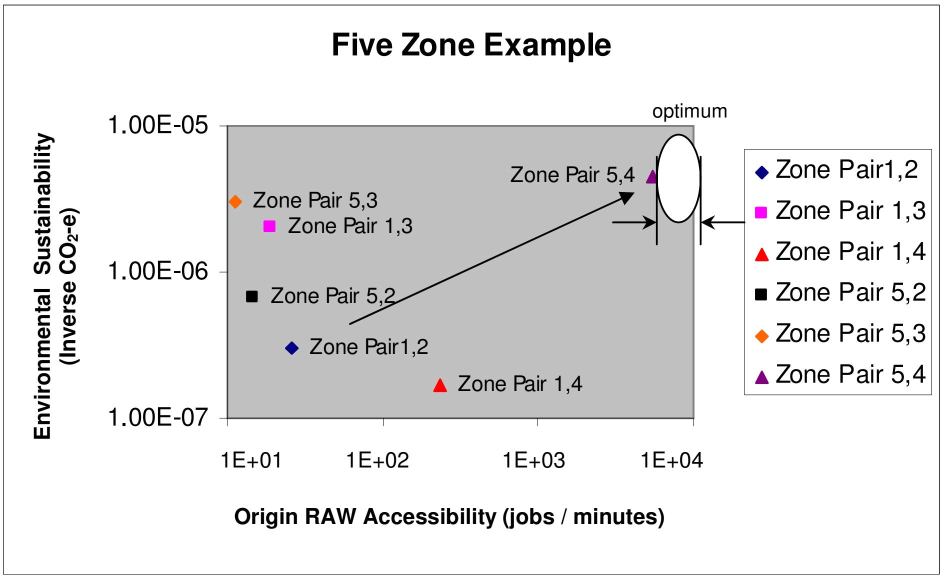


Figure 1.3 Environmental sustainability - accessibility space

The sustainability metrics developed were measures of environmental sustainability and accessibility in the form of scatter plot and prism map visualisations. These typologies were shown to indicate the sustainability performance characteristics for the three pillars of sustainability in terms of data set shape, frequency and spread in the “environmental sustainability – accessibility space”.

The following simple five zone example provides the fundamentals of the zone pairs. The scatter plot shown in Figure 1.4 shows the sustainability performance against the desirable trend in sustainability. A shift to the top right hand corner and a limited spread in accessibility is identified as the theorised optimum.



Notes:

1. Origin RAW Accessibility is defined as the accessibility to jobs at a destination zone (TZj) from an origin zone (TZi) calculated by dividing the total attractions from all origin zones to TZj by the transport impedance from TZi to TZj. Units are workers/ minutes, where workers are a proxy for jobs.
2. Environmental sustainability measure is defined as the inverse of CO_2 emissions from the total JTW trips between zone pairs, including an allocation of emissions from manufacture of vehicle and road infrastructure. This is calculated as a sum of the carbon dioxide equivalent (CO_2-e) per unit trip km at the average speed with the shortest path trip length and number of trips. The carbon dioxide equivalent (CO_2-e) is calculated as the sum of the quantity of greenhouse gas and the Global Warming Potential Index (AGO,2005,Appendix 3)

Figure 1.4 Environmental sustainability – “Raw” accessibility (Pillar3) goal

The metrics were able to be determined for large data sets for the Sydney case study (792 travel zones) by systematic analytical techniques using trip tables, network skims and car emission rates as inputs. These techniques have given the metrics a clear objective basis traceable to the source data. The visualisations although built from many thousands of pieces of data provided a simple representation giving a holistic view of the sustainability characteristics and trends. Figures 1.5 to 1.6 illustrate the scatter plot form of the visualisation.

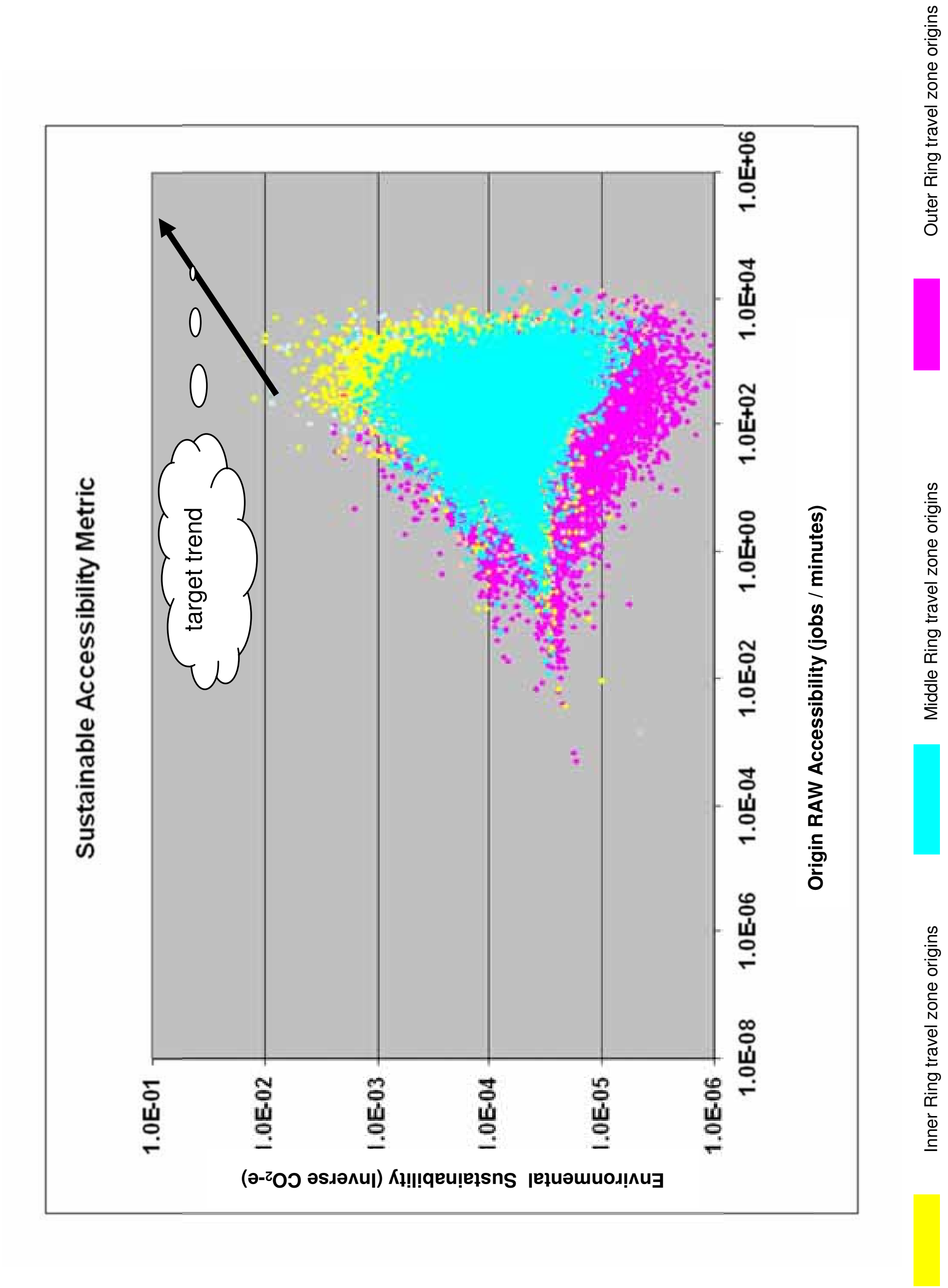


Figure 1.5 Scatter Plot form of sustainability performance of Inner , Middle and Outer Ring areas of Sydney in 2001

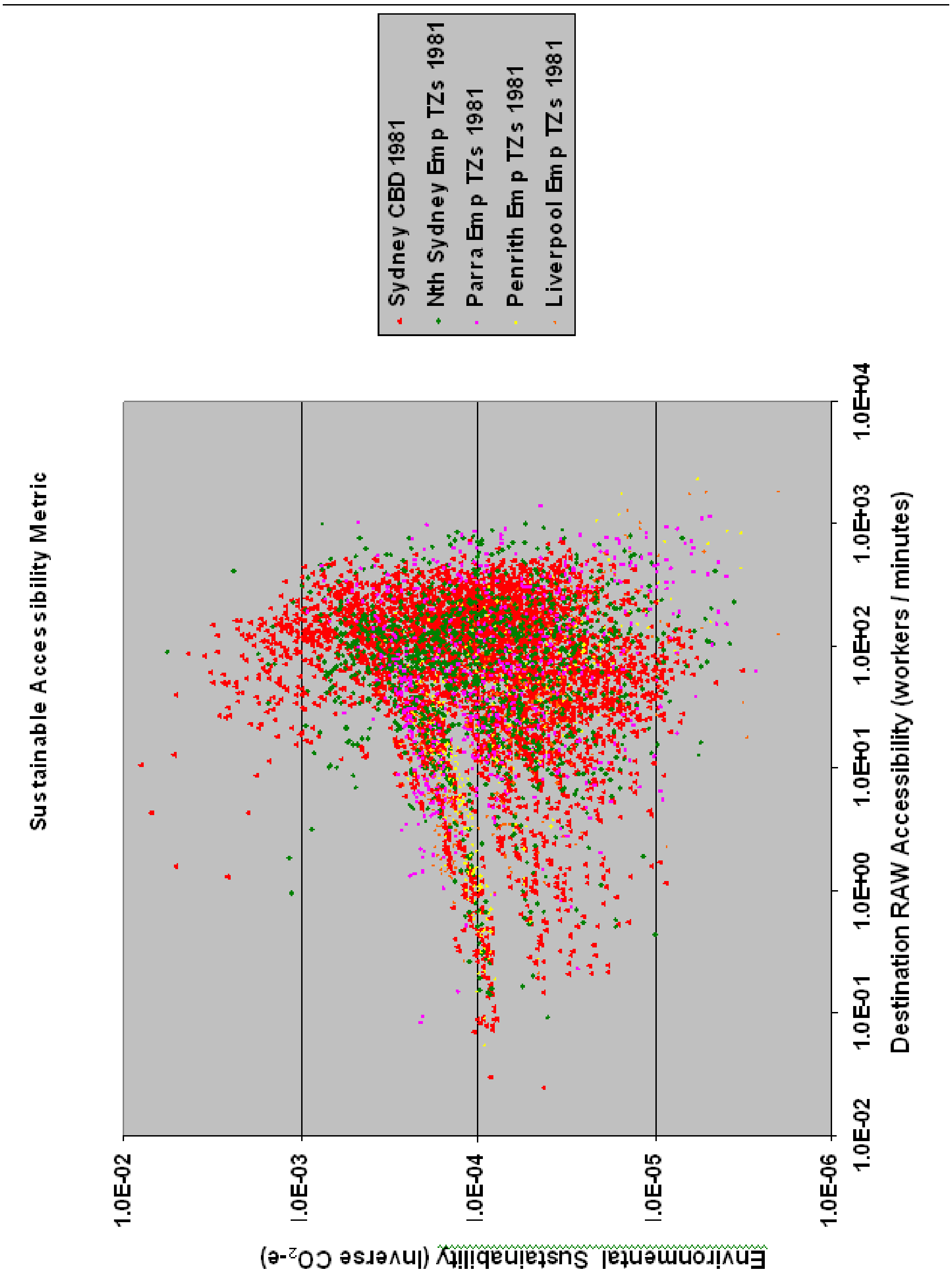
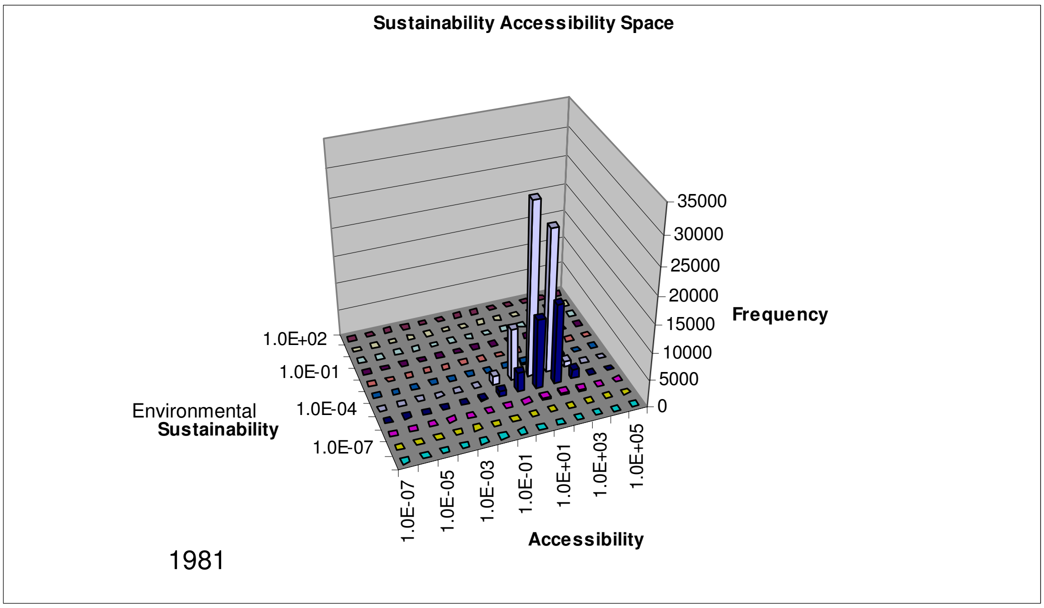


Figure 1.6 Scatter Plot form of sustainability performance of Sydney centres in 1981



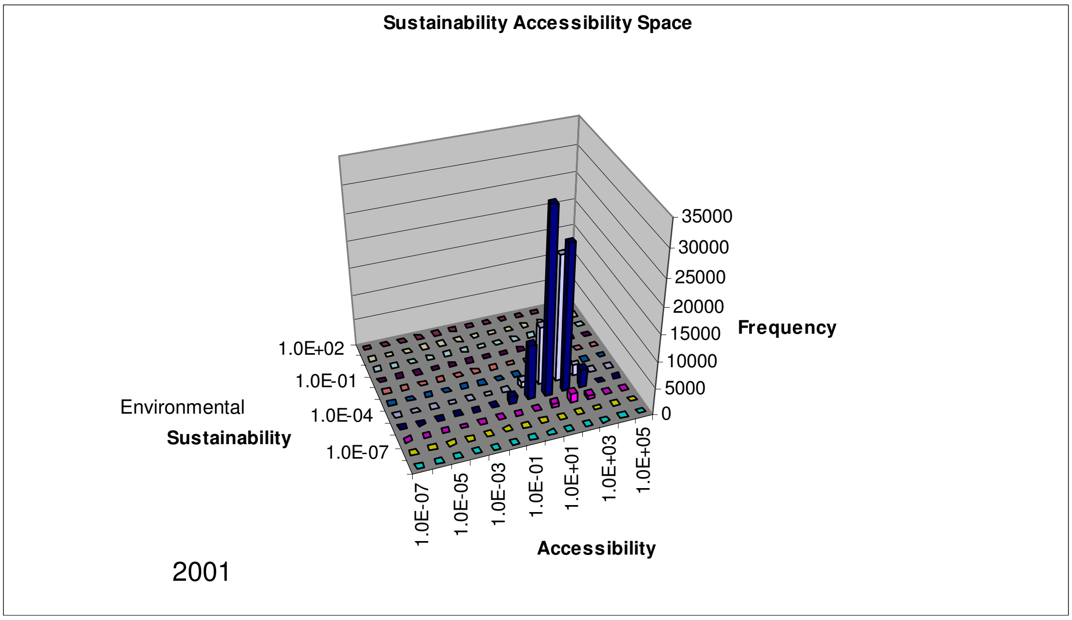


Figure 1.7 Comparison of prism map metrics 1981 and 2001

The richness of travel zone pairs in these sets makes it difficult to interpret the data within the sets from scatter plots, unlike the smaller sets where the internal patterns of the set is visible.

To give a greater degree of visualisation of the data sets, the “environmental sustainability – accessibility space” was divided into a grid. The grid overlays the log scales of the scatter plot, with each grid cell being one order of magnitude different to the environmental sustainability or accessibility cell next to it.

By counting the number of travel zone pairs that are positioned within grid cells, a visualisation is produced that summarises the concentration of points in the scatter plots. These are shown in Figure 1.7 as a prism map of the frequency in “environmental sustainability – accessibility space” for each of the sets. Through these three dimensional visualisations of the data sets, a number of differences between each set become visible.

An increase from 1981 to 2001 in the number of travel zone pairs in the bins with lower environmental sustainability indicates a shift away from the target direction. In particular an increase in the number of travel zone pairs with lower environmental sustainability values increases the frequency counts of the $1e^{-7}$ to $1e^{-6}$ and $1e^{-6}$ to $1e^{-5}$ bins from 1981 to 2001.

In summary it was found that the scatter plots provide the raw point to point spatial location and spatial distribution of the data sets, however they have the disadvantage that trends in internal travel zone pairs are swamped by detail when more than 20,000 travel zone pairs are in the set. The overlay of environmental sustainability – accessibility grid bins and the frequency count of travel zone pairs for each bin, enables these internal trends to be clearly seen through the prism map.

The grid concept can be further likened to a risk matrix allowing each zone pair to be assigned a sustainability risk rating. This sustainability risk rating can then be replotted back onto geographic space using GIS. Figure 1.8 to 1.10 illustrates the visual effectiveness of this technique.

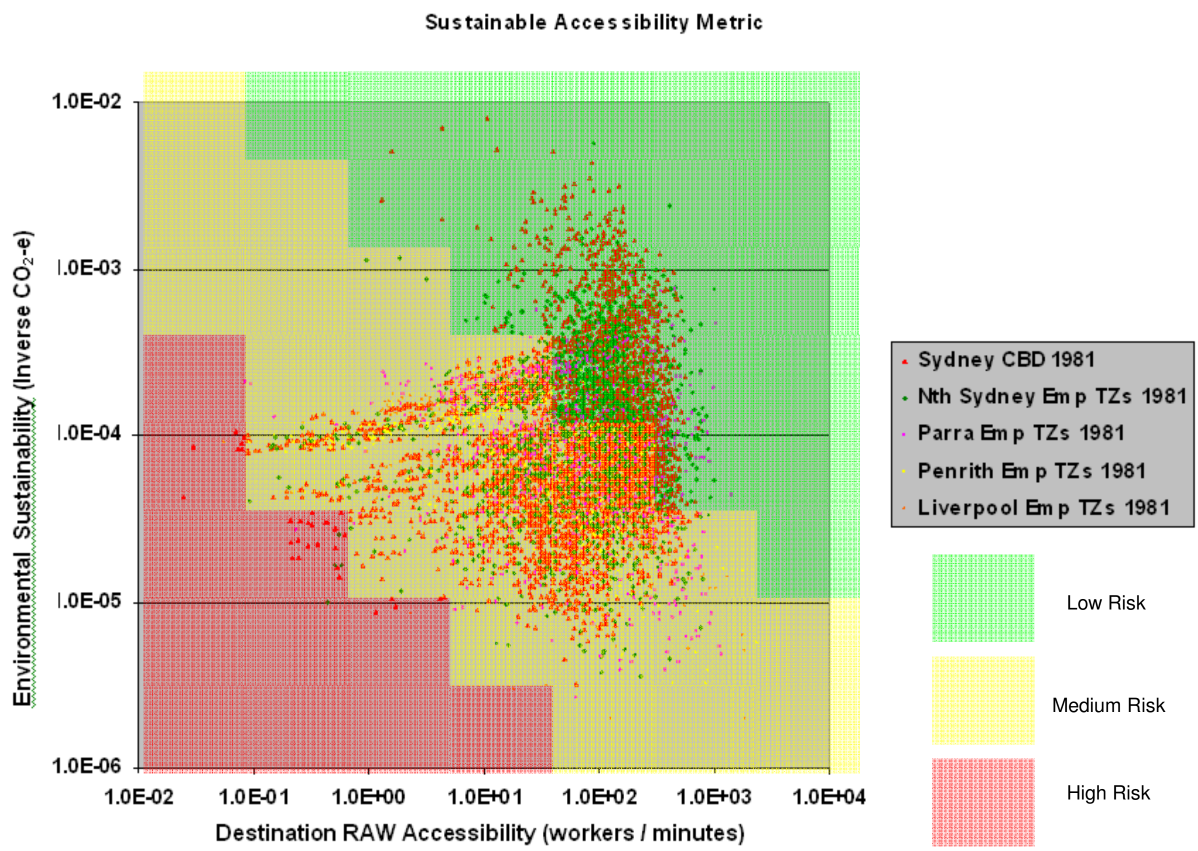


Figure 1.8 Sustainability Risk matrix

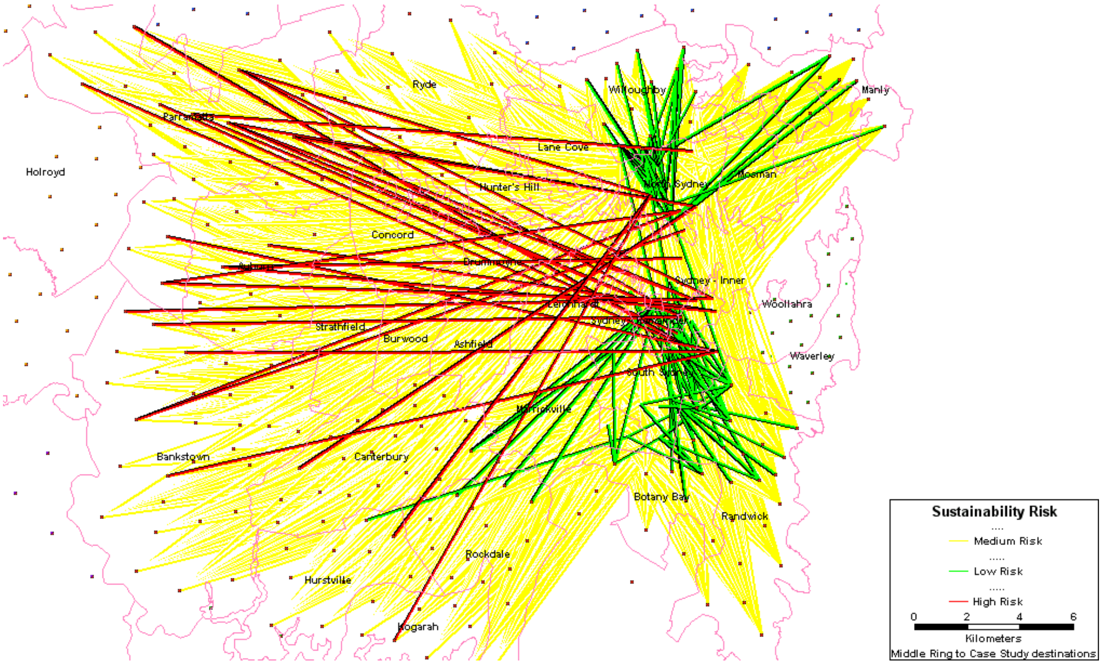


Figure 1.9   Sustainability Risk GIS plot

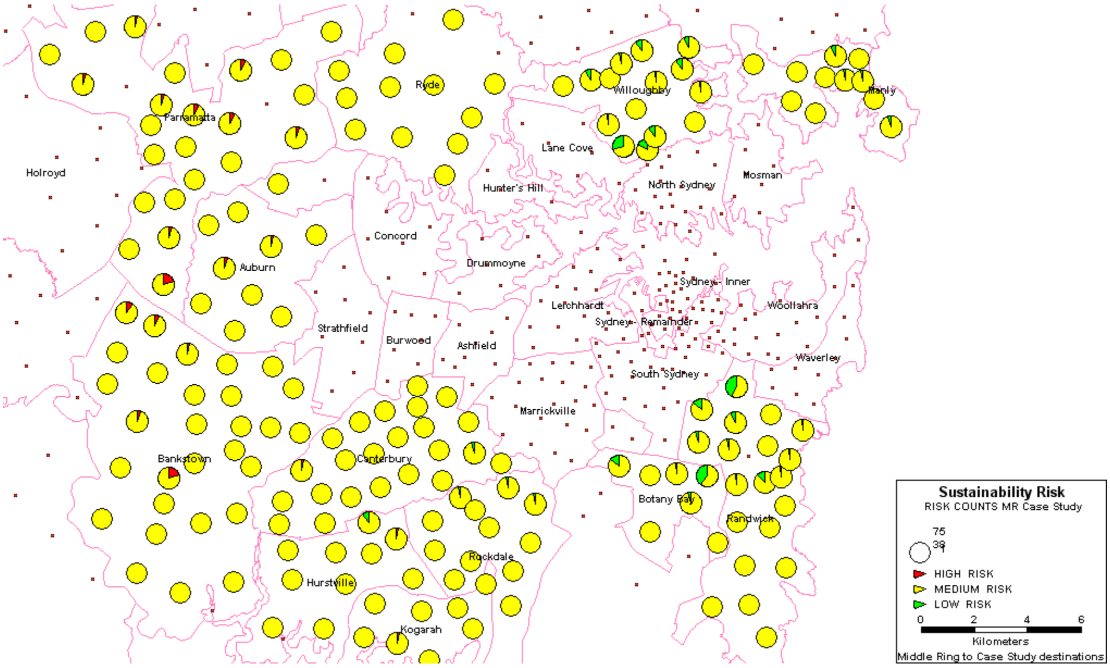


Figure 1.10 Sustainability Risk Origin Pie Chart Plot

Each of these visualisations provide insight into the position, spread and internal distribution trends for a city's urban sustainability pillars of environmental stewardship, social equity and economic efficiency. For community and decision makers these visual differences give a simple snapshot of overall sustainability performance, for each scenario being considered. Change the scenario, use the building block techniques and produce a new metric plot to see the sustainability effect. Stakeholders can see measurable change for their communities in relation to sustainability goals. The process provides another dimension to visioning and sustainability strategy development by adding the means by which community can measure and judge one infrastructure and urban form scenario with another.

A particular strength of using the sustainability framework and the metrics demonstrated 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/T 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.

An important aspect of the metric methodologies is their analytical basis. All visualisations 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.

5 Conclusion

The process of identifying sustainability performance and making a choice of planning instruments (policy, projects etc) is seen to benefit from metrics that are:

- Simple visualisations of triple bottom line trends.
- Quantifiable with transparency of data.
- Relatable to sustainability goals.

Visualisation methods discussed take advantage of geographic information systems, introducing measures in environmental sustainability – accessibility space.

Benefits include more engagement of community in testing of alternative scenarios, and ownership of outcomes. Benefits for decision makers are simple but well founded objective information on which to base decisions.

6 References

AGO (2005). *AGO Factors and Methods Workbook*, Australian Greenhouse Office, Australian Government, Canberra.

Black, J., Hayashi, Y., and Alpkokin, P. (2007a). *Asian Polycentric Employment Collaborative – Transport (APEC – TR); the Dynamics of Poly-Centric Employment Formation in Asian Cities: Report for EASTS Website by International Research Group IRG - 03 - 2005, September, 2007*, Eastern Asia Society for Transportation Studies.

Cosgrove, D. (2003). "Urban Pollutant Emissions from Motor Vehicles: Australian Trends to 2020." *Final Draft Report for Environment Australia*, Bureau of Transport and Regional Economics (BTRE), Australian Government, Canberra.

Doi, K., Kii, M., and Nakanishi, H. (2007). "An Integrated Evaluation Method of Accessiblity, Quality of Life and Social Interaction." *Environment and Planning B*, (advance online publication as of Jan 2008).

Doust, K. (2008) *Metrics of Environmental Sustainability, Social Equity, and Economic Efficiency in Cities*. Unpublished PhD thesis, University of New South Wales (submitted).

European Conference of Ministers of Transport (ECMT). (2004). "Transport and Spatial Policies: The Role of Regulatory and Fiscal Incentives: Round Table 124." Paris.

Expert Group on the Urban Environment. (1996). "European Sustainable Cities Report." European Commission, Brussels.

Kachi, N., Hayashi, Y., and Kato, H. (2007). "A Computable Model for Optimizing Residential Relocation Based on Quality of Life and Social Cost in Built-up Areas." *Journal of the Eastern Asia Society for Transportation Studies*, 7(0), 1460-1474.

Kachi, N., Kato, H., Hayashi, Y., and Black, J. (2005). "Making Cities More Compact by Improving Transport and Amenity and Reducing Hazard Risk." *Journal of the Eastern Asia*

Society for Transportation Studies, 6, 3819 – 3834

Warren Centre for Advanced Engineering. (2003). *The Sustainable Transport in Sustainable Cities Project*, University of Sydney. CDrom

World Commission on Environment and Development. (1987). *Brundtland Report -Our Common Future*, Oxford University Press, Oxford.