THE INTEGRATED LAND USE AND TRANSPORTATION INDEXING MODEL: ASSESSING THE SUSTAINABILITY OF THE GOLD COAST, AUSTRALIA

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Abstract

Urban sustainability and sustainable urban development concepts have been identified as the ultimate goal of many contemporary planning endeavours and have become central concepts on which the urban development policies are formulated. In the confinement of these concepts, land use and transport integration has been highlighted as one of the most important policy objectives considering the interrelationship between them and available intervention means of planning. While its interpretation varies, in Australia, it has been embraced as integration of land use and transport planning/policies and been an integral part of regional and local plans. Accordingly, a number of principles have been defined to guide its implementation, to name a few, planning for compact and connected urban development, encouraging active transport modes, creation of mixed-use activity centres and public transport precincts, provision of high quality public transport services, and enhancing character and amenity of urban areas. However, there is lack of an evaluation framework to measure the extent of achievement of implementation of these principles. In pursuit of filling this gap, this study aims to devise an evaluation framework to measure the performance of urban settings according to the integration principles in South East Queensland, Australia context and to demarcate problematic areas which can be intervened by planning tools.

In order to reach this end, firstly the literature was reviewed to discover how land use and transport issues are conceptualised with reference to urban sustainability, the content of integration of land use and transport, how urban sustainability and integration are elaborated in Australia context, and assessment methods employed to measure the performance of the urban areas. This review showed that sustainable urban form and mobility discussions in the literature clearly overlap with issues raised by policy documents in Australia; a considerable effort has been spent to frame the extent of land use and transport integration idea and to guide implementation by general principles; there is a tendency to measure urban sustainability performance with indicators; and neighbourhood scale provides the most effective tools to reach many of the integration principles. After this, literature review was deepened to define the qualities of a valid and reliable indicator system,

indicators used to delineate urban sustainability at neighbourhood scale, and properties of spatial composite indicators as an evaluation tool. By using the findings of this review, a large set of land use, transport and externalities indicators were extracted considering indicator theory and principles of land use and transport integration. This set was then consolidated to a total of 24 indicators, which were grouped into three themes and six categories according to their topical relevance by the inputs of the Gold Coast City Council and Queensland Transport and Main Road officers.

After selecting the indicators, relevant data items were collected from various governmental agencies and local government, and a number of data items were produced by using geographic information system tools on parcel level. This was one of the innovations of this study, computing various urban form and accessibility metrics for each parcel by using true network distances. Though computationally expensive, this enabled to conduct detailed indicator analysis results and helped to define intervention clusters. Following the generic methodology advised for composite indicator creation, all indicators were first normalised according to the benchmark values defined, were then assigned a weight according to the opinions of an expert panel, and finally aggregated by using linear addition. This procedure gave a composite indicator to portray an overview on the performance. All indicator analyses were carried out by using geographic information systems and mapped on a grid.

The findings of this study demonstrated that the study area yielded medium-low composite indicator score on average, and Helensvale yielded higher scores than Upper Coomera and Coomera. While suburb centres yielded relatively high scores due to the higher weight assigned to transport and land use indicators by experts, suburb peripheries benefited from low level of pollution and consumed fewer resources. Moreover, composite indicator scores were used to identify problematic areas and designate betterment strategies to reach land use and transport integration goal. While it was hard to infer neighbourhood level performance by only inspecting the composite indicator scores due to the compensation between high and low indicator values, category-based analyses were the best platform to scrutinise the categories compensating each other most and the extent of this compensation. This also revealed that there was a clear distinction between suburb centres and peripheries in terms of category-based indicator scores because of the negative correlation between urban form-transport and externalities categories. The robustness of the model was tested via a sensitivity analysis, and this confirmed that the model outputs were robust with respect to the alternative composite indicator schemes.

In overall, this study presented a review on elaboration of land use and transport functions from urban sustainability perspective by indicators, and advised a set of indicators considering the indicator theory, land use and transport integration principles and local policy context. Even though this indicator set reflects core land use and transport sustainability subjects of the South East Queensland, it can be replicated in other settings according to local policy context. It also discussed the potential of composite indicator methodology in measuring land use and transport sustainability performance at neighbourhood scale and highlighted deficiencies to be considered if the composite indicator will be used for policy formulation. In practice, this method can be used either to monitor the achievement of land use and transport integration principles by current planning schemes or to guide new urban development plans by demarcating the problematic areas.

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List of Abbreviations

3D	Density, diversity and design
ABS	Australian Bureau of Statistics
AHP	Analytical hierarchy process
AHURI	Australian Housing and Urban Research Institute
ARC	Australian Research Council
BEQUEST	Building Environmental Quality Evaluation for Sustainability
CCD	Census collection district
CO2	Carbon dioxide
DCDB	Digital cadastral database
DERM	Department of Environment and Resource Management
DIP	Department of Infrastructure and Planning
DOTARS	Department of Transport and the Regional Services
DPSIR	Driving force, pressure, state, impact and response
DSEWPC	Department of Sustainability, Environment, Water, Population and Communities
EC	European Commission
EEA	European Environment Agency
EIA	Environmental impact assessment
EM	Ecological modernisation
EU	European Union
FA	Factor analysis
GCCC	Gold Coast City Council
GCCTP	Gold Coast City Transport Plan
GDP	Gross Domestic Product
GHG	Green house gases
GIS	Geographic information systems
HOV	High occupancy vehicle
ILTIM	Integrated Land-use and Transport Indexing Model
IRTP	Integrated Regional Transport Plan
JTW	Journey to work
LCA	Life-Cycle Assessment
LOS	Level of service
LUD	Land use destinations
LUTR	Land Use and Transport Research
NDAI	Neighbourhood Destination Accessibility Index
OD	Origin-destination

OECD	Organisation for Economic Cooperation and Development
PIP	Priority Infrastructure Plan
PSR	Pressure, state and response
PT	Public transport
QTMR	Queensland Transport and Main Roads
QUT	Queensland University of Technology
SEA	Strategic environmental assessment
SEQ	South East Queensland
SLA	Statistical Local Area
SUD	Sustainable urban development
TDM	Travel demand management
TOD	Transit Oriented Development
UN	United Nations
UNDSD	United Nations Division for Sustainable Development
UOA	Unit of analysis
VC	Volume to capacity
VKT	Vehicle kilometres travelled
WAPC	Western Australian Planning Commission
WSUD	Water sensitive urban design

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature: _________________________

Date: _________________________

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This thesis is dedicated to my wife, Didem. Without her continuous support and encouragement it would not have been possible to complete this study. It is also dedicated to my two grandmothers, Hanife and Hatice. I would not be here without their support.

List of Publications

Journal Articles

Yigitcanlar, Tan & Dur, Fatih (2010). Developing a sustainability assessment model: The sustainable infrastructure, land-use, environment and transport model. *Sustainability*, 2, pp. 321-340.

Yigitcanlar, Tan, Rashid, Kushairi, & Dur, Fatih (2010). Sustainable urban and transport development for transportation disadvantaged: A review. *The Open Transportation Journal*, 4, pp. 1-8.

Conference Papers

Dur, Fatih, Yigitcanlar, Tan, & Bunker, Jonathan (2010). Evaluating sustainability of urban development and its contribution to a knowledge-base development. In Yigitcanlar, Tan, Yates, Peter, & Kunzmann, Klaus (Eds.) The 3rd Knowledge Cities World Summit, World Capital Institute, City of Melbourne and Office of Knowledge Capital, Melbourne Convention and Exhibition Centre, Melbourne, pp. 725-738.

Dur, Fatih, Yigitcanlar, Tan, & Bunker, Jonathan M. (2010). Towards sustainable urban futures: Evaluating urban sustainability performance of the Gold coast, Australia. In Proceedings of the 14th IPHS Conference: Urban Transformation: Controversies, Contrasts and Challenges, Urban and Environment Planning and Research Center, Istanbul Technical University, Taskisla Building and Cemal Resit Rey Concert Hall, Istanbul, pp. 113-131.

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Lee, Shinyi, Dur, Fatih, & Yigitcanlar, Tan (2009). An indexing model for stormwater quality in the Gold Coast. In Proceedings of the 4th State of Australian Cities Conference (SOAC 2009), University of Western Australia, Perth, Western Australia.

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Book Chapters

Dur, Fatih, Yigitcanlar, Tan, & Bunker, Jonathan M. (2010). Sustainable transport infrastructure: Perspectives for sustainable urban and transport development. In Yigitcanlar, Tan (Ed.) *Sustainable Urban and Regional Infrastructure Development: Technologies, Applications and Management*. IGI Global, Information Science Reference, Hershey, PA, pp. 44-61.

Dur, Fatih, Yigitcanlar, Tan, & Bunker, Jonathan M. (2010). A decision support system for sustainable urban development: The integrated land use and transport indexing model. In Yigitcanlar, Tan (Ed.) *Rethinking Sustainable Development: Urban Management, Engineering and Design.* IGI Global, Information Science Reference, Hershey, PA, pp. 56-72.

Award

The best post-graduate paper award in Melbourne 2010 Knowledge Cities World Summit in 16-19 November 2010.

Chapter 1: Introduction

The concept of sustainability and its applicability have been one of the most discussed issues in the literature. As rapid urbanisation and the growing population of cities are considered, the implications of changing life style related sustainability problems and how these are addressed could be considered as among the most pressing subjects of the urban planning profession. The complex nature of both cities and politics force urban planners to scrutinise the contemporary sustainability problems of cities more comprehensively and to produce more effective policy recommendations. It is evident that without an evaluation framework it is not easy to delineate sustainability policies, in particular when formulating urban development strategies for cities. In this respect, two important concepts, urban sustainability and sustainable urban development (SUD), could be associated with substantial and procedural considerations of both planning and policy making. Therefore, demarcation of the problems associated with urbanisation patterns according to their effects on urban sustainability can be a good starting point.

While urban sustainability encompasses a wide range of urban planning interests such as sustainable urban economy, infrastructure and services, integration of communities, green attitudes, public participation, and governance (Deakin & Lombardi, 2005; Finco & Nijkamp, 2001), most of the urban sustainability issues are discussed focussing on spatial considerations, particularly on the urban form and its effects on mobility patterns (Kenworthy & Laube, 1996; Yigitcanlar et al., 2008). Identifying this interdependence between the urban form and travel pattern of the individuals/households could make it possible to address the causes of and the intervention options to the pressing sustainability problems. These problems consist of urban sprawl, high vehicle kilometres travelled (VKT) and auto dependence, low public transport patronage, transport related pollution, excessive land consumption and disruption of ecosystems, and so on (Banister et al., 2000; Holden, 2007). In fact, the emergence of land use and transport integration approach is a direct consequence of the contemporary planning practice dealing with the aforementioned problems from a comprehensive perspective (DOTARS, 2003; Krizek & Levinson, 2005).

While policy frameworks involving sustainability of urban form and mobility considerations provide a conceptual clarification and a set of principles to achieve a comprehensive approach, studies focussing on the causality between urban form and mobility are invaluable sources for identification of the relationship between urban land use and travel demand (Crane, 2000; Handy, 1996; Krizek, 2003b; Stead & Marshall, 2001). Furthermore, the literature clearly evidences that neighbourhood level is the right scale to scrutinise land use and transport integration (Bagley & Mokhtarian, 2002; Cao et al., 2007; Crane & Crepeau, 1998; Knaap & Song, 2004).

In addition to the theoretical debates over the subject matter, measuring the sustainability level of an urban setting via various assessment methods to generate integrated and acceptable policy measures embodies the practical dimension of urban sustainability. Various evaluation methods are available to decide on the best alternative with respect to the criteria defined. These methods, most of which have been mandated by the government or embraced voluntarily to comply with the changing expectations of people, have been employed for a long time to assess the performance of plans, projects and even the production process of a product. However, due to relatively technical and sophisticated procedures of these methods as well as the drawbacks experienced in making social and environmental values tangible, sustainability indicators as a semi-structured and inherently context-dependent, and value-laden evaluation method have gained a wide acceptance and become a standard exercise in sustainability performance evaluation. Besides their use for monitoring and benchmarking purposes, they provide a common base for public debate on sustainability related matters, and have been employed as a communication tool, particularly by various local governments. However, formulating a reliable and valid indicator system requires a well-designed framework, and stakeholder involvement is the foremost consideration underscored by various studies.

While visualizing phenomena and highlighting trends (Warhurst, 2003), indicators reflect a scattered illustration of sustainability performance. Because of this, aggregation of indicators, at least categorisation as to the main dimensions, and providing an overall picture via composite indicators have recently become another practical approach to sustainability evaluation. Even though composite indicators have a number of methodological drawbacks (i.e., the subjectivity of weighting procedures, aggregation of non-comparable entities, trade-off between the indicators due to the aggregation method embraced) and practical difficulties (i.e., generalisation of findings), the number of studies on its reliable application for diverse interests has been growing. Furthermore, increasing availability and accessibility of data and computing power make it possible to produce an aggregated sustainability index. Along with the spatial content of urban sustainability, it has become a necessity to include urban form related indicators in the urban sustainability assessment process.

A review of the literature showed that even though the principles of land use and transport integration are clearly defined in the policy documents, there is no known mean to assess the attainment to the these principles. This is the main motivation of this research, to provide a decision support tool to evaluate urban settings from land use and transport integration perspective and help to develop plan alternatives for better and sustainable neighbourhoods. Accordingly, this study is an attempt to measure the sustainability performance of urban areas by only taking into account urban form and transport related concerns at the neighbourhood level with a well-designed indicator system and a composite indicator. This chapter aims to depict the overall aim, objectives and research questions of this study with reference to land use and transport integration and urban sustainability debate. It also reports the theoretical and practical contributions of this research to urban planning and assessment methodology literature. As a last note, even though land use and transport integration also covers all transport systems at regional or strategic level, in this study only passenger transport system issues are investigated at neighbourhood scale.

1.1 RESEARCH AIMS, OBJECTIVES AND QUESTIONS

The main aim of this study is to enhance the planning mechanism to facilitate the sustainable outcomes of the urban development. More specifically, this study aims to develop a composite indicator model for local governments in order for them to monitor the effectiveness of land use and transport policies at neighbourhood level and help to draw targeted urban development policies to achieve a more sustainable urban environment.

The following points are the key objectives of this research:

- To define the principles of land use and transport integration from a holistic perspective, which guide to consolidate theoretical discussion on a valid and reliable assessment method,
- To produce a set of land use and transport indicators for performance monitoring, which are comprehensive, coherent and relevant to the local sustainability concerns,
- To generate a composite indicator which portrays the sustainability level of the case study area from land use and transport integration perspective, and can be used for policy formulation and urban development scenario assessment.

In order to address the research objectives, the following two research questions have been identified:

- How can land use and transport integration be conceptualised to assess the performance of different urban settings at the neighbourhood level?
- How could land use, transport and environmental attributes of an urban area be measured in an integrated manner in the scope of neighbourhood sustainability through the design and implementation of indicators?

These questions demarcate the sub-components of the research and the literature to be reviewed. Accordingly, sustainability of urban form and mobility debate provides a context to formulate an assessment method for land use and transport integration. It also reveals the appropriate spatial scale for integration, requirements of a valid indicator system, composite indicator creation process, and the considerations of similar spatial indexing studies are regarded as the sub-components of this study.

1.2 IMPORTANCE AND SIGNIFICANCE

Theoretical importance: In urban planning, substantial and procedural dimensions constitute the main domains of the planning theories. The main aim of this study, attaining a sustainable urban form (substance) with more informed and effective decision making processes by integrating considerations of land use, transportation and environment (procedure), also corresponds to the idealistic definition of the comprehensive rational planning theory (particularly its holistic planning approach). Even though it has been criticised because of its unrealistic and hardly manageable planning process definition, today, by the help of the developments in information and communication technologies, an integrated approach to urban planning subjects (both substantial and procedural) is viable. From transport planning perspective, this study indirectly involves the internalisation of transport externalities, and regarding this, it is related to all forms of utility theories of transportation, which define accessibility and mobility as a tangible or intangible utility of the people in an urban area.

The indicator list formed by this study is a compilation of a number of land use and transport sustainability studies and reflects local policy considerations in South East Queensland, Australia context. While designing this list, literature of indicator theory was critically reviewed to define the qualities of a valid and reliable indicator system, and all considerations highlighted in this literature were embraced. In this sense, this study contributes to indicator research and the theories associated with it in terms of formulation of an indicator system for urban sustainability issues.

In terms of methodology, this study advises a number of urban form and transport indicator measures which can be quantified on parcel level taking into account true network distances. This innovation enables planners to analyse various attributes of an urban area (e.g., density, diversity, design and accessibility) in great detail, otherwise the only option is to use aggregated metrics (i.e., suburb, census collection district) or employing buffer analysis for each parcel.

Practical importance: The final product of the research, the 'Integrated Land-use and Transport Indexing Model' (ILTIM), can be used by the planning agencies of state and local governments, developers, planners and interested stakeholders to evaluate the performance of an area from land use and transport integration perspective. The sub-components of this model (i.e., indicator analyses) can provide very useful insights in analysing the different aspects of integration and help to decide on which urban form element is most suitable according to the planning scheme objectives. As a result, it will help to discuss sustainability policies on a concrete basis with a holistic perspective. Furthermore, the individual indicators of the model can form a public discussion platform, which, in return, helps to develop active public participation in implementing sustainability policies and measures.

1.3 STRUCTURE OF THE DISSERTATION

This chapter is followed by the first literature review part, which covers the urban sustainability concept, particularly by focussing on sustainable mobility and urban form sub-domains. After providing the main parameters of the sustainable urban form and mobility debate, integration of these two domains is elaborated considering the two prominent approaches, which are integration in a causality context and integration as a planning objective. This is followed by a discussion on different spatial scales of integration. Complying with the general approach adopted by similar studies, the neighbourhood level is explored together with the neighbourhood sustainability concept. The second part of the literature review involves the assessment methods in general and a more specific focus on indicator-based sustainability evaluation. This section is particularly important to show the best practice of indicator selection and composite indicator creation procedures. This chapter is concluded with a detailed review of spatial indexing studies.

Methodological details and analysis results of the model are separated into four chapters according to their topical relevance. First, the structure, the case study area, indicator selection, weighting and aggregation procedures, data sources, and the unit of analysis of the model are presented in Chapter 4. In the following three chapters, the results of indicator analyses are given together with the definition, calculation procedure, normalisation scheme and area-wide overview for each indicator according to the indicator themes. In Chapter 8, the application of the model to the case study area is shown according to the weights acquired from experts and linear aggregation method. This is the final product of the model, and the details of each sub-category scores are further discussed to disclose the performance of the area. In order to test the robustness of the model output, a sensitivity analysis is necessary and this is presented in Chapter 8. The comparison of the alternative index scores, which were acquired from alternative normalisation, weighting and aggregation schemes, are made, and the shortcomings of the model are discussed.

This dissertation is concluded by the conclusion part which covers the conversion of the model outputs to policy formulation, robustness of the model, limitation of the study and further research subjects with regard to the model’s performance.

1.4 SUMMARY

In this chapter, the background, aims, objectives and research questions of this study were introduced. Following this, the importance and significance of the study were disclosed with reference to the aims and objectives. Lastly, the structure of the dissertation was provided.

Chapter 2: Literature review: Part I

This chapter aims to clarify the conceptualisation of urban sustainability with reference to two interrelated urban functions, land use and transport. Starting from a review of urban sustainability definition and its scope, it elaborates underpinnings of land use and transport integration from two different perspectives, integration in causality context and integration as a policy objective. It should be noted that these approaches are not mutually exclusive, and there is a clear connection between them. The primary purpose of this separation is to clarify the reasons of different interpretations of land use and transport integration. Integration as a policy objective approach is explained in detail considering the widespread utilisation in Australia context. This discussion is then used to draw principles of land use and transport integration. In addition, this chapter sheds light onto how spatial scale demarcates various planning parameters in land use and transport integration discussion and shows the advantages of neighbourhood scale in elaborating the urban form and transport related problems by planning intervention. The structure of the first literature review part is summarised in Figure 2.1

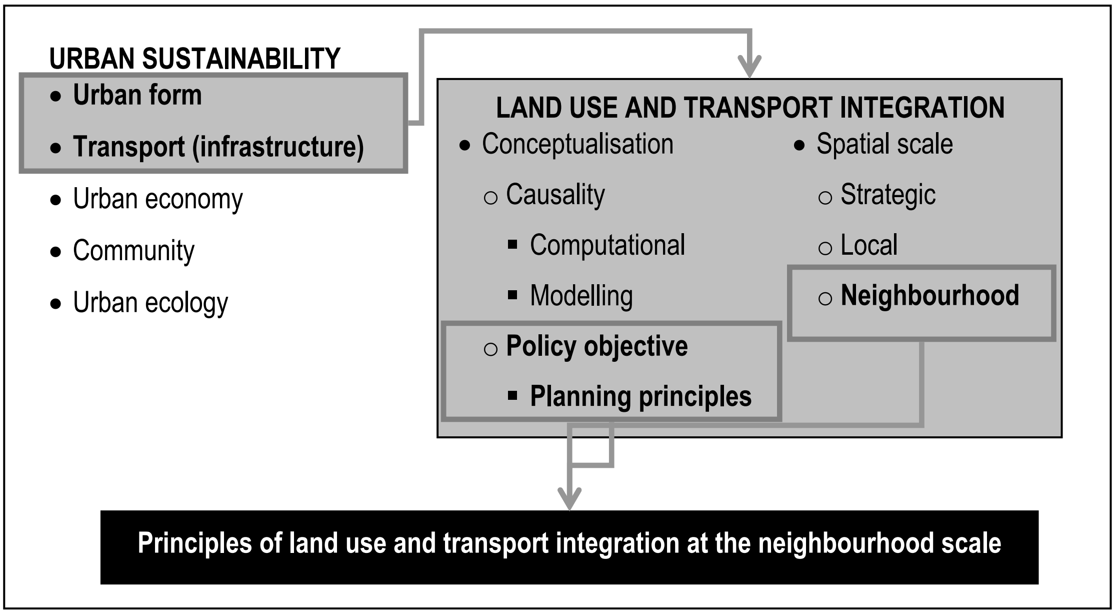


Figure 2.1 Structure of urban sustainability review

The specific questions which are addressed by this review are as follows:

- How do urban sustainability considerations frame land use and transport related issues?
- Where does the need for integration come from? How has it been elaborated and what are the main objectives of the integration of land use and transport decisions?
- What is the most convenient spatial scale to assess interaction between urban form and transport?

2.1 URBAN SUSTAINABILITY CONCEPTUALISATION

Berke and Conroy (2000) stated that "On the surface, sustainable development is a simple concept: Current and future generations must strive to achieve a decent standard of living for all people and live within the limits of natural systems" (p.22). However, how it can be operationalised is not an easy question due to the complexity of the sub-systems whose sustainability is in question. After reviewing constituent concepts coupled with sustainable development, Berke and Conroy gave a definition for the sustainable development: "Sustainable development is a dynamic process in which communities anticipate and accommodate the needs of current and future generations in ways that reproduce and balance local social, economic, and ecological systems, and link social actions to global concerns" (Berke & Conroy, 2000, p.23). This proposition has three implications. First, exploitation of any resource should be kept in the limits of carrying capacity of the other systems, particularly ecosystems. Secondly, "basic human needs must be met in an equitable and efficient manner" (Doughty & Hammond, 2004, p.1224). Lastly, the impacts on ecosystems and human environments, and responses to ameliorate these impacts should be reconsidered by taking into account the interactions between geographic scales, due to the cross-boundary effects of production and consumption processes (e.g., greenhouse gas emissions and climate change, pollution problems transcending national borders). This definition implies that any system we can think of designed to meet the needs of people should be reconsidered from ethical and efficiency perspectives, which point out optimal production and just distribution of benefits and costs over time (future generations) and space (intra generational issues and local-global interaction) (Næss, 2001).

Urban sustainability is one of the important concerns in sustainability debate due to two obvious reasons as stated by Lee (2006, p.10): “First, a large proportion of human population growth in the remainder of the demographic transition is projected to take place in cities”, which was also strongly highlighted by UN-HABITAT as the importance of local authorities in generating solutions for local problems (United Nations (UN), 1992); “Second, a large proportion of the choices that steer the world economy, and accordingly shape its environmental burdens, originates in urban populations, institutions and cultural settings – if only because of the high levels of urbanization in the world’s richest nations” (p.10).

Another definition for urban sustainability has been offered after UN-Habitat’s report series of The State of the World’s Cities, which delineates relevant domains for *Sustainable Cities*. After explaining the global urbanisation trend and the problems associated with this, it addresses “ … the pressing issues of urban poverty and wealth creation while simultaneously addressing urban environmental issues, both natural and built, and the social and cultural issues of urban communities” (UN-HABITAT, 2009, p.113). The most prominent critiques of this definition are its mostly human-centred recommendations and its inability to devise a common understanding on critical issues due to the complexity of the advised framework (Curwell et al., 2005). Instead of giving a formal definition, Curwell et al. (2005) purported that urban sustainability can be elaborated as a process for “adapting the existing built environment over time in a way that supports more sustainable patterns of living and working” (p.32). This is also the primary approach of the Building Environmental Quality Evaluation for Sustainability (BEQUEST) network, which is a European Commission (EC) initiative to provide a conceptual basis for urban sustainability matters and review assessment methods available to measure SUD. BEQUEST embraced PICABUE model of sustainable development (Curwell, et al., 2005; Mitchell et al., 1995), whose main components are ecological integrity, equity, public participation and futurity.

2.1.1 SCOPE OF URBAN SUSTAINABILITY

There are two similar concepts when sustainability of the urban areas is in question, urban sustainability and SUD. In the literature, terms of urban sustainability and SUD have been used referring to similar issues, implicitly or explicitly. “One way of distinguishing [urban sustainability and sustainable urban development], however, is to think of sustainability as describing a desirable state or set of conditions that persists over time. In contrast, the word 'development' in the term 'sustainable urban development' implies a process by which sustainability can be attained" (Maclaren, 1996, p.185).

Even though they were not explicitly referred as urban sustainability, environmental and socioeconomic concerns had been covered by most of the city planning endeavours before the occurrence of urban sustainability as a framing concept for urban plans. In essence, this was a search for a balanced development which is economically efficient, socially inclusive and environmentally sustainable, and predominantly a consequence of common sense and growing interest of the public on environmental problems (Berke & Conroy, 2000). A similar approach is evident in European Union (EU), and BEQUEST team defined four action domains corresponding to EU policies and assessment tools. These are:

- Interrelated *activities* of urban development process (planning, property development, design, construction and operation);
- A set of *sustainability issues* that surface concerning the environmental, economic and social structure of urban development;
- The *spatial level* of analysis according to the impact of urban development over various scale from city to building component;
- The *time scales* of impact (Bentivegna et al., 2002, p.91).

Some of the key characteristics of urban sustainability that are often mentioned in the literature and in policy documents are: "intra- and inter-generational equity (including social equity, geographical equity and equity in governance), protection of the natural environment (and living within its carrying capacity), minimal use of non-renewable resources, economic vitality and diversity, community self-reliance, individual well-being, and satisfaction of basic human needs via hard and soft infrastructure provisions" (Maclaren, 1996, p.185). These characteristics have been used to provide a framework to define relevant concerns coupled with wide-ranging urban sustainability concept.

In urban planning discipline, by using the aforementioned characteristics as a framework, a number of specific issues have been discussed from a wide perspective. These can be categorised as urban form (curbing sprawl, densification, infill development, enhancing and equalising accessibility), infrastructure (sustainability of transport infrastructure and modes, clean potable water provision, stormwater management, waste management and other soft infrastructures) (Banister, et al., 2000; Kenworthy & Laube, 1996; Litman & Burwell, 2006; Low & Gleeson, 2003; Shore, 2006), urban economy (efficient and responsible resource use, use of renewable energy, employment and job accessibility, development of human resources and soft infrastructure, just income distribution, local production and consumption) (Azapagic, 2003), community (safe urban environments, equal accessibility, empowerment of powerless groups, provision of affordable housing, protection of cultural values and heritage) (Briassoulis, 2001; Campbell, 1996) and urban ecology (using less pollutant technologies, revitalisation of disturbed/highly-exploited habitats, waste management, rectifying ecosystem connectivity, and so on). Among these, sustainable transport and urban form issues have become prominent subjects as to the intervention capabilities of local governments, and the interrelation between these and the other categories listed above (Yigitcanlar & Dur, 2010).

2.1.2 SUSTAINABLE MOBILITY

Sustainable mobility and sustainable transport have been used interchangeably in the literature, and by definition environmentally sustainable transport is "transportation that does not endanger public health or ecosystems and meets mobility needs consistent with (a) use of renewable resources at below their rates of regeneration and (b) use of non-renewable resources at below the rates of development of renewable substitutes." (OECD, 1996, p.11). Following this definition, nine principles were defined as access, equity, individual and community responsibility, health and safety, education and public participation, integrated planning, land and resource use, pollution prevention, and economic well-being (OECD, 1996). There are two challenging faces of transportation issues. Transport activities are one of the main drivers of economic growth and welfare, whose intensity generally follow the same trajectory as the population growth trend in urban areas. However, transport activities are also directly related to a number of externalities (i.e., use of a non-renewable energy source and greenhouse gas emissions, traffic congestion, unequal mobility opportunities, air and water pollution, accidents and fatalities, degradation of ecosystems) whose impacts should be mitigated to a level that neither current nor future generations are affected by these in terms of diminishing welfare and well-being (Yigitcanlar & Dur, 2010). Considering these, it could be said that there are mainly two considerations which frame the sustainable transport discourse. On the one hand, how the externalities of the current surface transport system can be minimised, if not completely internalised. On the other hand, how benefits of mobility can be maximised to sustain economic growth and vitality, in the mean time distributing mobility benefits equitably among different social clusters. In essence it is a search for a balanced development taking into account the well-known three tiers of sustainability. These subjects also constitute the main arguments of land use and transport integration in the literature and its elaboration by a number of principles. As highlighted in the subsequent sections, a need for land use and transport integration has matured in parallel to the wide-ranging discussions on transport related problems and its relation to the urban development patterns. Consequently, this debate outlines main problem areas of sustainable urban transport and framing concepts that are used for a better integration ideal.

When it comes to altering the performance of any transport system, there exist three action domains –vehicle, infrastructure and user– and improvements in each action domain demand different strategies (Figueiredo et al., 2001). Technological achievements in vehicle and road management system (e.g., renewable or clean fuel use, low emitting engines, use of sensor and control technologies, and so on) are the prominent strategies sought by both manufacturers and governments. These achievements are one of the main subjects of specific research areas in transport planning, which are called environment-friendly transport systems and Intelligent Transport Systems. In terms of user domain, measures grouped under travel demand management (TDM) encompassing generally soft and voluntary instruments aim to reduce car travel demand. These measures can be listed as: "targeted provision of infrastructure and services for modes such as transit walking and cycling, fuel taxation and congestion pricing, fuel efficiency standards and complementary taxation measures, the provision of incentives for modes with high occupancy rates, education campaigns and niche marketing" (Dur et al., 2009b, p.46).

In sustainable transport discourse, mobility and accessibility are the pivotal subjects (Yigitcanlar et al., 2010). Mobility could be defined as potential for movement or ability to travel from one location to other (Handy, 2002).That means proximity of locations, network features connecting these locations and available transport means are the main elements of the transport activity. Unfortunately, enhancing mobility has been translated into practice as more road investment (network elements) and dominance of car (mode) for daily travels. However, sustainable mobility does not take only the quantity and the effectiveness of transport activity, but also a number of other criteria, such as cost-efficiency, internalisation of transport externalities and equal share of benefit and opportunities (Malakzadeh et al., 2010). As defined by Zegras (2008), sustainable mobility means "providing more utility, as measured by accessibility, per unit of throughput, as measured by mobility", which also implies "…less total mobility consumption per accessibility derived" (p.23). Here, mobility consumption refers to capital depletion, such as worn shoes and tyres, energy sources and time spent for the movement, and so on. Regarding the previous discussion, "…for the same level of accessibility, walking is more sustainable than driving (or taking the bus or biking). For motorised modes (or any mode that can be shared), occupancy plays an important role since, *ceteris paribus*, higher occupancy means more people receiving accessibility benefit at less total mobility throughput" (Zegras, 2008, p.23). When thought with reference to transport externalities, this definition encompasses key considerations of sustainability in terms of carrying capacity of the environmental and economic systems. However, it falls short to cover two important aspects of mobility, equality of mobility and influence of spatial pattern of urban services on travel behaviours. These aspects are the main considerations of accessibility concept defined as "… the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)" (Geurs & van Wee, 2004, p.128).

Due to its importance in sustainable transport debate and relevance to this study, there is a need for a further elaboration of accessibility and measures to be employed to quantify it. As the definition implies, there are four interrelated parts of accessibility. These are network elements, spatial pattern and proximity of destinations, daily service hours of the locations and group(s) of individuals who want to travel between locations. These are also the main constituents of any accessibility measure. As put by Geurs and van Wee (2004), an accessibility measure encompasses opportunities not only supplied at each destination, but also demand and competition between these opportunities (land use), characteristics of the transport system in terms of travel time and effort (transport), temporal qualities in terms of servicing opportunities in different time spans in a day (temporal) and finally, needs, abilities and opportunities of the individuals (individual). If a measure does not explicitly refer to any of these parts, it does not mean they are not considered but a number of assumptions are made on them (e.g., equal utility for each individual for each location, same daily service hours, equal demand for each service, adequate network provision for each mode and so on).

Geurs and van Wee (2004) identified four categories for accessibility measures considering a number of accessibility studies. These categories are: infrastructure-based measures (i.e., availability and performance of transport network, e.g., level of service), location-based measures (i.e., accessibility to opportunities or services by taking into account spatial distribution and network impedance, e.g., number of jobs/parks/retail service reachable in a given time period), person-based measures (i.e., temporal frame of accessibility within the time budget of an individual also taking into account available infrastructure and service hours of locations, e.g., the number of recreation facilities accessible for after work-hours) and utility-based measures (i.e., benefits gained by accessing spatially distributed destinations, e.g., total cost of shopping [time and fuel spent, and goods purchased] from different locations). They also defined five criteria for the accessibility measures as theoretical basis, operationalisation, interpretability and communicability, accessibility as a social indicator, and accessibility as an economic measure. Among all, theoretical basis of the accessibility measure demands special attention. They expand this criterion as it "… should ideally take all components and elements within these components (land use, transport, temporal and individual) into account" (p.128).

On international level, there are a great number of studies related to sustainable transport (Banister, 2008; Bickel et al., 2003; Black et al., 2002; Campos & Ramos, 2005; Greene & Wegener, 1997; Holden, 2007; Jeon & Amekudzi, 2005; Kenworthy & Laube, 1996; Litman & Burwell, 2006; Low & Gleeson, 2003; Newman, 2006; Richardson, 2005; Wootton, 1999), and this subject is the primer of any transport policy document (Banister, et al., 2000; City of Vancouver, 1999; Department of

Infrastructure and Planning (DIP), 2009; Department of Sustainability, 2008; Department of Transport and Main Roads (DTMR), 2010; European Commission (EC), 2004; EC, 2007; Gold Coast City Council (GCCC), 1998; Organisation for Economic Cooperation and Development (OECD), 1994; Transportation Research Board (TRB), 2005; UK Department for Transport (DfT), 2010; UN, 2007). They generally cover the internalisation of transport externalities, TDM and behaviour change, and technology-led opportunities which would make transport infrastructure and modes, and management of the transport systems more efficient (Dur, et al., 2009b). As a general remark on how sustainable transport or mobility matters are researched, studies originating from the EU have approached this by firstly looking extensively at the theoretical dimension of the issues and tried to reveal the sector-specific sub-parts, which are generally represented by indicators. Due to the great interest in transport system sustainability, there are a vast number of indicator studies in the EU. Therefore, it is a very straightforward exercise to find different projects involving relevant indicators and indicator selection criteria. In the US, the dominance of the empirical studies is apparent, and researchers have tried to explain travel behaviours by focussing on the causality among factors affecting mobility and accessibility and travel behaviours. They have done this by referencing the micro-economic principles and, in the mean time, by controlling socio-economic variables. As an alternative to this approach, proponents of Smart Growth and New Urbanism have provided a comprehensive list of factors which might affect urban sustainability in different spatial scales, mostly focussing on design-led considerations in the US. In Australia, a mixture of the EU approach and the latter approach from the US is evident; however, it can be said that sustainable mobility issues are examined by various approaches which are rather similar to the EU studies.

2.1.3 SUSTAINABLE URBAN FORM

Sustainability of urban form is another key subject in land use and transport integration discussion considering the potential of urban form to moderate travel demand, the impact of transport infrastructure in shaping urban development, and the direct effect of urban development on resource consumption and environmental quality (Krizek & Levinson, 2005). Even though this literature is considered as complementary to sustainable mobility debate in outlining urban development related problems, and land use and transport integration principles with a special focus on "accessibility by proximity" subject, it also covers land use specific issues, such as achieving regional wealth, generation of dynamic and safe communities, and conserving cultural and environmental assets (Curtis & James, 2004).

The sustainable urban form debate involves the types of urbanisation model and process which could provide energy efficient and environment-friendly settlement and mobility patterns, and social cohesion mainly focussing on divergent spatial scales from metropolitan to neighbourhood. Consequently, it is possible to scrutinise the sustainability of urban form on three levels. On regional or metropolitan (strategic) level, ideal population size for self-sufficiency and limits to urban growth, macro-level effects of the urbanisation pattern (mono- or multi-centred cities and decentralisation) on energy consumption, locations of land uses and their mix on strategic level (basic and non-basic sectors), which support a multi-modal transport system, and protection of habitats and water resources constitute the parameters of discussion acknowledging the given geographical advantages and disadvantages (location, topography, proximity between existing settlements and infrastructure) (Godschalk, 2004). On urban level (local), in addition to the strategic level parameters, a number of issues, such as, energy efficiency and transport demand with regard to clustering of urban development, finer level of land use mix and density, provision of equal opportunities in reaching urban services (Stead, 2001), vitality and prosperity of activity centres, and protection of environmental and cultural assets and so on, stand forward. On neighbourhood level, the relationship between urban form qualities (land use mix, density and pedestrian friendly design) and travel patterns, enhancement of local characteristics, safety and community sense by design (Godschalk, 2004), and urban form dependent qualities of the buildings (solar orientation, imperviousness, efficient use of materials, and so on) (Næss, 2001) are the prominent subjects. This classification does not imply that these scales are mutually exclusive and independent. As explained by Mitchell (2005), "as in reality, macro level patterns emerge from micro level processes and behaviour, and micro level processes and behaviours are controlled by macro level constraints" (p.11).

In general, the studies related to sustainable urban form make descriptive comparisons (e.g., transport and building energy use, VKT, public transport patronage, waste and pollution generated, community integration, and so on) between compact and dispersed city forms, which also correspond to neo-traditional and suburban style urbanisation discussion (Yigitcanlar, et al., 2010). It is hypothesised that urban consolidation via intensification and mixed use reduces trip lengths and total travel, and also changes modal split from automobile-dominant to public and non-motorised transportation-oriented (Banister et al., 1997; Cervero & Kockelman, 1997; Ewing & Cervero, 2001). Additionally, in terms of social equity and accessibility to urban services, Burton (2000) stated that low density urban sprawl imposes economic and social burdens on low income groups towards deterioration of community sense and feeling powerless. It was also asserted that neo-traditional settlement form satisfying high density and mixed use features are more sustainable than suburban type urban development (Banister, et al., 1997; Cervero & Kockelman, 1997; Handy et al., 2002).

One of the most prominent discussions revolves around the macroform of the city on a regional scale, more clearly mono- and poly-centric urban development. The former focuses on curbing urban sprawl by revitalisation and densification of existing urban centre and surroundings as infill and brownfield development. In addition to improving the living conditions of inner-city and surroundings, creating safe urban areas, enhancing the provision of urban services and resolving traffic congestion are the main subjects associated with this approach (Vande Walle et al., 2004). While mono-centric development strategy is successful in increasing public transport patronage and energy efficiency, and lessening carbon emissions and conversion of greenfields to urban uses, its effectiveness is highly contentious due to its inability to meet current real estate market demand and difficulty of providing higher level of urban services by using the existing infrastructure (Breheny, 1997). The latter strategy involves directing urban development towards well-located sub-centres while consolidating the existing urban centre. This approach devises concentration around sub-centres to diminish urban sprawl and shorten the commuting distance (Vande Walle, et al., 2004). Even though this approach has been adopted in the EU and the USA, there is no evidence to prove its effectiveness in terms of shortening the commuting trips and increasing public transport use (Aguilera, 2005; Shore, 2006).

At large, sustainable urban form debate focuses on resource consumption, particularly, how energy is produced and consumed, and pollution emitted to environment without treatment. If we leave the energy spent for households' needs, and service and goods production aside, energy spent for transport takes one of the largest stakes in overall energy consumption. Moreover, it is one of the most important contributors to urban air and water pollution in the urban areas (Dizdaroglu et al., 2009; S. Lee et al., 2009). Because of this, the primary objective [of sustainable urban form] is to diminish urban sprawl and reduce frequency and length of everyday journeys via some planning and design principles, such as urban consolidation, mixed use, provision of public and non-motorised transport opportunities (Holden, 2007), as well as to make urban services and amenities more accessible (Yigitcanlar, et al., 2008). In this respect, car dependency and urban sprawl relationship is the most popular subject in the literature. (Banister, 1997; Banister, et al., 2000; Kenworthy & Laube, 1996; Litman & Burwell, 2006; Low & Gleeson, 2003; Shore, 2006). “Land use can affect transportation behavior, but the evidence is more compelling on how land use affects transportation behavior at the neighborhood scale than at the metropolitan scale” (Knaap & Song, 2004, p.20). Consequently, sustainable urban form discussion concentrates on types of neighbourhood and is about *density, diversity and design* (3Ds) of neighbourhoods (Cervero & Kockelman, 1997; C. Lee & Moudon, 2006).

Here, density implies the intensification of population and services in the designated zones, which increases the number and range of opportunities. By this, need for travel and travel times reduce, provision of more sustainable transport modes becomes viable, and local contacts and social cohesion flourish (Dur et al., 2009a). Diversity corresponds to mixing of uses or variety of job opportunities within the confinement of accessible urban area. Diversity connects density and accessibility concerns and helps to shorten commuting and daily trips as well as promoting non-motorised transport modes. Design is related to street design and neighbourhood layout in promoting public transport, walking and cycling. Connectedness, convenience, conspicuity, conviviality and comfort of pedestrian and cycling routes, layout and connectedness of the open spaces, location of public transport stops, and availability of fittings and facilities in public transport interchanges (park-and-ride, bicycle parking, and so on) are the specific design elements referred in the literature (GCCC, 1998).

Conceptualisation of aforementioned good policies has revealed various urban form approaches, such as Urban Village (Newman & Kenworthy, 1999), transit oriented development (Boarnet & Crane, 1997), Smart Growth (American Planning Association, 2002), decentralised concentration (Holden, 2004), New Urbanism (Katz et al., 1994), and sustainable urban matrix (Hasic, 2000). Transit oriented development, which means creating compact, mixed use and walkable communities around the public transport stops; Smart Growth, which involves strengthening communities by a number of urban development strategies, such as compact-mixed use development, walkability, preservation of cultural and environmental values, affordable housing and community involvement; and New Urbanism, which has the same principles as Smart Growth but with a bit more emphasis on the quality of architectural and urban design elements of a neighbourhood, are three widely known examples among them.

However, the opponents of urban consolidation put forward the questions of feasibility and acceptability of such policies. For example, Gordon and Richardson (1997) discuss high density and large investment in public transportation do not warrant a reduction in car travel because of contemporary preference towards car travel among people. Another claim opposing the compact urban form states that neo-traditional urban form does not necessarily make European cities less car dependent, but high public transportation patronage, high fuel prices and stringent tax policies force people to travel less by cars (Breheny, 1995). From the perspective of land market economics, they also add that urban containment and consolidation could result in an increase in land prices and real estate, and this strengthens the suburbanisation trend that stimulates car mobility in return (Breheny, 1995; Burton, 2000; Gordon & Richardson, 1997).

As a consequence of the growing interest on the neighbourhoods, sustainable neighbourhood design issues have grabbed a considerable attention. Particularly the principles of New Urbanism and Smart Growth have been used as a design framework for new urban development projects. Moreover, *sustainable neighbourhoods* have been used as a new marketing strategy due to the increase of public awareness towards environment-friendly and sustainable living environments (Dur et al., 2010a). The prominent examples of sustainable neighbourhood design and assessment tools are Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, Australian Housing and Urban Research Institute's (AHURI) Triple Bottom Line indicator suite, Victorian Governments' VicUrban, Tool for Urban

Sustainability - Code of Practice (TUSC) of Waitakere City Council, New Zealand, the South East England Development Agency (SEEDA) checklist and ARUP's SPeAR (Sustainable Project Appraisal Routine) tool. Even though they use different factors to convey sustainability performance of a neighbourhood (e.g., sub-division, suburb or precinct), they, in general, encompass four dimensions of sustainability, "environmental protection, social equity, economic viability and efficient use of natural resources" (Edwards, 2005, p.52).

2.2 INTEGRATION OF LAND USE AND TRANSPORT

It would not be fair to state that before the emergence of urban sustainability concept, land use and transport interaction had been scrutinised as if they were strictly separate entities in planning; however, it can be said that their interaction had been elaborated vaguely (Berke & Conroy, 2000). More clearly, before the integration was addressed as an important policy objective in urban plans, the general approach in planning was to make land use decisions by taking into account secondary or auxiliary contributions of transport investments, or to take land use plans as given and to design resulting transport system in the most efficient way (i.e., predict and provide approach). After SUD considerations have become prevalent in the local policy agenda (such as, reduction in energy use, energy efficiency, conservation of natural and cultural amenities, well-being of all living-beings and so on), the critical importance of where travel destinations are located and land use dependent factors on mode choice and transport investments has created a necessity to reconsider the integration of land use and transport decisions.

The land use and transport integration idea relies on the strong interrelationship between urban form and travel. More specifically, "the recognition that trip and location decisions co-determine each other and that therefore transport and land-use planning needed to be coordinated led to the notion of the land-use transport feedback cycle" (Vande Walle, et al., 2004, p.182) and "transport and land use can be considered as two basic and interrelated parts of a sustainable urban system" (Vande Walle, et al., 2004, p.182). Greiving and Kemper (1999) explained the main difference between land use and transport planning approaches to this relationship as the former aims to reduce the need for travel, the latter tries to make the current and anticipated traffic more sustainable. Obviously, these approaches have been strongly influenced by sustainable mobility debate. Curtis and James (2004) pointed out an alternative to this approach from land use planning perspective as “land use planning outcome as an orderly planning process that achieves regional wealth, conserves and enhances the environment and builds dynamic and safe communities. Based on this view, reducing the need for travel, or ‘accessibility by proximity’, is the desired outcome for land use and transport integration rather than just for land use planning” (p.280).

In the literature, land use and transport integration concept covers mostly overlapping considerations, and specification of the desired outcomes is the main source of its different interpretations. For example, as explicated by Curtis and James (2004), depending on the context it is used, it may refer to efficient design of transport modes (i.e., an urban pattern which facilitates seamless flow of passengers or freight), integration of policies/strategies (i.e., organisational restructuring for better policy formulation and decision making) or coordinated planning efforts. The common concern in all of these interpretations is to reduce the need for travel and make travel more sustainable, which also points out the main motivation of integration, delivering sustainable outcomes for cities (Curtis & James, 2004).

From planning practice perspective, a survey among transport practitioners conducted by Handy et al. (2002) revealed the top five topics to which special attention should be given in planning education due to their importance in contemporary practice. These were “the transportation and land use connection, regional transportation planning, public involvement, professional ethics, and land use planning” (Krizek & Levinson, 2005, p.307). Again, land-use and transport connection was stated as the most important topic by the practitioners. This is mainly due to the encapsulation of transport and land use as the correlated factors in policy documents and a need of coordination between them to help alleviate urban sprawl and car dependency problems.

The studies dealing with land use and transport integration can be separated into two major groups as to their practical approaches. The first group is the computational approaches trying to reveal the causal relationship between the two domains and make predictions according to the anticipated changes in the future or scenarios. This can be further divided to two sub-groups as empirical (explanatory) studies and modelling/simulation studies. The second group mainly considers integration as a policy objective and tries to give relevant principles on how it can be achieved. Even though this separation reflects the general approach to the subject matter, causal studies provide inputs to the policy documents in terms of determinants of travel demand and how it can be managed. Furthermore, empirical studies are used to test the hypothesised relationship between determinants of travel demand to reveal the effectiveness of the contemporary (alternative) urban development models. In this sense, designated integration principles and their implementation are the inputs of various causal enquiries.

2.2.1 INTEGRATION IN CAUSALITY CONTEXT

Empirical studies

Nearly all of the studies trying to reveal the underlying mechanism of urban form and transportation relationship have emphasised the complex nature of this phenomenon. Inherent complexity is mainly explained as the consequence of vast number of factors influencing urban form and transportation, joint effects of this relationship and time-dependent changes in urban structure. As put forward by Altshuler (1979), land use decisions affect transportation investments and system in the short run; however, travel pattern shaped according to transportation network affects land use decisions and future transportation system in the long run (Mindali et al., 2004). If so, how can we depict a causal relationship between land use and transport and assess the effects of each element on each other? One way of answering this question is to analyse the association between the factors of travel behaviour, which has been the main occupation of empirical studies.

In depth, the reviews made by Handy examining contemporary urban models (Handy, 1996; Handy et al., 2005) have showed that the relationship between urban form, travel pattern and individual/household background is more complex than anticipated. In her study, Handy (1996) initially classifies the studies undertaken to explain urban form and travel behaviour into five categories, “simulation studies, aggregate analysis, disaggregate analysis, choice models and activity-based analyses” (p.152). Simulation studies involve a hypothetical testing of urban form according to the assumptions about development determinants. Aggregate analysis is employed to reveal a comparative description of regions, sub-regions or cities as well as to infer a relatively crude explanatory relationship between the elements of analysis. Disaggregate analysis uses individuals or households as units of analysis and tries to associate individual characteristics and their relations to urban form and mobility demand. Behaviour patterns constituting the overall decision pattern of individuals are the main factors included into choice models. These models scrutinise options open to individuals and the probability of the selection of a relevant alternative. This gives insights about the causal relationship between socio-economic characteristics and travel decisions. Activity based analysis takes daily human activities as the analysis subject and tries to couple these activities with individual attributes of social and economic considerations.

Handy (1996; 2005) also mentions the travel decisions of drivers. According to her, the first problem discussed about the built environment and travel pattern relationship is the direction of the association. While it is evident that transportation investments boost the development around highway corridors, or as for transit, near the stops, the effect of urban form on travel behaviour is hardly asserted because of the relatively low explanatory power of proposed empirical models. Nevertheless, it is possible to mention the positive relationship between pedestrian-friendly urban/street layout and the trips made by walking and cycling. Also, some studies showed that the density of the settlements and the distance between uses are loosely related to the travel behaviour as opposing to prevalent belief (Schwanen & Mokhtarian, 2005a) and density has different influences on car travel depending on the location, i.e., in the city or suburbs. They revealed that some other population characteristics sampled, e.g., having an automobile, embracing walking or cycling as a daily activity and an active social life, etc., affect travel behaviour more than urban form does. Moreover, it is asserted that it is not high density and mixed land use neighbourhood type shaping people's tendency towards walk more and drive less, but households' predispositions on density and travel mode, and socio-demographic status lead them to prefer higher density and public transport oriented urban areas, and driving less. This phenomenon is termed as self-selection bias (Mokhtarian & Cao, 2008).

There is also evidence on changes in travel behaviour in accordance with the trip purposes. For example, home-work trips have high elasticity when travel costs, availability of public transportation options and higher accessibility resulting from high population density and mixed land use are taken into account, but home to non-work and work to non-work trips generally have low sensitivity to these factors. That is to say, people prefer to make non-work trips via automobile. When increasing proportion of VKT or number of home to non-work and work to non-work trips in overall VKT and trips are considered, this points out the relationship between socio-economic attributes and mobility characteristics of people (Handy, 1996; Handy, et al., 2005).

Interestingly, growing common interest upon public health and transportation relationship, particularly opportunities for physical activity or non-motorised transport mode preference, leads to convergence of two literatures, travel behaviour and physical activity research (Giles-Corti, 2006; Handy, et al., 2005; Holden, 2007; Mindali, et al., 2004; Roseland, 2000; Schwanen & Mokhtarian, 2005b). The common hypotheses of these studies are that a number of chronic health problems (e.g., obesity, diabetes, cardiovascular problems and so on) are related to travel patterns of people (i.e., car dependency). Moreover, urban patterns can affect travel behaviour, thus, the level of physical activity (especially walking and cycling). After conducting a large survey in Utah, the US, Brown et al. (2009) found a relationship between walkable land use type, and body mass index (also known as BMI) and obesity. They stated that selection of relevant land uses for land use mix calculation, which are deemed as walkable (i.e., multi-family housing, office, retail and education), is rather important than how land uses are equally mixed. Also, proximity to public transport stops and parks is associated with more daily walking and a balanced BMI.

Stead and Marshall (2001) reviewed a number of well-known empirical studies on urban form and travel patterns relationship and provided a summary of findings. Perhaps the most important quality of this study is that they provided a matrix of previous empirical studies considering the mostly used measures. They separated these measures to two groups as the travel patterns and urban form. While there are five measures of travel patterns, which are travel distance, journey frequency, modal split, travel time and transport energy consumption; there are nine measures of urban form, which are distance of residence from the urban centre, settlement size, mixing of land uses, provision of local facilities, density of development, proximity to main transport networks, availability of residential parking, road network type and neighbourhood type. After taking into account how travel measures are coupled with each urban form measure, they concluded that even though empirical studies are fundamental to understand the nature of the interrelationship between urban form and travel characteristics, there are a number of issues which should be treated carefully when drawing policy inferences from these studies. These are methodological limitations (selection of measures with respect to the spatial scale and theoretical framework used, availability and reliability of the data), robustness of the conclusions (direction of the causation and quantification of the relationships) and control of the socioeconomic characteristics of the study area (the interaction between demographics and urban form related travel patterns measures).

Modelling and simulation studies

By the improvements in computer technology and problem solving methodologies, at the beginning of the 50s, a large number of urban models developed considering urban economics, transportation and demographic changes to explain the evolving state of the urban form. Nearly all operational urban models have rooted from the theoretical and procedural approaches of this period. For example, linear analysis, operational research and simulation techniques have been used to model the dynamics of urban land-use, transportation and economics (Liu, 2009). However, great expectations from urban models had worn the assurance towards large scale examples with unsatisfactory explanatory outcomes of these models. Large urban models were criticised because of their focus on techniques existing rather than a theoretical comprehension of the dynamics of urban form (Liu, 2009). Recently, the ability of using disaggregate data in the urban models has led a novel interest in modelling approaches encapsulating behavioural and micro-economic aspects of location decision and travel pattern, such as choice models, activity based travel model, stochastic utility maximisation models and micro simulations (agent-based simulations or cellular automata), and so on. After the introduction of geographic information systems (GIS) tools, comprehension, computation, and visualisation capabilities of the models have reached to their contemporary level. Also the increasing concern on sustainability has directed modelling endeavours to the most prominent determinants shaping cities, urban form and mobility pattern.

In recent years, by the help of development in information technologies, some sophisticated simulation models integrating urban form and transportation related considerations have emerged. These models are used, particularly in the US and the

EU, to simulate/forecast transit and land use change by taking into account disaggregate data with different scales (household, neighbourhood or traffic analysis zone). The general mechanism of these models is more or less similar and for illustrative purposes procedural framework of MEPLAN is given in Figure 2.2.

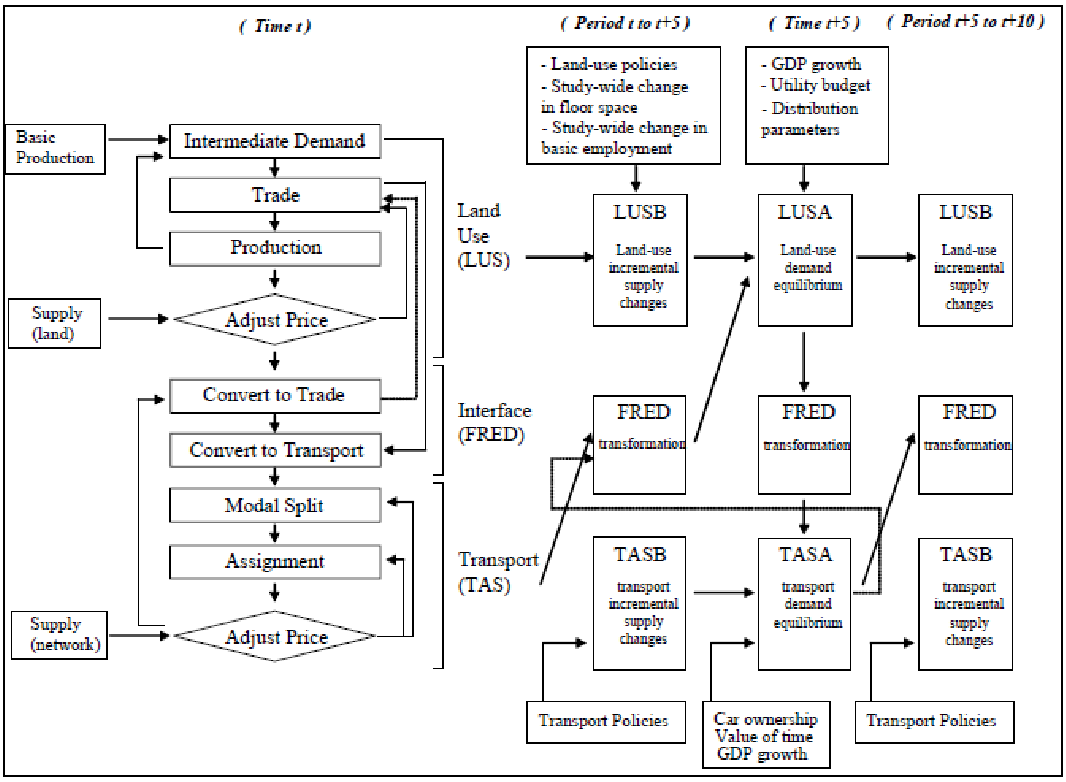


Figure 2.2 An example for modular simulation model for land use and transport integration (MEPLAN); from Nishiura & Matsuyuki, 2005, p.210

The first step in these models is to consolidate urban growth parameters with current land pattern and transport network. To achieve this function, for example, three modules have been designed in MEPLAN framework in a coordinated fashion. The land use module involves spatial location patterns of population and employment. It also considers how production activities invoke a trade pattern in the given setting considering the change in price of land. The transport module mainly assigns produced traffic to modes and network links. Between these two main modules there is an interface module (FRED in Figure 2.2) whose main function is to bridge these two modules, particularly to convert the trade pattern of land uses to transport demand and assess the effects of network loads on the trade pattern and the price of land (indirectly). Availability of the historical data of urban growth, land use change and transport demand has immense importance to accurately calibrate the initial state of the model. The second step is to estimate the land use and transport change for the following simulation period with regard to a number of parameters, such as population and employment change, type and floor area of different land uses, transport infrastructure investment, vehicle fleet characteristics, and so on. The last step involves prediction of the equilibrium state for land use and transport, or more specifically, how the urban land has changed its state in terms of land use and floor area and how this change has affected the mode choice and network loads for the simulated year. Finding the equilibrium in the system state is a dynamic process which requires information on how the predicted state of one module alters the state of the other and how this change affects the former in return. The prediction of the consequent periods can be done simply by iterating the second and the last steps.

The comparative review made by Hunt et al. (2005) examined six integrated urban models according to their 'operational' (is it used in a practical planning exercise?), 'comprehensive' (does it include spatial processes, such as location decisions and land development of agents –individuals, households or firms, which determine travel decisions?), and 'integrated' (does it take into account time dependent interactions of spatial processes and transport network?) qualities. After the inspection of six frameworks, ITLUP, MEPLAN, TRANUS, MUSSA, NYMTC-LUM and UrbanSim, they asserted that all frameworks have more or less differentiating aggregation levels and unit of analysis, but they excessively aggregate spatial information. Yet, these frameworks do not include any endogenous processes, such as automobile ownership and demographic change processes, etc., use static equilibrium assumption and rely heavily on classical four-stage transportation demand model. Despite these weaknesses, all of them have successfully embedded the microeconomic evaluation module, integrated land-use and transportation coherently, and considered multimodal transportation network (Hunt, et al., 2005). Moreover, Gustavson (1999) added a few notes on how modelling can be efficiently utilised as "… greater focus is required on modelling frameworks that can use incomplete data sets or qualitative information, and linking existing quantitative model structures to external qualitative models" (p.117).

In summary, Stead and Marshall (2001) stated that there is a clear relationship as well as distinction between empirical and modelling studies. While empirical studies use real data and rely on fewer assumptions, modelling involves use of data provided by empirical studies and inherently makes a number of assumptions depending on the complexity level of the phenomenon they are modelling. When compared to the modelling studies, empirical studies are more understandable and transparent (modelling is generally criticised as being a 'black box'), provide -statistically valid- causality and elasticity information between variables scrutinised (Stead & Marshall, 2001). On the other hand, empirical studies are not always conclusive or may obscure the causality. Also, the dissimilarity between the variables included in the empirical study (whether they are independent or control variables) makes the generalisation of the results hard for different settings (Stead & Marshall, 2001).

2.2.2 INTEGRATION AS A PLAN OBJECTIVE

There are a number of difficulties experienced while effectuating the outputs of causal and simulation studies, to name a few, inability to generalise the findings of the causal studies to other settings, large data needs of the simulation models and data collection costs, inaccessibility to personnel and software to run these models. In addition to these, people's expectations from governments in responding to pressing urban sustainability problems have led to proliferation of policy documents covering land use and transport integration. It should be noted here that particularly the studies discussing sustainability of current transport and mobility patterns have initiated the inclusion of sustainability concerns into classical transport policy documents (Vande Walle, et al., 2004).

For example, in the US, 'Coordinating Land Use and Transportation' has been considered as one of the primary responsibilities of Federal Highway Administration, which has given rise to a number of plans and programs initiated at state-wide, metropolitan and city level. Additionally, the US Environmental Protection Agency has elaborated integration along with Smart Growth to provide guidance in urban development projects. In Australia, integration of land use and transport has been considered as one of the main strategies to reach sustainable mobility goal and this was highlighted by the Department of Transport and the Regional Services (DOTARS, 2003). State governments of Victoria, Western Australia and Queensland have included integration as an objective in their regional plans. Integration of land use and transport policies is the main theme of the EU's Land Use and Transport

Research (LUTR) cluster, which has funded a series of connected and mostly overlapping projects (ARTIST [Arterial Streets towards Sustainability], ECOCITY [Urban Development towards Appropriate Structures for Sustainable Transport], FACTUM [Assess implementations in the frame of the Cities-of-Tomorrow programme], ISHTAR [Integrated Software for Health, Transport efficiency and Artistic heritage Recovery], PROMPT [New means to PROMote Pedestrian Traffic in cities], PROPOLIS [Planning and Research for Land Use and Transport for Increasing Urban Sustainability], PROSPECTS [Procedures for Recommending Optimal Sustainable Planning of European City Transport Systems], STRATEC [Sprawling Cities And TransporT: from Evaluation to Recommendations], SUTRA [Sustainable Urban TRAnsportation], TRANSPLUS [Transport Planning, Land Use and Transport Planning, Land Use and Sustainability] and VELO INFO [the European Network for Cycling Expertise]). The compilation of the outcomes of these projects constitutes the deliverables of Planning and Mobility for Europe (PLUME). In addition to PLUME, effective operationalisation of these deliverables has led to another umbrella project (originally, it is defined as accompanying measure [to LUTR projects]), ASTRAL (Achieving Sustainability in Transport and Land-use) whose task is “ … to develop planning tools, assessment methodologies and best practices aimed at managing future transport demand through integrated land use and transport policies, reducing individual motorised vehicle movements and encouraging greater use of collective and other sustainable transport modes” (EC, 2004, p.11). In Japan, integration of land use and transport has been encapsulated at inter-regional level, and generally, coupled with urban renewal projects.

A review of three well-known international approaches can provide good insights on the principles adopted in different policy settings. These are land use and transport measures of TRANSport Planning, Land Use and Sustainability (TRANSPLUS) project (Sessa, 2007), Smart Growth principles compiled by Smart Growth Network (SGN, 2002) in the US, and integrated land use and transport planning principles of Department of Infrastructure (DIP, 2009) in Australia. Table 2.1 summarises the main considerations and coverage of these approaches.

Table 2.1 Three international perspectives to land use and transport integration principles

Principles	**EU TRANSPLUS**	**Smart Growth**	**DIP**
Increasing compactness of settlements (including buildings) and their land use mix (short-distance mixed-use development)	✓	✓	✓
Planning new developments in close proximity to the existing urban services, as infill or brownfield development	✓	✓	✓
Encouraging active transport via design features to foster walkable neighbourhoods	✓	✓	✓
Improving accessibility to urban services by alternative modes	✓	✓	✓
Enhancing public transport service and quality, and encouraging public transport oriented settlement	✓		✓
Creating a range of housing opportunities and choices (affordable housing)		✓	✓
Enhancing the character and amenity of the urban areas to foster a strong sense of place and community		✓	✓
Encourage community and stakeholder collaboration in development decisions	✓	✓	
Preserving open space, farmland, natural beauty, and critical environmental areas		✓	✓
Developing new car restricted development along with parking regulations and control measures	✓		
Balancing travel costs of automobile and alternative modes, and changing travel behaviour by soft measures			✓
Make development decisions predictable, fair and cost effective		✓	
Relocation of road space	✓		

Note: Adapted from Sessa (2007, pp.58-59), SGN (2002, pp.88-93) and DIP (2009, p.101)

The first five principles, mostly shared by all initiatives, perfectly overlap with the contemporary definition of the 5D's of development (density, diversity, design, distance to transit and destination accessibility) (Ewing et al., 2011). This highlights the role of these core principles in supporting active and public transport, quality of life, community health and well-being and reducing automobile dependence (Banister et al., 1997; Cervero & Kockelman, 1997; Ewing & Cervero, 2001; Newman & Kenworthy, 1999). Provision of affordable housing, promoting urban character and amenity, encouraging public involvement in decision-making and conservation of natural assets are another set of qualities shared by given approaches and are also outstanding topics of sustainable communities, liveability and quality of life debate. Restricting automobile use by strict measures on road infrastructure is a distinctive property of the EU land use and transport policies. Formulating soft measures to encourage people to travel less by car and making development decisions considering economic implications on society are characteristics of approaches in Australia and the USA.

The main conclusion drawn from this literature review is that even though the conceptualisation of the main concerns varies regarding local context and values, the problems and remedies have started to saturate on a number of key issues. These issues are successfully covered in policy documents referring to the case study area, the Gold Coast, Australia in terms of level and quality of land use and transport integration. A review of these documents can form a backbone to build a sound argumentation. Particularly the South East Queensland (SEQ) Regional Plan and the Integrated Regional Transport Plan (IRTP), and the Gold Coast City Transport Plan (GCCTP) are three good examples to reveal the local dimension of the problems and conceptualisation of the policies to reach the desired ends.

South East Queensland Regional Plan

In 2009, the DIP released the updated SEQ Regional Plan (2009-2031). It provides the framing principles and policies for any urban development taking place in SEQ and encompasses 12 principal regional policies. They are: sustainability and climate change, natural environment, regional landscape, natural resources, rural futures, strong communities, engaging Aboriginal and Torres Strait Islander people, compact settlement, employment location, infrastructure, water management and integrated transport. Particularly, compact settlement and integrated transport policies cover similar issues mentioned previously. More specifically, compact settlement policies are clarified as follows:

- Supporting compact development, which is more efficient and also conserves land, and containing growth, which enhances liveability, transport efficiency and reduces car dependency;
- Enhancing the character and amenity of the urban areas by innovative design, particularly by considering sub-tropical design principles;
- Underlining the importance of connected, diverse and functional urban greenspaces as residential amenity and incentive to active lifestyle;
- Providing a variety of housing options which meet diverse community needs, particularly affordable housing;

- Designing activity centres which can support public and active transport infrastructure and attract businesses;
- Creating mixed-use activity centres to increase local accessibility, employment opportunities and social interaction, and reduce travel demand;
- Integrating land use and transport planning, which promotes the listed objectives in a comprehensive way;
- Developing strategies to enhance the sustainability of newly developing urban and rural residential areas with reference to the listed objectives.

In the regional plan, it is stated that "land use, transport and employment integration all play key role in achieving social, economic and environmental sustainability for SEQ. By shaping the development pattern and influencing the location, scale, density, design and mix of land uses, integrated planning can create complete communities" (DIP, 2009, p.101). The plan further explains the benefits of land use and transport integration as " …[it] reduces the need for travel; results in shorter journeys; provides safer and easier access to jobs, schools and services; supports more efficient land and existing infrastructure use; and maintains the environmental benefits of compact development" (DIP, 2009, p.101). It also gives the details of how this integration can be achieved as follows:

- Prioritise new broadhectare development sites with access to existing or planned transport infrastructure;
- Undertake land use and transport planning concurrently and sequence development with timely infrastructure provision;
- Plan new public transport routes, facilities and high-frequency services to ensure safe and convenient passenger accessibility, and support the interrelationship between land use and transport;
- Connect active transport routes to improve accessibility and encourage transport use by a broader range of people;
- Apply TOD principles and practices to the planning and development of transit nodes, having regard for local circumstances and character;

- Manage car parking provision in regional activity centres and high-capacity transport nodes to support walking, cycling and public transport accessibility;
- Ensure all new development within walking distance of a transit node or regional activity centre which maximises pedestrian amenity, connectivity and safety.

Integrated transport section ends with a strong emphasis on prioritisation of TOD as one of the main programs for SEQ. Principles and precinct typologies for TOD are also supplied in the closing of the issue.

South East Queensland Integrated Regional Transport Plan

Also known as Connecting SEQ 2031, the IRTP is the updated version of the SEQ Integrated Regional Transport Plan of 1997. It was prepared as a supplement to SEQ Regional Plan by setting a number of specific objectives and principles, which show how integrated transport can be operationalised in SEQ. These objectives and principles are explained as follows:

- Creating compact and connected communities: Promotion of the centres' access hierarchy and priority transit corridors to support higher density development; providing accessibility to community facilities by active transport and designing a series of 15-minute neighbourhoods (dense enough to support public transport) connected by public transport; promotion of the priority freight network which is well-connected to motorways to encourage industrial development which takes place at close locations to markets, airports and sea ports.
- Changing travel behaviour: Promoting TravelSmart program to direct people towards choosing active and public transport means; managing parking supply in activity centres and promoting public transport services in these areas; giving incentives to change travel behaviour; spreading peak hour traffic loads to off-peak hours via supporting changes in working hours.
- Improving transport system efficiency: Adopting one network approach for the management of the road system by taking into account the effects of

land uses on traffic loads and promoting integrated planning between state and local agencies; improving the efficiency of traffic movement via employing technologic means and travel time reliability via incident management schemes; designating bus priority and high occupancy vehicle (HOV) lanes to relieve congestion; improving the reliability of travel times for motorways and strategic freight routes; upgrading the rail system to increase efficiency.

- Supporting economic vitality: Servicing major employment centres with high-frequency public transport; management of both land and transport system for efficient operations of freight movement in industrial and commercial zones; separating heavy vehicles from suburban road network.
- Protecting environmental quality and health: Promoting a more fuel efficient, less polluting and lower carbon-emitting vehicle fleet; encouraging the use of active and public transport, and rail freight for the transport of goods rather than road.
- Delivering an integrated transport network: Designating a region of interconnected communities where transport contributes to a safe, healthy and accessible lifestyle; supporting infrastructure investment on public, active and freight transport as the priority for capacity building; focusing on rail transport as the principal passenger system of the future; enhancing bus network and services to meet the demand of growing urban areas.

Gold Coast City Transport Plan

The GCCTP was prepared in 1998 to inform the public about the future demand for transport in the city and provide policy options to cope with the externalities of the current transport system for the next 30 years. This plan starts with highlighting the challenging issues for the local authority, such as, high population growth, auto dependent travel patterns, problems related to urban growth, and so on. Then it explains why the city should have a sustainable transport system in order to ensure the well-being of the current and future residents, and to reach this end, the necessity for an integrated transport plan in accordance with the Queensland Government's IRTP for SEQ. In the GCCTP, the reasons for an integrated transport plan are explained as follows:

> An integrated approach to transport planning means all the relevant transport modes and opportunities, and the relationship between transport and land use decisions, are considered in the planning process. This is the best way to ensure the complex transport issues are dealt with in their true context, rather than relying on simple cause and effect relationships to identify solutions (GCCC, 1998, p.18).

Accordingly, it is stated that the transport plan should include "all modes of transport, safety and personal security issues, effects of car-dependent urban pattern on future travel choices, and funding" (GCCC, 1998, p.18). More specifically, these topics are covered with seven strategic objectives as follows:

- Quality public transport: Completion of major improvements and extensions in the line haul system considering the anticipated growth in demand and service levels of other public transport modes; betterment strategies for public transport services and infrastructure via reliable passenger information system; well designed stop locations and numbering, interchange fittings and facilities; affordable fare scheme; good accessibility for pedestrians and cyclists around interchange facilities; bus priority lanes; strategically located park-and-ride facilities; expanding public transport services to new growth areas and establishing an expansion program for newly developing areas; facilitation of new paratransit services using communication technologies.
- Co-ordinated land use and transport systems: Designating locations for 'public transport precincts' where alternative transport modes to automobile are encouraged, and major residential and commercial development is located to maximise public transport patronage; creating mixed use areas where residential and other uses are close to each other, which would reduce trip lengths, and where non-motorised modes are encouraged; curbing urban sprawl and offering incentives for infill development while protecting local character and the amenity of the existing urban areas; locating major new urban development close to the existing public transport services; improving pedestrian accessibility by providing more direct routes and comfortable walking environments; limiting parking supply particularly

in major urban centres to discourage driving, otherwise the most attractive travel option.

- Moderated growth in travel demand: Supporting current car pooling program (Car Pool Connection) and trial measures in telecommuting, and bettering the utilisation of vehicle fleets of the businesses; using various media to better inform public about externalities of transport activities; supporting other measures to better the utilisation of road service levels, such as staging working hours and trading hours to relieve peak hour traffic considering school and commuting trips.
- Attractive non-motorised transport: Provision of a connected, convenient, comfortable, convivial and conspicuous walking and cycling infrastructure; ensuring urban planning staff understands the needs of pedestrians and cyclist; education campaigns for the public on benefits of active transport and non-motorised transport opportunities provided.
- A safe and efficient road system: Undertaking the development program to meet future traffic demand and maintain the road system in terms of physical quality and service level; designation of HOV lanes to promote car-sharing; continuous evaluation of all road infrastructure to ensure the safety of passengers and drivers; providing a co-ordinated traffic signalisation system and a reliable road incident system; developing the Pacific Motorway specific strategies to ensure the smooth functioning of the motorway.
- Efficient freight and air transport operations: Supporting the effective functioning of freight transport by enhancing infrastructure (capacity improvement, signalisation, sharing HOV lanes, and so on), introducing technological betterment strategies and applying appropriate standards for loading zones; balancing costs and benefits of the air transport system considering noise pollution, industrial growth demand around the airport, effective utilisation of the airport capacity and the growth potential of commercial flights.
- Integrated and environmentally responsible transport system: Ensuring air quality as complied with the air quality goals of the Environmental

Protection Policy 1997 under the Environmental Protection Act 1994; supporting Air Care program of the IRTP to reduce the emissions from transport by education and enforcement measures, and use of technologies for cleaner engine and fuels; adopting a reporting and maintenance program for ‘smoky vehicles’; mitigating the noise impact of transport activities; maintaining social justice by supporting people with mobility difficulties.

In addition to these objectives, eight guiding principles are given for creating an integrated and sustainable transport system. Basically, these principles help to clarify actions and strategies to meet the GCCTP objectives by utilising scarce public resources in the most efficient way. These principles are as follows (GCCC, 1998, p.40):

- A multi-modal approach which emphasises meeting needs by the availability of a range of quality choices including public transport, walking, cycling and the private vehicle;
- Integration of road transport, public transport, walking and cycling into a cohesive transportation network;
- Integration of transport decisions with land use strategies, which help reduce travel growth and support the effective operation of public transport and non-motorised transport;
- Maximum use of beneficial technology to increase efficiency and improve quality;
- Minimising emissions to the environment and reducing wasted energy consumption;
- Ensuring the efficient use of roads without attempting to provide roads and parking to accommodate peak period car use by single occupant vehicles;
- Attention to lower cost solutions where possible;
- Achieving a better balance between the cost of using a private motor vehicle and the cost of using alternative, more environmentally friendly modes of transport.

In summary, it is one more time emphasised that the transport plan should aim to diminish car-dependent travel patterns and externalities coupled with these by giving special attention to alternative transport modes, TDM, technological improvements, and an integrated land-use and transport policy.

2.2.3 SPATIAL SCALE OF INTEGRATION

Computational and policy frameworks related to land use and transport integration provides a number of parameters to discuss on how it can be operationalised. However, there is one more question left, which spatial scale is the most convenient to obtain a clear understanding of the mechanism of integration? While reviewing urban form and sustainable transportation literature, Black et al. (2002) supplied a summary figure (as shown in Figure 2.3), which shows the general structure of the current discussion.

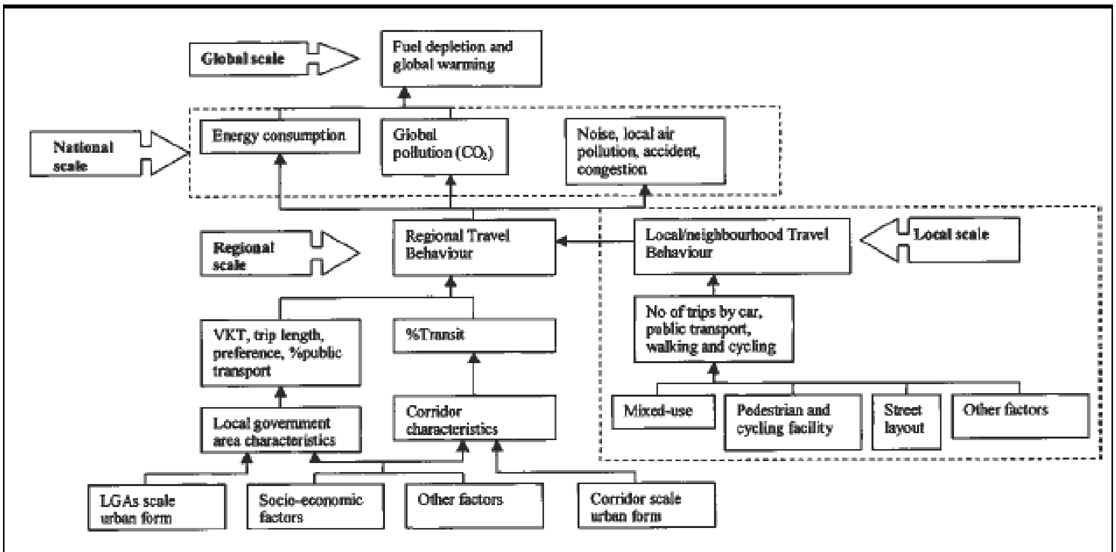


Figure 2.3 Connections between different spatial scales and urban form and transport sustainability; from Black et al., 2002, p.191

As it can be seen in Figure 2.3, there are four scales of urban form and sustainable transport discussion, global, national, regional and local. While the global and national considerations concentrate on energy consumption, green house gases (GHGs) and pollution, which are the main drivers of fuel depletion and global warming, the regional scale is mainly composed of regional travel behaviour components. On the local scale, local and neighbourhood travel behaviour is tied with the number of trips made by different modes, and this is mostly coupled with the density, diversity, design and availability of non-motorised facilities and public transport services. Although the local scale is depicted independently; in fact it is the building blocks of local government areas (LGAs) and corridor scale urban form and travel patterns.

From another perspective, more information on the influence of land use characteristics on travel behaviour can be acquired from Figure 2.4. As mentioned previously in spatial scale and sustainable urban form discussion, there are a number of characteristics matched with travel patterns. In Figure 2.4 below, local (city) scale covers the widest range of land use characteristics excluding only the geographic location of the city and the fine layout details of the settlement. Not surprisingly, neighbourhood scale encompasses the most operational characteristics, which are conceptualised as 3Ds, including the clustering of sub-centres in a city.

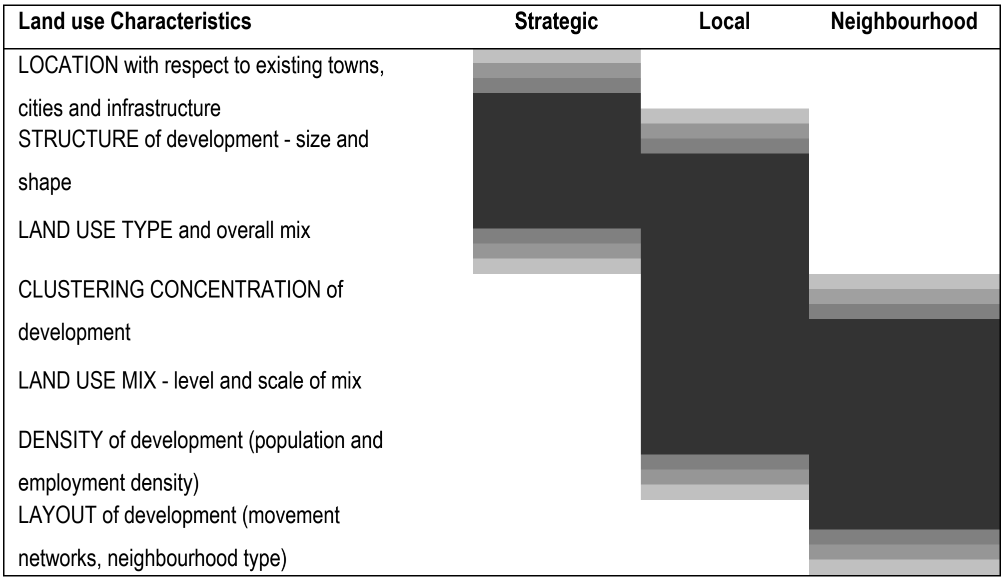


Figure 2.4 Effect of land use characteristics on travel behaviour according to spatial scales

Note. From Owens, 1986, cited in Stead & Marshall, 2001, p.114. The hues of gray show the degree of the association of each spatial scale with respective land use characteristics, the darker the hue the stronger the association.

Above mentioned figures provide an overall understanding about the spatial scale of integration, but do not answer the primary question asked in the beginning, which scale is the most workable to make robust inferences about the mechanism of integration? As well-evidenced in the literature (Bhat & Guo, 2007; Cervero & Kockelman, 1997; Frank et al., 2007; Handy et al., 2006; Krizek, 2003b; C. Lee & Moudon, 2006; Schwanen & Mokhtarian, 2005a; Zhang, 2006), the neighbourhood scale seems the right scale to discuss the urban form and transport integration. Knapp and Song (2004) clearly explained this as follows:

> Thus there indeed seems to be a land use-transportation behavior connection and we know how this relationship works at the neighborhood scale. We still don’t know much, however, how this operates at a regional scale, or how to manage land use so as best to serve the interests of those who would choose intense urban living over automobility as well as those who would choose otherwise (p.5).

In the UK and Australia, the neighbourhood design has been one of the planning tools considering “…the neighbourhood’s potential to reduce car use and encourage walking, and thereby foster a set of behaviours that are healthier, more social, less polluting and more environmentally benign, is what most attracts those pursuing more sustainable urban forms.” (Curtis & James, 2004, p.33). All of these considerations have also been covered under sustainable neighbourhood debate along with sustainable communities and liveability concepts.

2.3 SUSTAINABLE NEIGHBOURHOODS

Choguill (2008) defined neighbourhood level sustainability by taking into account four dimensions and specified a set of criteria for each dimension considering the definition made by famous urban theorists (i.e., Howard, Perry, Stein, Wright, Mumford and Fisher). According to him, the four dimensions of neighbourhood sustainability are as follows:

- Economic sustainability: Reducing the cost of transport and infrastructure, and providing an economic base for local establishments;
- Social sustainability: Defining an ideal population size, which enables interchange and pursuit of mutual benefits;
- Technical sustainability: How physical boundaries and the form of the neighbourhood defined (i.e., a boundary which enables social interaction and physical features, and provides safe and contained settlement);
- Environmental sustainability: Provision of green spaces as the facilitator of interaction and prevention from pollution.

The neighbourhood sustainability concept has become popular mostly because of the growing interest on two US-originated endeavours, Smart Growth and New Urbanism. While they have strongly emphasised that the urban sustainability problems experienced today are a direct consequence of poor management of urban resources, they have also underlined the design-led approach harnessed with liveability and quality life concerns can provide economic vitality, community well-being and environmental sustainability. It is possible to see similar initiatives, such as liveable neighbourhoods, TOD, Urban Village, design-led sustainable development, Greenhouse Neighbourhood, and so on, taking neighbourhood as the appropriate spatial scale to reach sustainable community goal. Among sustainable neighbourhood initiatives, two national examples demand a close examination to discover how this concept has been elaborated within the confinement of national and state regulations, policy orientation, and real estate market. These are *Liveable neighbourhood* of the Western Australian Planning Commission (WAPC) and *VicUrban* of Victorian State Government.

2.3.1 LIVEABLE NEIGHBOURHOOD

Liveable Neighbourhood Design Code is an initiative of the WAPC involving creation of sustainable urban areas, which is recognised by various international consortiums as the successful endeavour and won the Congress for New Urbanism Charter Award in 2001 (Curtis & James, 2004). Liveable neighbourhood initiative has provided a set of design elements to define a good neighbourhood. These are community design, movement network, lot layout, public parkland, urban water management, utilities, activity centres and employment and schools (WAPC, 2007). These elements compile similar endeavours undertaken by nearly 15 governmental institutions in Western Australia. After disclosing the aims of this initiative, they presented a background on 'neighbourhood design approaches', which also constitutes the building blocks of the design elements. According to the WAPC (2007), neighbourhood design has been changing since the 1970s in a way that compromises low density housing on large parcels, curvilinear road network leading to low levels of connectivity and clearly defined boundaries with roads or walls. Recently, however, this design approach has evolved to another state which encompasses the economic, social and environmental aspects of the sustainable neighbourhood concept. Well-known examples of this new state are transit-oriented design, urban village, greenhouse neighbourhoods, traditional neighbourhood design, and so on, whose main aims are to diminish energy consumption by changing parameters in planning, building design and personal consumption levels, and to provide safe, attractive, accessible living environments (WAPC, 2007). In order to reach a liveable neighbourhood end, the following 11 objectives should be achieved (WAPC, 2007, p.1.6):

- To achieve sustainability targets in the urban development process by reducing energy use and car dependency, encouraging self-containment and self-sufficiency of neighbourhoods and conserving natural and cultural assets,
- To meet the changing needs of people and community and offer a range of options of housing, leisure, employment (local), and community and commercial services,
- To develop compact walkable neighbourhoods with intense and mixed use central locations, which provide benefits for local economy in terms of employment, and for social opportunities,
- To support and enhance local character and identity, and promote a sense of community via a site-responsive approach to urban development,
- To supply a connected, convenient and safe movement network which promotes accessibility to urban services and public transport, encourages walking and cycling, and minimises the impacts of traffic,
- To provide safe, connected and well-distributed public open spaces and recreation areas,
- To comply with the environmental constraints of a neighbourhood, such as soil erosion, bushfire risk and flooding,
- To adopt good urban water management techniques relating to stormwater quality, water conservation and re-use, and the health of ecosystems and public,
- To provide a good balance between sustainable and efficient land consumption and protection of environmental assets,
- To promote public transport on a level in which it can compete with private cars,

- To equitably provide public utilities in a timely, cost efficient and effective manner.

2.3.2 VICURBAN INITIATIVE

VicUrban was founded by the State Government of Victoria in 2003 by 'Victorian Urban Development Authority Act, No: 59/2003' to lead urban sustainability initiatives, more specifically, to reach the goal of sustainable communities. In the act, the function of VicUrban is defined as acquisition of urban land, which will be developed for residential or other urban uses by VicUrban alone or by a partnership in the support of competitive land market in Victoria. Promotion of "best practice in urban and community design and development, having regard to links to transportation services and innovations in sustainable development" (Victorian Urban Development Authority Act, 59/2003, p.5,), and improving housing affordability and provision of consultancy for land development are the other functions listed by the act. The prime functions of VicUrban have been consolidated to five objectives which are given below:

- Community Well-being (Developing and supporting green lifestyle programs, participation of residents in design, management and decision making processes, creating a sense of place, and planning for the mix of uses and services);
- Environmental Leadership (Supporting innovations in the environmental performance of built environment via including WSUD and climate friendly housing elements in design and construction of settlements);
- Economic Viability (Maintaining local businesses and employment via revitalisation projects, supporting affordable living via diversity in products and customers);
- Urban Design Excellence (Promoting the health and vibrancy of urban communities via cohesion with the surrounding areas, and good internal and external connectivity of the urban areas);
- Affordable Living (Providing access to quality, affordable housing that is located close to services, transport, employment and community facilities) (VicUrban, 2011)

2.4 SUMMARY

Urban sustainability concept covers mostly interrelated and critical concerns, and it is possible to discuss the implications of each concern within a confinement of spatial scale. Among all issues of urban sustainability, the sustainable mobility niche requires a special attention due to the externalities attributed to transport activities. They are, to name a few, global climate change, air and water pollution, traffic congestion, traffic accidents and fatalities, degradation of environmental assets, inequality in sharing transport benefits, or costs among social groups. In itself, even sustainable transport sub-domain encompasses wide ranging issues, which are hard to conceive broadly. However, we can narrow our focus a bit and concentrate on what makes people travel more. With this respect, sustainable urban form debate can provide more insights about how urban form influences travel behaviour. In summary, the main topics of sustainable urban form discussion are to diminish urban sprawl and reduce frequency and length of everyday journeys via some planning and design principles, such as urban consolidation, mixed use, provision of public and non-motorised transport opportunities (Holden, 2007), as well as to make urban services and amenities more accessible. This debate is also the main topic of integration of land use and transport decisions literature.

There are two general approaches to how integration of land use and transport can be specified, computational and policy-based approaches. While the former tries to find association between urban form and travel behaviour variables by controlling socio-economic variables, the latter conveys principles and objectives on how it can be achieved. In Australia, more exclusively in the study area, integration of land use and transport decision has been one of the key components of the regional and city plans as an urban sustainability objective. Therefore, it can be said that the latter approach to the integration prevails the former in the local context. A review of these policy documents clearly demarcate 13 principles aimed to be achieved by the plans. These are supporting compact and connected development; prioritising new broadhectare development sites with access to existing or planned transport infrastructure; creating mixed-use activity centres; planning new public transport routes, facilities and high-frequency services; designating locations for ‘public transport precincts’; designing activity centres via embracing a multi-modal approach; connecting active transport routes to the activity centres and high-capacity transport nodes to improve accessibility; achieving a better balance between the cost of using a private motor vehicle and the cost of using alternative; enhancing the character and amenity of the urban areas; providing a variety of housing options; limiting parking supply; changing travel behaviour by various programs; and protecting environmental quality and health.

A close examination of these principles shows that while they are in concordance with the primary claims of international and academic studies, they also enable us to categories relevant concepts. Accordingly, they specifically underscore the sustainability of transport with reference to keeping the demand for *mobility* in a sustainable level, in the mean time, enhancing the *accessibility* to urban opportunities with various modes. Furthermore, they place a special emphasis on compactness and connectedness regarding the *density* and *land use mix*, and *design* of non-motorised transport infrastructure and greenspaces in a city. Lastly, environmental externalities of transport are mentioned as efficient *resource consumption* and less *pollution*.

Another concern is related to the spatial scale, which enables us to discuss the mechanism of land use and transport integration. In this regard, neighbourhood scale comes forward considering the evidences from the literature. For example, it provides fine-grain details of the association between urban form and travel behaviour, advised plan principles can be easily adapted to neighbourhood scale, it can clearly show specific localities whether there is a need for intervention and finally, it has been one of the basic design units in planning education and practice with a long history and, as a result, intervention tools. Of course, it should be noted that sustainability of the neighbourhoods covers more than land use and transport considerations. In the next chapter these principles extracted by the review of urban sustainability and land use and transport integration literature are used to formulate a monitoring and evaluation framework via indicators by focussing on neighbourhood level characteristics of the urban areas.

Chapter 3: Literature review: Part II

After defining principles of land use and transport integration, the next step is to decide on an assessment methodology to monitor and evaluate the effectiveness of these principles. Accordingly, the main aim of this chapter is to reflect on the available sustainability assessment tools that can be utilised to evaluate the achievement of land use and transport integration principles. To reach this end, first available assessment methods are reviewed. Considering the practical advantages and its relevance to the objectives of this study, indicator-based sustainability assessment method is further elaborated. After clarifying the primary requirements of a valid and reliable indicator system, indicators of land use and transport sustainability are analysed and their qualities are reported. Additionally, composite indicator creation process and spatial indices are explored to define the merits of a well-designed composite indicator framework. The structure of this review is given in Figure 3.1.

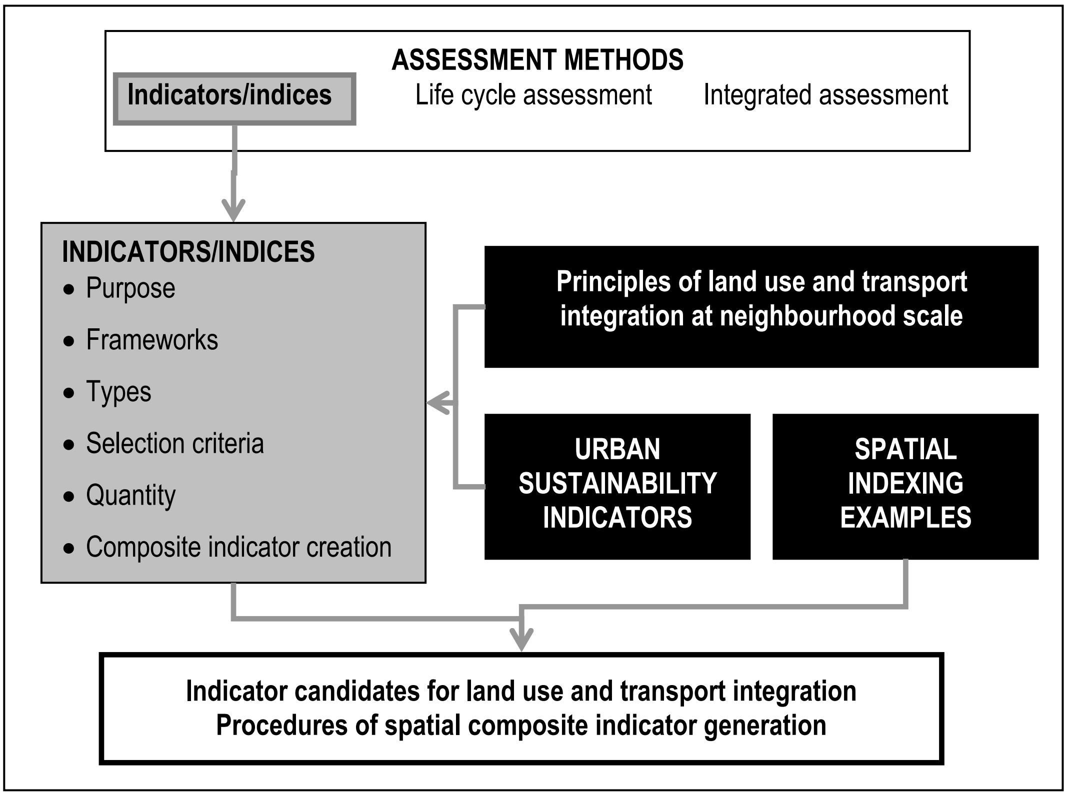


Figure 3.1 Structure of assessment methods review

With regard to Figure 3.1, specific questions answered in this chapter are as follows:

- How can the sustainability performance, whether the predetermined objectives are attained, be assessed with available sustainability assessment tools? What are the main characteristics of these assessment methods in terms of problem definition, measurement strategy, evaluation process and the final product? Which evaluation method fits best to reflect on land use and transport integration principles and why?
- Which set of indicators best reflect the mechanism of land use and transport integration? How can they be presented spatially in a simple, valid and reliable manner?

3.1 CLASSIFICATION OF ASSESSMENT METHODS

The main aim of evaluation research is to provide a well-founded basis for assessment, and to give reliable information and effective measures for policy making process. This research domain also encompasses a number of interdisciplinary issues and has intrinsic controversies. Particularly, public administration studies, urban studies and environmental sciences are the main beneficiaries of sustainability assessment studies (Hezri & Dovers, 2006). Conceptualisation of the same problem with different measures, the spatial scale and local characteristics of the problem areas (i.e., a scale ranging from global trade transactions to life cycle of a product, and cultural differences in values) are the main sources of controversies.

The framework provided by Ness et al. (2007) is perhaps the most succinct overview related to available assessment tools. As depicted in Figure 3.2, these tools sit in a temporal frame showing retrospective and prospective characteristics of the available methods. Depending on the position in this temporal frame, these tools can be disaggregated as to their general foci. Indicators and indexes suggested by various organisations have been used generally at government or corporate level to picture the overall performance of the institutions. In other words, they usually convey the *retrospective* aspect of institutional performance and provide a historical perspective about progress towards a target. On the other hand, in order to assess the environmental impacts of plans, programs or projects, more formalised and *prospective* assessment methodologies are employed, such as, the environmental impact assessment (EIA), strategic environmental assessment (SEA) and the EU Sustainability Impact Assessment (Hacking & Guthrie, 2008; Pope et al., 2004). In between these two nodes, product-related assessment methods take place due to the *contemporary* characteristic of production, transportation and marketing of a product. Therefore, life-cycle of any product is highly dependent on and should be flexible to fit in changing external environment (introduction of a competing product, new international trade and environmental regulations, changing customer tendencies and so on). The number of methods is not limited to the listed ones. However, giving different names even to the studies with a very similar conceptual construct usually makes it hard to delineate the boundaries of an assessment method. As emphasised by Hacking and Guthrie (2008), the alphabet soup of acronyms and terms currently makes for a rather confusing picture.

Having reserved the discussion related to the indicators and indices in the next section, other tools will be clarified according to the given assessment domains starting from the Life-Cycle Assessment (LCA). As the product-related assessment method, the LCA involves accounting the environmental impacts of all stages and processes related to a product or service starting from the extraction of raw material for its production to the end of its life as recycled and disposed in the landfill (Rebitzer et al., 2004). Depending on the stages of the processes, the complexity and comprehensiveness of the LCA can change drastically. Because of this, the current practice of the LCA as embraced by companies takes into account major processes in terms of their possible environmental impacts (Joshi, 1999). In order to provide a generalised approach for the LCA, International Standards Organisation released a series of standards. These "standards being developed for inclusion under ISO 14000 include principles and guidelines for conducting LCA for product evaluation" (, p.94; Tibor & Feldman, 1996 cited in Joshi, 1999). Growing public interest in environmental problems has led to a growth in popularity of eco-labelling, eco-products and ethical products, which in turn has directed producers to embrace the LCA and other environmental accounting methods as an integral part of their production processes.

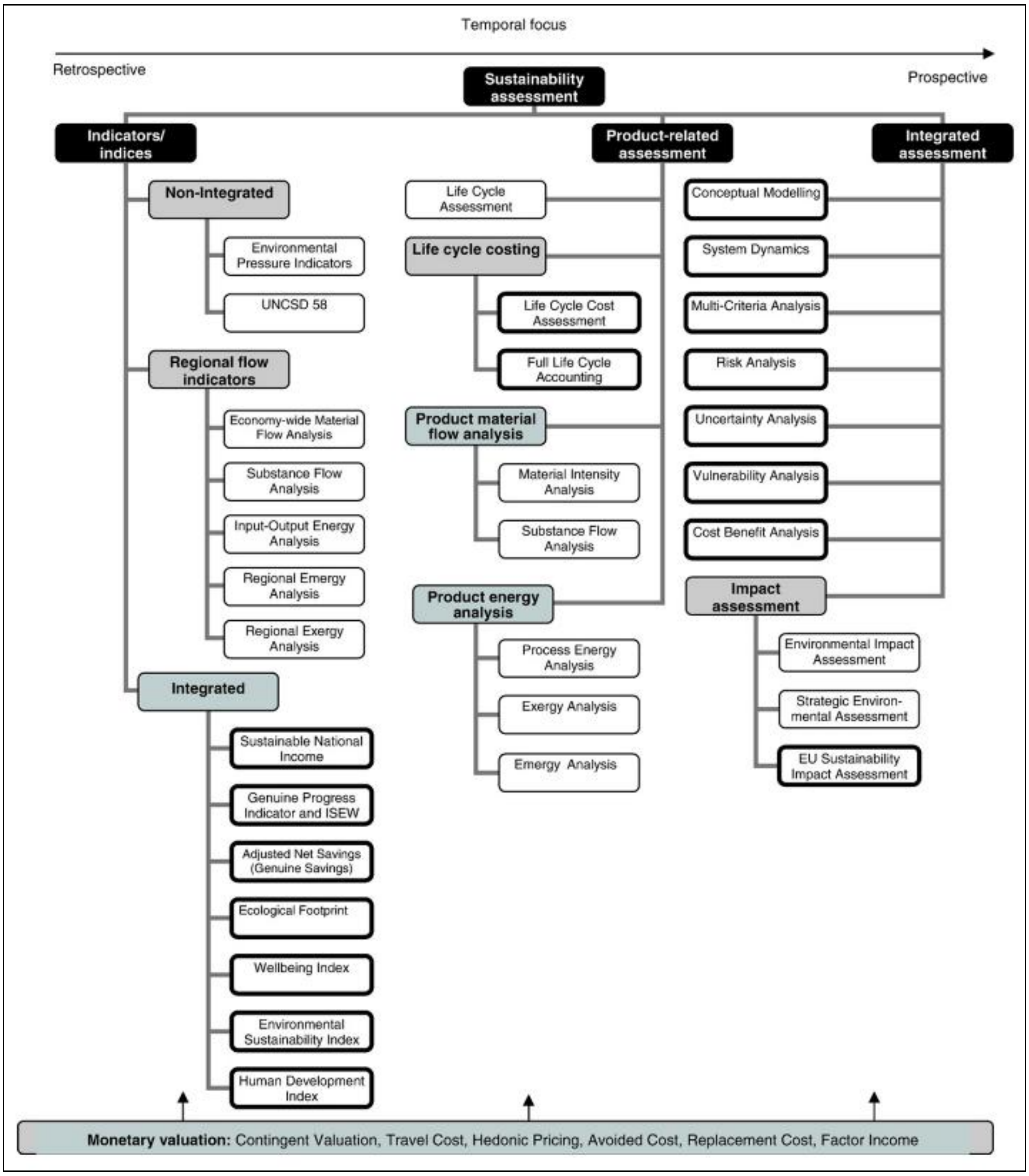


Figure 3.2 A framework for sustainability assessment methods; from Ness et al. 2007, p.500

Among integrated assessment tools, the EIA is the most widely utilised assessment method internationally. The reason for this is that almost all the governments have environment laws making the EIA preparation compulsory for projects before implementation. Even if selected criteria and their weights in the decision making process change as to the priorities of the countries, the main aim of the EIA is to quantify the environmental costs generated by projects and to help decision makers to make selection among alternatives according to the designated goals of protecting and maintaining environmental assets. As it can be seen in the figure above, there are different techniques grouped under the integrated assessment domain as well as monetary valuation tools, which have been widely used in the EIA preparation. Criticism of the EIA due to its limited scope, which is applied generally at project level, its disability to cover broad environmental goals (Shepherd & Ortolano, 1996), and the changing definition of sustainable development give rise to a search for new assessment methods. As an alternative to the EIA, the SEA method has been introduced and become one of the most debated subjects in the literature. In general, the SEA is currently understood to be a process for identifying and addressing the environmental (and also, increasingly, the associated social and economic) dimensions, effects and consequences of plans, policies and programs (PPP) and other high level initiatives (Dalal-Clayton & Sadler, 2005). Shepherd et al. (1996) explain main qualities of the SEA as follows:

- Its scope encompasses cumulative, secondary and indirect impacts;
- Similar to higher level the EIAs, the SEA covers multiple tiers, i.e., economic, social, environmental and institutional, along with project level;
- It starts at the conceptual level of projects, i.e., determination of goals and initial planning efforts, which gives opportunity to agencies in rethinking over policy alternatives and program modifications;
- Because of its holistic and comprehensive qualities, applying sustainability principles to a whole decision making process is viable.

The EU Sustainability Impact Assessment, the updated version released in 2009, may be the most comprehensive assessment framework encompassing key issues in the sustainability discourse. By definition, “it is a process that prepares evidence for political decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impact” (EC, 2011, p.1). The main aim of this framework is to standardise the steps to be followed in the assessment process and provide an integrated approach encompassing the costs and benefits of the projects by giving specific implications as to the three tiers of sustainability (see Table 3.1). In the mean time, it covers important concerns related to the accountability and relevance of the framework (i.e., stakeholder participation level, transparency in the assessment process, reasons of why a specific action should be taken and how).

Table 3.1 EU Sustainability Impact Assessment considerations

Impact category	Category sub-headings
Economic impacts	Functioning of the internal market and competition; Competitiveness, trade and investment flows; Operating costs and conduct of business/Small and Medium Enterprises; Administrative burdens on businesses; Public authorities; Property rights; Innovation and research; Consumers and households; Specific regions or sectors; Third countries and international relations; Macroeconomic environment
Social impacts	Employment and labour markets; Standards and rights related to job quality; Social inclusion and protection of particular groups; Gender equality, equality treatment and opportunities, non -discrimination; Individuals, private and family life, personal data; Governance, participation, good administration, access to justice, media and ethics; Public health and safety; Crime, Terrorism and Security; Access to and effects on social protection, health and educational systems; Culture; Social impacts in third countries
Environmental impacts	The climate; Transport and the use of energy; Air quality; Biodiversity, flora, fauna and landscapes; Water quality and resources; Soil quality or resources; Land use; Renewable or non-renewable resources; The environmental consequences of firms and consumers; Waste production / generation / recycling; The likelihood or scale of environmental risks; Animal welfare; International environmental impacts.

Note. From EC, 2009

The remaining items in Figure 3.2, which are not explained in this section, are the variations (product material flow and energy analysis) or auxiliary tools (multi-criteria, risk, uncertainty, cost-benefit analysis and so on) of these general frameworks. As stated by Ness et al. (2007), the given typology is particularly helpful to discuss sustainability issues by focussing on either the spatial scale (indicators and indices, integrated tools) or at product level (product-related tools). Also, monetary valuation tools, as depicted at the bottom of the figure, can be used with any assessment tool where applicable.

The indicator-based sustainability assessment is selected and elaborated further in the following sections due to policy assessment nature of this study. More clearly, both life cycle assessment and integrated assessment methods require a clearly defined set of parameters (e.g., the amount of energy required for production, use, maintenance and disposition of a product, or for an industrial facility, annual carbon gas emission, air and water pollution to be produced, risk of hazardous spill and possible cost of the reclamation, and so on) which can be quantified by monetary, energy or other biophysical terms (e.g., carbon footprint). This is hardly the case for assessment of urban sustainability because of the complexity of demarcating the factors coupled with urban sustainability and, in most of the cases, the inability to quantify them. For these reasons indicators are the most preferred assessment framework by similar urban sustainability studies (see Section 3.3 for a detailed outlook of these studies). Furthermore, in Australia, local governments have a tendency to use indicators for urban sustainability assessment. Therefore, employing indicator-based assessment has practical advantages when making comparisons among other urban settings. Considering this, the methodology used in this study can be placed under "Indicators/indices" heading in Figure 3.2, and more specifically it is an example of an "integrated indicator/index" study.

3.2 INDICATOR-BASED ASSESSMENT

The OECD defines indicators as "a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value" (OECD, 2003, p.5). The main instrumental purpose of the indicators is that "…by visualizing phenomena and highlighting trends, indicators simplify, quantify, analyse and communicate otherwise complex and complicated information" (Singh et al., 2009, p.10). The use of indicators for policy purposes has a long history, and the first initiative dates back to 1929, when national indicators project was initiated by the Research Committee on Social Trends (Sawicki & Flynn, 1996). Indicators as assessment tools were used for the first time in the 1960s and improved by the rationalist/system approach of the era. In the 1960s, the indicators were mainly quantitative and based on statistics. By the 1970s, as a result of a shift towards health, quality of life and environmental indicators, qualitative factors started to be covered by different studies as shown in Table 3.2 (Coplak & Raksanyi, 2003, p.64).

Table 3.2 History of indicator development

Time frame	**Indicator area**
1920s–1930s	Social indicators
1940s–1950s	Economic indicators
1960s	Quality-of-life indicators
1970s	Environmental and health information system indicators
1980s	Healthy communities and quality of life indicators
Current	Sustainability indicators

Note. From Innes, 1990; T. Hodge, 1997; Schlossberg & Zimmerman, 2003

When the assessment of sustainability by indicators is scrutinised, the first point on which the majority of the academic society agrees is that the sustainability concept is value-laden and context sensitive (Dur et al., 2010b). Because of this, it is neither possible to clearly demarcate the intervention domains, nor to provide a unified method which can be used to evaluate it. As a result, there is a need for a semi-structured and flexible assessment method which can easily fit in the local context and be used for policy development. It is these qualities of indicators making them a plausible alternative for sustainability assessment. For over two decades, there has been a proliferation in indicator research, which is mainly due to the emerging need of sustainability assessment. The main characteristic of contemporary indicator studies, which differentiates them from the previous endeavours, is their focus on the inclusion of socio-economic and environmental indicators and their interaction as clearly stated in Brundtland Report. Also, the key role of indicators in Local Agenda 21 processes was expressed as "indicator of sustainable development needs to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems" (UN, 1992, Chapter 40.4). As stated by Flood (1997, p.1640) "there will be no indicators without policies and no policies without indicators", which is a common phenomenon in the assessment of sustainability.

The rationale and advantages of using indicators for the assessment of multi-dimensional and complex considerations are well-supported, but the most critical question remains: how can the indicators be selected in a coherent, participatory and valid way? The answer to this question is closely related to the assessment theory itself, more specifically, a loosely defined sub-domain in the assessment theory, indicator theory. The main considerations of indicator theory involve five issues as follows:

- Purpose of using indicators for assessment;
- Frameworks used to delineate indicators;
- Types of indicators and structure of the indicator sets;
- Criteria for indicator selection and;
- Number of indicators.

The reasons behind the use of indicators for sustainability assessment have been provided previously. In terms of frameworks used, Maclaren (1996) generated a typology of sustainability indicator studies. In essence, these frameworks are a clear reflection of how sustainability is embraced at theoretical level. In general, there are five approaches as given in Table 3.3. Goal-based frameworks encompass the classical three tiers of sustainability, which have been the most preferred framework for a great deal of studies. This approach involves the classification of the issues as to their relevance to the 3 Es. As a further refinement, the intersections of each domain have also been used to classify sustainability issues, since it is not always possible to contain one issue in one domain (cross-boundary factors and interactions between domains). Some researchers have preferred to use the concentric conceptualisation of the three domains rather than the intersecting representation. Generally, environment is used as the overarching domain embracing social and economy, which is placed inside the social as a sub-domain. However, the framework of the three Es is criticised due to mainly two considerations. Firstly, it does not sufficiently guide decision making and policy generation, so it is not very practical. Secondly, it does not take into account the interaction of issues defined. For example, high unemployment, increasing crime and unauthorised forest clearing can be grouped under different domains, though the last two considerations can be the direct consequences of the first factor.

Casual frameworks reflect the OECD's pressure, state and response (PSR), and the European Environment Agency's (EEA) driving force, pressure, state, impact and response (DPSIR) frameworks. In this framework, by defining system boundaries and considering this in isolation, a cause and effect relationship is formed for each sub-system. For example, the climate change problem can be placed in the DPSIR framework as follows: production and consumption patterns (driving force), the GHG emissions (pressure), the amount of the GHG in the atmosphere (state), global warming and climate change (impact), and international GHG treaties and carbon taxation (response). It provides a clear understanding about the interaction among elements and helps to resolve how a designated action might change other elements. However, there are a few backdrops of causal framework. They are: it is not always an easy task to delineate system boundaries in which the elements are defined in isolation, and they require a vast amount of data, in some cases it exceeds the financial capacities of the institutions.

Table 3.3 A typology for frameworks of sustainability indicators

Domain Based	**Goal Based**
- Environment - Economy - Society - …	- Carrying Capacity - Basic Human Needs - Social Well-Being - Economic Prosperity - Participation in Governance - …

Sectoral	**Issue Based**
- Housing - Welfare - Recreation - Transportation - Environment - Economic Development - …	- Urban Sprawl - Solid Waste Management - Crime and Society - Job Creation - Industrial Pollution - …

Causal		
Conditions	**Stresses**	**Responses**
- Air Quality	- Automobile Use	- High Occupancy Vehicle Lanes
- Unemployment	- Inadequate Education	- Special Training Programs
- Human Health	- Air Quality	- Pollution Warnings
- …	- …	- …

Note. From Maclaren, 1996; three dots at the end of each column represent the items not listed in the boxes.

Even though the remaining three frameworks are examined separately, the mutual characteristic of them is that they are policy-oriented frameworks to a great extent. All sectoral, goal-based and issue-based frameworks demonstrate an institutional preference on how to demarcate institutional values, responsibilities, objectives or problem definitions. Because they are derived from institutional qualities, they are very closely related to policies; more specifically, they can be placed under response indicators in a causal framework. The reason of using these frameworks is rather simple. As explained by Niemeijer and de Groot (2008b), selecting indicators on which an institution have control enhances the policy formulation and the efficiency of the actions. The main advantage of these frameworks is that while placing a special emphasis on policy considerations to guide decision making, they are also flexible enough to be converted to domain-based or causal frameworks.

As a last note, it is possible to see a combination of these frameworks. As exemplified by Ghosh et al. (2006), in order to define the scope of sustainability, the

UN Division for Sustainable Development (UNDSD) first created a set of 134 indicators with the categories of society, economics, environment, and institutions (domain-based). Following this, a vertical division was applied according to the sub-themes defined (sectoral and issue-based, e.g., chemicals, mining, sustainable consumption and production, transport and waste management), and then a horizontal division showing causal linkages among items, which is similar to the EEA's DPSIR framework but containing merely DSR items, was made. By this, each sector and issue specific factor was shown with a nearly complete scope.

In terms of types of indicators, Josza and Brown (2005) made a simple classification as input and outcome indicators. While the former refers to public resources devoted to advance in community sustainability, the latter refers to the amount of progress that has been achieved in sustainability. A more detailed classification was provided by Maclaren (1996). While it is not strictly a typology, she clearly stated that indicators can be grouped as integrating, forward-looking and distributional indicators. She also added that they should be designated via multi-stakeholder involvement, which is the foremost characteristic of any indicator study. More specifically, these types can be explained as follows (Maclaren, 1996):

- integrating indicators reflect the interaction in the three tiers of sustainability or composite representation of prominent issues (similar to key indicators or composite indicators);
- forward-looking indicators have three sub-types: trend indicators show the movement towards a target or benchmark; predictive indicators reflect the causal relationship between a few items and help to predict future states; conditional indicators involve what if scenarios about how a change in one condition affects others while avoiding making crisp predictions;
- distributional indicators show the spatial (inter-generational) and temporal (inter-generational) distribution of the conditions;
- participatory indicators are developed with input from multiple stakeholders in the community (not strictly an indicator type but a must-have characteristic).

The EEA (1999) advised another classification for indicators. According to this, the indicators can be divided to four groups as follows:

- Descriptive indicators: What is happening to the environment? (State-like indicators, e.g., amount of NOx in the atmosphere);
- Performance Indicators: Does it matter? (Similar to impact indicators, e.g., number of people exposed to traffic noise);
- Efficiency indicators: Are we improving? (Similar to response indicators, e.g., water consumption per household, carbon dioxide [CO2] emissions per vehicle km);
- Total welfare indicators: Are we on the whole better off? (Composite indicators, e.g., Green GDP).

Related to the types of indicators, there is another typology discussion on the designation of indicator sets. Mitchell (1995) identified three main types of indicator sets as depicted in Figure 3.3. The first group reflects all-purpose indicators, which include dozens or hundreds of relevant indicators mostly relying on the available data. The main aim here is to provide a concise picture by disclosing all dimensions, which will fully inform the public and decision-makers about the policy issue (Innes & Booher, 2000). The second approach is using one or more composite indicators by highlighting interplay between various factors and presenting it in a much summarised form. It is very similar to integrating indicators of MacLaren (1996) and total welfare indicators of the EEA (1999). Lastly, it is possible to see a mixture of the previous two approaches, defining key and composite indicators together. Here, key indicators refer to the key data items, which are frequently used by similar studies due to their critical importance in explaining a phenomenon. Essentially, they are the main instruments that make comparisons between various settings possible. Composite indicators are one of the main tools of this study, and there are a number of important considerations, such as, why there is a need for a composite indicator to reflect a very simple outlook of the subject matters, and how composite indicators can be created referring to validity and reliability considerations. These will be covered extensively in later sections

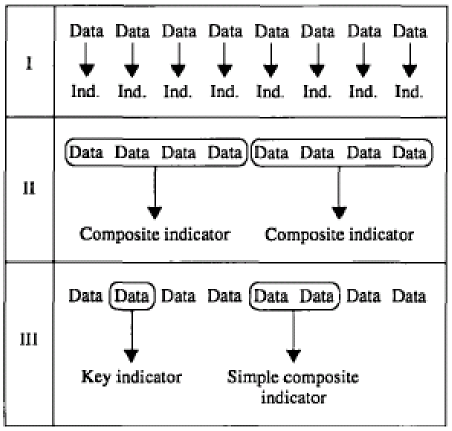


Figure 3.3 A typology for indicator sets

Notes. From Mitchell, 1995, p.114; I. Many specific indicators; II. A few composite indicators; III. Key and simple composite indicators.

Perhaps the most central problem of indicator studies is how the indicators are selected. While a purely participatory process can be considered as the most legitimate approach to selection, others advise a number of criteria in combination with the public participation or expert involvement (Yigitcanlar & Dur, 2010). However, which set of criteria yields a consistent and legitimate set of indicators is another subject debated in the literature. It can be said that the criteria to be used in selection depends on the combination of two considerations. These are rational thinking (i.e., validity and the reliability of indicators) and lessons learned from previous indicator practices (i.e., what is working or not). Because of its importance, the discussion on this subject is considerably wide ranging. For example, Niemeijer and de Groot (2008a) reviewed a number of indicator studies and listed 34 criteria, which are grouped according to the dimensions. These dimensions are scientific (i.e., valid and credible from scientific perspective), historic (i.e., historical records of indicators and reliability of them), systemic (i.e., sensitivity and responsiveness to changes in the system considering space and time), intrinsic (i.e., measurability, ability to quantify and apply in different settings), financial and practical (i.e., cost and availability of the data), and policy and management (i.e., relevance, simplicity and compatibility of indicators with regard to policies, targets and audience) dimensions.

Similarly, Hodge and Hardi (1997) published a set of principles to guide the assessment of sustainable development and determination of the indicators, which are also known as Bellagio principles. These principles are grouped under 10 headings as follows: guiding vision and goals (a clear vision of sustainable development), holistic perspective (inclusion of the three tiers of sustainability and taking into account the synergy between these domains as well as positive and negative movements), essential elements (inclusion of ethical, intra- and inter-generational equity, and non-market considerations), adequate scope (accounting a relevant time and space extent which connects the past to the future and local to global), practical focus (focussing on designated goals, policy targets and benchmarks within an adequate scope), openness (accessible and transparent), effective communication (facilitating effective communication between stakeholders in a simple way via addressing the needs of users), broad participation (embracing a number of participants from different backgrounds, ages and sexes), ongoing assessment (revision of goals, frameworks and indicators with feedbacks and new insights, and promoting active-collective-learning) and institutional capacity (building capacity for data collection, manipulation and maintenance as well as assigning responsibilities within institutional structure and providing ongoing support for assessment) (Hodge & Hardi, 1997, pp.11-20). Moreover, acronyms have been advised for criteria such as SMART (specific, measurable, achievable, realistic, and timely) (Kettner et al., 2000) and 5-R (reliable, relevant, reproducible, representative and realisable) (Wilson & Buller, 2001). As a result, there are six criteria on which a clear consensus has been emerging (M. Alberti, 1996; Bickel, et al., 2003; Burton, 2002; Coombes & Wong, 1994; Dale & Beyeler, 2001; Lautso et al., 2002; National Research Council (NRC), 2000; Niemeijer & de Groot, 2008a; OECD, 2001). These are:

- Relevance to issues and target audience: Correspondence between indicators and sustainability objectives, targets and benchmarks on which stakeholders or users agree;
- Relevance to management: Coherence between indicators and current management practices in terms of policies and intervention capabilities;
- Analytical soundness: Clear scientific basis in terms of conceptual formulation and practical soundness evidenced by the previous studies;
- Sensitivity to change: Adaptability to changing policy time frame and boundary;

- Measurability: Ability to be measured quantitatively or qualitatively with minimum statistical uncertainties (with reference to the reliability of available measurement tools and quality of available data);
- Data requirements and availability: Cost-effectiveness of acquisition and management of data.

In addition to these criteria, Maclaren (1996) purported that, as a rule of thumb, indicators cannot be designed without participant/user inputs, and ethically, indicators should be explicit and transparent. While these two considerations provide legitimacy, the criteria listed above further empower the validity and reliability of indicators (i.e., do the indicators reflect issues and values of the given context in scientifically valid, flexible, robust and cost-effective ways?).

The last issue in the list is the minimum or ideal number of indicators which best reflect the policy questions at hand. A general observation on previous studies reveals that there are differences in the number of indicators depending on the spatial scale. While international and national studies use a large number of indicators (between 40 and 100) to delineate the problem, at local level the number of indicators tends to be small and concise (between 10 and 40). For example, on international and national level, there are 134 urban sustainability indicators for the UNDSD (2005), 88 sustainable transport indicators for the EU (Bickel, et al., 2003), 78 environmental indicators for human settlements used by Environment Australia (Newton et al., 1998) and 68 sustainability indicators for the UK (Department for Environment, 2008). On urban level, there are 40 indicators for Sustainable Seattle (Atkisson, 1996), 31 desired environmental outcomes indicators for the Gold Coast, Australia (GCCC, 2006b), and so on. The main point here is that the number of indicators highly depends on the available data at aggregate level for the nation or city.

There are two different sides to the number of indicators problem. As one side involves how a comprehensive indicator system can be presented to depict all relevant subjects, the other asks how it can be done in a cost-effective way. Since every indicator requires at least one data item, the cost of data collection may go beyond the financial capabilities of the institutions if a comprehensive and large indicator set is used. Moreover, a greater number of indicators do not always translate into a better indicator system because of the increasing ambiguity with the number of factors taken into account at once (diminishing comprehension and concentration of participants with the increasing number of variables) as well as the likelihood of the correlation between indicator data. Because of this, there is no unified approach or tool to answer this question, but the solution can be formulated as finding an optimum point within the comprehensiveness and cost-efficiency of the indicator system. Being related to this problem, the use of composite and/or key indicators is encouraged to define a manageable scope for an indicator endeavour (Mitchell, et al., 1995). Similarly, a few principles were advised in the literature, for example, "the number of indicators should be as small as possible, but not smaller than necessary. That is, the indicator set must be comprehensive and compact, covering all relevant aspects" (Bossel, 1999, p.7). Also, as explained by Hák et al. (2007), indicators are merely assessment tools; therefore, the cost of improvements should not limit the capacity of implement policy and must be matched in cost-effective ways.

Another important consideration is about the primary function of the indicator endeavours. Specifically, to what extent are indicators used in developing policies and strategies? Rydin et al. (2003) reported that early literature on sustainability indicators mainly focused on the design of a framework and selection of relevant indicators. This approach unintentionally puts a lot of emphasis on technical matters while subordinating the basic function of indicators, which is facilitating communication via active involvement of the stakeholders. They also said that this led to a new research agenda in indicator initiatives, which asserts the foremost quality of the indicators as their direct linkage to policies. This was also confirmed by Gudmundsson (2003, p.1) as: "an important role ascribed to indicators is thus to provide policymaking support".

Innes and Booher (2000) stated that previous studies are not utilised efficiently because of giving very little importance to the participatory nature of the indicators. As a result of this, "… millions of dollars and much time of many talented people has been wasted on preparing national, state and local indicator reports that remain on the shelf gathering dust" (Innes & Booher, 2000, p.174). Lack of operational use of indicators is mostly related to top-down (scientific groups or experts) formulation of the selection process and not paying due attention to bottom-up nature of the policy problems. Nevertheless, participatory processes do not guarantee the efficiency or currency of the indicators. The participatory process has its own flaws. For example, selection process may be dominated by specific pressure groups, and the final outcome may mostly reflect the main considerations of those. Furthermore, it is not always possible to come up with a final list which satisfies all stakeholders (Rametsteiner et al., 2011). In these cases, a loose consensus on core issues might be regarded as a success.

In summary, indicators have numerous operational advantages as well as procedural flaws. Even though it has been more than a decade, Gustavson's claim (1999) about indicator studies could be considered as valid to a great extent: "… the selection and modelling of sustainable development indicators is far from an exact science. It will likely remain a judgmental art for some time to come" (p.117).

3.3 URBAN SUSTAINABILITY INDICATORS

As an earlier endeavour in urban sustainability indicators with a great coverage, after Habitat II summit in 1996, the list of 46 core indicators was disseminated to participating countries. 236 cities participated to this program, and the collected data were compiled in the Urban Indicators Database, which has helped to audit the problems as well as initiating a global action plan for capacity-building programs, progress monitoring and informing local governments (Flood, 1997). This has created a tradition of urban sustainability indicators and led to a proliferation of various initiatives globally. It can be questioned whether they have provided formalised and solid bases for decision-making, but they have steered the embracement of sustainability as a key policy objective, particularly, the inclusion of environmental and equity considerations in local plans and public involvement and consultation on key issues.

As a general remark, it can be said that a great deal of urban sustainability indicator studies have employed the three Es (i.e., environment, economy and equity) and issue-based frameworks. The general approach has been, primarily, classifying urban sustainability issues according to relevant policy domains (urban sprawl, housing affordability, protection of environmental assets, and so on), and then further categorising them according to their conformity to the three tiers of sustainability to see their interaction and balance between local considerations. That does not mean causal frameworks have not been used, but indicators have been selected from considerations close to impact and response domains in the DPSIR framework. By this way, it has been possible to capture the most prominent sustainability issues which demand an assessment framework, and this has helped to formulate policies to ameliorate their impacts.

A recent study made by Tanguay et al. (2010) analysed 17 urban sustainability studies and 188 indicators. Their findings revealed that selected indicators frequently take place in the intersections of the three tiers of sustainability due to the cross-domain nature of the indicators. Moreover, nearly 10% and 48% of these indicators are directly and indirectly, respectively, related to the social domain. This proves that urban sustainability is coupled with social considerations to a great extent. This also gives a detailed understanding on how environmental and economic considerations are coupled with social issues. Interestingly, only 21.3% of them are categorised in the global intersection (see Table 3.4).

Table 3.4 Classification of urban sustainability indicators

Domain	**Number of indicators**	**Ratio**
Environment	2	1.1%
Social	19	10.1%
Economic	17	9%
Liveable (Social-Environment)	37	20%
Viable (Economic-Environment)	21	11.2%
Equitable (Social-Economic)	52	27.7%
Sustainable (Global Intersection)	40	21.3%

Note. Adapted from Tanguay et al. 2010, p.411

While Table 3.4 presents a general picture with regard to sustainability domains, Tanguay et al. (2010) also showed how these indicators are placed under different categories (see Table 3.5), which closely resembles the aforementioned issue-based framework (Maclaren, 1996).

It is not surprising to see in Table 3.5 that indicators are accumulated on a number of specific issues, such as, transport (25), housing (18), air quality (15), green space, ecosystems and heritage (16), and household income and expenses (13), which are underlined by similar studies. Furthermore, transport related indicators are the largest in number and as many as economic indicators. Tanguay et al. (2010) purposefully categorised transport in the environment domain to reflect the general approach embraced, which couples transport with environmental externalities.

Table 3.5 Categorical distribution of indicators by total number and frequency

Sustainability Domain	Indicator Category	No. of indicators in the category	Number of indicators used			
			One or two times	Three times	Four times	Five or more times
Environmental	Energy (excluding transport)	8	7	1	0	0
	Transport	25	20	2	2	1
	Air quality	15	10	3	0	2
	Noise	3	3	0	0	0
	Drinking water	7	4	2	0	1
	Green space, ecosystems and heritage	16	12	1	1	2
	Waste	5	3	0	0	2
	Other indicators *	6	3	2	1	0
	Sub-total	85	62	11	4	8
Social and inst.	Demographics	10	7	2	1	1
	Housing	18	15	1	1	1
	Education	11	7	2	1	1
	Security	5	4	0	0	1
	Health	9	8	1	0	0
	Well being	3	3	0	0	0
	Social and community services	11	8	1	2	0
	Governance	4	1	1	0	2
	Expenses and public admin.	6	4	0	0	1
	Sub-total	77	57	8	5	7
Economic	Household income and expenses	13	8	1	0	4
	Employment	8	5	0	0	3
	Businesses	5	3	1	0	1
	Sub-total	26	16	2	0	8
	Total	188	135	21	9	23

Notes. From Tanguay et al. (2010, 411)
* Ecological footprints, natural catastrophes, level of exposure to natural and industrial risks, consumption of equitable products, urban intensification, and soil use.

When we look at integration of land use and transport issues and how it has been contained in indicators of urban and transport sustainability context, Table 3.6 provides important hints on how to frame the topic as to the main categories. Table 3.6 is a compilation of 28 urban and transport sustainability studies and nearly 1,300 indicators. This table was primarily formed by considering the main themes of the subject, transport, built environment and externalities. Following this, each theme was separated into categories with regard to previous discussions as follows:

- Transport (Accessibility and mobility);
- Built environment (Density, diversity and design);
- Externalities (Pollution and resource consumption).

Then, all indicators were analysed as to their concordance with the aforementioned categories, and the irrelevant ones (i.e., some of these studies cover other urban sustainability indicators together with transport and built environment, such as quality of life, housing affordability, education, security, institutional capacity and so on; and these indicators are deemed irrelevant) were excluded from the list. This process left 790 land use and transport related indicators. In the last step, the content of indicators was analysed, and 47 indicator sub-categories were formed according to the similarities in the content of these indicators. Finally, the distribution of 790 indicators is as seen in Table 3.6.

Not surprisingly, a battery of indicators accumulate on three categories, mobility, pollution and resource consumption. This finding is very similar to the categorisation of Tanguay et al., such that, transport domain is predominantly represented by mobility patterns and sub-components of mobility (249); and the bulk of the indicators are related to pollution (133) and resource consumption (189) as a consequence of these mobility patterns. While accessibility is covered by 69 indicators, there are 150 built environment indicators. When these two figures are combined, we could extract another dimension of the integration issue, which does not only encompass the 3Ds of urban form, but also the locations of destinations. Actually, this is very similar to a novel conceptualisation of urban form by 4Ds (density, diversity, design and destinations) (Criterion Planners, 2011; Dock & Swenson, 2003) or 3D+R (plus routes) (C. Lee & Moudon, 2006). Another important implication of this table is that it clearly delineates the problem areas as well as revealing prominent indicator categories, which can be used to define a new set of indicators for assessment of another setting.

Table 3.6 Categorical distribution of urban form, transport and externalities indicators

Theme	Category	Indicator sub-categories	Frequency †	Category total
Transport	Accessibility	Access to basic services by all modes	15	69 (23+46)
		Access to city centre by all modes	4	
		Access to open spaces by all modes	4	
		Access to basic services by public transport (PT) and non-motorised modes	20	
		Access to PT stops by non-motorised modes	18	
		Access to open spaces by PT and non-motorised modes	2	
		Access to other services by PT and non-motorised modes*	6	
	Mobility	Number of trips made by automobile	44 (30+14)	249 (106+99+44)
		Travel distance or time by automobile	38 (27+11)	
		Length of road network	13	
		Parking space availability in activity/city centre	9	
		Average travel speed by automobile	7 (6+1)	
		Occupancy rate of automobile travels	4	
		PT service availability/coverage and ridership	40 (25+15)	
		Affordability, safety and design features for disadvantaged people of PT	27	
		Travel distance or time by PT	11 (0+11)	
		PT service frequency	11	
		Average travel speed by PT	1 (0+1)	
		Number of walking and cycling trips	16 (5+11)	
		Travel distance or time by walking and cycling	9 (0+9)	
		Households without car or non-auto trips, if exist	5	
		Length of walking and cycling network	4	
		Average travel speed by walking and cycling	1 (0+1)	
		Others **	9	
		Theme total	***318***	
Built environment	Density	Dwellings	18	37
		Population and employment	15	
		Parcel size	4	
	Diversity	Land use mix	27	35
		Job to housing ratio	8	

Table 3.6 (Continued)

Theme	Category	Indicator sub-categories	Frequency †	Category total
	Design	Open space availability and design	27	78
		Pedestrian network and facilities	23 (15+8)	
		Cycling network and facilities	15 (7+8)	
		Neighbourhood street layout and design of civic areas	13	
		Theme total	***150***	
Externalities ‡	Pollution	Emissions of air pollutants	49	133
		Emissions of greenhouse gases	31	
		Noise pollution	20	
		Cost of pollution	11	
		Internalisation of pollution	22	
	Resource consumption	Accidents and fatalities	32	189
		Energy used for transport activities	30	
		Individual cost of transport	28	
		Land converted to urban uses	27	
		Public cost of transport	17	
		Land devoted to transport infrastructure	13	
		Ecological disturbance	12	
		Internalisation of resource consumption	24	
		Others ***	6	
		Theme total	***322***	
		Grand total	***790***	

Notes. Adapted from Atkisson, 1996; Cervero & Kockelman, 1997; GCCC, 1998; Newton et al., 1998; Gilbert & Tanguay, 2000; Ravetz, 2000; European Commission (EC), 2001; Mackay, 2001; Black et al., 2002; Bickel et al., 2003; Minken et al., 2003; World Business Council for Sustainable Development, 2004; Handy et al., 2005; Jeon & Amekudzi, 2005; Josza & Brown, 2005; Alshuwaikhat & Aina, 2006; Repetti & Desthieux, 2006; Litman, 2007; Allen, 2008; Department for Environment, 2008; EEA, 2009; Mameli & Marletto, 2009; Maoh & Kanaroglou, 2009; Campaign for Better Transport, 2010; Carse, 2010; Tanguay et al., 2010; Ercolano & Romano, 2011; Sustainable Measures, nd.

† The first figure in the parenthesis shows how many times this indicator category was explicitly included in the reviewed studies. The second figure shows how many times this category was stated as an element of the indicator. For example, in design category, the length of the network is given as 'length of *pedestrian and cycling network'* 8 times without specifying which mode is being referenced, explicitly.

‡ Internalisation of pollution and resource consumption indicators encompass the measures used to reflect the desired change as the consequence of institutional effort to ameliorate transport and urban form related externalities and are similar to response indicators, such as, pollution prevention and renewable resource use in vehicle fleet, percentage of low emission vehicles in the fleet, justice to exposure to pollution, number of noise pollution stations, change in water quality, total area of infill urban development, investment dedicated to environmental protection, percentage of recycled material from vehicle end-of-life or recycling rate, and so on.

* Accessibility to city centre, schools and employment centres

** Multi-modal travel, modes of transport and school trips

*** Consumption of raw materials, theft and violation of traffic rules

3.4 COMPOSITE INDICATORS IN ASSESSING SUSTAINABILITY PERFORMANCE

The composite indicator refers to an aggregate metric derived from a set of indicators which are selected to define a multi-dimensional, generally complex concept by using mathematical and statistical inference tools. In the literature, the terms of composite indicators and indices are considered as synonymous (Munda, 2005; Singh, et al., 2009). Recently, due to their simplicity, they have gained a great deal of attention and been used for various purposes, such as performance monitoring, benchmarking comparisons, public communication, policy analysis and decision making (Nardo et al., 2008; Zhou & Ang, 2009). As summarised succinctly by Saisana (2005), "…the temptation of stakeholders and practitioners to summarise complex and sometime elusive processes (e.g., sustainability, single market policy, etc.) into a single figure to benchmark country performance for policy consumption seems likewise irresistible…" (p.308). As expected, the growing attention on indexing has led to proliferation of numerous examples. For example, Bandura (2008) found that there were 178 different composite indicator initiatives worldwide by 2008. Another important point here is that while the final product of some studies is a composite indicator, the others produce a series of comparable sub-indices, which are grouped according to the environmental, economic and social tiers (Lautso, et al., 2002). This is so mainly to show how individual indicators are grouped and policy relevance of composite indicators to the three tiers.

The Gross Domestic Product (GDP), Gross National Income (GNI), and Consumer Price Index (CPI) are three well-known metrics used to measure the economic development and to make comparisons between countries. Even though they are not strictly composite indicators, the GDP and GNI are presented in monetary units as an aggregation of different economic components at national level, and are evaluated as monetary terms. But the CPI does not have a unit which shows the changes in buying power of money as to the reference year(s). Such metrics give the overall status of an economy or wealth of a country; however, it is very hard to use them for social or environmental evaluation. In order to rank countries according to their development level using other than solely economic measures, the UN has developed the Human Development Index (HDI), which aggregates life expectancy, education and knowledge (literacy and schooling), and the GDP by giving equal weights to each item. Although the HDI incorporates crucial social attributes with economic metrics to measure the development from a broader perspective, it is generally criticised that it does not comprehend other crucial domains, which could be coupled with development concept, particularly environmental concerns. After the introduction of sustainable development concept, there have been various studies trying to embody the three domains of sustainability (Costantini & Monni, 2004), such as the Environmental Sustainability Index (ESI), the Index of Sustainable Economic Welfare (ISEW, later renamed as Genuine Progress Indicator, GPI) the Sustainable Development Index (SDI), the Wellbeing Index, and so on, but no one method or index can be deemed as the best assessment tool alone. There exist a number of spatial indexing methods inspired by the early indexing endeavours, which are used to evaluate the sustainability level at different spatial scales. A review of these studies will be given in the following sections.

If the measurement unit is the same for each indicator aggregated as a composite indicator, e.g., monetary value, carbon (or ecologic) footprint, and so on; then indices can be aggregated over the same unit. However, if there is any disparity in units, then a normalisation of the factors is necessary, and this process yields a composite indicator value without a unit. This is the main characteristic of the indices, which makes a comparison between the cases (e.g., countries, cities, candidates) possible.

3.5 CREATING A COMPOSITE INDICATOR

There are a vast number of composite indicator studies which used more or less overlapping considerations. Having been involved in a number of composite indicator studies, Nardo et al. (2008) published a handbook to provide a comprehensive outlook to the composite indicator creation process, which would make it possible to see the required procedures in detail, and the alternative methods, which can be used for each step in this process. In this part, the information provided by these authors is summarised to disclose the procedures in the composite indicator creation step by step. According to this, there are 10 steps which are generally embraced by composite indicator studies. These are as follows (Nardo, et al., 2008, pp.20-21):

1. Developing a theoretical framework;

2. Selecting variables/indicators;
3. Imputation of missing data;
4. Multivariate analysis;
5. Data normalisation;
6. Weighting and aggregation;
7. Robustness and sensitivity analysis;
8. De-composition of CI;
9. Linking composite indicator with other known measures;
10. Presentation and dissemination of composite indicator findings.

The main aim and methodological details of each step are as follows:

Developing a theoretical framework: This is the starting point of any indicator endeavour as well as composite indicator studies. The theoretical discussion of the subject matter by which the composite indicator will be generated should be made regarding relevant concepts and factors to provide a clear understanding about interrelated issues. The main aim here is to cover all considerations related to the final single figure (namely the CI) by stakeholder inputs, and to review the literature and policy documents. It also helps to group conceptually close factors into sub-groups or themes, and to decide on selection criteria for indicators. Involvement of experts and stakeholders is critical to prevent missing important factors or over-specification of one or more categories.

Selecting variables/indicators: In the second step, selection of the indicators "should be based on the analytical soundness, measurability, coverage, and relevance of the indicators to the phenomenon being measured and relationship to each other" (Nardo, et al., 2008, p.20). Other important considerations here are the availability and quality of the data and the use of proxies if data is not available. Before proceeding any further in the composite indicator process, it is advised that strengths and weaknesses of each indicator should be discussed, and the final indicator list should be released after reaching a consensus among stakeholders.

Imputation of missing data: Naturally, it is not always possible to find the necessary cross-sectional or time-series data of indicator for each case (e.g., country, urban region or a city itself). However, the problem of missing data is particularly the case in international studies which compare or rank countries as to their relative performance in one or more issues. In this case, the best solution is to impute missing data by using data mining techniques to have a complete data set. Depending on the nature of the missing data, there are three general methods for data imputation. These are: case deletion, single imputation and multiple imputations (Nardo, et al., 2008). Whichever method is used for data imputation, the reliability of the imputation process should be reported via variance estimates and outliers, if any.

Multivariate analysis: Multivariate analysis is necessary to reveal two aspects of selected indicators. First, it shows how well the underlying data structure between indicators fits in the sub-categories defined at the first step. It can also help to discover the hidden dimensions in the data, which might help to formulate a new classification. Moreover, it would be possible to cluster indicators or unit of analysis according to their statistical similarities. Second, it shows any multicollinearity problem in the dataset due to the inclusion of perfectly correlated variables, which can yield inconsistent results when statistical tests are applied. In this case, one of the highly correlated data items can be excluded from the dataset, which makes the framework of the study more parsimonious. There are three statistical methods generally employed to discover the underlying structure of the data. These are principal component analysis, Cronbach coefficient alpha and cluster analysis (Nardo, et al., 2008).

Data normalisation: As explained previously, if there is a disparity in measurement units of the indicators, applying any arithmetic operation on the dataset, i.e., weighting and aggregation, will be a fundamental error. Therefore, normalisation is required to represent the measurement units in the same scale (basically, after normalisation, data becomes unit-free). There are various methods to normalise indicator values as explained by various authors (Freudenberg, 2003; Jacobs et al., 2004; Nardo, et al., 2008). They are simple ranking, z-score standardisation, min-max normalisation, distance to reference values, transformation to categorical scale (expert opinion or distribution dependent values, e.g., percentiles), threshold dependent normalisation, percentage difference from the leader or annual change, and logarithmic transformation. The method chosen to normalise the indicator values mostly depend on the distribution of the data and reference point taken as ideal value (i.e., the best performance among cases or central tendency of performance score distribution). In most of the cases, normalisation helps to reveal the relative performance of the cases with regard to the ideal case, or to fix the skewness of the distribution.

Weighting and aggregation: Weighting and aggregation are the most critical steps in the composite indicator creation process. Generally, weights are used to reflect the relative importance of each indicator (trade-off between indicators), or to correct the information overlap of correlated indicators, to ensure that the results do not display a bias (Hanafizadeh et al., 2009). Even though there is a number of alternative weighting methods in the literature, they can be grouped under three headings. These are statistical inference techniques (Factor Analysis, data envelopment analysis, unobserved component analysis, and so on), expert opinions (Delphi, public opinion, budget allocation process, analytical hierarchy process [AHP], conjoint analysis, and so on) and equal weighting (Kondyli, 2010; Nardo, et al., 2008). The procedure followed in weighting also points out the main weakness of the composite indicators. The weighting methodology carries value-dependent biases and, in some cases, weighting with linear aggregation causes substitution among indicators giving rise to acquiring overly-normalised index values (Munda, 2005). Furthermore, from another perspective, excluding an indicator or variable from investigation inevitably corresponds to assigning zero weight to respective indicator (Atkisson, 1996).

Aggregation, following the normalisation, is employed to exert the final composite indicator figure. Nardo et al. (2008) listed three mostly used aggregation methods: simple linear addition, geometric aggregation and multi-criteria approach. The most critical problem coupled with aggregation is that this process, in some cases, may cause critical information losses, which make it difficult to identify the negative or positive changes in the indicator due to the offsetting effects of positive indicators on negative ones. CIs have also been criticized for their inabilities to show the negative movements of particular indicators, making it difficult to implement strategies that target specific problem areas (Neuman, 2006). This problem is generally touted as the compensatory effect of indicators, and linear and geometric aggregation procedures allow compensation with varying degrees. While linear aggregation leads each item to compensate other items on the same degree, geometric aggregation favours high scoring cases, which means high values have more effect on the final composite indicator value. As explained by Nardo et al. (2008), if compensation between different dimensions are not desirable, non-compensatory multi-criteria approach is the most viable but costly (number of permutation increases if the number of cases are large) method. Or, giving sub-index score of each dimension together with the composite indicator would help to see the performance of each dimension separately and discuss the implications regarding the criticality of each dimension.

Robustness and sensitivity analysis: The final composite indicator value is an outcome of a series of consecutive judgements. Starting from the conceptual construct of the study, every decision made in each step inherently carries mostly subjective judgments. In order to assess the robustness of the composite indicator value, either uncertainty or sensitivity analysis is necessary to show the dependencies between the judgments made and the final composite indicator score. “Uncertainty analysis focuses on how uncertainty in the input factors propagates through the structure of the composite indicator and affects the composite indicator values. Sensitivity analysis assesses the contribution of the individual source of uncertainty to the output variance” (Nardo, et al., 2008, p.34)

De-composition of composite indicators: After sensitivity analysis, it becomes viable to differentiate the individual contribution of each sub-category and indicator on the final composite indicator score. By using this information, the cases under scrutiny (e.g., countries, urban areas, neighbourhood, and so on) can be further elaborated to see under which sub-category or indicator they are performing well or not. This provides very good insights about the strengths and weaknesses of the cases and helps to portray policy options.

Linking composite indicators with other known measures: After producing the CI, as a further refinement, a search is advised by Nardo et al. (2008) to show the relationship between this new measure and known measures. It might provide more insights on the effects of framing factors on the composite indicator score. For example, a positive correlation between the technological achievement index (TAI) and the GDP on country level may imply that a high technological achievement helps to generate wealth for a nation, which is measured by the GDP, as well as higher level of wealth thrives technological achievement (Nardo, et al., 2008). However, as a rule of thumb, a simple correlation does not always mean causality.

Presentation and dissemination of composite indicator findings: At the last step, presentation of composite indicator outcomes in a clear and well-designed format is required to accurately and succinctly convey the messages acquired from the composite indicator process to decision makers and end-users. It would also facilitate the communication between stakeholders. Here, the most important considerations are the selection of graphical language and media to spread the word. Depending on the target audience, the most effective graphical language, such as, tables, graphics or maps, should be selected. Also, in the knowledge era, media used is as important as the graphical language and helps to grab the attention of a wide audience tackling with similar issues.

In summary, the composite indicator process contains consecutive steps, and particularly judgments made in selection of indicators, normalisation, weighting and aggregation greatly determine the final score. Their simplicity and usability for case-based comparison are the primary advantages, “they usually cannot withstand modest critiques however, and accordingly they have not been widely used to actually influence policies, allocate funds or guide other decisions” (Innes & Booher, 2000, p.176). As an overall outlook of the CI, Table 3.7 summarises the advantages and disadvantages.

Table 3.7Advantages and disadvantages of composite indicators

Advantages	Disadvantages
Can summarise complex or multi-dimensional issues in view of supporting decision/policy makers	May send misleading, non-robust policy messages if a composite indicator is poorly constructed or misinterpreted
Can provide a big picture which is easier to interpret than trying to find a trend in many separate indicators	May invite politicians or stakeholders to draw simplistic policy conclusions
Can offer a rounded assessment of countries' or regions performance	May involve stages where judgmental decisions have to be made
Can reduce the size of a set of indicators or include more information within the existing size limit	May disguise failings in some dimensions and increase the difficulty of identifying proper remedial action
Can facilitate communication with general public, e.g.,citizens and media	May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored

Note. From Saisana et al., 2005; Saltelli, 2007; Nardo et al., 2008; Zhou & Ang, 2009

3.6 SPATIAL INDICES

Spatial index is a variant of general composite index methodology that takes into account spatial patterns and their interactions, which tend to employ disaggregate level data. The main aim of it is to represent a multidimensional issue with a simple spatial metric considering space-dependent relationship (Reardon & O’Sullivan, 2004). Spatial indexing has been used by some disciplines for various purposes. Particularly, the widespread use of GIS has led to the emergence of many indexing studies in the literature. Among all disciplines using the GIS technology, environmental management is an area in which spatial indexing with GIS has been widely applied. Risk assessment of environmental assets (water, forest, and endangered habitats), catastrophes, pollution and suitability analysis for habitat are the subjects in which indexing is employed as the research method. Also, in geography and urban planning, this method has been used by various researches to explore and describe urban issues. Particularly, indexing is used for the analysis and visualisation of spatial segregation, accessibility to urban services and land suitability analysis.

In the scope of this study, a targeted review was conducted for different spatial indexing approaches. Instead of considering specific simulation and assessment tools, such as MEPLAN (Hunt & Echenique, 1993), Integrated Transportation Land Use Package (ITLUP) (Putman, 1998), UrbanSim (Waddell, 2002), A Methodology for Enhancing Life by Increasing Accessibility (AMELIA) (Mackett et al., 2008) or other AUNT-SUE tools, Accession (Citilabs, 2011) and so on, a number of academic and local initiatives were analysed to determine which methodological preferences were made in terms of composite indicator creation process. An intensive review gave 22 relevant spatial indexing approaches involving either a specific aspect or the overall content of urban sustainability. As it can be seen in Table 3.8, these approaches cover wide ranging considerations, such as, urban sustainability, urban form and mobility sustainability, urban sprawl, public transport and pedestrian accessibility, economic sustainability of buildings and so on. Again, various spatial scales are used as unit of analysis in these studies. One important observation on how the main factors are conceptualised is that they generally employ variants of the three sustainability tiers or issue-based frameworks.

Table 3.8 Spatial indexing endeavours of urban sustainability

Name	Location	Spatial scale	Framework	Reference
Land Use Sustainability Index (LUSI)	Emilia-Romagna, Italy	Regional	DPSIR	(Gardi et al., 2010)
Sustainable Mobility Index	Belo Horizonte, Brazil	Urban regions	3Es under 5 sub-categories	(Campos & Ramos, 2005)
Sustainable mobility indicators	Lyons conurbation, France	Urban (Conurban)	3Es and mobility	(Nicolas et al., 2003)
Composite Sustainability Index	Atlanta, USA	Metropolitan	3Es and transport system efficiency	(Jeon, 2007)
An Index of Regional Sustainability (AIRS) for south west Victoria	South West Victoria, Australia	Regional	3Es	(Graymore et al., 2009)
A composite indicator for North Aegean islands	9 Northern Agean Islands, Greece	Island confinements	3Es	(Kondyli, 2010)
Urban compactness indices	25 English towns and cities, UK	Urban	Three sub-domains of compactness	(Burton, 2002)
Urban Sustainability Index	Four Chinese cities	Urban	Issue-based	(van Dijk & Mingshun, 2005)
The Dashboard of Sustainability for Padua	Padua, Italy	Urban	3Es	(Scipioni et al., 2009)
Taipei sustainability index	Taipei, Taiwan	Urban	3Es and institutional	(Y.-J. Lee & Huang, 2007)
Spatial network analysis for multimodal urban transport systems (SNAMUTS)	Perth, Australia	Urban	N/A	(Curtis & Scheurer, 2010)
Index of Sustainable Urban Mobility (I_SUM)	Curitiba, Brazil	Urban sub-divisions	Issue-based	(de Freitas Miranda & da Silva, 2010)

Name	Location	Spatial scale	Framework	Reference
Housing Sprawl Measure	13 US cities	Urban	Issue-based	(Galster et al., 2001)
Sustainability Synthetic Index (ISS)	Paraíba do Sul river basin, Brazil	Municipal districts	3Es, institutional and sectoral	(Vianna et al., 2009)
Neighbourhood Accessibility Index	Central Puget Sound, Washington DC, USA	Neighbourhood	3D of neighbourho od	(Krizek, 2003a)
Pedestrian Environment Factor (PEF)	Portland, USA	Transportation Analysis Zones	N/A	(MLUTRAQ, 1993)
Land Use and Public Transport Accessibility Index (LUPTAI)	Gold Coast, Australia	Neighbourhood	N/A	(Yigitcanlar et al., 2007)
NewHeartlands Sustainability Index 2006	Liverpool, Sefton and Wirral Councils, UK	Neighbourhood	Issue-based	(Liverpool City Council and NewHeartlands, 2009)
Neighbourhood Destination Accessibility Index (NDAI)	North Shore City, Waitakere City, Wellington and Christchurch, New Zealand	Neighbourhood	Issue-based	(Witten et al., 2011)
Building earthquake risk index	Akola, Maharashtra, India	Buildings	Issue-based	(Ralegaonkar, 2010)
Office location sustainability index	Bristol city-region, UK	Office buildings	Issue-based	(Dalton, 2009)
TxDOT Sustainability Enhancement Tool (SET)	Texas, USA	Road segments	Objective-based	(Ramani et al., 2009)

All relevant methodological details of these approaches can be found in Appendix (see p.291). The distribution of preferences for each step is given below:

- Indicator selection approach: Author(s) – 73%; Stakeholders – 13.5%; and Experts – 13.5%;
- Normalisation: Linear – 31.8%; z-scores – 13.6%; Formula – 9.1%; Expert opinion – 4.5%; Benchmark values – 4.5%; Not addressed – 36.4%;
- Weighting: Equal – 40.9%; Expert consultation (mostly AHP) – 36.4%; Factor analysis – 9.1%; Not addressed – 13.6%;
- Aggregation: Linear – 68.2%; Functional – 4.5%; Multiple Criteria – 4.5%; Not applicable – 4.5%; Not addressed – 18.2%;
- Output presentation: Maps – 45.5%; Tables only – 18.2%; Graphs only – 13.6%; Tables and graphs – 13.6%; Tables and maps – 4.5%; No output – 4.5%.

In summary, it can be said that mostly the author(s) of the study or project team selected the relevant indicators, and generally these indicators were normalised linearly, weighted using either equal or expert opinions, aggregated linearly, and presented mainly by maps, and tables and graphs. Even though the conclusions drawn for each study change according to the content of the urban sustainability problem and spatial scale, nearly all the authors have agreed on a number of qualities of spatial indexing. These are:

- Spatial indexing method has produced a satisfactory assessment of the problem and proved its usefulness in terms of showing locations for specific policy action or of the best performance (ranking) and helping in selection of competing alternatives (Gardi, et al., 2010; Graymore, et al., 2009; Y.-J. Lee & Huang, 2007; Nicolas, et al., 2003; Scipioni, et al., 2009; van Dijk & Mingshun, 2005; Yigitcanlar, et al., 2007);
- Once presented with its constituents (sub-domains), it reveals which issue needs more attention, is dominant; whether there is a trade-off between indicators, and also yields easily understandable and consistent results (Galster, et al., 2001; Krizek, 2003a; LCC and NewHeartlands, 2009; MLUTRAQ, 1993; Nicolas, et al., 2003; van Dijk & Mingshun, 2005; Witten, et al., 2011);
- If the indicator data belonging to previous periods exists, it shows the temporal change as well as progress towards sustainable development (Scipioni, et al., 2009; van Dijk & Mingshun, 2005);
- The limitations and assumptions of the approach should be made clear beforehand and acknowledged while generalising for other settings and using policy formulation and forecasting purposes (Jeon, 2007; Scipioni, et al., 2009; van Dijk & Mingshun, 2005).

3.7 SUMMARY

An inquiry on which assessment methods can be used in evaluation of sustainability gives us a number of options. Broadly, they can be grouped as indicators and composite indicators, life cycle assessment tools and prospective integrated assessment tools. When compared to other assessment frameworks and tools, indicators are semi-structured (flexible to encompass relevant sustainability issues within different conceptual frameworks, e.g., domain based, issue based or causal) and context dependent tools (demarcation of indicators considering local-policy-context), which makes them clearly advantageous over other methods due to their simplicity and practicality. As a consequence of this, it is possible to see numerous indicator studies taking into account different indicator sets in different spatial scales. Yet, this maybe one of the most important drawbacks of the indicators; it is not possible to find a unified method for indicator system formulation, and one indicator can be operationalised with different measures (Zegras, 2008). Even so, there exists a refinement in indicator studies dealing with sustainability issues, which makes a comparison viable. In this review, indicators related to urban form and transport sustainability were analysed. This analysis specifically shed light onto which indicator categories can be used for conceptualisation in the given case study area. Moreover, the review on indicator theory provided underpinnings of valid and reliable indicator selection process. It also provided a set of criteria, which is the prerequisite for a robust indicator system. In addition to the stakeholder participation, these are as follows:

- Relevance to issues and target audience;
- Relevance to management;
- Analytical soundness;
- Sensitivity to change;
- Measurability;
- Data requirements and availability.

The review of urban sustainability indicators showed that environmental and social issues are pervasive compared to the economy, and there is a general tendency to pair environmental and economic issues with the social counterparts, placing a special emphasis on the social determinants of urban sustainability problems. This review also showed that transport, housing, air quality, and green spaces, ecosystems and heritage are prominent subjects. Another review was conducted to disclose how transport and urban form issues are covered in indicator studies. This review confirmed that indicators related to transport sustainability and externalities associated with transport are major topics, and particularly indicators of travel patterns, and availability and quality of the transport infrastructure have the greatest share. Urban form indicators are limited in number, but they refer to very specific subjects as elaborated in the sustainable urban form/design literature.

Finally, it has been realised that spatial indexing is a powerful tool to depict an overall picture of an urban area in terms of sustainability performance. Even though there are serious criticisms about the theoretical validity of aggregating different entities into a single metric, the tendency of stakeholders and practitioners in using one measure for performance evaluation and policy formulation has led to proliferation of different studies. The critical point here is that the decisions and assumptions made in each step of composite indicator generation should be made clear, and the sensitivity of final score should be tested with relevant parameters if the results of composite indicator will be used for policy formulation.

Chapter 4: Methodology

This chapter gives an overlook of methodological approaches adopted and aims to explain the reasons for selection of case study area, indicator selection process, data requirements and quality of the data, and selection of 100 m grid cell as the unit of analysis. The framework for the proposed model and a number of key decisions which delineate the scope of the study are given in the following section to demonstrate the overall research strategy. In this section, each step is matched with the corresponding step in composite indicator creation process, and also a scheme showing the specific section of this dissertation, where each step is explained in details, is provided. Following this, the three equally important subjects are clearly demarcated. These are the case study area, the study variables or indicators, and the unit of analysis of the study. Firstly, the reasons for selecting the case study area and the characteristics of the area are explained. Secondly, the indicator selection process and the final indicator list are introduced. Thirdly, the issues experienced when deciding on the unit of analysis of this study and the selection of grid cells as the unit of analysis are clarified.

4.1 THE STRUCTURE AND INDICATORS OF THE MODEL

The model consists of four parts connected to each other in a linear fashion as depicted in Figure 4.1. Each part defines the critical tasks required to produce a scientifically valid (i.e., each indicator and the overall indicator framework should reflect conceptualisation of land use and transport integration and its connection to the urban sustainability as elaborated in the relevant literature, and measures used to quantify indicators should be acquired with valid methods and reliable instruments) and practical (i.e., it should cover local policy considerations and be user-friendly, and help to draw inferences about the overall performance of the study area) composite indicator. Because of this, the respective composite indicator steps are given in the middle column in the figure. Furthermore, each part consists of sub-components, which were grouped according to their relevance, generate an input to the next part. More detailed information for each part is provided below.

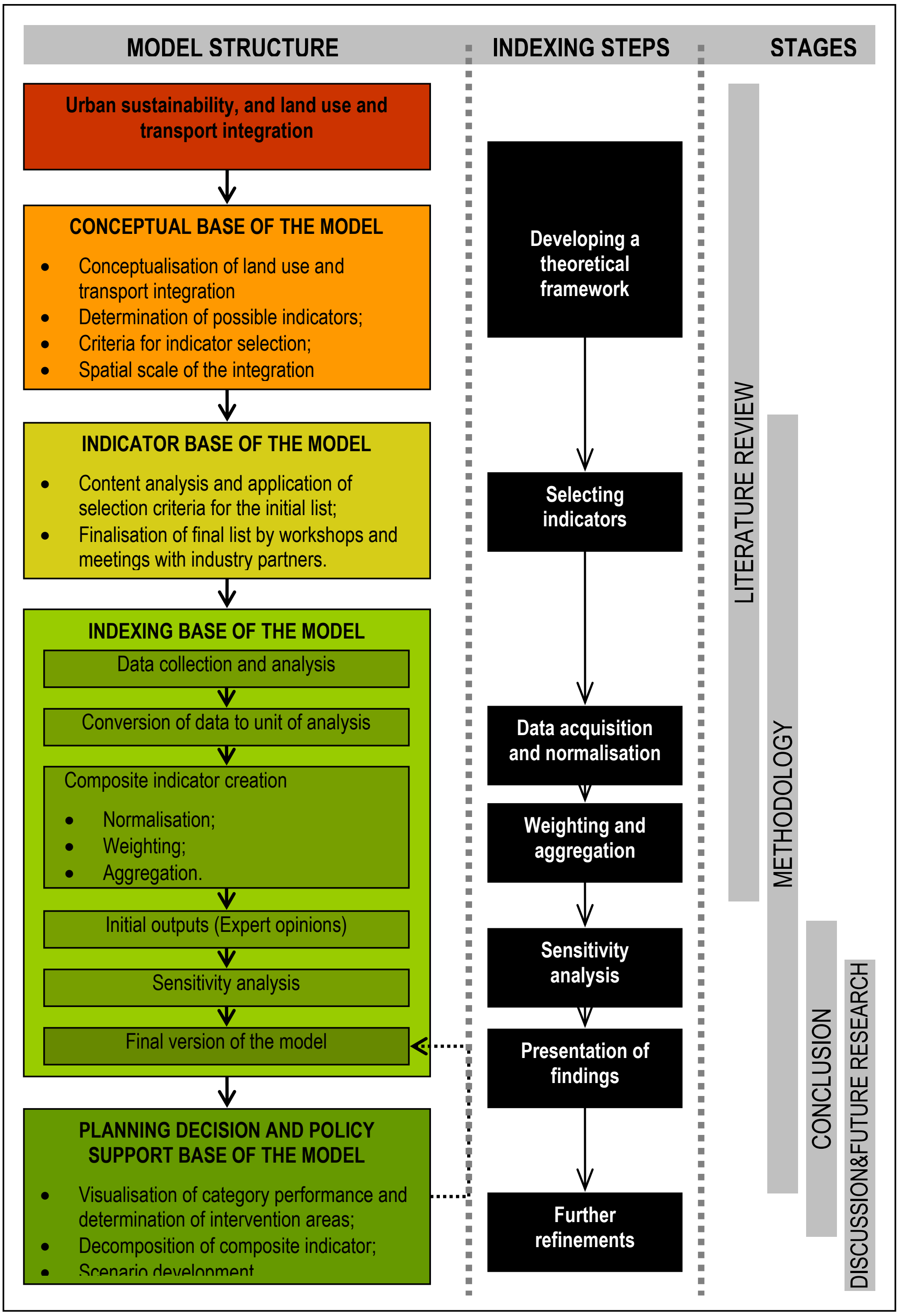


Figure 4.1 Structure of the indexing framework and relation to research steps

4.1.1 THE CONCEPTUAL BASE OF THE MODEL

The concept of sustainability and its spatial dimension constitute the theoretical foundation of this model. More specifically, these are urban sustainability concerns tied with land use and transport interaction. As it can be seen at the top row of Figure

4.1, the literature on land use and transport integration is the main inputs of the conceptualisation base. While the former delineates the main categories which should be taken into account when examining the relationship between transport activities and air and stormwater pollution, the latter provides a number of principles and variables to define the parameters of the discussion at the neighbourhood scale. Since the indicator-based assessment method was selected as the evaluation method, this base also involves the qualities of relevant indicators and selection criteria. With reference to the steps in composite indicator generation, this part corresponds to the first step, which is 'developing a theoretical framework'. Information related to the conceptual base of the model was covered in the literature review chapters.

4.1.2 THE INDICATOR BASE OF THE MODEL

This part mainly encompasses the determination of indicators and the selection process, which was mentioned in the literature review chapter as the main considerations of indicator theory. Accordingly, this process involves deciding on a suitable framework, types of indicators, criteria for selection and quantity of indicators. There are three information sources which were employed to decide upon a framework and indicator categories to formulate initial version of the indicator list. These are scientific literatures on indicator theory, land use and transport interaction in the scope of urban sustainability indicators, and strategic and local policy documents. While the indicator theory discussion revealed the theoretical and practical considerations for forming an indicator system matching with the main concepts of this study, land use and transport sustainability indicator studies yielded a list of potential indicators. In addition to these, policy documents helped to define the prominent issues and how the indicators can be evaluated in terms of policy relevance. Following the review of literature and producing the initial version of the indicator list, the next step was to finalise the selection of indicators. Here, the inputs from the prospective users were required, and in this study, this was accomplished by a number of workshops and meetings with the industry partners. In terms of composite indicator creation procedure, this part corresponds to 'selecting indicators'. While the literature related to indicator-based assessment and practice-oriented considerations of the similar studies were summarised in the literature review chapter, the generation of the final indicator list is the first subject in the methodology part of this study.

4.1.3 THE INDEXING BASE OF THE MODEL

The indexing base is the main part of this diagram and involves consecutive steps. ‘Data acquisition and normalisation’, ‘weighting and aggregation’, and ‘sensitivity analysis’ steps of composite indicator creation procedure take place in this stage. This is where the most subjective decisions are made to generate a composite index. This subjectivity is usually inescapable due to the value-laden nature of the indicators, but an indexing strategy basing upon a well-designed indicator system and critical evaluation of every decision made in composite indicator creation could yield a valid and reliable final product. According to the indicator and indexing literature, the advantages and disadvantages of any data or arithmetic manipulation required for composite indicator creation should be made clear and discussed with users or stakeholders. Because of this, perhaps the most critical component of this part is sensitivity analysis where all the judgments made on the previous steps can be tested, and the shortcomings of the model can be revealed. This analysis provides invaluable information about the use and limitation of the model. Because of this, this base was examined in two sub-parts. At first, the model was run according to benchmark values for indicators and the expert opinions. Then, sensitivity of change in normalisation scheme, weighting and aggregation system was tested via different alternative options.

4.1.4 THE PLANNING DECISION AND POLICY SUPPORT BASE OF THE MODEL

This is the final compartment of the model. It involves how the results of the final model are presented and how these results can be used to formulate urban development strategies. From the feedbacks provided for the early versions of this study, it is anticipated that giving sub-category scores together with the overall index score can be very insightful in seeing the area performance in detail. It also reveals the trade-offs between different categories. Moreover, different scenarios or development alternatives can be evaluated by the model if the relationship between population growth and land use destination (LUD) supply, public transport service and travel demand are known. In its current formulation, the model shows the performance of the area only for the current time span, and because of this, it can be regarded as static. Scenario evaluation capability can enhance the model's usefulness and makes it more dynamic.

4.2 THE CASE STUDY AREA

Three suburbs of the Gold Coast consisting 47 census collection districts (CCD) are the case study area of this study. In this section, selection of the case study area is explained. Moreover, expected urban development trend is presented for each suburb considering growth patterns of previous years.

4.2.1 SELECTION OF CASE STUDY AREA

This study was part of Australian Research Councils (ARC) Linkage project and at the initial phases of the ARC Linkage project, Planning, Environment and Transport Department of the GCCC was asked to advise the project team on a number of air and stormwater sample collection locations where there is a variety of land uses and traffic characteristics. The GCCC was also informed about the sampling procedures, such as required repeats and time span of each sampling process (for example, dry deposition sampling requires seven consecutive days of dry period, might take more than three hours to complete and should be performed at least once). Considering these, the utmost concern of the GCCC was to minimise traffic disturbances (i.e., traffic congestion as a result of safety measures taken for the sample collection, which decrease the road volume and traffic speed) which might occur because of the sample collection process. Accordingly, they provided a list consisting of a number of roads, and then the sample locations were determined by site visits. Table 4.1 below lists these sites where the air and stormwater samples were collected. The hierarchy of these roads as well as urban characteristics (land use and population density) of surroundings vary. This diversity in urban characteristics and road hierarchy were particularly important to examine the causal relationship between traffic volume and pollution and to form a robust mathematical relationship.

Table 4.1 Sites selected for measurement of air pollution and stormwater runoff

Suburb	Land Use	Site Name	Capacity (vehs/hour)	Traffic count-2010	Volume prediction-2011
Coomera	C	Abraham Rd	800	8742	8149
Coomera	R	Reserve Rd	800	10027	8144
Coomera	R	Peanba Park Rd	600	30	6420
Coomera	R	Billinghurst Crs	400	1964	628
Upper Coomera	I	Beattie Rd	600	4633	3822
Upper Coomera	I	Shipper Dr	600	2236	2501
Helensvale	C	Hope Island Rd	2200	25578	26506
Helensvale	C	Lindfield Rd	500	8599	14091
Helensvale	C	Town Centre Dr	800	5931	9860
Helensvale	R	Dalley Park Dr	900	997	2888
Helensvale	R	Discovery Dr	800	10690	6856

Notes. C: Commercial; R: Residential; I: Industrial.

In addition to achieving a content integrity in the ARC project, there are three more reasons for the selection of these suburbs, Coomera, Upper Coomera and Helensvale, as given in below:

- One of the industry partners of ARC Linkage project, the GCCC, would like to determine the effects of expected rapid urban development process in terms of environmental effects of urban form and transport patterns in these three suburbs;
- These three suburbs are geographically adjacent to each other, but they are in different phases of the urbanisation process. A comparative study on urban form and travel can shed light onto the likelihood of urban form and travel pattern change for other developing suburbs of the Gold Coast in the near future, and the results can be used to anticipate possible problems;
- As a rapid population growth is expected in the study area for the next 15 years, the GCCC planning office would like to produce targeted planning policies for the area as explicated in the planning scheme. Accordingly they would like to revise the planning decisions on the area in the next planning scheme started to be updated during this study.

The locations of these sites are given in Figure 4.2. These are located in the northern part of the Gold Coast urban footprint and are expected to accommodate most of future Gold Coast urban dwellers in the next 10-15 years.

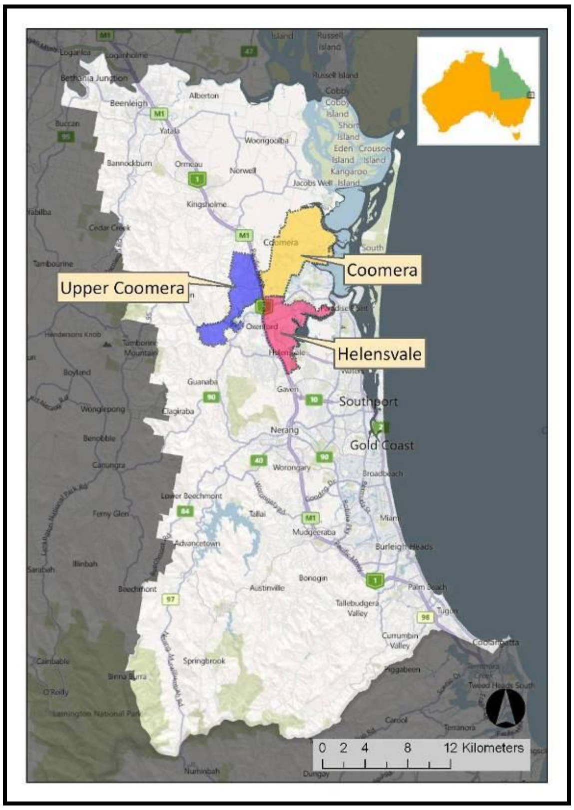


Figure 4.2 Case study area

4.2.2 THE STUDY AREA CONTEXT

The Gold Coast is the second mostly populated urban area in the state of Queensland, Australia, with nearly half a million residents as of 2006, and is expected to accommodate a million people by 2030. While its economy was mostly dependent upon agricultural, mining and tree-logging activities some 170 years ago, now it is one of the most important tourism centres attracting more than 10 million visitors annually. The long coastline, sub-tropical climate and a number of tourism theme parks have been the main drivers of tourism economy. It has also been a popular real estate destination for aging and retired population due to its climate and availability of developable land. It is located 80 km south of Brisbane, the state capital of Queensland. This close proximity to the state capital and tourism potential have played an important role in urban formation of the Gold Coast. Once consisted of small settlements with mostly agricultural characteristics, it has become a wide-spread urban area and one of the fastest growing settlements in Australia.

As explained by Mayere et al. (2010), the fast urbanisation process of the Gold Coast began in the 1930s, and the embracement of popular British urban development approaches of the date by Australian planning professionals shaped the urban character of the area. Particularly, the 'Garden-city' model and canal-estate developments similar to the US sun-belt region (e.g., Florida, California) were the two prominent approaches employed by the planners (Mayere, et al., 2010). Construction of high-volume transport systems (e.g., the Pacific Motorway and railway), and increasing car ownership have been the other two important factors which gave pace to linear urbanisation along the coastline and the region between Brisbane and the Gold Coast. Of course, high urbanisation has come with a cost, environmental degradation. Since the area has a number of internationally recognised environmental qualities, after the 1990s, the protection of ecological diversity and the environmental assets (e.g., estuarine and marine systems, beaches and dunes, native vegetation, and so on) of the area have become the hot topic in the planning schemes. For example, the current planning scheme was formed around sustainability concept with a strong emphasis on ecological sustainability. Moreover, the form and intensity of the urban development, facilitating a sustainable economic base for the key sectors, provision of sustainable urban infrastructure, preservation of local characters and heritage, enhancing the health of residents and housing affordability, and management of bush fires and landslides have been the key issues of the planning schemes.

There are two key considerations which should be explained to show the correspondence between the scope of the ARC Linkage project and problems related to the fast urbanisation of the area. Firstly, the GCCC has supported research activities related to the Gold Coast in order to reveal the sources of sustainability problems from a scientific perspective. The findings of these studies have been used to guide the planning schemes. Among the programs which have been realised by the council, 'Healthy waterways' program is the inspiration of this ARC Linkage project. Closely related to the scope of this program, the contribution of transport activities to the urban water quality has always been a major issue. It is stated in the city transport plan that "emissions from motorised transport vehicles are responsible for over 70% of air pollutants, as well as making the most significant contribution to urban noise problems" (GCCC, 1998, p.133). The main reason why transport activities are the biggest contributors of air – as well as stormwater pollution is that there is no significant industrial activity in the Gold Coast. Particularly, this problem is directly correlated to the travel patterns of the Gold Coast residents. It can be said that low density urban development and intensification of urban services around major suburban centres make people travel more generally by their cars. In overall, this is the main motivation of this research, elaborating the land use and transport relationship with regard to the air and stormwater pollution by taking into account the future changes in the climate.

After this brief introduction on the Gold Coast area, the estimations of future population and urban growth, planning scheme provisions and the characteristics of the case study area are provided in the next sections. This information is particularly important in anticipating the future urbanisation trend of the area. Therefore, the Priority Infrastructure Plan (PIP) could be a good starting point to reveal the underpinnings of the planning scheme provisions.

4.2.3 PRIORITY INFRASTRUCTURE PLAN

The PIP delineates trunk infrastructure plans and charges in accordance with the Sustainable Planning Act 2009 (SPA) and SPA Infrastructure Guidelines. Trunk infrastructure includes water supply, wastewater, transport and stormwater networks, and recreation facilities. The planning scheme and the city transport model use the same urban growth parameters employed in the PIP. These parameters mainly depend on a number of assumptions which reflect the previous trajectories of the development trends. In essence, the PIP calculations base on projections on population and employment growth in the Gold Coast and respective land use provisions which are defined by the Planning scheme. As explained in the PIP, the main function of using assumptions is to " …define the anticipated type, scale, location and timing of development in the Gold Coast to 2021 and form the basis of the trunk infrastructure planning contained within the PIP" (GCCC, 2003, p.10). More specifically, all of the growth projections depend on a set of factors as follows (GCCC, 2003):

- Population growth trend;
- Land available for development;
- Changing household sizes;
- Workforce trends;

- Floor-space utilisation rates for non-residential development;
- Planning scheme provisions.

According to the PIP, population and employment growth is projected as given in Table 4.2 and Table 4.3. These projections were amended as of 2009 as well as the Gold Coast Planning scheme in 2010; however, the forecasts for the transport infrastructure were generated by employing 2004 and 2005 projections. In Table 4.3, the aforementioned amended population projections are given for the period of 2006-2031. When compared, slight differences between Table 4.2 and Table 4.3 are noticeable due to the corrections made after 2006 census. Moreover, it is estimated that the household size will decrease slightly from 2.83 to 2.55 for detached dwellings, whereas the household size of multiunit dwellings will remain at 1.72 from 2004 to 2021.

Table 4.2 Projected population growth to 2021

Population	2004	Mid 2006	Mid 2011	Mid 2016	Mid 2021
Total	534,209	557,910	640,094	707,845	769,616
Visitors	59,452	61,367	67,285	75,477	86,049
ERP	474,757	496,543	572,809	632,368	683,567

Notes. From GCCC, 2003; ERP: Estimated residential population

Table 4.3 Amended population projections for the Gold Coast (2006-2031)

Forecast series	ERP	PRP					AAPC
	2006	2011	2016	2021	2026	2031	
	no.	no.	no.	no.	no.	no.	%
High series	466,433	549,879	635,791	718,173	797,677	875,457	2.7
Medium series	466,433	544,165	613,280	677,929	739,276	798,417	2.2
Low series	466,433	540,579	593,016	640,508	684,072	724,492	1.7

Notes. From GCCC, 2003; ERP: Estimated resident population; PRP: Projected resident population; AAPC: Average annual population change

Expected annual population change rate for the Gold Coast is estimated as 2.2% which will result in a 1.71 times increase in the residential population for the 25 year period (2006-2031). As given in SEQ Regional Plan (DIP, 2009), "… by 2031 an additional 143,000 dwellings will be required to house the Gold Coast's expected regional growth and demographic change. Broadhectare development can accommodate 32,000 dwellings, including land at Coomera, Hope Island, Pimpana, Ormeau, Maudsland and Reedy Creek... the broadhectare supply is expected to be largely exhausted by 2016" (p. 19). Because of this, infill development and densification around local centres are advised as the most viable options to accommodate the future population. It should be noted that even though the population increase seems not alarming, being less than doubling in 15 years, the main concern of the GCCC is the pattern of urban development. More specifically, current trend of low density and auto dependent urban development does not conform with the goals of the planning scheme, and this will cause additional urban development pressure towards the environmentally sensitive areas of the Gold Coast due to the scarcity of developable land.

4.2.4 PLANNING SCHEME PROVISIONS FOR THE STUDY AREA

From land available for development and the planning scheme provisions perspective, the study area encompassing three suburbs, Coomera, Upper Coomera and Helensvale will continue to grow and act as the main land stock for the future urban development demand. Particularly, Coomera and Upper Coomera will experience a rapid population growth within the next five year period. Land use plans for the study area according to 2001 Statistical Local Area (SLA) boundaries are given in the appendix (see p.294).

It is foreseen that population of Coomera-Cedar Creek will be 74,167 and 86,782 for 2016 and 2021, respectively. In the mean time, 17,200 new positions will be available for the future employees. Coomera centre will be the main focus of the expected development. Additionally, nearly a quarter of the population will live in multiunit dwellings in the areas around Coomera centre which are defined as interconnected walkable neighbourhoods. In the planning scheme, it is particularly highlighted that “the concept of transit-oriented development and walkable neighbourhoods can be achieved by ensuring that individual developments are connected with a coordinated system of streets, parks and walkways” for Coomera (GCCC, 2003, p.9.1). Moreover, there are other considerations in terms of qualities of expected urban development, such as, the conservation of remnant vegetation along creeks and drainage lines, significant upgrades in the road system to meet the needs of emerging communities, providing densities in the ranges of 15 and 25 dwellings per hectare, physical constraints (slope, flood risk, habitat corridors, major transport routes and etc.), and so on.

In the PIP, Helensvale is mapped together with Coombabah and Oxenford, but projections are provided separately for each SLA. Due to the lack of available land for urban development, a slight increase in the population of Helensvale is expected. In the PIP the population is projected as 16,228 and 16,610 for 2016 and 2021, respectively, and employment will increase marginally by 63 people for each five-year period. Only 12% of the population will live in multiunit dwellings. In the planning scheme, the main considerations for the urban development in the district can be summarised as:

- Creation of an integrated centre which provides a strong sense of place and a good mix of urban uses and services by utilising mobility advantage of the railway infrastructure;
- Provision of medium and high density dwelling options to meet lifestyle choices and accessibility needs, and in the mean time, to mitigate adverse effects of commercial uses and to support residential amenity, and;
- Protection of important natural features and environmentally significant areas in the area (Coombabah Wetlands) as well as enhancement of the water quality of the Coomera River and Saltwater Creek.

4.2.5 CHARACTERISTICS OF THE STUDY AREA

The main characteristics of these settlements can be listed as follows (GCCC, 2006a):

- They represent the general pattern of newly developed suburbs in the Gold Coast reflecting some specific features, such as low density, detached housing and auto dependent travel patterns, and so on;
- They consist not only of residential areas but also other urban functions (e.g., commercial, industry, recreation, and so on), which makes it possible to study the effects of different land uses on various indicators;
- While Coomera and Upper Coomera can still be considered as periphery settlements with mostly residential characteristics, Helensvale has a relatively balanced distribution of commercial, industrial and residential uses due to its proximity to the Gold Coast CBD;

- They are situated along the Pacific Motorway and Queensland Rail Gold Coast line with different proximities to the Gold Coast CBD and other employment centres;
- While they have similar urban development patterns, the residents of Coomera and Helensvale are relatively advantageous than the residents of Upper Coomera in terms of SEIFA index;
- Coomera is the only suburb where 30% of the dwellings are classified as medium density (12% and 8% for Helensvale and Upper Coomera, respectively);
- While newly developed, they have started to experience a transformation process from urban village style settlement pattern (a special residential land use domain applied for the greenfield developments by the local council, which aims to diminish the disturbance generated by development via very large lot size, limited building floor area and protection of native vegetation) to suburb style residential pattern with large parcel size;
- While the unemployment rate is around 3%, nearly half of the residential population is employed in a full or part time job. The ratio of full time workers to total number of workers is around 70%;
- Coomera has the largest non-urbanised area (67%), and most of the residential areas have rural characteristics (12% rural residential). On the other hand, 23% and 30% of Upper Coomera and Helensvale, respectively, are occupied by urban residential lots. However, while 28% of Upper Coomera is covered with rural residential, this figure decreases to 12% in Helensvale. This information also provides a historical perspective for the urbanisation process of the area. In time, areas close to the current urban footprint has converted to a more urbanised character (e.g., Helensvale and partially Upper Coomera). While some areas are still in transition period (e.g., peripheries of Upper Coomera), some others are planned for future development via conversion of greenfields to urban parcels (e.g., Coomera), and;

- The ratio of commercial and industrial uses in the case study area is considerably small (i.e., 0.4% and 2.1% for Coomera, 5.3% and 1.5%for Helensvale, and 2.6% and 0.9% for Upper Coomera, respectively). The yachting industry in Coomera and the neighbourhood centre in Helensvale are two prominent industrial and commercial activities, respectively.

While this information gives an overall outlook of the area, the last section of this chapter, indicator analyses, provides location specific attributes with regard to transport, land use, and transport and land use related externalities. Important demographic and urban form characteristics for each CCD of the study area can be found in Appendix (see pp.295-301).

4.3 SELECTION OF INDICATORS

Indicator selection process involved a series of consecutive steps and was specifically designed to engage the stakeholders in reaching a consensus point by their involvement and inputs. This was achieved by a number of workshops and meetings. At first, an initial indicator list was prepared and shared with the industry partners. According to the feedbacks obtained, a new version was produced and discussed iteratively in each meeting. The indicator list was finalised via mutual understanding on relevance, viability, comprehensiveness and practicality of the indicators. More specific details of this process are given in the next sections.

4.3.1 INDICATOR SELECTION PROCESS AND FINAL INDICATORS

The program of activities by which the indicator list was finalised is given in Table 4.4. In this table, the meetings with the GCCC and Queensland Transport and Main Roads (QTMR) representatives were the platform where the overall progress of the project was discussed according to the milestones achieved by the PhD researcher. On the one hand, it was not always possible to discuss every detail of each research project in these meetings; they contributed much to formulate a conceptually robust indicator system. On the other hand, indicator workshops were invaluable opportunities to discuss the details of each indicator with the professionals who provided planning inputs to planning endeavours in their institutions. In these workshops, the participants were asked to reflect on three issues. First was the relevance of the indicator to the investigation domain and local policy context.

Second was the specification level of the indicator (should it be separated to its sub-components or merged with others to form a more general or composite indicator?). Third was the suggestions of participants as the additions to the list. In order to show the evolution of the final indicator list, an example of the initial list is given in Appendix (see p.293). Basically, the discussions on this initial list did not only help to refine the indicators, but also helped to gain a clear understanding about the indicator theory.

Table 4.4 Indicator selection activities

Date	Activity	Participants	Action
4/9/2009	Industry partners meeting	GCCC, QTMR, QUT	The first version of indicator list was presented
2/10/2009	Indicator workshop	GCCC, QUT	A revised version of the indicators was discussed
5/3/2010	Industry partners meeting	GCCC, QTMR, QUT	Modifications made according to workshop were discussed
7/4/2010	Indicator workshop	QTMR, QUT	A new categorisation and changes in the indicator list were discussed
24/6/2010	Project progress meeting and indicator workshop	QTMR, QUT	A revised version of the indicators was presented
8/10/2010	Industry partners meeting	GCCC, QTMR, QUT	Final indicator list was produced

In time, the discussions on the indicator system focused on a number of considerations summarised as follows:

- The indicators which are grouped in the same category but have a causal relationship between them should be selected carefully or omitted, because it is hard to evaluate such indicators in terms of their importance (mixing driving force indicators with pressure or state or response indicators, which creates the egg and chicken dilemma);
- Considering the previous item, demographics indicators can be excluded from the list (i.e., car ownership, number of cars, household composition, labour force participation) and indicators can be selected from only one domain of DPSIR framework to avoid cause-effect confusion;

- Household level consumption indicators are rather indirectly related to urban form and can be excluded from the list (electricity and water consumption, and wastewater production of households);
- Policy relevance of the indicators should be checked initially from policy documents and then unclear points to be discussed in detail;
- Components of land use and transport should be more refined, for example, instead of using various density measures of different dwelling types, either dwelling or population density can be used, or different urban services whose proximity to residential areas by public transport and walking is going to be measured should be more specific (e.g., shopping centres, schools, open spaces and so on);
- Overlapping indicators to be excluded from the list in order to avoid double-counting problem;
- Air and stormwater pollution indicators to be defined by referencing to only transport related pollution sources;
- In order to assign a logical rank and weight to each indicator, there needs to be more than one indicator in each category, and;
- The number of indicators should be decided considering manageability and comprehensiveness of the indicator system. Additionally, the wording of indicators should be clarified to reflect the same impression on the readers.

4.3.2 THE INDICATORS OF THE STUDY

By matching the concerns raised in workshops and meetings by industry partners with the theoretical bearings of similar urban sustainability indicators studies, a final list was prepared via a consensus among industry partners. Here, three protocols determined the structure of the final indicator list. These were 'the principles of land use and transport integration', which were acquired from strategic and local policy documents, 'indicator selection criteria', which were summarised in the literature review chapter and 'practical considerations of stakeholders', which were disclosed during the meetings as given in the previous section. In fact, the first protocol was also an integral part of the first indicator selection criteria, which is policy relevance. The remaining criteria were tested for each indicator, and it was seen that the final list clearly matched with the criteria defined. Industry partners' feedbacks had always been the most critical protocol among others and considered as the main input for this study. In essence, the final list consisted of the indicators which took place in the intersection of these three protocols. The final indicator list together with measures and units adopted is given in Table 4.5.

Table 4.5 Final indicator list, and measures and units

Theme/Category/Indicator	Measure	Unit	Mode
TRANSPORT			
Accessibility			
Access to public transport (PT) stops	Average walking distance to the closest PT stop within 800 m	m	Less is better
Access to land use destinations (LUDs) by PT	Number of LUDs can be reached by 30 minute PT trip	NDAI Score	More is better
Access to LUDs by walking	Number of LUDs can be reached by 800 m walk (10 mins walk)	NDAI Score	More is better
Access to LUDs by cycling	Number of LUDs can be reached by 4 km cycling (15 mins cycling)	NDAI Score	More is better
Mobility			
Number of car trips	Average number of car trips per household	car trips/HH	Less is better
Commuting distance	Average distance travelled for work by all modes	km/employee	Less is better
Parking supply in employment centres	Probability of finding a parking space in the activity centres	probability	Less is better
PT service and frequency	Average number of weekday PT services	services/day	More is better
URBAN FORM			
Density and Diversity			
Parcel size	Average parcel size in the urbanised area	m²/lot	Less is better
Population density	The number of residents per hectare	people/ha	More is better
Land use mix	Entropy of land use mixing	ratio	More is better
Housing and jobs proximity	Job opportunities to employee ratio	ratio	Has two tails
Design and Layout			
Street connectivity	Internal connectivity	ratio	More is better
Traffic calming	Ratio of road segments with traffic calming measures to overall network	ratio	More is better
Pedestrian friendliness	Ratio of road segments with pathway(s) to overall network	ratio	More is better
Open space availability	Average open space area per household	m²/person	More is better
EXTERNALITIES			
Pollution			
Air quality	Concentration of lead in the air	µg/m³	Less is better
Greenhouse gases from transport	Average tons of CO_2 produced by transport activities per capita	tonnes/person	Less is better
Traffic noise	Road traffic noise pollution	dBA (L_{18})	Less is better
Stormwater quality	Concentration of lead in the stormwater	mg/lt	Less is better
Resource Consumption			
Land area occupied by urban uses	Ratio of urbanised area to neighbourhood boundary	ratio	Less is better
Land area occupied by roadways	Land area dedicated to roads per capita	m²/person	Less is better
Traffic congestion	Average level of service	LOS	Less is better
Traffic accidents	Number of accidents	count	Less is better

Table 4.6 Spatial units, data sources and measurement methods of the indicators

Theme/Category/Indicator	Spatial unit of the original data	Data source	Method of measurement
TRANSPORT			
Accessibility			
Access to public transport (PT) stops	Parcel	GCLUP, GCRNP, TransLink stop locations	Network Analysis tool
Access to land use destinations (LUDs) by PT	Parcel	GCLUP, GCRNP, YellowPages, WhitePages, Google Maps, TR-RT	Network Analysis tool, VBA code
Access to LUDs by walking	Parcel	GCLUP, GCRNP, YellowPages, WhitePages, Google Maps, TR-RT	Network Analysis tool, VBA code
Access to LUDs by cycling	Parcel	GCLUP, GCRNP, YellowPages, WhitePages, Google Maps, TR-RT	Network Analysis tool, VBA code
Mobility			
Number of car trips	CCD	2008 QTMR Household Travel Survey, 2006 ABS Census	Estimated via regression analysis
Commuting distance	CCD	2006 ABS Census (Customised journey to work data [JTW]), GCRNP	Network Analysis tool
Parking supply in activity centres	CCD	2004 GCCC Parking Strategy, 2006 ABS Census, JTW	Estimated via averaging
PT service and frequency	CCD	TR-RT	Direct measurement and simple averaging
URBAN FORM			
Density and Diversity			
Parcel size	Parcel	GCLUP	Direct measurement and simple averaging
Population density	CCD	2006 ABS Census	Direct measurement and simple averaging
Land use mix	Parcel	GCLUP, GCRNP	Network Analysis tool, VBA code
Housing and jobs proximity	CCD	2006 ABS Census, GCLUP	Direct measurement and simple averaging
Design and Layout			
Street connectivity	CCD	GCRNP	Topology tool
Traffic calming	CCD	Visual inspection, GCRNP	Direct measurement and simple averaging
Pedestrian friendliness	CCD	Visual inspection, GCRNP	Direct measurement and simple averaging
Open space availability	Parcel	GCLUP, GCRNP	Network Analysis tool, VBA code
EXTERNALITIES			
Pollution			
Air quality	Road segments	ARC Linkage team, GCPIP	Spatial interpolation
Greenhouse gases from transport	CCD	GCPIP, 2006 ABS Census	Estimated via vehicle size assumption and engine GHG production factor hypothesis
Traffic noise	Parcel	GCLUP, GCPIP	Estimated via CoTRN method using VBA code, Spatial interpolation
Stormwater quality	Road segments	ARC Linkage team, GCPIP	Spatial interpolation
Resource Consumption			
Land area occupied by urban uses	CCD	GCLUP	Direct measurement and simple averaging
Land area occupied by roadways	CCD	GCLUP	Direct measurement and simple averaging
Traffic congestion	CCD	GCPIP	Direct measurement and simple averaging
Traffic accidents	CCD	2009 QTMR reported road traffic accidents	Direct measure

Notes. ABS: Australian Bureau of Statistics; GCLUP: 2006 GCCC land use plan; GCRNP: GCCC road network plan; TR-RT: Translink route timetable; GCPIP: GCCC priority infrastructure plan traffic forecasts; VBA: Microsoft Visual Basic for Application

4.3.3 NORMALISATION OF INDICATOR VALUES

In this study 'benchmark-based normalisation' was employed for all indicators. More specifically, literature related to each indicator was reviewed to find benchmark values which were used to evaluate the performance of the respective indicator. If the benchmark values were supplied in the literature, they were briefly discussed and adopted with marginal modifications if necessary. Accordingly, a 5 point Likert scale was formed representing low (0-1), medium-low (1-2), medium (2-3), medium-high (3-4) and high (4-5) performance, 0 being the lowest and 5 the highest normalised value for each cell. All raw indicator values recorded for each cell were transformed to this Likert scale linearly (please see details of the linear scales used for normalisation in Table 4.7). It should be noted that while rescaling/normalising, raw values were not converted to a *discrete* scale according to benchmark values (i.e., 1, 2, 3, and so on). Instead, all raw values were normalised according to a *continuous* scale linearly to preserve the scales in the original data (e.g., if the benchmark values for low (0-1) scale are 100 and 200, indicator value of 160 for a cell is recorded as 0.60, not 1). Unfortunately, it was not always possible to find benchmark values in the desired resolution (5 point Likert scale), or there were no benchmark values at all. In the former cases, which generally occur when an ideal state is reported only, the values were placed to the scale according to the performance definition. For instance, if a value was embraced as an ideal, it was placed at the middle of the scale, or if the value was deemed as the best case, it was selected as the cut-off value for the high performance. In the latter cases, either min-max normalisation (dividing the range of indicator values to equally spaced bins) was used for the sake of preserving the original distribution of the data, or percentile values were adopted as benchmark values if the distribution of the data could provide a better insight about the performance. In general, min-max normalisation was used for the ratio values whose minimum and maximum values can vary only between 0 and 1 (i.e., the worst and the best case), only if there were no benchmark values. More specific details of normalisation procedures are given in the following analysis chapter. In the analysis chapters, the same colour scheme, ranging from red to green, is used for visual convenience, red being low (i.e., worst), yellow medium (i.e., average) and green high (i.e., best) normalised indicator values.

Table 4.7 Benchmark values of indicators

Theme-Category	Indicator code	Unit	Benchmark values 0	1	2	3	4	5	References for benchmarks
Transport-Accessibility	Access to public transport (PT) stops	m	≥1000	800	600	400	200	0	(Yigitcanlar, et al., 2007)
	Access to land use destinations (LUDs) by PT	NDAI Score	0	14	34	68	102	135	Linear composition*
	Access to LUDs by walking	NDAI Score	0	14	34	68	102	135	Linear composition
	Access to LUDs by cycling	NDAI Score	0	14	34	68	102	135	Linear composition
Transport-Mobility	Number of car trips	car trips/HH	≥13	9	6	4	2	0	Quintiles of the distribution
	Commuting distance	km/employee	≥35	30	15	10	1.6	0	(Dodson & Berry, 2005)
	Parking supply in activity centres	probability	≥0.1	0.08	0.06	0.04	0.02	0	Linear composition
	PT service and frequency	services/day	0	20	40	60	90	≥150	(Booz&Company, 2008)
Urban form-Dens./Div.	Parcel size	m²/lot	≥4000	2400	1200	800	400	≤250	(GCCC, 2003)
	Population density	people/ha	0	5	15	30	50	≥100	(Litman & Steele, 2011)
	Land use mix	ratio	0	0.2	0.4	0.6	0.8	1	Linear composition
	Housing and jobs proximity	ratio	0|2.5	0.2|2.3	0.4|2.1	0.6|1.9	0.8|1.7	1|1.5	(Cervero, 1996) and linear composition
Urban form-Des./Layt.	Street connectivity	ratio	0	0.2	0.4	0.6	0.8	1	Linear composition
	Traffic calming	ratio	0	0.2	0.4	0.6	0.8	1	Linear composition
	Pedestrian friendliness	ratio	0	0.2	0.4	0.6	0.8	1	Linear composition
	Open space availability	m²/person	0	5	10	25	50	≥100	(Australian Capital Territory Government, no date; GCCC, 2006c)
Externalities-Pollution	Air quality	µg/m³	≥0.5	0.375	0.25	0.125	0.05	0	(Department of Sustainability, Environment, Water, Population and Communities, 2001)
	Greenhouse gases from transport	tonnes/person	≥5.7	4.52	3.34	2.26	1.13	0	(Australian Greenhouse Office, 2002)
	Traffic noise	dBA (L_{18})	≥90	75	65	55	45	0	(GCCC, 1998)
	Stormwater quality	mg/lt	1	0.5	0.2	0.1	0.02	0	(National Health and Medical Research Council, 2004; The Natural Resource Management Ministerial Council, 2000)
Externalities-Res.cons.	Land area occupied by urban uses	ratio	1	0.8	0.6	0.4	0.2	0	Linear composition
	Land area occupied by roadways	m²/person	≥300	200	133	66	33	0	(Litman, 2003)
	Traffic congestion	LOS	≥2	0.9	0.8	0.7	0.6	0	(Austroads, 2009)
	Traffic accidents	count	≥19	4	3	2	1	0	(Whitelegg & Haq, 2006)

Notes.
* Linear composition corresponds to setting benchmarks according to possible min-max values. For example, possible value range for land use mix is between 0 and 1, so this was divided to five equal bins with 0.2 increments.
** Job to housing ratio has two tails corresponding to job scarcity and abundance on both ends. Therefore, the benchmark values adopted have two figures on both tails, 1-1.5 being the best case.

Mathematically, the formulas used for normalisation are as provided below:

$$\begin{array}{ll} i-\dfrac{(I-B_{i-1})}{(B_i-B_{i-1})} & \text{if } I \geq B_i \text{ and } I < B_{i-1} \\ 0 \text{ and } 5 & \text{if } I \geq B_0 \text{ and } I \leq B_5, \text{respectively} \end{array}$$

if the lower indicator values are better.

$$\begin{array}{ll} i+\dfrac{(I-B_{i})}{(B_{i+1}-B_{i})} & \text{if } I \geq B_i \text{ and } I < B_{i+1} \\ 0 \text{ and } 5 & \text{if } I \leq B_0 \text{ and } I \geq B_5, \text{respectively} \end{array}$$

if the higher indicator values are better. In the formulas, I corresponds to the indicator value, B_i is the benchmark value defined for bin i (i=0,1,...,5 which refers to performance in a Likert scale, see Table 4.7).

4.3.4 INDICATOR WEIGHTS

As it is reported in “Results and discussion” (p. 217) chapter, the final composite indicator scores were calculated according to the weights assigned by the experts. First, a survey was designed considering the similar studies in the literature with consultation of the supervisory team. After approval of ethical clearance, the expert survey was conducted. The details of this survey are given in the next sections.

Expert opinion survey preparation

In order to assess experts’ opinions about the relative importance of the indicators, a survey consisting two parts was designed. In the first part, various snapshots of the study area were prepared to ask the experts to assign a neighbourhood level sustainability score by visual inspection (see the sample survey page on p.319) and by the information provided for each snapshot (i.e., values for land use, transport and externality indicators). For this, the snapshots of 11 sites, which show spatially and statistically different clusters of the study area, and cover an area of 100 hectares, were selected. In order to select the most appropriate snapshots, two clustering methods were used. While k-means cluster analysis was employed to detect statistically similar clusters, Anselin local Moran I statistics was used to reveal spatially similar areas. The main criterion here was to ensure that, while cell values in each snapshot were spatially and statistically similar, each snapshot should capture unique clusters in the area. The details of these analyses can be found in the appendices (see p.310). The main measurement strategy here was to introduce the indicators and show the changes in indicator values for the given snapshots. This part was used as a leverage to raise the participants' awareness on the indicators and a means to reveal if there were any questions related to the definition of the indicators. It was also used to measure the concordance between weights assigned and the scores given to each snapshot by the experts. In summary, this part was particularly designed to prepare the participants to the second part of the survey.

In the second part, all indicators were listed with three empty columns (one for category-based ranking, one for the category weights and one for the indicator weights, - see the sample survey on p. 110). While the initial version of this part consisted only the final indicator weight column, as a further refinement, two extra columns were added (i.e., ranking and category weights) for the convenience of the participants. This was done considering the feedback acquired from the trials of the initial versions of the survey. The main strategy here was to ease all pairwise comparisons among the indicators by firstly evaluating the indicators within each category by considering the first two columns. More specifically, while the ranking column was designed to clarify the relative importance of each indicator in the category and to direct the participants to think the relative distances between the indicators in each category, the category weights were asked to disclose what the participants think about the relative importance of each category with respect to the other categories. The scores given in the last column were the main target of this survey, and to reach this end, these two columns were used as leverage.

Selection of experts

The purposive sampling technique was adopted due to the scope of the study and the case study area selected. In order to determine the survey participants, the contact persons from industry partners were asked to advise a number of experts who have expertise on urban planning, urban design, transport planning, environmental planning/sciences or landscape architecture, and are familiar with the Gold Coast region, particularly with Coomera, Upper Coomera and Helensvale. Even though more than 40 candidates were invited via contact persons, only 15 of them accepted the survey invitation. The two main reasons which led to a relatively low response rate, as reported, were the long survey time (45-60 minutes) and the unavailability of the experts for the given survey period. The profiles of the participants can be seen in Table 4.8 below.

Table 4.8 Profile of the survey participants

	Industry partners			
Profession	**GCCC**	**QTMR**	**QUT**	**Total**
Environmental planning/science	2	1	-	3
Transport planning	1	4	-	5
Urban planning	-	-	3	3
Civil engineering	3	-	1	4
Total	**6**	**5**	**4**	**15**

Equal representation of each industry partner and discipline in the survey were two objectives pursued and were accomplished to a great extent. Most of the participants were from transport and civil engineering disciplines. The main reason behind the interest of these professionals participating the survey was the close relationship between the subjects of the study and the organisational duties of these people. It should be noted that even though QUT is primarily an educational institution, it has strong connection with the industry, particularly with the governmental agencies in Queensland, and provides research support and consultation services to transport, construction and infrastructure institutions. Nearly all participants selected from QUT have industry connections and have provided inputs for transport related policy making processes, directly or indirectly. As the last note, during this survey, the GCCC planning office was working on the new planning scheme, and not all of the invited urban planning professionals were able to participate this survey due to their workload. Other urban planning professionals invited from QTMR rejected to participate due to the long survey time.

Application of the survey

The surveys were conducted in face-to-face style and in a place preferred by the participants. In order to standardise the information provided to each participant, a 15-minute introductory video, which explains the structure of the study and the survey, and gives the basic calculation procedures employed (accessible from https://sites.google.com/site/fdurexpertsurvey/), was prepared. Furthermore, another video was prepared to give the specific details of each indicator (the importance, definition, measure, normalisation scheme, calculation steps, and the result of the indicator analysis).

First, each participant's written consent was sought after they read the 'participant information sheet' approved by QUT-UHREC. After obtaining the consent of the participant, a briefing was given on the structure of the survey. Next, the introduction video was shown. The second video was shown if the participants had any questions related to a specific indicator. Before starting the survey, the participants were asked to review the indicator list and state if they needed any further information regarding the indicators. The main aim of this was to make sure that the participants were fully informed about the indicators and measures used in this study. After the clarification of the issues raised by the participants, the survey proceeded with the first part. Here, the structure of the first part was explained and the information with which the evaluation was going to be made was clarified verbally one more time.

After the first part, the participants were asked first to rank and then to assign a weight for each category and indicator. The budget allocation method was used for the weighting exercise, and the participants were given 120 points to distribute to each category and indicator according to their professional opinions. In the initial versions of this survey 100 points were used. However, during the testing phase of the survey, it was realised that dividing 100 points among these indicators and categories are tedious and impractical, so the number closest to 100 point and divisible to 24 (i.e., number of indicators) and 6 (i.e., number of categories) were selected as total points, which is 120. After the participants finished the second part, they were asked one more time to review the scores given in the last column, the individual weight of each indicator, by comparing them pairwise with other indicators and to make small adjustments, if necessary. The survey was concluded after this final review. An example of the main survey page is given in Figure 4.3 for referencing purposes.

2 Ranking and weighting the indicator groups and indicators

Please first rank the indicator as to their in-group importance, then assign a weight for each group and assign another weight to each indicator according to its in-group importance.

	Indicators	Rank of the indicator in the group	Weight of the group	Weight of the indicator in the group
ACCESSIBLITY	Access to public transport stops			
	Access to LUDs by public transport			
	Access to LUDs by walking			
	Access to LUDs by cycling			
MOBILITY	Average number of trips made by car per HH			
	Average commuting distance to work			
	Off-street parking in employment centers			
	Public transport service and frequency			
LAND USE & DENSITY	Average parcel size			
	Population density			
	Land use mix ratio			
	Housing and jobs proximity			
DESIGN	Internal street connectivity			
	Traffic calming			
	Walkability, pedestrian friendliness			
	Open space availability per HH			
POLLUTION	Air quality			
	Greenhouse gases from transport per capita			
	Exposure to traffic noise			
	Stormwater quality			
RESOURCE CONSUMPTION	Land area occupied by urban uses			
	Land area occupied by roadways per capita			
	Traffic congestion			
	Accident and fatalities			
			120	120

Figure 4.3 Example of the second part of the survey.

Results of the expert survey

After the finalisation of all the surveying process, the indicator weights assigned by the experts were averaged to yield final indicator weights. An overview of the responses of experts is given in Figure 4.4.

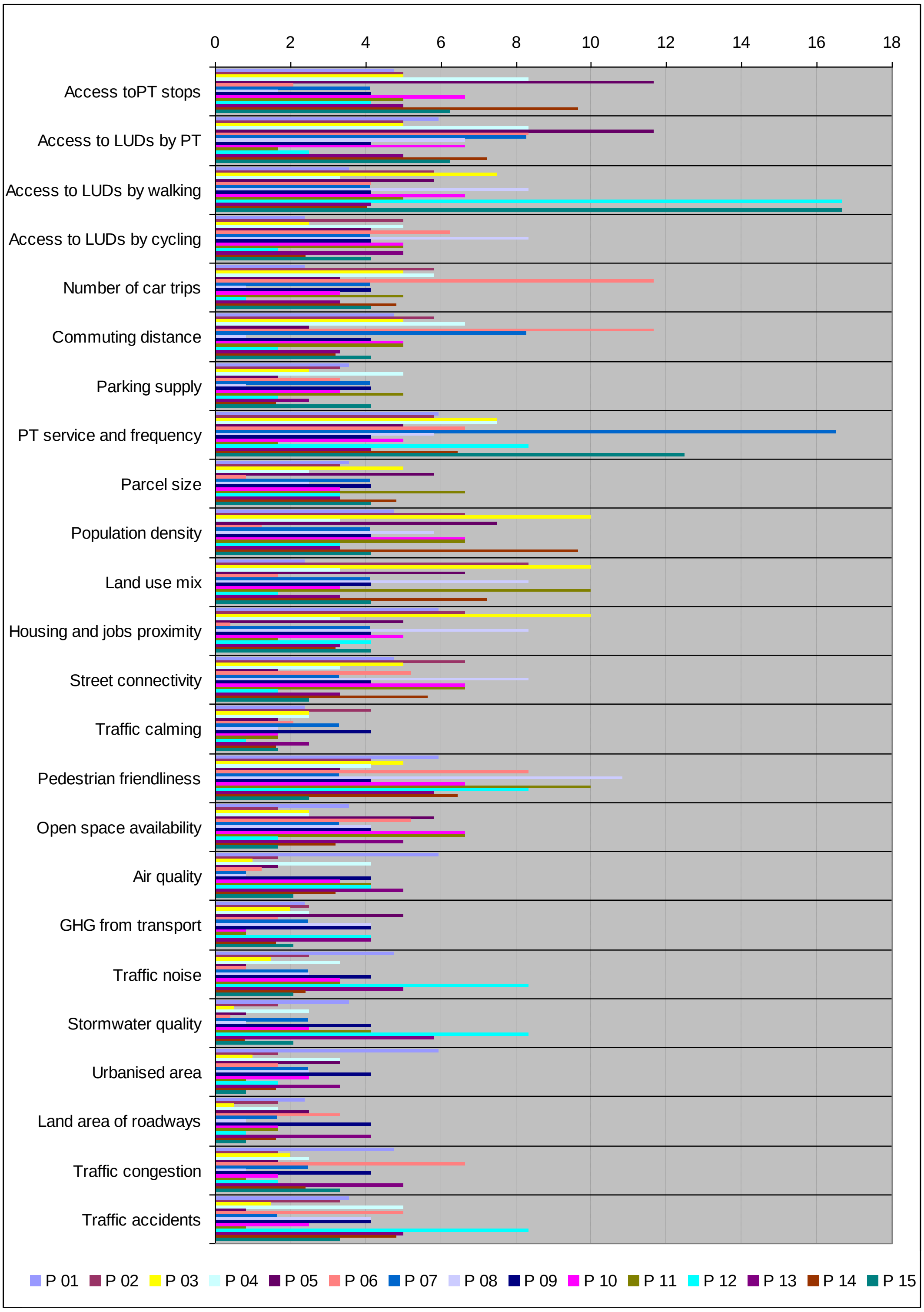


Figure 4.4 Indicator weights assigned by the participants

In Figure 4.4, it is possible to see the level of agreement among the experts on the relative importance of the indicators. The weights of transport and land use indicators are generally high and have spikes showing the differences between the opinions of the experts, whereas the weights of externalities indicators are comparatively low and look stable. It was observed that while the participants with civil engineering and transport planning background tend to give higher weights to transport indicators, externalities indicators were comparatively more important for environmental planners. Particularly accessibility to LUDs by walking, and public transport service and frequency were two indicators on which participants' interpretation showed a great variety (it can also be observed from the standard deviations in Table 4.9). It was also observed that there was small discrepancy in assigning low weights (i.e., general agreement on the low relative importance of these indicators among participants). The final category and indicator weights are given in Table 4.9. The first three most important indicators according to the experts were 'public transport service and frequency', 'access to land use destinations by walking' and 'access to land use destinations by public transport', while the least important indicators were 'land area occupied by urban uses', 'traffic calming' and 'land area occupied by roadways'. Overall, the transport indicators yielded higher weights and the externalities were deemed as less important. Among all externalities, 'traffic accidents' and 'traffic noise' were the highest ranked indicators. These were not unexpected outcomes in general, although the participants' tendency to give higher weights to the public transport related indicators and place the air and stormwater quality by the end of indicator list was a bit surprising. Therefore, the weighting scheme given in Table 4.9 was used for the final calculations. As the last note, the last column in Table 4.9 shows the rank of the indicators when sorted in ascending order according to the given weights and is presented here for referencing purposes only.

4.3.5 AGGREGATION OF THE INDICATORS

Aggregation is the last computational step in composite indicator creation. This step simply encompasses adding up all normalised and weighted indicator values by using a simple arithmetic operator or a functional form. The fundamental question of aggregation is whether the compensation between indicators is allowable. While simple arithmetic operators allow compensation among indicators, the non-compensatory multi-criteria approach (NCMC) seeks to diminish compensation as much as possible. However, the latter approach is viable if the number of cases is limited, and the preference and indifference thresholds between alternatives are determined. In practice, the latter approach requires pairwise comparisons, which means the number of comparisons can reach to the factorial of cases (Nardo, et al., 2008).

Due to its spatial content and multiple attributes in evaluating a phenomenon, this study has a close affinity with multi-criteria decision models and multi-attribute decision rules (i.e., normalisation/standardisation, weighting and aggregation of 24 indicators). In essence a decision rule corresponds to "a procedure that allows for ordering alternatives. [...] the decision rule dictates how best to order alternatives or to decide which alternative is preferred to another. It integrates data and information on alternatives and decision maker's preference into overall assessment of the alternatives" (Malczewski, 1999, p.197). In overall, it aims to find the best *alternative* according to the decision variables and objectives. This is the main difference between multi-criteria decision models and metric advised by this study, there is no search for a best alternative or ranking of unit of analysis in this study. It simply calculates a composite metric for each grid cell (see unit of analysis section on p.120), which can be used for monitoring and evaluation purposes. Even though various decision rules, such as simple additive weighting, utility function approach, analytic hierarchy process, ideal point method, concordance method and fuzzy aggregation (Malczewski, 1999) seem appropriate for combining multiple attributes into one metric, considering the previous explanation these options will not be explored in this study.

Among a limited number of alternatives, simple additive weighting or linear aggregation is by far the most preferred option (Campos & Ramos, 2005; Gardi, et al., 2010; Kondyli, 2010; Y.-J. Lee & Huang, 2007; Scipioni, et al., 2009; Vianna, et al., 2009) and was used as the principal aggregation scheme. The composite indicator (CI) was calculated according to the formula given below:

$$CI = \sum_i I_i w_i \qquad i = 1, 2, \ldots, 24$$

where I and w correspond to the score and weight of each indicator given by the experts, respectively.

Table 4.9 Final category and indicator weights assigned by the experts

Category/Indicator	Weight	Standard deviation	Weight rank
Accessibility	**0.23**		
Access to public transport (PT) stops	0.056	0.026	5
Access to land use destinations (LUDs) by PT	0.062	0.024	3
Access to LUDs by walking	0.067	0.042	2
Access to LUDs by cycling	0.043	0.016	11
Mobility	**0.19**		
Number of car trips	0.043	0.025	12
Commuting distance	0.048	0.026	8
Parking supply in employment centres	0.031	0.012	17
PT service and frequency	0.069	0.035	1
Density and diversity	**0.19**		
Parcel size	0.038	0.014	14
Population density	0.054	0.024	6
Land use mix	0.053	0.028	7
Housing and jobs proximity	0.046	0.023	9
Design and layout	**0.17**		
Street connectivity	0.046	0.019	10
Traffic calming	0.023	0.009	23
Pedestrian friendliness	0.059	0.024	4
Open space availability	0.039	0.017	13
Pollution	**0.12**		
Air quality	0.029	0.016	18
Greenhouse gases from transport	0.027	0.013	21
Traffic noise	0.032	0.018	16
Stormwater quality	0.027	0.021	20
Resource consumption	**0.11**		
Land area occupied by urban uses	0.025	0.014	22
Land area occupied by roadways	0.02	0.011	24
Traffic congestion	0.028	0.016	19
Traffic accidents	0.036	0.019	15
Total	**1.000**		

4.4 DATA REQUIREMENTS AND QUALITY

Table 4.6 shows spatial units, data sources and measurement methods used. Similar to other urban sustainability indicator studies, number of required data items is large and they come from various data sources. In this section, these data sources are explained to show how they were produced with reference to the data quality considerations.

The GCCC land use plan is a GIS layer (map) which was acquired from the GCCC at the early stages of the study. In fact, it is an extended version of the digital cadastral database (DCDB) which is a digital representation of property boundaries, and contains a number of attributes of these boundaries. It was produced and is managed by the Department of

Environment and Resource Management (DERM). The attributes contained are lot on plan number, area, road and street names, river and creek names, feature names, locality names, alphabetic codes for tenure, numeric codes for local government, and parish and locality (DERM, 2010). When the actual land use is assigned to each property boundary in the DCDB, it becomes the land use plan and is used as a base for the planning schemes. While the DCDB uses Geocentric Datum of Australia (GDA94), land use plans are generally projected to the respective national map grid. For example, for the Gold Coast, this is GDA94 the Map Grid of Australia *(*MGA) Zone 56. The reliability and currency of the DCDB is provided by continuous updates of the following items (DERM, 2010):

- Survey control data and survey plans;
- Registered plans of subdivisions;
- Government gazettes and administrative notifications, and;
- Upgraded data and survey control network received from local authorities.

The GCCC road network plan, which is also known as the State Digital Road Network, is another GIS layer which was collected from QTMR. It contains the shapes and locations of each road segment (from one intersection to another) and other attributes (street name, address ranges, road classification, one-way direction indicator, alias name, local government authority code, locality code, unique feature identifier). It was produced by MapInfo Australia Pty Ltd and has been marketed by a number of contracted national resellers. It uses the same map projection as the land use map, which is GDA 1994 MGA Zone 56. Spatial accuracy of the data is explained in the metadata of the respective GIS layer as follows (MapInfo Australia Pty Ltd, 2006, p.1):

> Road objects derived from casements are aligned generally to the centre of road casements except where more accurate source data is available. The alignment of dual carriageways is an estimation of best fit within the road casements except where more accurate source data is available. MapInfo does not guarantee that the DCDB source data is a valid representation of the location or existence of roads (particularly in rural/remote areas). Data is being subjected to a program of validation in rural areas using alternative data sources to provide a more accurate representation of reality.

Since the acquired version of the data is dated to 2006, a number of roads were absent on the map, specifically the roads in the newly developing residential areas. Only the geometry of these roads was updated by visual inspection of aerial images. Since the geometry of the road network was used for various GIS analysis, digitising absent road segments by visual inspection was the only and the most effective way to update the map.

TransLink stop locations were provided in a tabular format as global positioning system (GPS) readings of the stop locations by TransLink (Public transport authority in Brisbane metropolitan area). Originally, this information has been used for a number of public transport system operations (route optimisation, determining public transport patronage by smartcard readings, and so on). Original data in the tabular format was converted to a point layer in GIS. GPS readings were in 1984 World Geographic Coordinate System (WGS1984), and they were projected to GDA 1994 MGA Zone 56.

YellowPages and WhitePages are two prominent business directories in Australia and they are registered trademarks and the trademarks of Telstra Corporation Limited. Registration to complimentary listing is free-of-charge for the firms if they have an Australian Business Number (ABN) or Australian Company Number (ACN). Having been confirmed as a real company by the registered business number, the firms are added to free listings of both sites. Because of this, it provides a great coverage for businesses particularly in the metropolitan areas in Australia to be found by the customers. On demand, they can provide extra assistance in building a web site, giving information about the prospective customers, reporting site activities and so on for a price. On their web sites, there is no information regarding the data quality assurance, but a great number of trials to find business addresses extracted from these sites showed that the information provided was reliable and current to a great extent.

Google Maps is the trade mark of Google Inc and provides free map browsing services. In this study Google Maps was used for two purposes. First was to obtain the geographic coordinates of the addresses acquired from YellowPages and WhitePages via Google Maps API (application programming interface). Second was to check the accuracy of the addresses obtained from the first step via official website or Street View. It is known that all map data in Google Maps has been provided by MapData Services Pty Ltd, which is the reseller of PSMA

Australia Pty Ltd, the main reseller of wide variety of geographic data produced and managed by governmental institutions. For example, in Queensland, the main custodian of the products sold by PSMA is DERM. That means, Google Maps actually conveys the same data, which was produced while the DCDB was created, with many additional web functionalities. A number of trials showed that the address information provided by this web site was mostly correct. All inaccurate coordinate reporting was corrected via finding the right coordinate and entering it into the database manually. Resulting point layer representing the locations of searched business categories were checked one more time with DCDB layer in GIS, and the layer which was used for accessibility measures was generated. All relevant LUDs were scrapped by a VBA code written in MS Excel and 6801 records were geocoded over a four-month-period.

*Translink route timetable*s were acquired from the TransLink website in a tabular format, and the number of public transport services information in a weekday was assigned to each public transport stop in the case study area. Since the information provided in the web site is shared by the public and have been used by the people for daily travel planning purposes, the information is always up to date and accurate. Furthermore, the information given in the website has been shown as the place where 'up to date public transport information within South East Queensland' can be found in the official public transport service brochures.

2008 QTMR Household Travel Survey (HTS) is a database consisting of the raw records of household travel survey conducted between 2006 and 2008 in SEQ (2,064 Gold Coast households and 16,849 trips made by the residents of the Gold Coast were surveyed in 2008) by The Urban Transport Institute and I-view Pty Ltd. A copy of this database had been given to Queensland University of Technology (QUT) to be used in academic studies, and this copy was used for this study. It was conducted by an experienced firm complying with the minimum standards required for the similar studies. Each step and relevant procedures followed (sampling, data imputation, training of survey staff, phases of the survey, data entry and checking, and reporting) were well-documented, and consistency and reliability of the data was checked by QTMR. One important note about this database is that after the completion of the survey, the contracted firms applied a series of 'sample expansion' techniques and assigned weight for each person, household and trip, accordingly. In this study, only raw survey records were used for calculations and aggregated to CCD level.

2006 Census was produced by the Australian Bureau of Statistics (ABS) in 2006. This is the most recent available census data in Australia in 2011. The reliability and consistency of the Census data has been determined by a number of official data collection, updating, management and reporting protocols. It can be considered as the most accurate data source and has been used by numerous academic and commercial studies in Australia. The only problem with this data is that in order to protect the confidentiality, the data disclosed to third parties contains random adjustments and it is particularly the case if the value in a cell is smaller than 3 samples. These protocols can be found in the official website of ABS (http://www.abs.gov.au/ websitedbs/D3310114.nsf/home/Census+Data+Quality#Relevance).

2004 GCCC Parking Strategy was prepared by Eppell Olsen and Partners for the GCCC. It provides detailed surveys related to short-, long-term and off-street parking, loading zones, and disabled parking. It also gives information related to relevant directional signage and parking management measures for the employment centres in the Gold Coast. After the investigation of the 2004 parking provision, population and employment growth trends, the parking behaviour of the residents and expected changes in floor spaces of retail and office uses in the area, the contracted firm generated generic strategies and local centre specific actions considering the future demand and parking space availability. This data was produced by the firm via site visits and car parking demand surveys. Even though the specific details of the data collection procedures were not expressed explicitly, it was assumed that the information provided in this document was checked by the GCCC staff to be sure about the reliability. This document was the main data source for parking provision in the Gold Coast area and used to compute the possibility of finding publicly provided parking space metric (see calculation details on p.152).

The GCCC Priority Infrastructure Plan traffic forecasts were produced by Veitch Lister Consulting Pty Ltd. ZENITH software, a multi-modal transport simulation model which uses traditional four step transport demand modelling method, was run and estimates for 2011, 2016 and 2021 were mapped. In the transport model, estimates of travel demand between 1,106 travel zones (653 for the Gold Coast region and 453 for the surrounding areas of SEQ and New South Wales) were derived from the 1992 household travel survey. Final model estimations were validated according to the traffic counts of inner and outer cordon screenlines. Actually, an impressively accurate correspondence between the estimates of the model and the actual counts did not necessitate a validation procedure, and the model results were accepted. Even though the main function of the forecasts was to estimate the charges for the consumption of the trunk road infrastructure, the estimates of the model were used as the basis for calculating traffic congestion, noise pollution, and air and stormwater quality in order to evaluate the different aspects of traffic forecasts.

Aerial images were provided by the GCCC in the early stages of the study and used for various operations which required the visual inspection of the features of the area. They are dated to 2009 and were produced by Sinclair Knight Merz Pty Ltd in the scope of AUSIMAGE project. They were provided as 1km to 1km ortho-rectified tiles with 15 cm pixel resolution in ECW format.

The ARC Linkage team delivered the air and stormwater pollution data and the equations to estimate the pollution for other road segments. These results were also the main findings of the ARC Linkage project and involved a number of rigorous air and stormwater sampling and analysis processes. The details of these studies can be found in Mahbub et al. (2011; 2011) and Gunawardena et al. (2011).

2009 QTMR reported road traffic accidents were acquired from the Road Safety and System Management Department of QTMR. It was an MS Excel file consisting the locations, dates, severity, road and weather conditions, and very specific details of the crashes. In the data quality assurance document attached to the file, it was stated that this information was gathered from police records from 2009 to 2011. While the 2009 data was complete, 2010 and 2011 data was showing preliminary figures and incomplete. This was mainly due to the introduction of the new crash reporting system in Queensland and unexpected delays in reporting. Because of this, the 2009 crash data was used for the indicator calculation.

A number of indicator measures, probability of finding a parking space, entropy measure of land use mixture, concentration of lead in air and stormwater, and noise pollution, were calculated according to the advised methods in the literature by employing GIS tools (e.g., noise, air and stormwater pollution) or generated by processing the base datasets provided (e.g., probability of finding a parking space was generated by using the GCCC parking study and employment census from ABS, and land use entropy was calculated by using land use map and transport network of the Gold Coast). The calculation details will be given in the following sections.

4.5 UNIT OF ANALYSIS

In the GCCC workshops and industry partners meetings, one question arose related to the unit of analysis (UOA) of the study. More specifically, the GCCC staff warned the research team about the individually identifiable parcel problem which had been experienced before due to the selection of parcels as the UOA by previous academic studies on the Gold Coast. 'Individually identifiable parcel' problem simply occurs in a way that either the council members or the public can identify their own or others' parcels and raise questions about the information collected or judgements made by these studies. It may even lead the council members to direct serious criticisms towards the council staff over the confidentiality of this kind of information and also the validity of the findings depending on the personal point of view. Because of this, it was advised not to present any parcel level analysis, instead, to produce aggregated level information. Accordingly, the second best option was to aggregate parcel level information to CCD level and conduct analyses together with other CCD datasets. However, CCD level lacks in providing fine-grain details on a number of important issues at neighbourhood level, such as local accessibility to LUDs and public transport services, urban form characteristics and pollution level. It should be noted that in this study context, neighbourhood was not considered as a strictly population-dependent administrative spatial unit as done by ABS, but a spatial scale which covers certain qualities of an urban area that allow to specify what to measure in detail. As being the finest geographic census collection unit, CCD can be regarded as a good representation of neighbourhood (even SLA can give a better approximation to neighbourhood if taken as solely population dependent unit); however, a number of measures mentioned in the literature refer to local level considerations which can be elaborated at parcel level or street level, and this gives the most detailed outlook for an urban area when compared to suburb or city scales. Being inspired by similar studies, it was agreed on an interim spatial scale between parcel and CCD, which is grid cell. The main advantages of employing grid as the UOA are twofold. First, it allows an aggregation which prevents the study from the individually identifiable parcel problem. Second, it helps to reveal local level details in an acceptable level of accuracy. However, the size of the grid is another concern here which can drastically change the quality of the output from the analyses. This issue actually corresponds to the level of aggregation which can provide the most detailed and accurate results. Considering this, another analysis was required to define the ideal grid size.

4.5.1 SELECTION OF GRID SIZES

Any areal unit can be aggregated to a polygon shape. As this statement implies, the shape can be determined arbitrarily to form different spatial arrangements, and thus, they are modifiable (Jelinski & Wu, 1996). That is why this problem is termed as modifiable areal unit problem (MAUP) (Openshaw, 1984). There are two dimensions of this problem as mentioned by Jelinski and Wu (1996), scale and zoning. While the former corresponds to "the variation in results that may be obtained when the same areal data are combined into sets of increasingly larger areal units of analysis" (p.130), the latter is "any variations in results due to alternative units of analysis where n, the number of units, is constant" (p.130). It is possible to discuss the implications of these dimensions with regards to any lattice or administrative boundary. For example, if a regular geometry is overlaid on an area, selecting different sizes gives different results (scale), whereas picking a different starting point for the lattice may also alter the outcomes (zoning). If the case is administrative boundaries, say CCD boundaries which are defined according to a predetermined number of dwellings, it is possible to adopt a new boundary which contains more dwellings but with the same average census parameters (scale), as well as to use different human-made or natural features to demarcate boundaries (even though we produce the same number of CCDs in the end), which might give the same average census values (zoning).

Selection of the ideal grid shape and size mostly depends on the resolution of the data at hand. For example, a number of studies employed square grids owing to the minimum resolution of the raster image available (100 metre in the US if land use rasters were used), or lattice shape was chosen according to the benchmark values used in the analysis (500 metre, 800 metre, 1 kilometre or half-a-mile if the subject involved analyses related to the average walking distance). However, the dominance of square lattice is apparent in the literature, with regards to computational convenience and tendency towards selecting a simple regular shape for aggregation and comparison. Considering these qualities, square form lattice was selected as the shape of the UOA. After this, the problem became relatively simple: finding the right size which minimises the number of individually identifiable parcels and maximises the accurate representation of the local level characteristics in detail (which implies less aggregation).

In order to gain more insights about the individually identifiable parcel problem, an analysis was conducted to show how many parcels could be detected individually by trailing different grid sizes. Before starting to explain the analysis, there is a need to clarify the meaning of ‘detectable’ with reference to parcel and grid size. A general remark on the relationship between parcel and grid size is that if the area of a parcel is greater than the size of the grid, the probability of this parcel to be covered by more than one grid is equal to unity. On the other hand, if the parcel is smaller than the grid area, the probability of being covered by minimum one and maximum four grid cells is higher than being covered by more than four grids. So, it is possible to separate the parcels into two groups according to their sizes for calculation convenience: parcels whose areas are greater than the trailed grid cell (big parcels) or parcels whose areas are smaller than the trailed grid cell (small parcels).

As a rule of thumb, if one grid is shared by more than one parcel, it could be considered as not-detectable individually to a great extent. But, what happens if the most of a grid cell is covered with one parcel while a very small portion is covered with the other parcel? Here, we need a bit more clarification on the ‘portion’ concept as well, because there might be such cases that, even if the grid encompasses more than one parcel, it can still be detectable.

In summary, we can talk about three types of detection regarding to this discussion:

- Detectable small parcels covered by only one grid, and no or very small portion of the other parcels exist in the same grid (Type II);
- Detectable big parcels covered by only one grid (Type I);
- Non-detectable parcels (Type 0).

A set of ‘portion’ criteria were applied to specify Type I and Type II according to the grid and parcel relationship. By visual inspection, it was concluded that if a parcel is ‘small’ and more than 10% of it is covered in a grid, it cannot be detectable. Similarly, if a parcel is 'big' (covers more than one grid) and more than 10% of the grid(s) (which cover(s) this big parcel partially) is encompassed by this 'big' parcel, again the parcel cannot be detectable. An application of these principles and the result of the analysis are depicted in Figure 4.5.

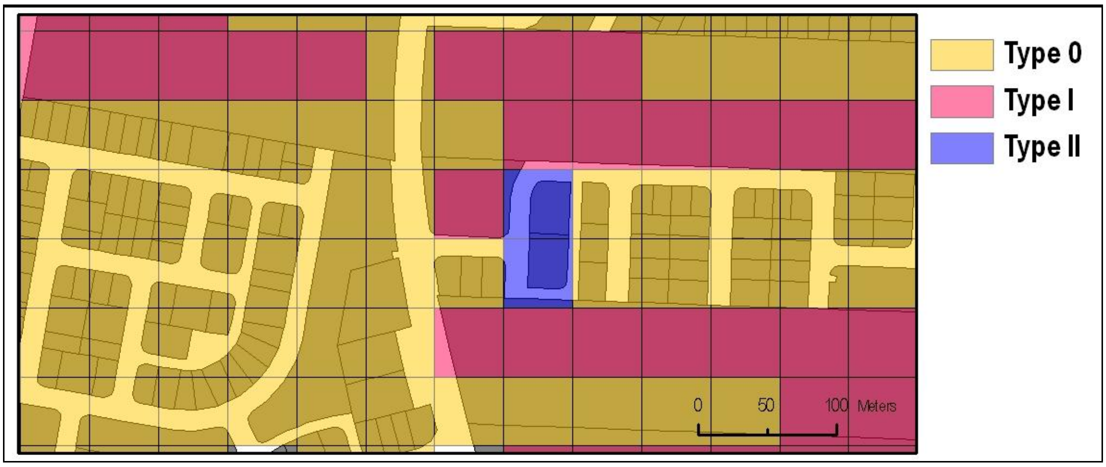


Figure 4.5 Three types of detection if parcel is identifable

Note. 50 m grid is used here to depict the types because it contains all three variations.

In Figure 4.5, Type 0 cells cover more than one parcel either small or big, and cannot be detected individually according to the criteria defined above. As for Type I, these cells cover a big parcel completely, or the big parcel covers more than 90% of the grid cell if it is sharing the same cell with others. Type II cells are the main consideration of this analysis and the identifiability of the small parcels is the main problem. These cells may either contain only one 'small' parcel or cover more than one small or big parcel. Depending on the number and type of the parcels covered in these cells, they are deemed as not identifiable if less than 10% of *them* are covered by big parcels, and less than 10% of the *small parcels* are in these cells (see blue coloured cells in Figure 4.5).

For this analysis, 50, 100 and 150 metre grid settings were trialled and the results are given in Table 4.10. This table reports the total number of grid cells in each configuration and the descriptive information related to the types of detection. It should be noted that, depending on the size of the parcels, the possibility of finding Type I cells will usually be the case. As expected, selecting a coarser resolution for grids decreases the number of Type I cells, but this has two implications. Firstly, the level of details and locational accuracy decrease if the grid resolution is coarser. Secondly, increasing the grid size without losing locational accuracy of the grids does not guarantee the occurrence of zero Type I cell. Similarly, in the selected grid configurations which have an acceptable locational accuracy, the occurrence of Type I cells was unavoidable. Because of this, more attention was devoted to Type II cells in this analysis. As it can be seen in Table 4.10, the only problematic configuration is 50 m grid size, which contains six grid cells with individually identifiable parcels. Consequently, 100 and 150 m grids are the best options available for this analysis.

Table 4.10 Summary for the number of idenfiable parcels with different grid sizes

Grid information	**50 m grid**	**100 m grid**	**150 m grid**
Total number of grids *	13691	3531	1554
No of Type 0 grids	9556	3009	1441
No of Type I grids	4129	522	113
No of Type II grids	6	0	0
Ratio of Type I grids	30.1%	14.7%	7.2%

Notes. Number of Type I and II grids were only calculated for residential, industrial and commercial parcels.
* The grid cells whose halves are covered by the urbanised parcel(s)

In the second stage, another analysis was carried out to measure the loss of details due to the aggregation of parcel information to grid cells. In order to reveal this, it was first required to define which indicator was the best option to perform this analysis. As the principle, the best candidate should show the most variability in terms of data distribution by which it could be possible to measure the quantity of error the aggregation process might yield. Four lot level indicator data were selected due to the high variability in their distribution by visual inspection. These are public transport stop distance, parcel size, noise pollution and land use mix. In addition to selecting the candidates, another concern arose from the evenness of this variability among defined distribution intervals. While diverse, the indicator data should also be distributed as equal as possible to each frequency bin to allow us to test the extreme condition in variety, which is called evenness in diversity. Actually, it is similar to finding an indicator dataset in which the probability of picking a parcel from one frequency bin is as equal as possible to picking one from another frequency bin (for example, it is not possible to know the numbers when a fair die is thrown, because the probability of each side is equal). For instance, in Figure 4.6, while relative ranges of the indicator data are wide, it is the noise and land use mix data whose distributions among the bins are nearly equal. This is to say that, when converted to grid cells, the number of cases in each frequency bin is going to be more diverse with noise data (of course, if five bins are used as in the figure). On the other hand, parcel size distribution is dominated by the grid cells belonging to the first bin (274-3,635 m²) and if this bin configuration is used, most of the cells will be in the first bin.

In order to find the indicator whose diversity is distributed evenly among the defined frequency bins, Shannon's Evenness Index (SEI), one of the frequently preferred methods in the literature (Janssen et al., 2007; Li et al., 2004; Palmer, 2004; Payne et al., 2005), was used. It is basically a derivation of Shannon-Wiener Index or Shannon's Diversity Index and can be calculated by dividing the diversity index by its maximum. This division corrects biases in diversity index, which occur due to the size and richness of the sample, and yields an index changing between 0 and 1. Mathematically:

$$\text{SEI} = - \frac{\sum_{i}^{n} P_i \ln(P_i)}{\ln(n)}$$

where P is the proportion of the number of observations in each defined frequency bin (i.e., the relative abundance of observations) and n is the total number of frequency bins. The result of this calculation is used to decide on the best option for this analysis out of four indicators.

The distribution and descriptive statistics of the data are given in Figure 4.6. This figure only reflects one of the possible frequency distribution options (five bins), and the superiority of noise and land use mix indicators is obvious. A general observation about Figure 4.6 is that the wider the data range, the more the skewness of the distribution is. It may create data quality problems and data winsorising, or the trimming operation, can help to fix this problem. In order to reduce the impact of the outliers on overall analysis results, the data of all indicators were trimmed by 5% cumulatively on each tail. This means raising values smaller than 2.5 percentile to corresponding percentile value (2.5%) and lowering values greater than 97.5 percentile to 97.5 percentile value. These percentile values can be seen at the two ends of axis along with the original minimum and maximum values of the distribution in Figure 4.6 for comparison.

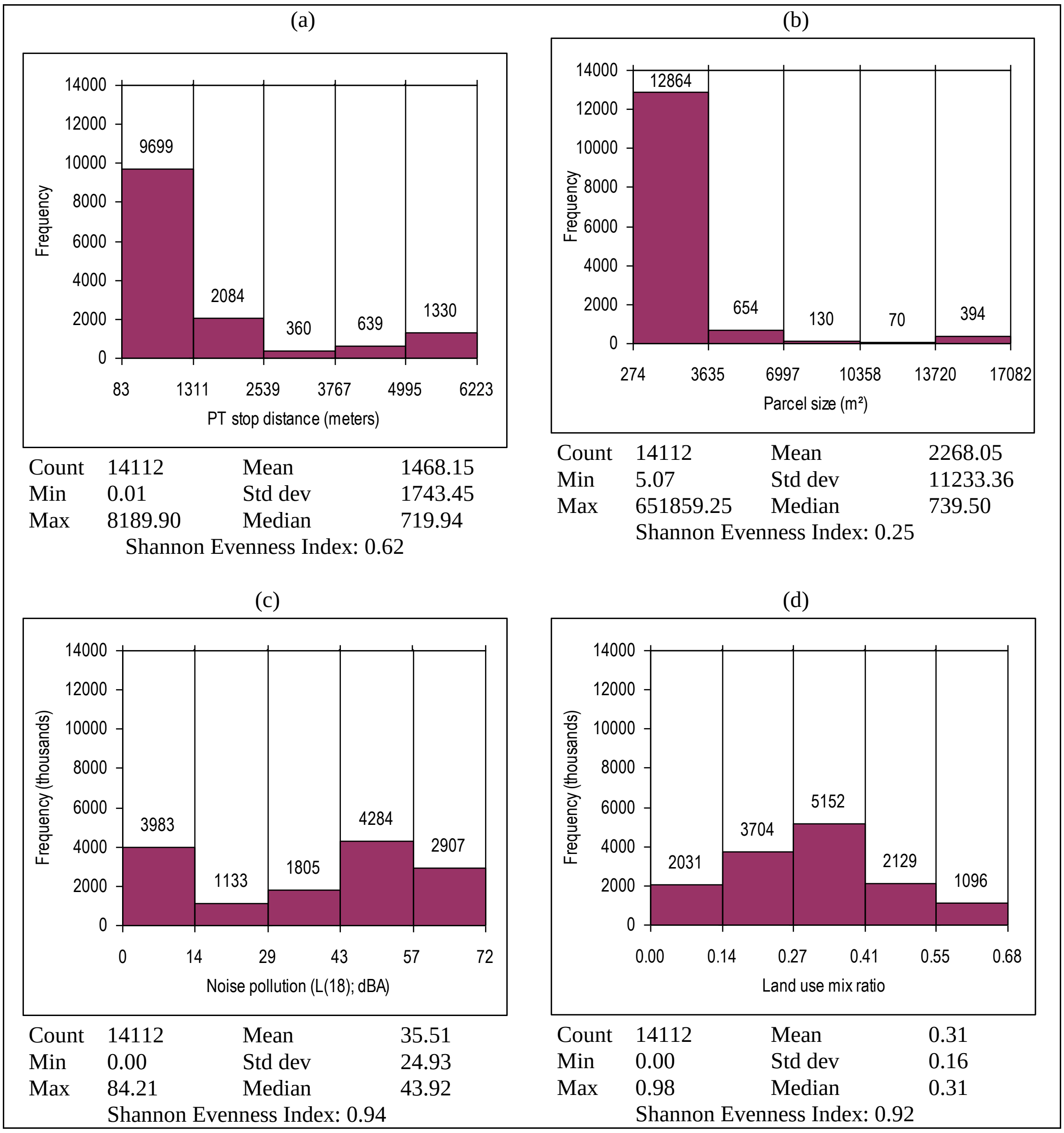


Figure 4.6 Frequency distribution of the selected indicators

Notes. (a) Distance to public transport stop; (b) Parcel size; (c) Noise pollution; (d) Land use mix

Figure 4.6 provides a crude idea about interpreting the evenness of diversity for each indicator, but merely five-bin configuration is not enough to come up with a decision. Because of this, Shannon Evenness Index for each indicator was tested for different number of frequency bins to evaluate how changing the number of bins affects the evenness index. By this way, it could be possible to find a global maximum for evenness score as well as to see the stability of the index score which is an indication of consistency in data distribution. For this, the data range was divided to different number of bins ranging from 3 to 45 and the evenness scores were recorded as it can be seen in Figure 4.7. Even though the noise data showed the highest evenness score around 0.97 in the beginning, it decreased slowly to 0.84. On the other hand, the land use mix started at 0.89 and climbed up to 0.94 by the increase in bin numbers. Additionally, the index value of public transport stop distance was at a relatively low value and then reached a plateau value around 0.8. In overall, the land use mix was selected for the second part of this analysis due to its highest evenness index score and stability by the increase in the number of bins.

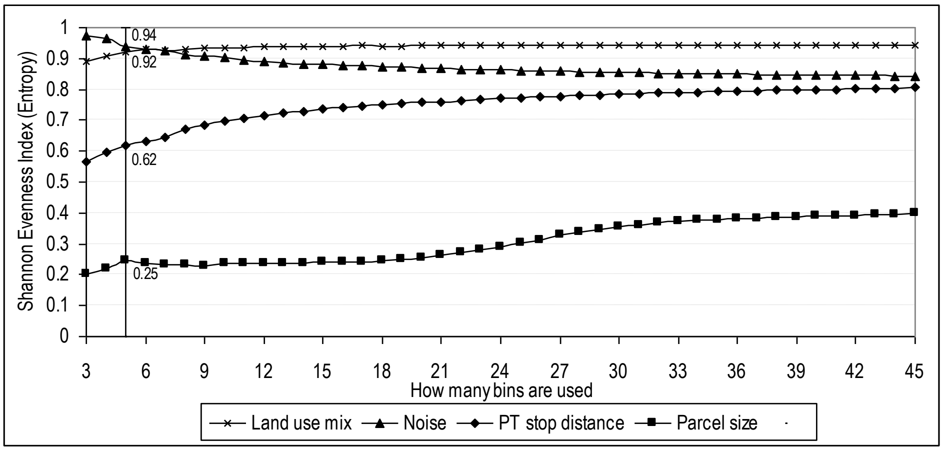


Figure 4.7 The change in evenness index scores with the number of bins used

Having decided on using land use mix data for this analysis, the second stage of the ideal grid size analysis proceeded with the conversion of land use mix information of parcels to grid cells and then comparing error values arising from each grid configuration. Figure 4.8 shows how almost one CCD can be represented by different grid sizes, and obviously, each configuration entails different resolutions for aggregation. Therefore, the aim of this stage of the analysis was to calculate two types of errors occurring from aggregation. First was the calculation of the quantity of error occurring while averaging parcel values to grids and then aggregating them to CCDs. Second was revealing the errors due to cross-boundary representation of CCDs by grid cells (as it can be seen in Figure 4.8, even though all grids shown belong to one CCD, they overlap with the neighbouring CCDs, and vice versa). For clarification, in aggregation by using averages, either from *parcels* to grid cell or from *parcels and grids* to CCDs, land use mix values were weighted according to the parcel area.

Additionally, centroids of both *parcels and grids* were intersected with the CCD layer in GIS and a CCD identifier was assigned to each entity (e.g., parcel or grid cell) according to the location of the centroid over the respective CCD.

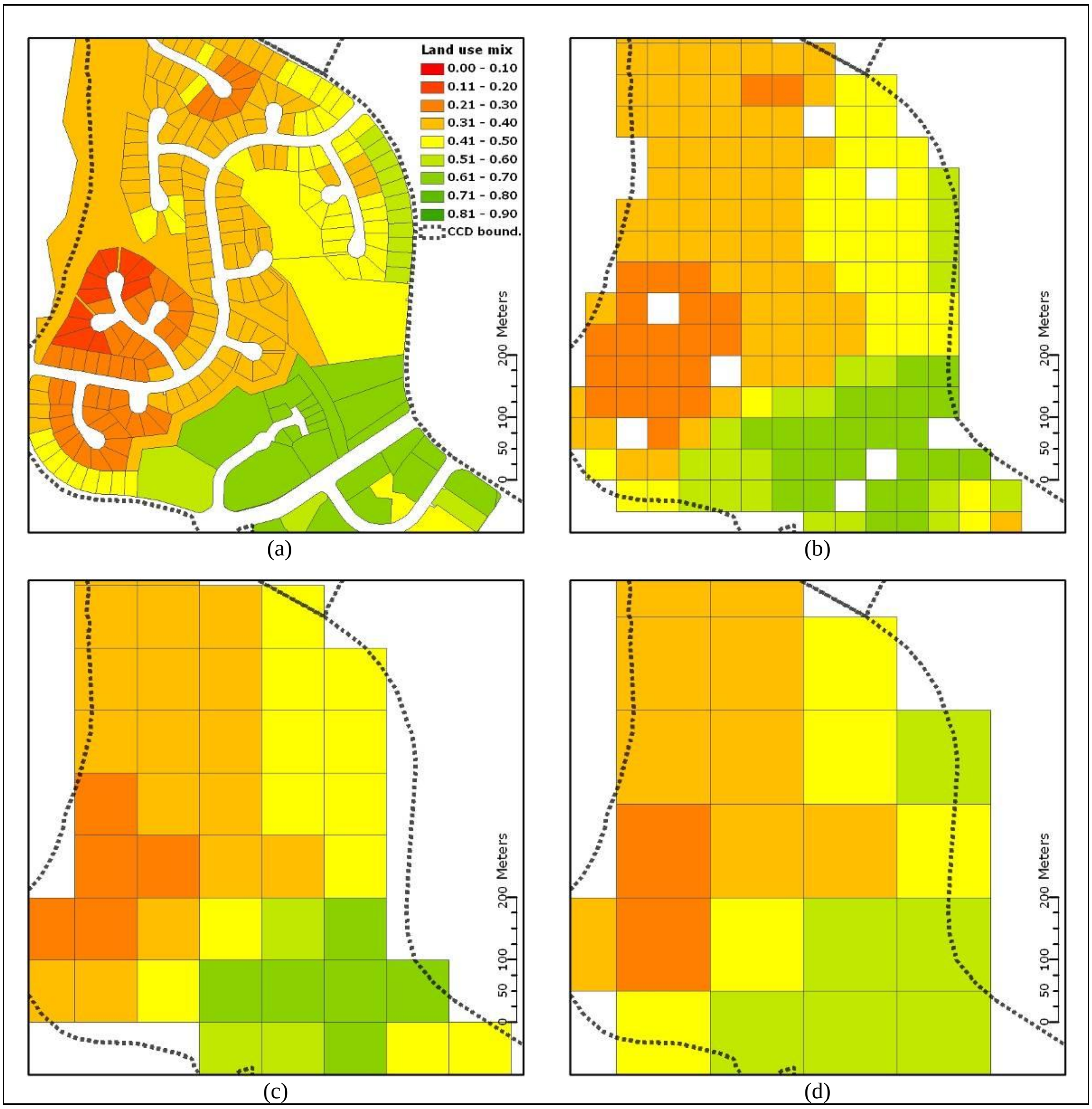


Figure 4.8 Representation of parcel information via different grid sizes

Notes. (a) Original land use mix (parcel-based measurement); (b) 50 m grid representation; (c) 100 m grid representation; (d) 150 m grid representation.

After assigning the land use mix values to parcels and averaging them to different grid settings as shown in Figure 4.8, these values were averaged one more time to 47 case CCDs. Figure 4.9 shows the frequency distribution of parcel-based averaging and errors occurring by averaging according to different grid sizes. As expected, finer grid resolution yields less error when compared to coarser ones. Three error measures are reported in the figure, sum of squared error (SSE), mean absolute error (MAE) and mean squared error (MSE). Because all information provided here belongs to the *case population (47 CCDs)*, it is not possible to give any statistical measure to disclose the best fitting grid option to real distribution, but at least it is possible to decide on how much error can be acceptable. When we look at the error figures, all of them are marginal, most probably because of the averaging procedure applied considering the size of parcels. That means, this error values are actually the result of cross boundary representation of CCDs by grid cells. So, the 50 m grid gives less error when compared to the other two options. As stated by Francis et al. (2009), every aggregation procedure produces errors and it is meaningless to ask which of the aggregation techniques is the best. The ultimate aim of these techniques is to diminish the aggregation error to zero as muc as possible.

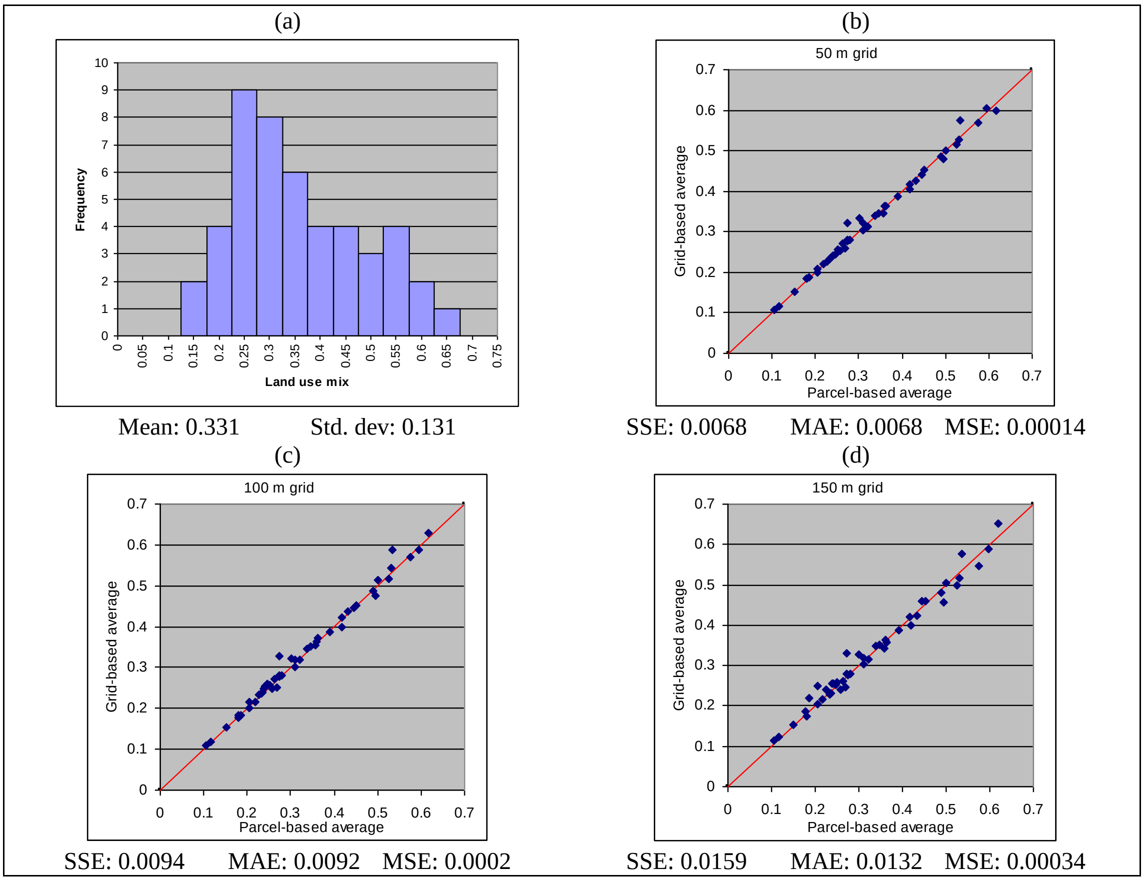


Figure 4.9 Analysis of aggregation error

Notes. (a) Frequency distribution after aggregating original parcel land use mix information to 47 CCDs; (b) 50 m grid aggregation errors; (c) 100 m grid aggregation errors; (d) 150 m grid aggregation errors.

This stage of the analysis did not give a conclusive result, but revealed that all grid configurations result in different magnitude of errors depending on the resolution. In overall, two problems stated at the beginning of this section were addressed. In summary, 50 m grid is not suitable as the UOA due to its low performance in addressing individually identifiable parcel problem. When it comes to aggregation error problem, all options could be considered as viable. All in all, 100 m grid was selected as the UOA for this study due to its acceptable performance in this analysis and the resolution which is the second best after 50 m. Spiekermann and Wegener (1999, 2003) have also utilised the same grid resolution considering the finer disaggregate representation of space to reflect on local, environmental and social impacts of policies.

4.6 SUMMARY

In this chapter, the structure, case study area and indicators of the model were explained in a connected manner. The structure of the model was the introductory issue and aimed to provide a big picture about how the model was structured and what the critical tasks and steps were in the model by referencing the composite indicator creation process and the classical research dissertation sections. The discussion on forming a reliable and valid indicator system was the main tier on which this model was built. The case study area was selected considering the urban form and transport related attributes of three newly developing suburbs of the Gold Coast, Coomera, Upper Coomera and Helensvale, and the local council's planning initiatives to diminish urban sprawl and distances travelled for daily trips in this area considering expected population growth in the next 15 years. In addition to these, achieving a content integrity with the ARC Linkage project was another reason for this selection. After highlighting the urban development process of the area from city and suburbs perspectives, planning scheme provisions and urban form characteristics were mentioned. Following this, the procedures followed in reaching the final indicator list were summarised with reference to the indicator theory concerns, which were discussed in the literature review. All indicators and measures used to quantify these indicators were given together with normalisation and weighting schemes adopted. After this, data acquisition and quality aspects were demonstrated. While the selection of indicators and accessing the data were the central topics in this study, selecting the UOA was another important consideration of the industry people from the GCCC. After agreeing upon the grid as the UOA, all the data collected from various sources was converted to a grid lattice overlaid on only urbanised areas by using GIS tools. The analysis results of each indicator are given in the next chapters according to the indicator themes defined.

Chapter 5: Analysis: Part I

The following three chapters report the theme level analyses (i.e., transport, urban form and externalities) of the indicators. This chapter aims to discuss the measures selected to quantify transport theme indicators with reference to the literature and the normalisation scheme adopted for each indicator, and to report the individual transport indicator scores for the case study suburbs. It reflects on the location specific indicator score changes, clusters and overall distribution of the scores by comparing suburbs with each other and the whole area average. It also gives an idea about category level performance (i.e., accessibility and mobility) of the area. This chapter concentrates on quantification of accessibility considering available alternative mode network (i.e., public transport, cycling and walking) and given land use destinations, and mobility by analysing automobile-dependent travel patterns and service level of public transport. These theme analyses are particularly helpful in comparing location specific accessibility advantages and the residents' tendency to choose transport modes.

Each sub-heading starts with a definition and an emphasis on the importance of the indicator and the measure used. Following this, the procedures used in generating the indicator scores are explained with reference to the data sources and calculation details. Lastly, the normalised indicator scores are discussed. It should be noted that the term 'bin' used in the explanations of frequency figures refers to the range or resolution which is used to divide frequency axis. For example, 'high performance bin' corresponds to either indicator scores ranging between 4 and 5 or the benchmark values adopted as the indication of high performance.

5.1 ACCESS TO PUBLIC TRANSPORT STOPS

The first indicator of the study is proximity to public transport stops. As a rule of thumb, the distance required to reach the closest public transport stops is the most prominent factor affecting people's attitude towards using public transport means. In the literature, 800 metres or 10 minute walking distance is considered as the benchmark value for public transport stop accessibility (Bader et al., 2010; Cervero & Kockelman, 1997; Currie, 2010; Smith & Taylor, 1994). If public transport service quality and route directness are put aside, distribution of the stops over the urban area can give useful insights about the service coverage and, indirectly though, public transport patronage.

In order to calculate public stop proximity, bus stop locations and route information were acquired from Translink in tabular format. In this table, the geographic location of the stop and servicing bus route numbers were recorded for the study area. Then, this information was transferred to GIS as a point layer. Additionally, railway stations were added to this layer. By taking each urban lot as a travel origin, the closest stop was found by using ArcGIS Network Analysis tool as an origin-destination (OD) matrix. This information was converted to a raster layer by using spatial interpolation tools to yield an area-wide coverage showing distances to the closest stop. Following this procedure, raster layer was overlaid by grid lattice layer and the average distance to the closest public transport stop was recorded for each grid cell. In the cases where there is more than one public transport stop accessible to a parcel, the closest distance was recorded for parcel as the indicator value without making any separation between public transport modes (i.e., it is not the average of distances to public transport stops).

In order to normalise access to public transport stop values, benchmark values used by Yigitcanlar et al. (2007) were adopted. In a similar accessibility indexing study (LUPTAI), they considered ranges of up to 200, 200- 400, 400-800 and 800-1,000 metres walking distance to public transport stops as benchmark values for high, medium, low and poor performance, respectively. In order to convert these benchmarks to 5-point Likert scale, an additional value, 600 metres, was considered as a medium-low value. In the figure below, normalisation thresholds are given graphically.

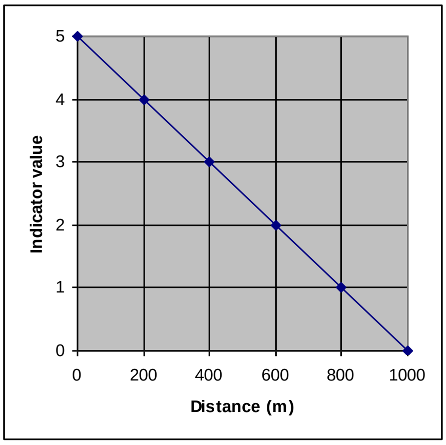


Figure 5.1 Normalisation thresholds for access to public transport stops

As seen in Figure 5.2, the close vicinities of the bus stops and railway stations yield high performance in terms of accessibility, for instance, in the middle section of Upper Coomera and central area of Helensvale. On the other hand, especially Coomera experiences a scarce provision of bus stops, which leaves residents no chance but to travel by automobile to the desired destinations. More dramatically, in the northeast corner of Coomera, some 8 km should be travelled to reach the closest bus stop. While insufficient public transport service discourages people from using public transport, from public finance point of view, it is not a cost-efficient policy to provide newly developing areas with very low densities with these services. In the future, it is expected that the south of Coomera and the northern part of Helensvale will be the areas where public transport provision would be most viable in terms of cost-efficiency because they can be easily served by the current network with expansions, and are in close vicinity to the Pacific Motorway and Pimpama-Coomera employment centre. Average distances to the closest public transport stops are 3,900, 780 and 1,190 metres for Coomera, Helensvale and Upper Coomera, respectively. The average distance for the overall area is 1,840 metres.

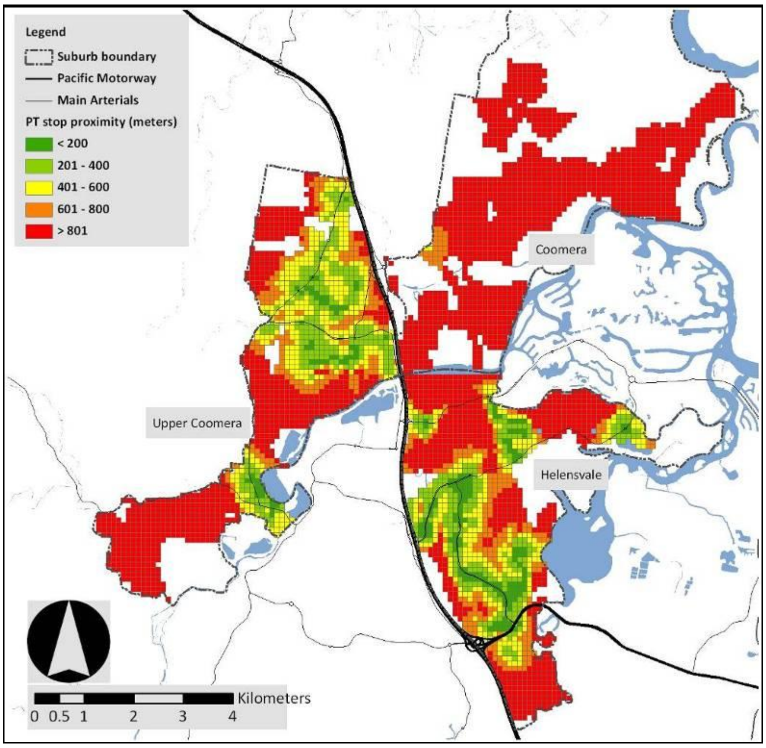


Figure 5.2 Public transport stops proximity

As we can see in Figure 5.3 , 40% of the area is served by public transport stops within less than 800 m walking distance. Again, Coomera stands out with its scarcity of the public transport services. The walking distance required to reach the closest stop or station is more than 800 m for 98% of Coomera. Only 2% of the grids are situated around the Coomera railway station. It is possible to purport that underutilisation of this station can be fixed by supplying ring services connecting residential areas of Coomera to the railway station.

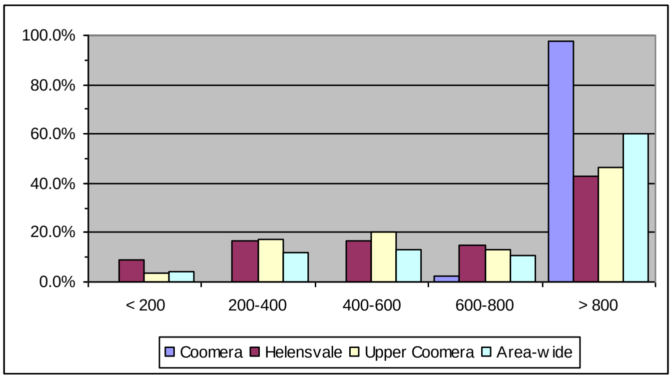


Figure 5.3 Distribution of grid cells in the study area by public transport stop proximity

5.2 ACCESS TO LAND USE DESTINATIONS BY PUBLIC TRANSPORT

By definition, accessibility refers to an individual's ability to reach the desired goods, services and activities (Litman, 2003; Yigitcanlar, et al., 2007). Accessibility to any location in a city, particularly with non-motorised or public transport means, is one of the prominent qualities of sustainable neighbourhoods. This section presents the accessibility assessment of the study area as to different modes, starting with public transport. There are only two public transport modes available for the residents of the area. All calculations were made considering these two modes only.

In the definition, places which are referred as LUDs provide goods, services and activities for residents who can reach them, and are the one end of shopping, education, recreation or personal trips. Naturally, people tend to access a very wide range of destinations to satisfy their needs. While frequency of the trips to reach these destinations and people's demand for variety and quality of the goods and services highly depend on the households' characteristics, such as income, age, household composition, personal taste, and so on, the location of the destinations determine the distance needed to be travelled to reach these destinations. Because of this, variety and proximity of the destinations within a defined boundary or time span are the most important factors affecting trip distance, frequency and transport mode. If the main goal is to diminish the number of car travels and kilometres travelled in a neighbourhood, accessibility to various LUDs can be a very useful measure to reveal the advantageous neighbourhoods.

A modified version of Neighbourhood Destination Accessibility Index (NDAI) (Witten, et al., 2011) was used to designate LUD categories and to provide a measurement for accessibility via public transport. It was modified because the original NDAI method uses only proximity as the main criterion for each category, which takes into account LUD variety in the category level, which is very broad at lot level. More specifically, it is sufficient to yield a full score for a neighbourhood from a category if only one of the LUDs in a category is accessible. For example, if there is a day care facility – a sub-domain in education category- in the defined neighbourhood, this neighbourhood yields 4 points. Here, it is not important whether any primary or secondary schools are within the neighbourhood boundary. This category-based score assignment issue is mostly related to the scope and unit of analysis of the original study, which is the mesh block consisting 114 people (as the median value). Contrary to the original methodology, in this study, the case of having a day care facility might yield a 4/3~1.33 point for a lot, and in order to yield a full score of 4 points from education category there should be at least one primary and one secondary schools within the accessible area. The other parameters of the original index, which are the number of LUD categories and their weightings, were used without modification.

In the modified-NDAI[1], a number of LUDs are defined and these are classified as follows (the maximum sub domain score attainable and weight of the category are given in parenthesis, respectively):

- Education: day-care, primary schools, secondary schools (3; 4);
- Financial: financial institutions (ATM, bank, credit union), post office (2; 3);
- Food retail: supermarket, convenience store, petrol station, fast food outlets, butchery, bakery, greengrocer (7; 5);
- Health: general practitioner, pharmacy (2; 2);
- Other retail: shopping centre, video shop, op shop (3; 4);
- Recreation: open space, gym-fitness (6; 5);
- Social: civic uses (Art gallery, museum), library, church, cinema, community services (community centre, community hall), social spaces (cafe, restaurant), alcohol outlets (bottle store, club, hotel, tavern) (7; 3), and;
- Transport: public transport stops (3; 5).

Calculation of the NDAI score is very straightforward and the equation given below is used:

$$S_i = \sum_j s_j$$

$$NDAI = \sum_i S_i w_i$$

[1] Originally, this list consists of very specific LUDs of New Zealand, such as, marae and plunket. These items are excluded from the list.

where *j* is the sub-domain in each category, *s* is the binary or tertile value[2] of the sub-domain, *i* is the LUD category (*i=1,2,…,8)*, *S* is the score of the LUD category and *w* is the weight of the LUD category given as above. For example, by using public transport means, if a household residing within 200 metres proximity to a bus stop can access to one primary school, one general practitioner, one pharmacy, one church, one cinema and two restaurants, this lot will have a total NDAI score of 32 (200 metres to the public transport stop gives a sub domain score of 3 and the weight of this category is 5, which equals to 15 points [3 x 5]. Additionally, it will yield 4 points from education category [1 x 4], 4 points from health category [2 x 2] and 9 points from social category [3 x 3]). Note that in this example, even if two restaurants are accessible via public transport in this lot, only one of them counts. According to this calculation procedure, the maximum attainable modified-NDAI score in this study is 135 while in the original method is 31, which is equal to the sum of given weights.

Modified-NDAI values varying from 0 to 135 reflect how many LUDs can be accessible via selected transport mode. In this analysis, all urban parcels were considered as trip starting locations. In order to find the geographic locations of various LUDs listed above, which were taken as destination locations, an intensive web scrapping procedure was employed. By scrapping the records given on the web pages of two prominent online local business directory databases, Yellow Pages™ and White Pages™, all destination locations were extracted via a Visual Basic for Applications (VBA) code, which was written in Microsoft Excel to list all the LUDs. In order to cover all the LUDs in the Gold Coast, QLD and Tweed Heads, NSW, all suburbs were searched from Beenleigh in the North to Murwillumbah in the South. Additionally, the results found were double checked by using another online business directory, TrueLocal.com.au™ to have a consistent and reliable list. After completing the final list, the locations of each LUD were converted to a Keyhole Markup Language (KML) file, which is native to Google Maps™ and Google Earth™, and imported to Google Maps for

[2] As for recreation and transport domains, the scale is originally defined as tertile, which means that the scores attainable due to proximity to these facilities are calculated as to the distance. For example, assume that we are considering the NDAI score for walking, and if the closest public transport stop to a lot is 200 metres (which is within the first bin defined as one third of 800 metres, which equals to 266.6 metres), then this lot will have a score of 3. If this distance was greater than 533 metres (two third of 800 metres), it would yield a score of 1. In the case of the distances greater than maximum threshold value, which is 800 metres for walking, this lot will not have any point.

geocoding purposes. By this, it was possible to check whether the geographic locations (i.e., addresses) given by online business directories were correct. The successfully geocoded KML file was exported as a text file and then this file was imported to ArcGIS as a point layer. Once the origins (lot centroids moved to the closest road segment) and destinations (facilities scrapped from the online directories) were acquired, ArcGIS™ Network Analysis tool was used to generate an OD matrix. By using this matrix, the NDAI score was calculated for each lot. In order to transfer the NDAI scores to grid cells, lot scores were averaged according to the lot area to the corresponding grid cell.

In this analysis, 30 minute public transport journey was taken as the benchmark following the classical one-hour travel time budget hypothesis (Zahavi, 1974) and a similar study conducted by the UK Department for Transport (DfT, 2010) concerning the number of people/households within a Super Output Area who can reach the destination within 30 minutes by public transport. By assumption, the time spent to reach the closest public transport stop was considered as negligible.

In their analyses, Witten et al. (2011) used different aggregation procedures for their analyses, so that it was not possible to directly adopt benchmark values defined by this study. Due to this limitation, synthetic benchmark values were assumed for this analysis. Provided that the NDAI score encompass a range from 0 to 135, midpoint (half of the attainable maximum score) of this range was taken as the upper limit for medium performance range. Following the similar approach, 75%, 25% and 10% of the maximum score were assigned to the upper limit of medium-high, medium-low and low performance ranges, respectively. The corresponding cut-off values for NDAI were determined as 135, 102, 68, 34, 14 and 0 when sorted from the highest to the lowest, which is presented in Figure 5.4.

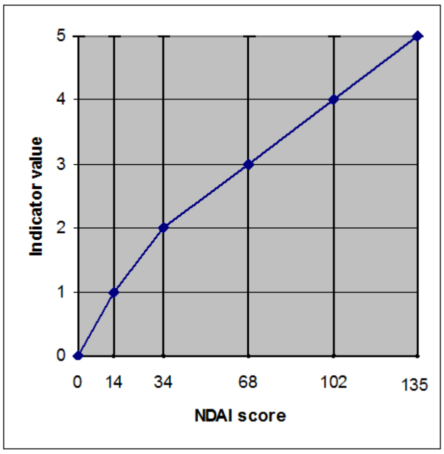


Figure 5.4 Normalisation thresholds for the NDAI score

As shown in Figure 5.5, nearly all the areas close to bus stops and railway stations have the highest scores (see also Figure 5.2 for stop locations). This means, by using public transport services, it is quite possible to reach at least one of the LUDs listed above within 30 minutes in these areas. Although the NDAI score does not provide any information about public transport service quality or frequency in a specific location, it gives a general picture about advantageous and disadvantageous locations in terms of accessible LUDs by public transport. Another important observation from the NDAI score is that the areas with low scores are newly developing regions in the study area, and are suffering from scarcity of urban services (e.g., public transport, shops, cultural and recreational facilities, and so on) and long distance travels are required to reach these services. This phenomenon can be generalised from a similar perspective for the following NDAI figures for walking and cycling. The average NDAI scores for public transport are 19.6, 87.8, 88.0 and 67.9 for Coomera, Helensvale, Upper Coomera and area-wide, respectively.

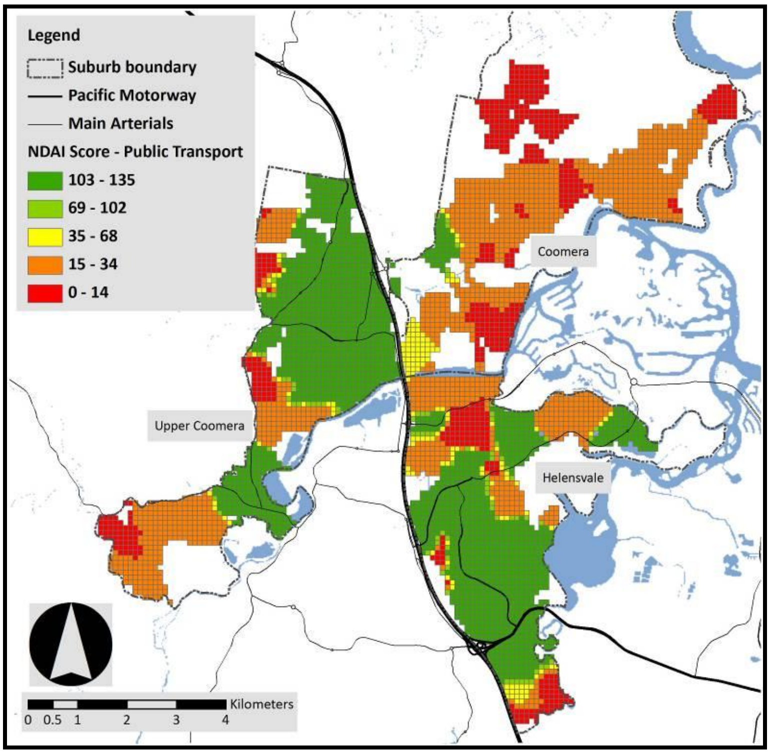


Figure 5.5 NDAI scores for public transport in urban footprint

In Figure 5.6, the first observation is that there are two peaks in the distributions of the NDAI scores. The first consists of 103-135 bin, the second one is two bins from 0 to 35. The former, in general, represents the accessibility advantage of the areas close to the public transport stops, the latter shows a very limited LUD accessibility by walking only (roughly, one third or less of the LUDs listed above can be reached by walking in these areas). Also, from economics point of view, LUDs are naturally located close to other complementary uses in an area and need a certain amount of patrons for their daily businesses. This implies that these uses demand a dense population in the area as well as an established transport infrastructure (roadways, parking areas, and also public transport stops) to attract people. Because of this, it is not surprising to see a correlation between the population density, the intensities of public transport stops and LUDs. Providing public transport stops in a residential area does not guarantee the accumulation of LUDs around the stops; however, it increases the number of LUDs accessible with a 30 minute trip.

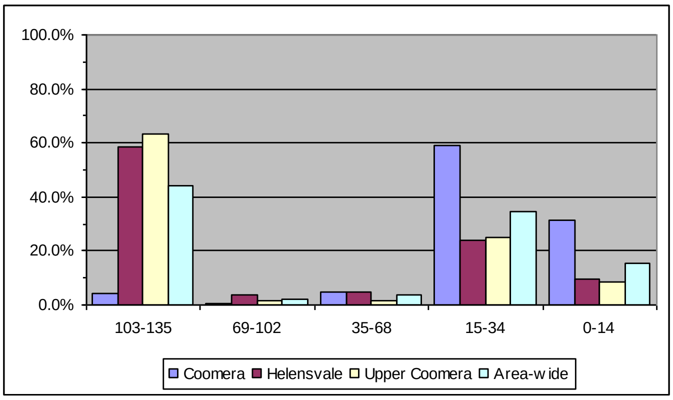


Figure 5.6 Distribution of grid cells in the study area by NDAI scores for public transport

5.3 ACCESS TO LAND USE DESTINATIONS BY WALKING

As the third accessibility indicator, this time the NDAI scores were calculated for the walking mode.

Following the aforementioned procedure, this time the NDAI scores were calculated for walking mode. 800 m walking distance was taken as benchmark value for LUD accessibility as suggested by similar studies (Algert et al., 2006; Austin et al., 2005; Witten, et al., 2011).

The same procedure explained in Section 5.2 was employed to normalise the indicator values.

In Figure 5.7, it can be clearly seen that there are three areas with above average NDAI scores, which are the surroundings of Helensvale Railway Station, Coomera City Centre and Upper Coomera State College. Particularly areas close to Helensvale centre have the highest NDAI scores in overall. While these areas are encircled by average-scored neighbourhoods, the periphery of Coomera and Upper Coomera yield NDAI scores of 35 or less. As stated before, newly developing regions of the area have the lowest NDAI scores due to the scarcity of urban services within walking distance. The average NDAI scores for walking are 15.7, 45.3 and 35.5 for Coomera, Helensvale and Upper Coomera, respectively. For all three suburbs, the average NDAI score is 33.2. Because of the variety of the LUDs and the good mix of uses around Helensvale central area, Helensvale presents a very good performance in terms of accessibility by walking.

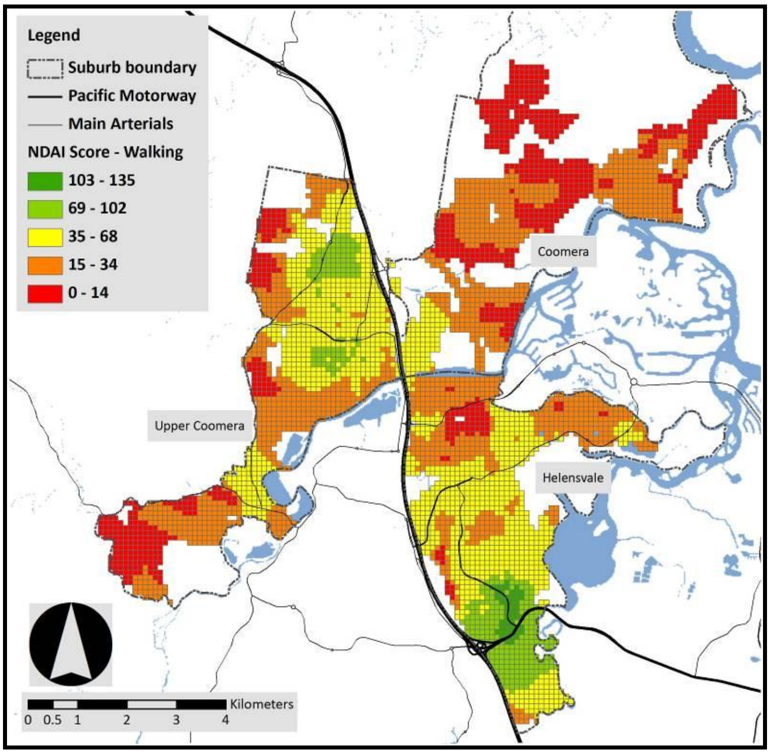


Figure 5.7 NDAI scores for walking

The distribution of the NDAI scores (Figure 5.8 below) confirms the relative superiority of Helensvale in walking accessibility. However, a large proportion of the area (93%), particularly Coomera region, yields average or below average NDAI scores, which indicates that walking might not be the most preferred mode for daily trips to reach the desired LUDs.

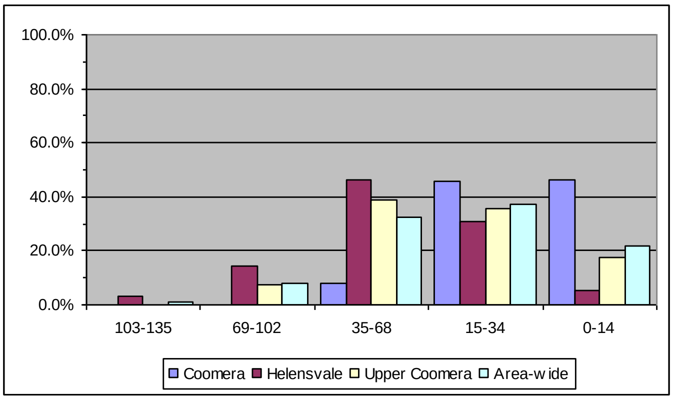


Figure 5.8 Distribution of grid cells in the study area by NDAI scores for walking

5.4 ACCESS TO LAND USE DESTINATIONS BY CYCLING

After the analysis of walking mode, as the last accessibility indicator, another non-motorised transport mode, cycling was analysed in terms of NDAI score.

In order to evaluate the NDAI scores with cycling mode, 4 km (or a 15 minute bicycle ride) was taken as the benchmark value. By using the transport network available for cyclists, the number of LUDs was calculated, which then was used to generate the NDAI score. The same procedure explained in Section 5.2 was employed to normalise the indicator values.

The most striking observation about the figure below is that nearly 50% of the residents in the study area can reach one or more LUDs listed above by cycling. More specifically, the surrounding areas of the shopping centres within cycling distance have the highest NDAI scores. Only a small section of Upper Coomera and the northeast part of Coomera have the below average score. In overall, it can be interpreted as bicycle might be the best transport means to reach the LUDs in the area. The average NDAI scores for cycling are 49.3, 110.9, 84.7 and 83.5 for Coomera, Helensvale, Upper Coomera and area-wide, respectively. Again, Helensvale comes forward with a very good accessibility score.

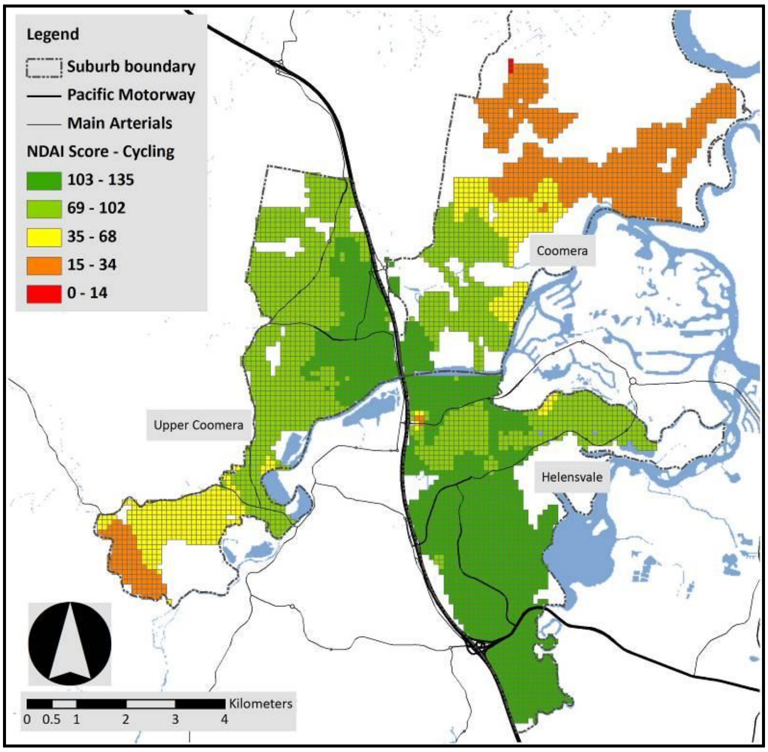


Figure 5.9 NDAI scores for cycling

The same conclusions can be acquired by scrutinising Figure 5.10. While 82% of the area has the average or more NDAI scores, half of the Coomera region falls into below average bin, which is the general case for all NDAI calculations for Coomera. Accessibility problems in Coomera could be solved in time by the increase in population density, which will lead to increase in public transport services and a variety of land uses as well.

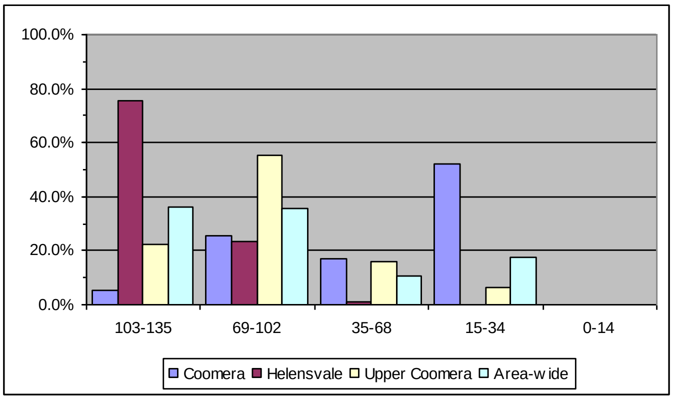


Figure 5.10 Distribution of grid cells in the study area by NDAI scores for cycling

5.5 NUMBER OF CAR TRIPS PER HOUSEHOLD

Another important subject in sustainable neighbourhood design is to decrease the number of car trips by providing urban services close to residents, non-motorised transport infrastructure and adequate public transport services. From this perspective, the average number of trips made by car per household is a good indicator to reveal the car dependency problem.

In this study, the average number of car trips per household information was estimated by the survey data acquired from QTMR HTS (QTMR, 2009), which was conducted from 2006 to 2008 in Brisbane, the Sunshine Coast and the Gold Coast. In this survey, sampled households were asked to note their daily trips belonging to the day before the survey was filled out. The households were also asked to give information about family demographics (household size, age, income, number of vehicles, education, employment status, and so on), details of their personal trips (origins, destinations, time span, mode, purpose, and so on) and some specifications of the personal vehicles used for these trips (fare paid, parking fare paid, fuel type, year made, car brand, and so on). In the survey, 5,671 households (2064 Gold Coast households as of 2008) and 46,343 trips (16,849 trips made by the Gold Coast residents as of 2008) were recorded. The total number of households with at least one motorised vehicle was 1964. Among all households surveyed in the Gold Coast, 14,940 automobile trips (88% of total trips), which were made by 1815 households (88% of total households), were recorded. In 2008, the Gold Coast residents with at least one motor vehicle made 7.61 trips/day on average. By using the survey information, the average number of car trips was estimated by using household size, number of vehicles and the number of school age children from 2006 Census. The procedure followed here was very similar to the first step of the classic four-step transport demand modelling, which is trip generation (production only). The multiple regression equation used to generate indicator values is as follows:

[Total Number of Household Car Trips] = -0.955 + 2.018 x [Household Size] + 1.270 x [Number of Vehicles] + 1.302 x [Number of School Age Children]

Note. $R^2=0.414$, $F=486.07$, which is significant at $p<0.001$, and all regression coefficients are significant at $p<0.001$.

In order to normalise the number of car trips information, percentiles from the distribution of car trips in the Gold Coast were used. There are two interrelated reasons behind this decision. Firstly, there is no literature related to the ideal number of household trips which could be considered as an indication of sustainable travel pattern. Secondly, the number of car trips can change drastically from setting to setting depending on the local supply of urban services. Considering these, the best option to classify the number of trips information could be using ‘area specific distribution’. The main advantage of using area-specific distribution is that it makes it possible to disclose the travel patterns depending on the given urban form and transport system parameters, and it provides evidence related to car dependency, which then can be compared with the local and national benchmark values.

By using HTS information, the distribution of the number of household car trips is depicted in Figure 5.11. Since the distribution is right skewed, determining benchmark ranges centring on the mean value might give misleading information on the distribution. So, the median value was selected as the centrality measure of the distribution and the multiples of 16.6% were employed as the percentile values (see vertical red lines in Figure 5.11). Accordingly, the corresponding average number of trip values were determined as 2, 4, 6, 9 and 13. The last percentile which corresponds to 13 or more car trips was considered as the worst case for this indicator. As a natural outcome of using percentiles, nearly equal number of observations fell into each range, which is 327 observations on average. More clearly, distribution specific benchmark ranges show that half of the households recorded in HTS made 6 or less trips daily and it is lower than the average figure. Also, depending on the location of urban uses and the infrastructure opportunities provided in the study area, it is evident that there are households who made 2 or less trips daily (the best case), or 4 or less trips (the second best case). Note that the spikes at even numbers in the figure are an expected outcome of round trips.

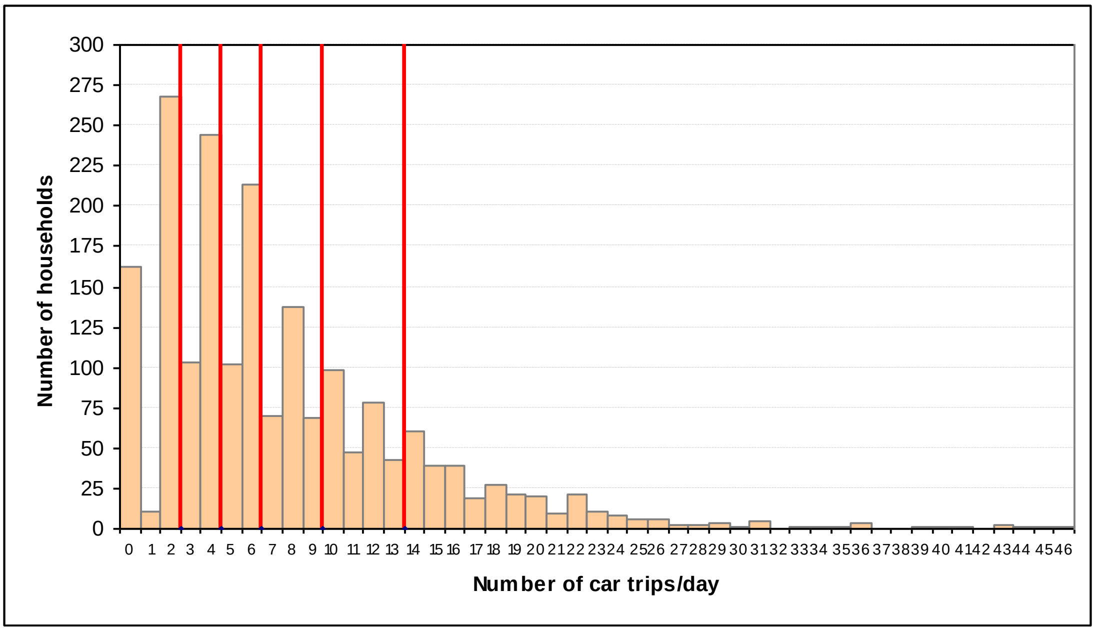


Figure 5.11 Distribution of daily household car trips

In Figure 5.12, the indicator values assigned considering the aforementioned normalisation process are given.

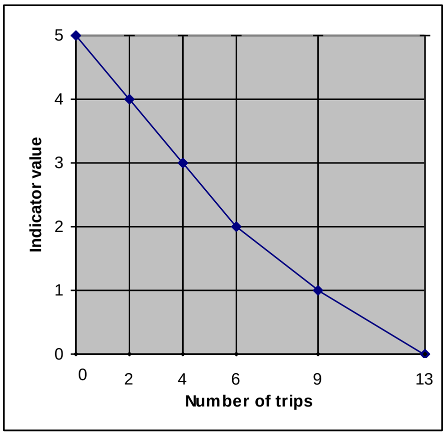


Figure 5.12 Normalisation thresholds for average number of household car trips

If it is assumed that there has not been a substantial change in the demographics of the households living in the study area since 2006 to date, it can be said that a great part of households have made six or more trips daily (Figure 5.13 and 5.14). The average of (average) number of trips per household are 7.2, 7.5, 8.1 and 7.6 for Coomera, Helensvale, Upper Coomera and the study area as a whole, respectively.

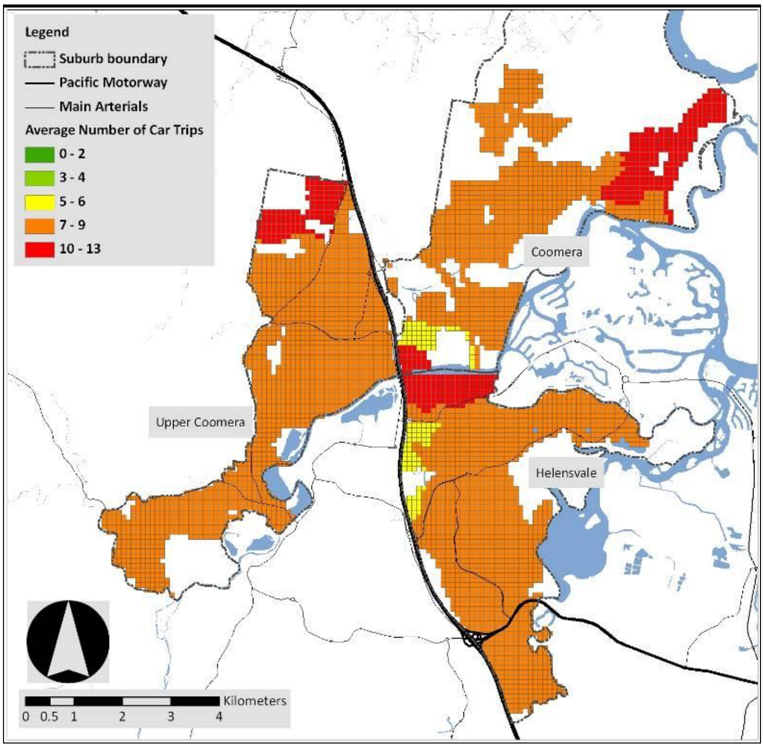


Figure 5.13 Average number of car trips per household

When the distribution of the grid cells in the area is analysed, the households in three suburbs occupy the last two bins which correspond to more than 7 or more trips daily. It could be said that, it is hardly possible to find an area with an average number of trip value less than 7. Moreover, this estimation also conforms with the average trip number of HTS results. An important note here is that when all transport means are considered, the average number of trips decreases to 6.65 (QTMR, 2009)

These figures reflect only the averages of each CCD, so it is not possible to draw inferences about households' daily trips individually; however, it conveys a basic idea about the car dependency problem in the area. In general terms, it can be said that the study suburbs are highly auto dependent, which is also confirmed by the travel to work data acquired from ABS. As for work trips, 81% of the people prefer the automobile for their work trips (ABS, 2010) and on average they travel 20 km to work (one way) (for more information see the next section). The same figures have been found for the whole Gold Coast as 93% of the people drive to work and they travel 17.9 km on average in HTS (QTMR, 2009).

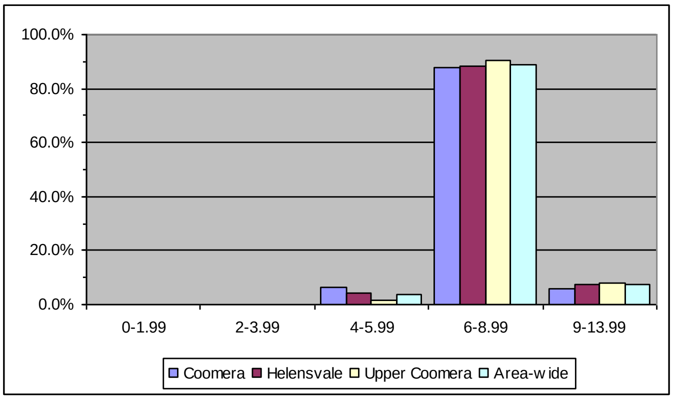


Figure 5.14 Distribution of grid cells in the study area by number of trips per household

5.6 COMMUTING DISTANCE

As urban areas grow, the distances required to reach the desired destinations become larger. Some urban services proliferate along with the development of residential areas, such as education institutions, shopping centres, recreational and social uses. However, office and industrial uses which fit in classical workplace definition are less elastic when compared to the other uses, which means they are generally situated in a fixed location in a city (CBD or industrial zone, for example), or it takes more time for urban areas with a centre-characteristic to develop. Because of this, working trips show relatively less elasticity when compared to other trip purposes, and growing urban areas inherently lead to long distances required to reach work places. Urban growth pattern (or urban macroform) is another factor affecting the work trip characteristics, and average commuting distance per employee is one of the key indicators to detect urban form change. Particularly, it helps to identify the urban sprawl problem. Also, commuting encompasses a great deal of daily trips. According to HTS, nearly 20% of daily travels are home-based work travels in the Gold Coast and 94% of the people use personal motorised vehicles (84.1% as vehicle driver, 8.8% as vehicle passenger and 0.7% as motorcycle driver) for these trips. Home-based work trips are followed by 20% home-based shopping, 16% home-based social and 15% home-based education trips, which add up to 74% home-based trips (QTMR, 2009). According to 2006 Census data (see Table 5.1), a similar distribution can be observed. In the study area, 77.2% of the people used the car or motorcycle for commuting. The difference between the census and HTS can be explained by either the local variations in the study area or the possible positive automobile usage ratios of “did not go to work”, “works outside of the area” and “two or more methods” categories which could not be captured fully in the census. The average distance and time for work travels considering all the modes are 18 km-26 mins and 20 km-16.5 mins as to HTS of the Gold Coast and ABS data of the study area, respectively.

Journey to work (JTW) data of ABS was the main data source used to generate values of this indicator. Initially, the web page of ABS was searched to find JTW information. However, the open access data provided is on SLA level and it is not possible to create a custom table with the information consisting both origins and destinations by transport mode. Because of this, a customised Census table containing JTW trips starting from the case CCDs and ending at the SLAs inside a 200 km buffer around the study area was ordered from Client and Business Services of ABS. This table consists of JTW information for 47 case study CCDs and 336 SLAs with 15 different transport modes. In the mean time, an OD matrix showing the shortest distances was constructed by taking 47 CCDs as origins and 336 SLAs as destinations by employing ArcGIS™ Network Analysis tool. It was assumed that every work travel started from the centroids of the CCDs and ended at the central locations of

SLAs[3]. By combining this matrix with JTW data, the average numbers of work trips as well as the distances travelled for these trips were calculated for each CCD.

Table 5.1 Method of travel to work by number of trips, average distance and time *

Method of travel	Number of work trips *	Ratio of mode	Average distance travelled for work (km)	Average time travelled for work (mins)**
Car, as driver	9030	70.04%	21.35	15.95
Car, as passenger	836	6.48%	17.70	13.40
Motorbike/scooter	114	0.88%	21.43	15.24
Truck	172	1.33%	24.33	25.43
Taxi	9	0.07%	25.94	20.21
Bus	73	0.57%	29.38	71.75
Train	129	1.00%	54.30	47.78
Walked only	179	1.39%	13.10	57.20
Bicycle	53	0.41%	8.36	35.13
Two or more methods	207	1.61%	40.58	N/A
Worked at home	621	4.82%	6.97	0.00
Did not go to work	1280	9.93%	16.93	N/A
Other	57	0.44%	17.74	N/A
Not stated	133	1.03%	14.74	N/A
Grand Total	12893	100.00%	20.46	16.49

Note. * These figures exclude 832 “not applicable” and 1316 “works outside of the area” trips, which represents work trips longer than 200 km or more, adding up to a total of 15041 work trips.
** Free-flow speeds were used as approximation without taking into account peak-hour congestion factor.

In this study, average commuting distance values were grouped under five bins according to the benchmark values in the literature. First bin consists of 1.6 km walking distance, which is the best case for any location, and then 10 km was adopted as the second best as advised by AHURI as ideal commuting distance for Australian cities (Dodson & Berry, 2005). This was followed by the 10-15 km bin, which more or less corresponds to half-an-hour public transport or short car journey to work, which is the indication of preference of the residents towards selecting *local* workplaces. The next bin, 15-30 km, gives clues about the emerging automobile dependent commuting patterns. The last bin corresponding to more than 30 km work trips is a clear indication of urban sprawl, and the most prominent feature of these trips is the longer time spent for transport, which is mostly made by automobile.

[3] The central locations of each SLA, where commercial and civic uses intensify, were found by visual inspection

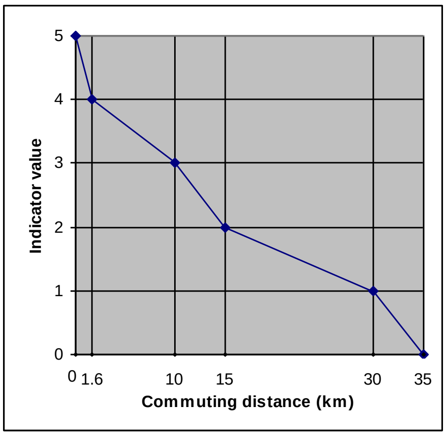


Figure 5.15 Normalisation thresholds for finding a public parking space in employment centres

The average commuting distances are shown for the study area in Figure 5.16 below. As it can clearly be seen from the figure, most of the area falls under the 15-30 km bin, which means the area is underperforming in terms of commuting distances and has started to show a sprawling urban pattern. This finding also conforms with the descriptive statistics given above. More specifically, the average distances travelled for work in the study area are 23.7, 18.3, 22.9 and 20.5 km for Coomera, Helensvale, Upper Coomera and all area, respectively.

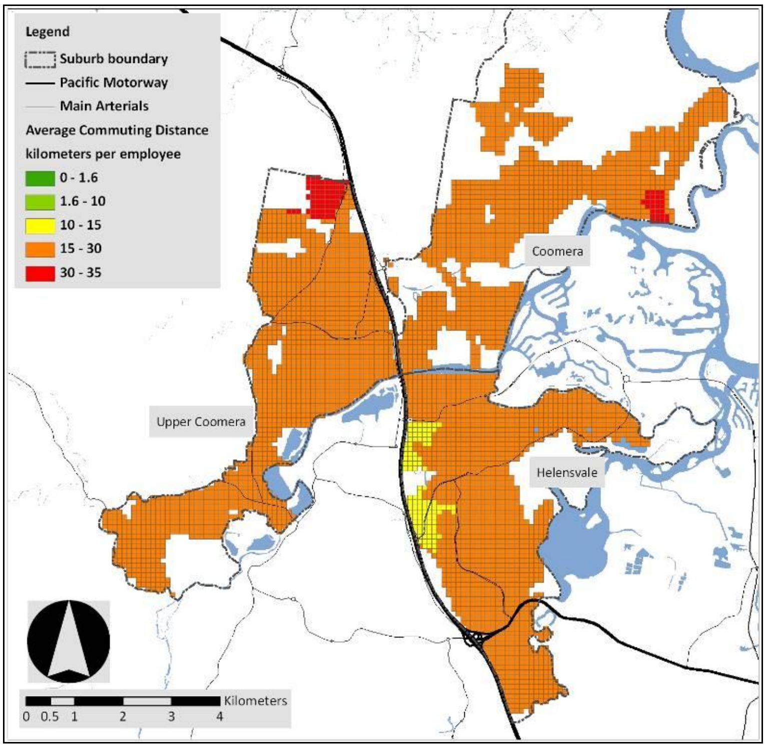


Figure 5.16 Average distance travelled for work

Figure 5.17 gives a more detailed picture of the distribution of commuting distances in the study area. While most of the area is located in medium-low range, only a small portion of Helensvale has medium performance.

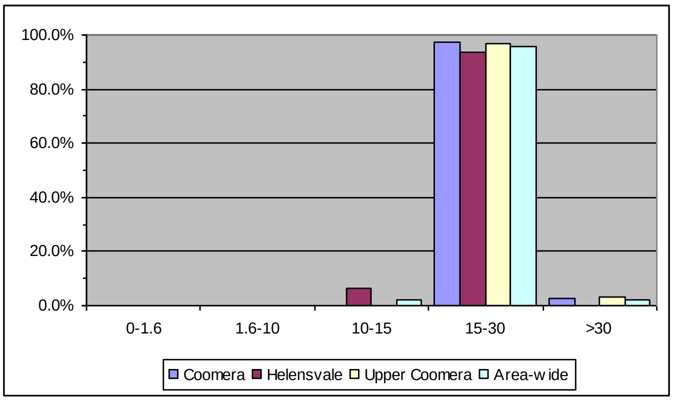


Figure 5.17 Distribution of grid cells in the study area by average distance travelled for work

5.7 PARKING SUPPLY IN EMPLOYMENT CENTRES

The provided transport infrastructure affects people's mode preferences to some extent. In terms of car travel, if we say that accessibility to the desired destination via roadways is the main motivation for driving, finding a convenient parking place complements car usage. Big cities suffering from high automobile use and inherent traffic congestion problem have started to employ TDM policies to discourage automobile usage. As an integral part of these policies and more specifically in order to solve car parking problem, they have been applying a number of disincentives, such as, limiting the number of parking places, high parking fares, time restrictions, locating parking places far from central areas, and so on. While discouraging, they have also provided alternatives to compensate mobility disutility created, such as, ride-sharing programs, park-and–ride facilities, better public transport services, and so on. Among them, an integrated approach to parking management is shown as the invaluable tool in increasing the accessibility of the urban centres (Bertolini & Le Clercq, 2003). Moreover, there is evidence showing that stricter parking restrictions can help to increase public transport use and walkability in city centres and sub-centres (Cervero & Landis, 1995). In this analysis, probability of finding a publicly provided parking space in employment centres was used as an indication of parking space supply.

In this section, the main focus is on public parking place provision in employment centres and its utilisation regarding long-term parking demand. The GCCC Parking Strategy document was used as the main data source (Eppel Olsen and Partners, 2004). The main aim of this document is to estimate the future demand for parking spaces and loading zones in the employment centres according to the expected residential and employment growth and to advise appropriate locations and parking management strategies for growing demand regarding the available parking space stock, traffic impact, misuses of parking areas and time span of parking (short- or long-term parking). Also, it provides the Gold Coast specific trends in parking demand and how this demand has been managed with publicly provided parking spaces. Considering the parking demand profile for the previous years, it is assumed that 25-30% of the employees who prefer driving to work will demand publicly provided long-term parking spaces. Moreover, two alternatives, one with no change in travel patterns (same trend in driving to work in 2006) and the other with new public transport opportunities provided according to the growing public transport usage, are compared and the *parking quantum* for each alternative is calculated. Nearly all employment centres studied show a slightly upward trajectory until 2010, then a slight downward trajectory due to the public transport investments realised.

By using the information given in this document, long-term parking places supplied by the council were extracted for each employment centre for 2006[4]. Using the similar assumptions in the document, a demand probability was calculated for each employment centre. For this, the total number of employees driving to work for each employment centre was acquired from ABS Census. Then, the total number of long-term parking places was divided to one fourth of the total employee number (25% of employees look for public parking spaces) to find the probability of finding a parking space in this employment centre. For example, 3,577 people out of 5,243 came to Beenleigh to work by driving, where there were 92 long term parking spaces. By assumption, 895 of these people looked for a parking space in Beenleigh and in this case their chance of finding a parking space was 10.3% (92 divided by 895). The same procedure gives a range of probabilities for each employment centre ranging from zero to 0.62 (i.e., 62%), for example, in Broadbeach and Coolangatta, respectively.

At the next step, for each study CCD, the number of the residents travelling to these employment centres by driving was extracted from ABS Census. By matching this information with the employment centre probabilities, the overall probability of finding a *publicly* provided parking place in the respective employment centre was calculated by weighted aggregation as to the number of employees. For clarification, assume that there are 400 employees who use their cars to go to work and live in one of the CCDs. Further assume that 200, 100 and 100 of them go to Beenleigh, Coolangatta and Broadbeach for work, respectively. As a result of this distribution, the total probability of finding a parking place in any of these employment centres is 16% ([(200 x 10.3%)+(100 x 62%)+(100 x 0%)]/400). Mathematically, this procedure can be represented as follows:

$$P[x_i] = \frac{4p_i}{L_i}$$

$$P[y_j] = \frac{\sum_i E_{ij}\, P[x_i]}{E_j}$$

where i is the employment centres, j is the study CCDs, $P[x_i]$ is the probability of finding a parking place in employment centre i, $P[y_j]$ is the weighted total probability for CCD j, p is the number of parking spaces in the respective employment centre, L is the number of employees driving to the employment centre, E is the number of employees in the CCD. It should be noted that for computational convenience, it was assumed that people who would like to use these parking spaces come and leave approximately in the same time span in the morning and the evening (i.e., time of visit is omitted), and only long-term parking was considered.

The literature encompassing parking and sustainability relationship is mostly coupled with congestion measures and involves the strategies controlling parking demand, such as pricing measures, location disincentives, limiting parking provision in the CBD region, and so

[4] These employment centres are Beenleigh, Broadbeach, Bundall, Burleigh Heads, Chevron Island, Coolangatta, Coomera, Currumbin Beach, Kirra, Main Beach, Mermaid Beach, Miami, Mudgeeraba, Nerang, Nobby Beach, Palm Beach, Paradise

on. In fact, the method embraced in this study has similarities with ‘parking adequacy analysis’, which yields a measure showing the extent the parking supply can accommodate the parking demand in an area or facility. The main difference between these two methods is that while the adequacy analysis reflects the probability of parking shortage, this method gives the relative probability of finding a parking place for a neighbourhood.

Since there are no benchmark values in the literature which could be employed to designate cut-off values, one more time the area-specific probability values were divided into 5 bins as to the minimum and maximum values. In the study area, the probability of finding a parking place ranges from 0% to 10%. This means that the suitable benchmark values are 0-2%, 2-4%, 4-6%, 6-8% and more than 8%. How these values are assigned to indicator values is given in Figure 5.18.

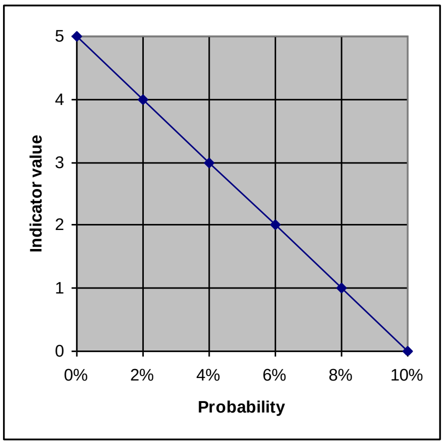


Figure 5.18 Normalisation thresholds for finding a public parking space in employment centres

As it can be seen in Figure 5.19, a great portion of Helensvale and the periphery areas of Coomera and Upper Coomera perform over average, while most of the area presents average performance. The average probabilities for each suburb are 4.4%, 4.2% and 4.9% for Coomera, Helensvale and Upper Coomera.

Point, Southport, Surfers Paradise and Tugun.

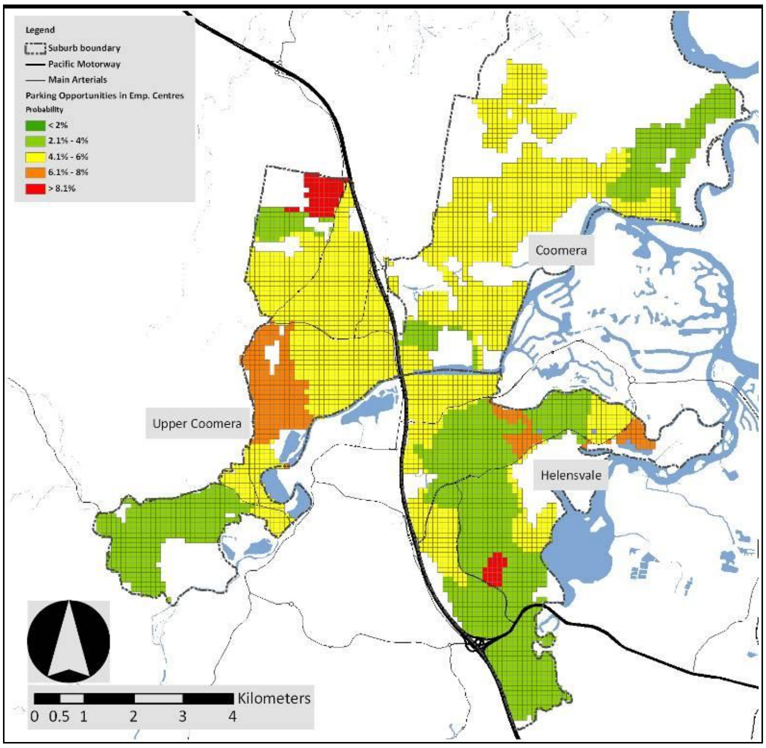


Figure 5.19 Probability to access public parking opportunities in employment centres

When the distribution of probabilities in the area is analysed, two third of Helensvale is located in 2-4% range, while nearly 80% of Coomera sits in 4-6% range. There are no best performing CCDs in the area. There are only two CCDs, one in Upper Coomera and the other in Helensvale, whose residents have a relatively good chance of finding a public parking place in these centres. It should be noted that only the Gold Coast employment centres and people travelling to these centres in the study area were considered, and other remote centres, such as, Brisbane CBD, Logan and Tweed Heads area, were excluded from the analysis due to data limitations.

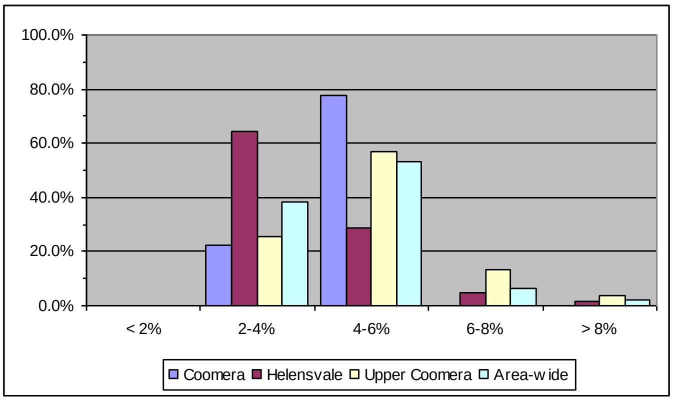


Figure 5.20 Distribution of grid cells in the study area by parking opportunities in employment centres

5.8 PUBLIC TRANSPORT SERVICE AND FREQUENCY

Previously, the analysis of mobility and accessibility issues focussing mainly on car mode in the study area was presented. As an alternative to car mobility, public transport mobility or quality of public transport services in terms of frequency and area serviced there is another dimension that should be scrutinised. The public transport service area was analysed previously with the NDAI score assessment considering the supply side of the LUDs. In this section the public transport frequency for each CCD to reveal how many services are available in a weekday were analysed. Naturally, this analysis was relevant for the areas where public transport stops were available.

The table, which consists of the bus stop and railway station locations and route information, acquired from Translink to calculate the stop proximity for the first analysis was used one more time for the calculation of this indicator. Firstly, in order to find the number of daily services for public transport, the routes servicing the area were recorded in a separate spreadsheet. By parsing daily schedule of these routes from Translink website (Translink, 2011), the average number of daily services was extracted and recorded in this spreadsheet. Following this, the data on the spreadsheet was joined to the public transport stop locations layer by GIS. The resulting joined layer gave the number of public transport services for each stop in each CCD. Then, the maximum number of services was assigned to the respective CCD by using overlay tools in GIS, which showed the number of public transport services for the CCD.

As the benchmark, the golden standard value of 60 daily services (15 hours of services with 15 minute intervals) (Booz&Company, 2008) was assumed as the desired service level and was assigned to the upper limit of medium performance. Similarly, 90 and 150 daily services were adopted as the upper limits for medium-high and high ranges. The lower end of the benchmark values was designated relative to 60 daily service standard and 20 and 40 daily services were taken as medium-low and low thresholds. In Figure 5.21, how these benchmark values were converted to indicator values is shown.

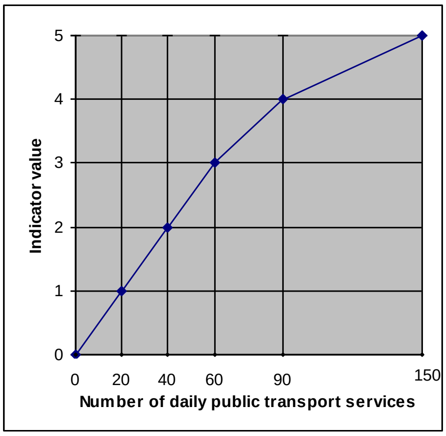


Figure 5.21 Normalisation thresholds for public transport service

As it can be seen in Figure 5.22, areas around Helensvale centre have the highest number of daily services. This is an expected outcome, because there are various bus routes connecting the surrounding residential and commercial areas to Helensvale railway station and all of these routes elevate the number of daily services. At the same time, the northern part of Helensvale centre and the close vicinity of Coomera railway station yield an average performance. The rest of the area including the central part of Upper Coomera, where public transport services are available, is evaluated as below average. The areas where there are no public transport services have a zero score as expected. The average public transport service figures are 10, 56, 17 and 29 for Coomera, Helensvale, Upper Coomera and the whole study area, respectively.

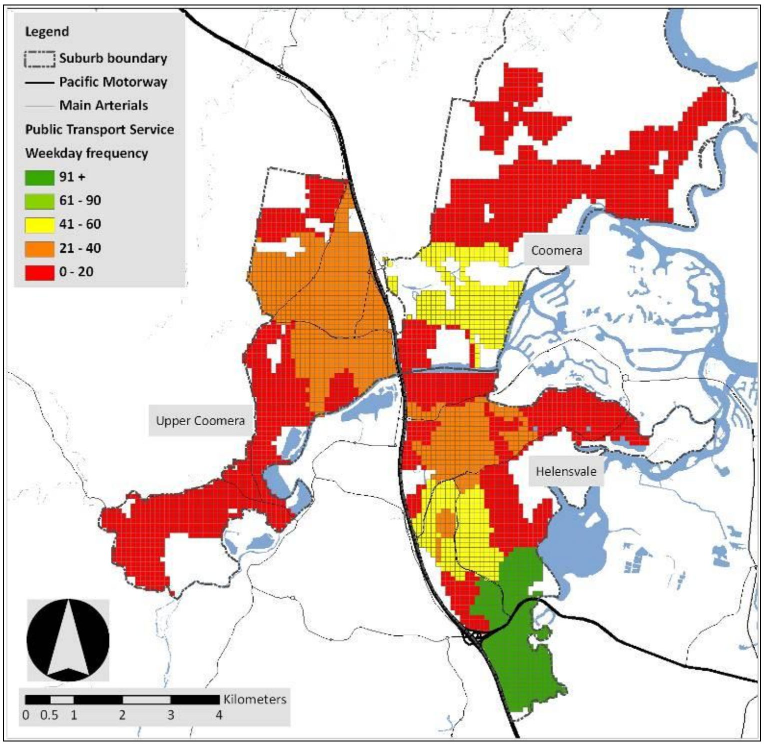


Figure 5.22 Public transport service based on stops

The distribution figure below clearly shows the scarcity of the public transport services for the great part of Coomera. In addition, when the whole area is considered, there is an accumulation in the last two bins that correspond to values of less than 40 daily services. As commented on the public transport service supply in this section, it should be stated that this supply is also the natural consequence of public transport patronage (in some sense the demand side of public transport), which is also correlated with car usage. While the existence of the railway station and the bus service interchange in Helensvale promote the number of daily services, it does not provide any insight about public transport patronage. Nonetheless, only supply information can help to detect the areas where incentive programs for public transport use might be viable.

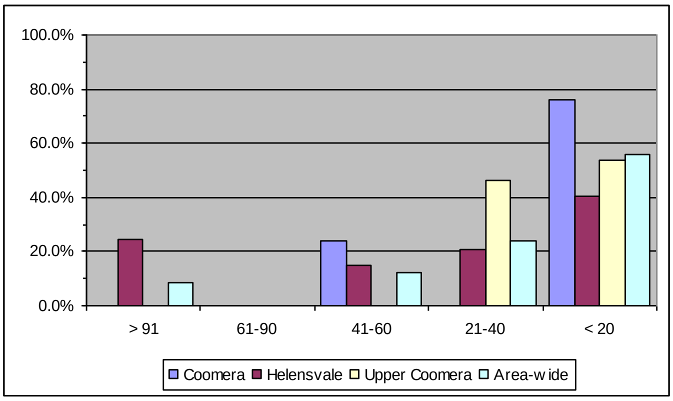


Figure 5.23 Distribution of grid cells in the study area by public transport service based on stops

5.9 SUMMARY

The transport theme indicator results were presented in this chapter. At first, the accessibility category performance was analysed with regard to four indicators. Access to the public transport stops results showed that only 40% of the area had a public transport stop within 800 m walking distance. Among all suburbs in case study area, Helensvale was the most advantageous in terms of public transport stop accessibility, whereas Coomera was the most disadvantageous. There were three main results related to accessibility to LUDs with different transport modes. First, people who had access to public transport service could virtually access to every LUDs considered. Second, the people living in and around the suburb centres benefit from variety of LUDs and could access them by walking very easily. The opposite was the case for the periphery areas of the suburbs, and Coomera was particularly problematic in terms of pedestrian accessibility. Last, cycling appeared to be the prominent candidate for accessibility enhancement. According to the given distribution of LUDs in the area, 82% of the area has an acceptable level of accessibility by cycling.

Following the accessibility category, mobility category indicators were examined. The analysis results clearly showed that people living in the study area prefer automobile as the main transport mode and made more than 6 trips/day on average. Moreover, they travelled approximately 40 km/day on average for commuting. When we looked at the JTW data in detail, the Pacific Motorway was the main transport link connecting both ends of work trips. Parking space provision in the employment centres by the GCCC analysis showed that according to the given CCD and employment pairs, people driving to work have a relatively low probability of finding a parking space. Lastly, public transport service and frequency was examined to portray whether public transport was a good alternative to automobile in terms of service availability and coverage. Primarily, this analysis revealed the advantageous and disadvantageous locations in the study area. According to this, Helensvale centre showed a far better performance than other areas due to the availability of public transport services accumulated around the railway station and bus interchange. The rest of the study area where public transport service was provided performed medium-low or mostly low. This analysis shed light onto public transport provision from supply side; however, it did not provide any information related to the public transport patronage level, which can well be the main reason for limited public transport service provision.

In summary, a clear separation was evident in terms of accessibility advantages between suburban centres and peripheries. Moreover, accessibility to LUDs was limited to the suburb centres and areas, where public transport service was provided, by walking and public transport, respectively, but bicycle came forward as the most advantageous transport mode in terms of accessibility. It can be said that the study area had the well-known characteristics of the auto-dependent travel patterns, and public transport was not a serious alternative to automobile, yet. When taken into account together with these findings, urban form qualities of the study area can provide more insights about accessibility problems and mobility patterns, and these are discussed in the next chapter.

Chapter 6: Analysis: Part II

In this chapter the analyses results of urban form theme are presented, which encompass two categories and eight indicators. The main aim of this chapter is to discover urban form characteristics coupled with the auto-dependent travel patterns and pedestrian friendliness of a neighbourhood by investigating availability and quality of pedestrian network. While parcel size and density are the classical metrics used to measure compactness of a settlement and urban sprawl, land use mix and housing-job ratio are used to demonstrate diversity of land uses and self-containment according to a proximity definition. The latter measures are employed together with accessibility indicators to better understand the effects of land use diversity and self-containment on travel patterns. The design category indicators focus more on street level design features from walkability and connectedness of the network perspective. In overall, these are well-known measures for elaborating 3Ds (i.e., density, diversity and design) of urban form and the linkage between transport and urban form (Cervero & Kockelman, 1997; Jenks et al., 1996; Krizek, 2003a; C. Lee & Moudon, 2006; Song & Knaap, 2004).

Each section starts with an elaboration of the importance and definition of the measure used, followed by normalisation procedures embraced. The last part of each section is devoted to analysis results, which present area specific overview of the indicator, cluster formations and a comparison of distribution of indicator scores for three suburbs and overall area.

6.1 AVERAGE PARCEL SIZE

One of the prominent characteristics of urban sprawl is low density residential units with large parcels. Initially, large parcel size elongates the distances to reach urban services and increase the amount of impervious road surfaces (Condon, 2010). Considering this, imposing restrictions for the parcel sizes has been one of the prominent strategies for densification and compact development due to direct linkage between population density and parcel size. However, there are counter arguments against planning for small parcels; more specifically, Alberti and Marzluff (2004) put forward that large parcels have important sustainability benefits in terms of self-sufficiency, reduced recreational trips and less impervious surfaces. They also added when designed according to the native vegetation, they can help ecological resilience. On the other hand, Hall (2003) stated that small parcels produce a more public and lively city environment. Moreover, degradation of natural vegetation and fragmentation of ecosystems are the other undesired effects of devotion of low population densities occurring with large-one-family parcels (Alberti & Marzluff, 2004). Because of the unique qualities of the Gold Coast in terms of climate and environmental assets, the aforementioned considerations demand a great attention when selecting locations for urban development. In order to protect the natural environment and to match people's housing demands at the same time, the GCCC has advised a special domain for residential use, which is park living, in the planning scheme. According to this, people are allowed to convert a very limited portion of the very large properties for residential area while protecting natural vegetation and landscape (GCCC, 2003). Park-living style residential pattern promises a desired attitude for SUD, but it also embarks a risk of conversion to large residential parcels by the urban growth due to the population growth pressure in the area. This has started to be experienced in some parts of the study area. So a special attention should be given to preserving park-living pattern for a long time and initiating densification or infill development strategies to match the housing demand of the growing population.

Average parcel size is the first indicator analysed in urban form domain. Average parcel sizes in the study area were calculated basing on 100 x 100 metre grid cells, which correspond to one hectare. Firstly, the DCDB layer from the DERM was acquired and topological mistakes were corrected. After that, the area of each parcel was calculated. In order to find the proportion of each parcel falling inside the overlaying grid cell, overlay analysis tools of GIS were used. By using these proportions as weight for each parcel, a weighted average was calculated to find the average parcel size for each grid cell. Note that areas devoted to roads were excluded from this analysis to avoid calculation bias. Mathematically, the average parcel size for each grid cell was calculated according to the equation as follows:

$$\overline{P} = \frac{\sum p_i A_i}{\sum p_i}$$

where $\overline{P}$ is average parcel size for a grid cell, p_i is the proportion of parcel *i* coinciding with the grid cell, A_i is the original area of parcel *i*.

While defining benchmark values for this indicator, 400 m² was considered as the lower limit of the best case reflecting classical Queenslander style parcel design, which allows a balanced living area and garden ratio, when the predominance of one family dwelling taken into account. Also, 400 m² parcels are encouraged in planning scheme to allow high density residential areas and advised as a strategy to consolidate urban form (GCCC, 2006b, p.8.14). As for upper limit for the best case, the constraints applied to each precinct in local area plans (in the Planning scheme) were taken as standard. According to this, central locations of the study suburbs are designated as RD-3, which is a variation in 'residential choice and tourism-residential' domain, and it corresponds to the average parcel size of 250 m² (GCCC, 2003). By using the new residential development constraints in the planning scheme, the average parcel size for the second cluster in 'detached dwelling' typology, which is 800 m², was assumed not the best but above average pattern for the average parcel size regarding multifamily dwellings. Following the same constraints, 1200 m² was regarded as the limit for the average parcel size in terms of the expected parcel characteristics in the area. Next, 1,200-2,400 m² range was considered as below average and as low performing if it was greater than 4,000 m², which was a clear indication of ineffective exploitation of land for residential uses in terms of neighbourhood sustainability. The distribution of the benchmark values as to the corresponding indicator values can be seen in Figure 6.1 more clearly.

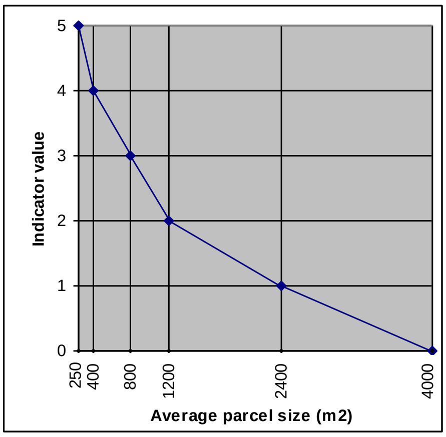


Figure 6.1 Normalisation thresholds for average parcel size

Analysis shows that the relatively older parts of the study area represent above average performance whereas newly developing areas and suburb peripheries yield below average performance. The average parcel sizes for Coomera, Helensvale and Upper Coomera are 45,904, 67,792 and 25,454 square metres, respectively. These figures are extremely high due to very large parcel sizes in the periphery areas, which are zoned as rural residential in the planning scheme. Because of this, the overall average parcel sizes for suburbs above actually do not give useful information to help draw a meaningful comparison, but the differences in average parcel sizes can be easily observed in Figure 6.2. While the areas close to the suburb centres consist of smaller parcels, surroundings of these centres are encircled with very large residential parcels. For referencing purposes and in order to have a clearer understanding about the parcel sizes, median values for each suburb are extracted. The median parcel sizes for Coomera, Helensvale, Upper Coomera and all three suburbs are 28,373, 3,446, 7,944 and 5,749 m^2, respectively. These figures support the first observation about the older parts of the study area and are given here for referencing purposes. Furthermore, it might give some clues about the conversion process of larger parcels to smaller ones by time. While smaller parcels are regarded as more sustainable in this analysis, from another perspective, the provision of the large parcels by the planning scheme (e.g., rural living and urban village domains) to conserve natural assets of the area might be considered as a good approach. However, in order to meet the residential development demand of the growing population, these large parcels might be altered to smaller but still large residential parcels, and this may lead to the degradation of the environmental amenities of the area in the long run.

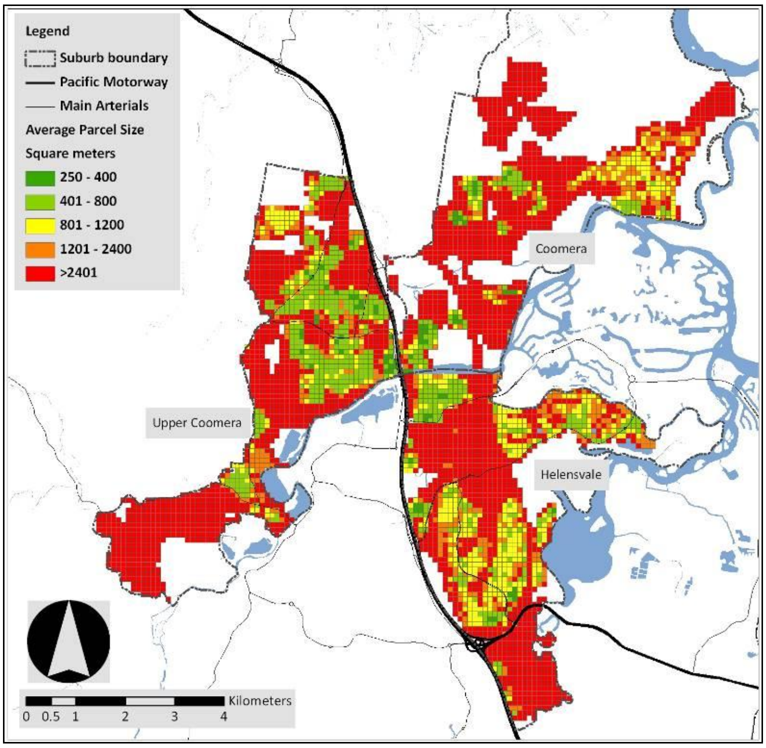


Figure 6.2 Average parcel size

In Figure 6.3, Helensvale shows a balanced distribution of parcel sizes when compared to other suburbs. Similar to other analyses, a great deal of Coomera (72%) yields a very low performance. While more than half of Upper Coomera is placed in the last bin (the worst case), it outperforms others in the 400-800 m² bin (nearly 20% of the grid cells are in this range) where there is an accumulation representing relatively small parcels in the central locations of three suburbs.

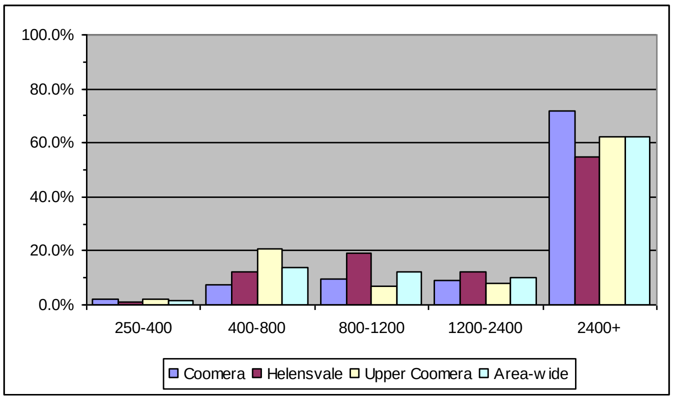


Figure 6.3 Distribution of grid cells in the study area by average parcel size

6.2 POPULATION DENSITY

Parallel to the previous average parcel size discussion, population density together with the average parcel size information can provide practical hints about urban pattern, environmental degradation and per capita land consumption.

Population densities were calculated for each CCD according to 2006 Census data and land use map of the GCCC. In order to accurately calculate the urban population density, the total area of irrelevant land uses other than urban residential and rural residential areas adjacent to urban residential uses was subtracted from the overall CCD area. Then, the population of each CCD was divided to the total area of the residential uses in the respective CCD.

For this analysis, the population density classification made by Litman and Steele (2011) regarding effective use of land resource in terms of urban sustainability was used. By using the advised benchmark values, indicator values were divided to 5 bins ranging from 0.5 to 100 people per hectare. Here, it was assumed that the family and dwelling characteristics (average family size, dwelling type and parcel size) of the study area had not changed substantially from 2006 to 2011. Figure 6.4 shows how these benchmark values were converted to indicator scores, graphically.

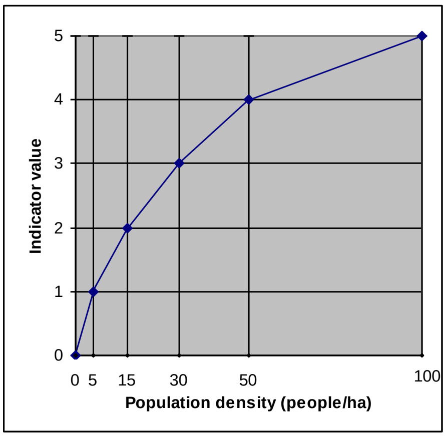


Figure 6.4 Normalisation thresholds for population density

As it is shown in Figure 6.5, a similar pattern to parcel size distribution has emerged. The central locations of the suburbs perform average or marginally above average density figures, while the suburb peripheries show below average or low performance. The average population densities as to the suburbs are 3, 11, 8 and 8 for Coomera, Helensvale, Upper Coomera and the whole area, respectively.

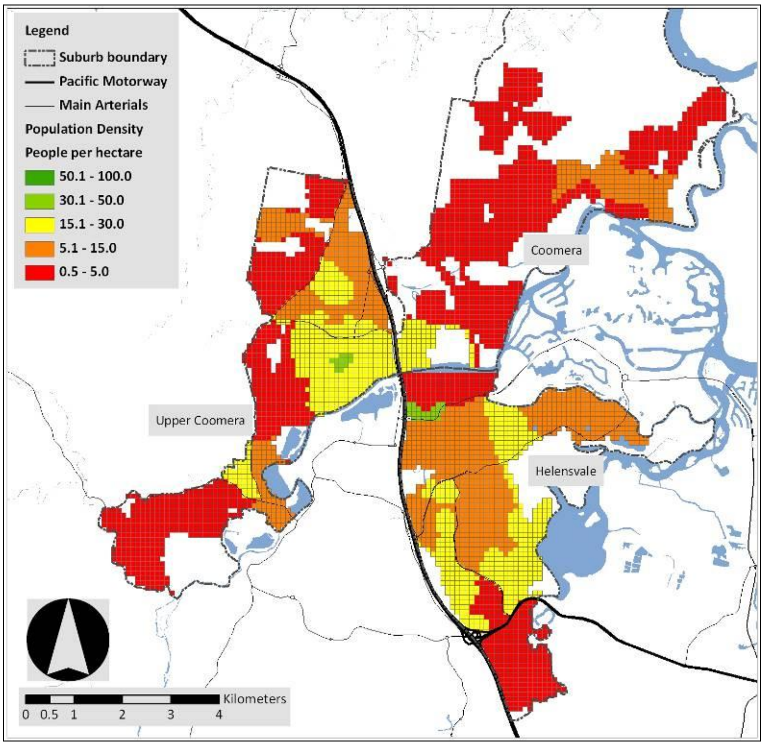


Figure 6.5 Population density

According to Figure 6.6, only 20% of the area can be considered as with medium density. Upper Coomera region has varying population densities from medium to very low, while most of Coomera region takes place in very low density range (82%). As considered together with parcel size information, low densities in Coomera region are not so surprising due to the large parcel sizes. The variety in parcel sizes in Helensvale and Upper Coomera inherently leads to diversity in population densities. Another important observation about the area is that half of the area has a density of less than 5 people per hectare, which is an indication of urban sprawl problem.

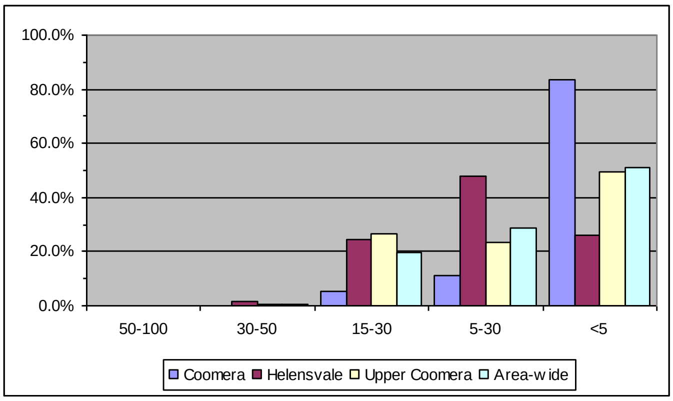


Figure 6.6 Distribution of grid cells in the study area by population density

6.3 LAND USE MIX RATIO

After the embracement of urban sustainability as a policy direction, most of the planning endeavours have started to come up with various strategies. Among them, provision of a mixed land use may be the most popular strategy option, which can be found in a number of urban development related policy documents. The most important function of mixed land use is that it helps to reduce car travels by providing diversity in locally accessible urban uses which simultaneously enhances local economy and community sense. Instead of applying zoning regulations which strictly separate each urban use by a boundary, local governments have directed new developments towards a mixed fashion where different complementary urban uses take place in the same region with the same proportions. Nowadays, it is very common to see new urban development projects containing residents, retail and social activities and office uses together.

In land use mix ratio analysis, four different land uses to calculate the land use mix ratio were considered. These were residential, retail and office, industrial, and open space uses. In crude terms, land use mix ratio is a reflection of areal distribution of different uses within a defined boundary. On the one hand, if the areas devoted to each land use type are equal, then land use mix ratio yields a score of 1, which is the best case for this indicator. On the other, if the defined area has only one land use type, it is not possible to talk about a land use mix, so the ratio equals to zero for this area.

Instead of using classical calculation practices (i.e., dividing the area into grid cells and calculating each grid cell's value by averaging surrounding eight neighbouring cells), 800 m walking distance was taken as the benchmark value considering the similar studies (Algert, et al., 2006; Austin, et al., 2005; Bader, et al., 2010; Cervero & Kockelman, 1997; Wong et al., 2011) and the ratio of four land uses by using the road network was analysed. The main advantage of this approach was that the effect of the road network on accessibility to uses was taken into account; otherwise the whole area was assumed to be homogenous. Inherently, it increased the complexity and time of calculation process.

Firstly, the land use plan of the GCCC was converted to a point layer, and these points were shifted to the closest road network element. By using the pedestrian network layer, an OD matrix was constructed by setting 800 m as the cut-off value. In this matrix, every point representing lots with aforementioned four land uses was processed as both origin and destination. Then, for each point the land use mix ratio was calculated by using the formula (Frank et al., 2004) given below:

$$Land\,use\,mix = -\frac{\sum_{i}^{n} P_i \ln P_i}{\ln n}$$

where n is the number of different land use types used for the analysis, P_i is the proportion of the land use in the defined area (in this case, lots within 800 m walking distance relative to the selected lot). It should be noted that this formula is the same as Shannon-Evenness Index formula, which was employed previously in finding the most varying indicator data for the ideal grid cell size analysis. For clarification, if all the lots within 800 m walking distance have the same land use, the nominator of the aforementioned formula equals to zero (i.e., 100% being equal to 1 and *ln* (1) = 0), which results in a zero land use mix value. If the total area of the lots within 800 m is 10,000 m² and the distribution of this area to predefined four land-use types is 40% (4,000 m²), 10% (1,000 m²), 30% (3,000 m²) and 20% (2,000 m²), then nominator of the land use mix formula is -[(0.4 * *ln*(0.4))+ (0.1 * *ln*(0.1))+ (0.3 * *ln*(0.3))+ (0.2 * *ln*(0.2))] and the denominator is *ln*(4), which gives 0.92 (a nearly perfect land use mix ratio).

There is no clear indication for benchmark values for ideal or sustainable land use mix in the literature. Furthermore, the ideal land use mix generally depends on the zoning structure of planning scheme and location. Because of these, and for the sake of simplicity, possible minimum and maximum land use mix values were divided in five equal ranges, namely by taking into account the cut-off values of 0, 0.2, 0.4, 0.6, 0.8 and 1. Figure 6.7 below shows the indicator values with respect to these cut-off values.

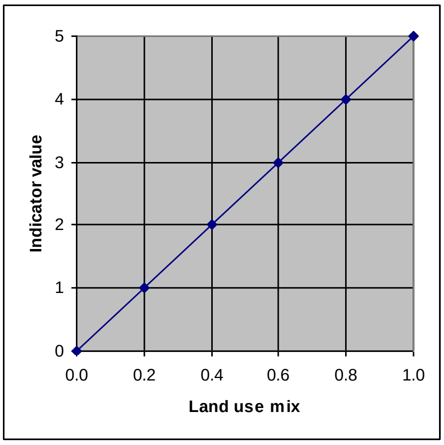


Figure 6.7 Normalisation thresholds for land use mix

As it can be seen in Figure 6.8, areas with a commercial character and in close vicinity of the Pacific Motorway, where the industrial uses exist, have a good land use mix ratio, whereas areas with mostly residential character have the lowest ratios. The northern part of Helensvale, the northeast of Coomera and the southwest of Upper Coomera have below average or low land use mix due to their mostly residential characteristics. Additionally, a relatively high land use mix is evident in areas encircling the arterial roads depending on the locations of commercial uses. The average land use mix ratio shows no difference throughout the area (around 0.31 for all suburbs).

When Figure 6.8 is compared with the NDAI scores for walking (Figure 5.7), a close resemblance between the distributions of NDAI score and use mix ratio can be easily detected. The main reason behind this is that the four different land uses used to calculate use mix ratio also correspond to the LUDs used to calculate the NDAI scores particularly for retail and recreational uses. This comparison also provides some interesting insights about the sources of differences in some areas. For example, there are two regions in Coomera, the areas around Beattie Road and Tooraneedin Road, with good use mix ratio, which had average or less NDAI scores for walking in the previous analysis. It means that these areas could be considered as good candidates to become pedestrian friendly with local government's intervention, such as walking and public transport infrastructure enhancements. The same proposition could be put forward for the areas around Siganto Drive starting from the corner of Helensvale Road and Siganto Drive.

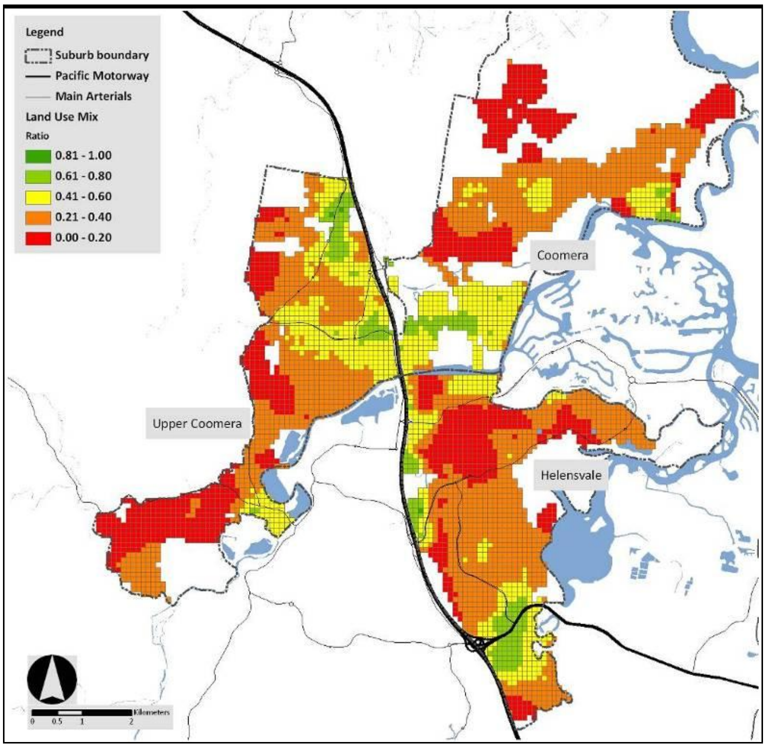


Figure 6.8 Land use mix ratio

The distribution of land use mix ratios highlights the similar distribution of three suburbs. The average land use mix ratio figures of three suburbs are almost the same as the area-wide averages. As expected, they accumulate around the overall mean value of 0.31 in the fourth bin. Moreover, only 25% of the area yield average or above average land use mix ratio.

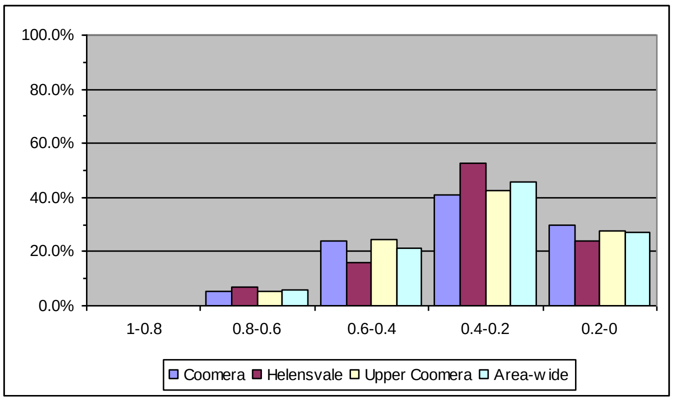


Figure 6.9 Distribution of grid cells in the study area by land use mix

6.4 HOUSING AND JOBS PROXIMITY

Job to housing ratio is generally used to quantify local working opportunities for the residents in an area. It helps to reveal how easy it is to access a job without sparing too much time for travel and people's awareness of local working opportunities. While the former is about job supply, the latter is more or less related to people's perception towards travel time and distance for work trips, or people's demand for job opportunities as to their proximity. In this analysis, an approach similar to the former one was adopted and job to employee ratio as an approximation of job to housing ratio was embraced. In fact, they are very similar but the latter includes the dependency ratio. One of the main disadvantages of job to housing ratio is that it does not take into account the employment patterns in the settlements. As a result of this, the inclusion of dependency ratio in the analysis can provide further insights about the match between employment and job opportunities.

By using ABS 2006 census data, the total number of working people in each CCD (employment data) and the total number of employees working (place of work data) in each of the three SLA, Pimpama-Coomera, Helensvale and Kingsholme-Upper Coomera were extracted. Then, the total number of people coming to work by using average floor areas per employee for commercial, industrial and education uses was calculated. This average floor area was calculated by dividing the total land area devoted to these three land uses for each SLA to the number of employees in each employment subclass. Finally, a job to employee ratio was generated by dividing the total number of job opportunities to the total number of employees for each CCD.

Cervero (1996) argued that communities with an effective job-housing balance (0.75-1.50 jobs per household) are more self contained and as a result of this, have shorter and fewer work trips by automobile. When the number of families by the average dependency ratio for each CCD was multiplied, a ratio changing between 1 and 1.5 was found. Accordingly, it was assumed that a job to employee ratio of 1-1.5 is the best case in this study. In the meantime, zero or values greater than 2.5 were assumed as the worst cases. Apart from the normalisation process embraced for the other indicators, job to employee ratio has two tails representing job opportunity rich and employee rich ends of the distribution (see Figure 6.10). For example, the ratios on the left hand side of the figure are mostly the case for residential areas where there are less number of jobs when compared to the number of employees. The opposite is the case for the right hand side. Due to the nature of this distribution, both tails are divided into five equal ranges as it can be seen in Figure 6.10.

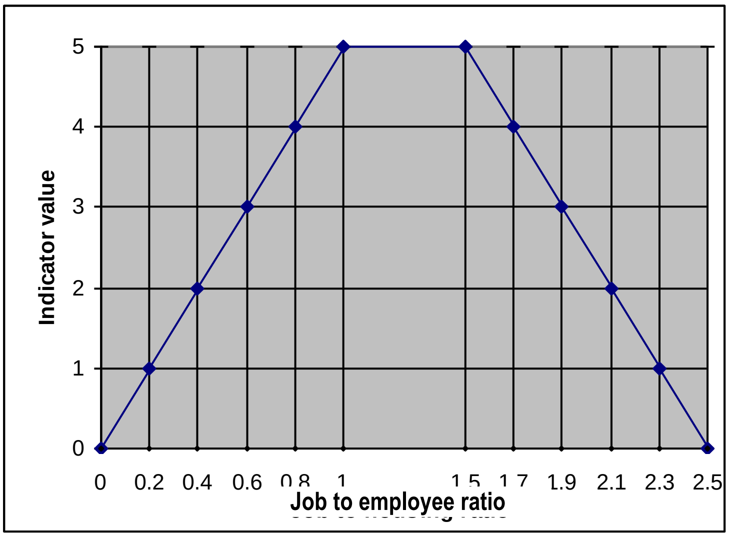


Figure 6.10 Normalisation thresholds for job to employee ratio

In Figure 6.11, job to employee ratio is shown as to the study area CCDs. While the central locations of Upper Coomera and Helensvale present a very good employee-job balance, it is interesting to see that Coomera employment centre performs a very low ratio. It means either the number of job opportunities is greater than local employment, or the residents of central Coomera do not prefer working in this centre. Moreover, areas typically having residential or commercial characteristics have below average ratios due to the lack or abundance of job opportunities provided.

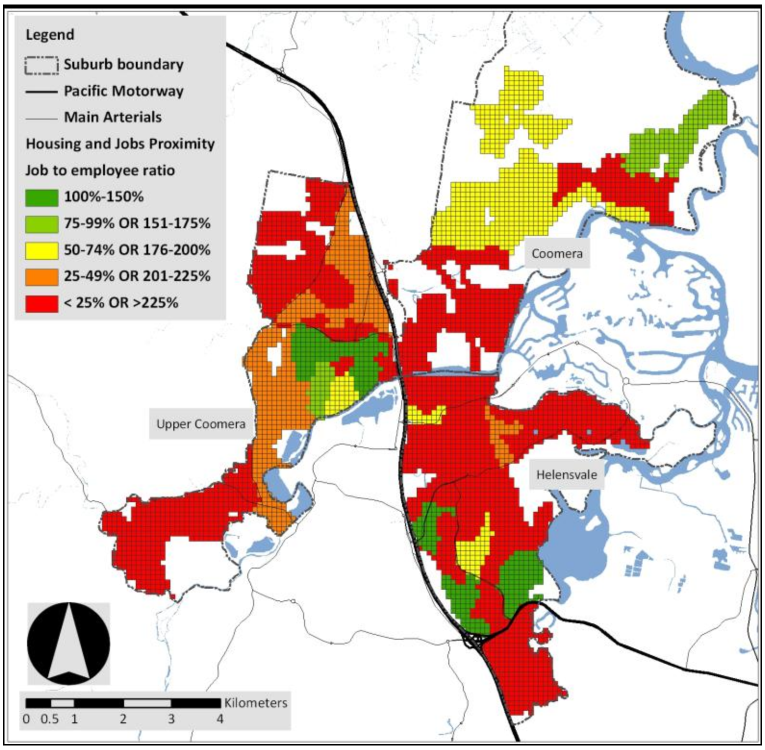


Figure 6.11 Housing and job proximity

The averages of job to employee ratios are 4.99, 1.62, 3.16 and 3.15 for Coomera, Helensvale, Upper Coomera and the whole area, respectively. Even though Helensvale has a nearly perfect average job to employee ratio, this does not conform with the map above, where only a limited portion has the best ratio. The reason behind this is that high and low job to employee ratio of the CCDs in Helensvale, which are all coloured red on the map, compensate each other, and this causes an over-normalisation when averaged, as can be seen in Figure 6.12. However, this is still an undeniable advantage for Helensvale, which can be easily turned into a well-balanced ratio.

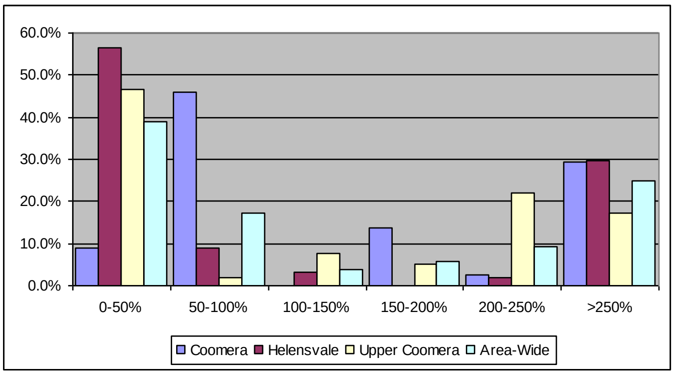


Figure 6.12 Distribution of grid cells in the study area by job to employee ratio

6.5 STREET CONNECTIVITY

Walkability or pedestrian friendliness of a neighbourhood is a desired quality in terms of neighbourhood sustainability. Providing direct routes as far as possible for pedestrians who want to easily access an urban service is an important quality which encourages not only walking, but also cycling. Therefore internal street connectivity is a well-known measure to assess how the road network gives a connected route for pedestrians (Cohen et al., 2006; Ewing & Cervero, 2001; Kashef, 2010; Song & Knaap, 2004). Here, the main issue is to decrease the number of cul-de-sacs which generally elongate the walking distance by detours even if they provide a confinement for the residents' surrounding.

There are other measures in the literature to quantify connectivity, such as alpha, beta and gamma (Cohen, et al., 2006). Considering the wide utilisation, internal street connectivity is used as the metric for this indicator. While other mentioned measures take into account the street and nodes together, internal connectivity only involves nodes, and it has been found practical and very successful in measuring route directness and walkability of a neighbourhood (Ewing & Cervero, 2001; Kashef, 2010; Song & Knaap, 2004). Internal street connectivity is the ratio of the number of intersections (non-cul-de-sac nodes) to the total number of intersections and cul-de-sacs (Song & Knaap, 2004). If this ratio is close to one, that means there are no cul-de-sacs within the defined analysis boundary. This ratio approaches to zero if a network consists of cul-de-sacs. In this analysis, the number of nodes was extracted from the updated road network via the topology tools of GIS, and the internal connectivity ratio was generated by following the procedure explained previously for each CCD.

Due to the lack of information on which level of internal connectivity can be considered as ideal for a settlement, one more time, possible minimum and maximum values of internal connectivity were divided in five equal intervals and then the indicator values were normalised as given in Figure 6.13.

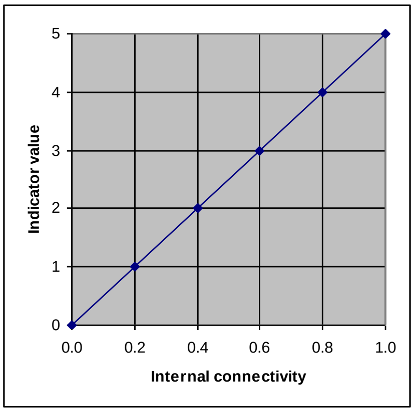


Figure 6.13 Normalisation thresholds for internal connectivity

The map below shows the internal connectivity ratio for each CCD in the study area. Obviously, while there is no area with a low internal street connectivity ratio, various average or above average ratios can be observed throughout the area. Coomera centre and the northern parts of Upper Coomera are the best two locations with very low number of cul-de-sacs. Coomera performs better when compared to the other analyses due to its more connected and pedestrian friendly street network. The average internal connectivity figures are 0.65, 0.62 and 0.62 for Coomera, Helensvale and Upper Coomera, respectively.

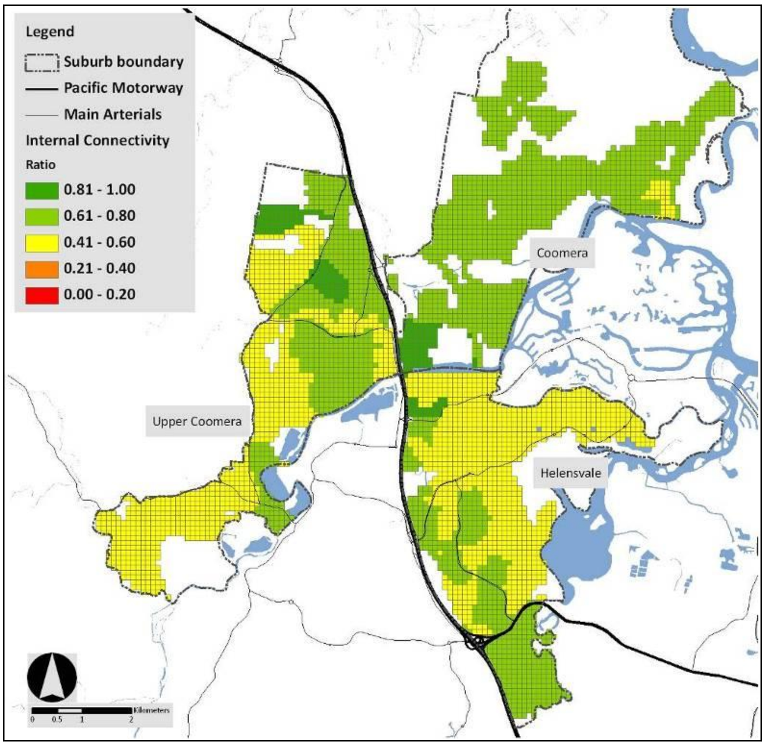


Figure 6.14 Internal street connectivity

The distribution of the grid cells also highlights the good performance of Coomera where 97% of the area has a ratio of 0.6 or higher. More than 60% of the whole area sits in the range of 0.6-0.8, which is above average. Another observation is that mostly the residential regions of Upper Coomera and Helensvale yield average score, which can be interpreted roughly as half of the intersections consist of cul-de-sacs and it discourages walking to some degree.

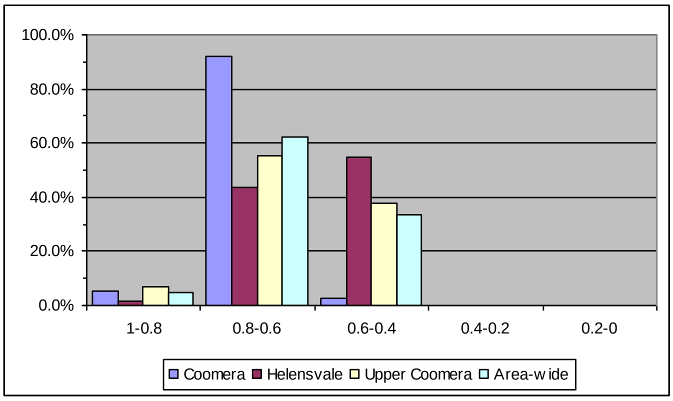


Figure 6.15 Distribution of grid cells in the study area by internal street connectivity

6.6 TRAFFIC CALMING

Another practical strategy to encourage walking is to slow down the traffic speed and to decrease the traffic volume on local roads. This helps pedestrians to travel smoothly and safely from a location to another. This strategy is considered as the complementary to other walkability and accessibility policies (Elkin et al., 1991; May et al., 2006; Newman & Kenworthy, 2000) and its link to overall urban sustainability is indirect. There is also serious criticism related to net benefits of these measures, such as public funds required to reconstruct the streets, increase in congestion and transport energy use (Replogle, 1995). However, when integrated with other travel demand management measures, it is very effective in enhancing road safety, air quality and fuel efficiency (May, et al., 2006; Replogle, 1995). The main strategy of traffic calming is to build soft man-made barriers on the roads to decrease the traffic speed and to deter drivers to travel on local roads, which also decreases traffic volume. Available measures vary with the goal of traffic calming. While vertical and horizontal deflections and narrowing are used to decrease traffic speed, diverting roads or restricting access to local roads help to decrease the traffic volume.

In this analysis, all traffic calming measures on the ground were located by visual inspection of the aerial images provided by the GCCC for each road segment. If any calming application was evident on the road segment, this road segment was flagged according to the type of measure (speed or volume). Following this, the ratio of the length of roads with traffic calming measures to the overall length of the roads was calculated and mapped as shown in Figure 6.16.

Traffic calming measures are auxiliary measures in sustainable urban design taken locally to regulate the traffic and to enhance the safety of the pedestrians. Therefore, it is hardly possible to find clearly defined benchmark values for traffic calming, which reflects the ideal condition in a local road segment. Because of this, the range of 0 to 1 was divided in five equal bins as done for the internal connectivity and land use mix indicators. As expected, the cut-off values are 0, 0.2, 0.4, 0.6, 0.8 and 1 for the indicator values of 0, 1, 2, 3, 4 and 5, respectively (see Figure 6.13 for a similar outcome of normalisation process).

In the figure, particularly the central locations of Upper Coomera and the northeast of Helensvale stand forward with very high traffic calming ratios. Nearly every road in these regions applies at least one of the calming measures. Interestingly, Upper Coomera accommodates the largest area for both the best and the worst ratios in the area. Furthermore, there are a very limited number of traffic calming measures in Coomera employment centre and the western residential areas of Upper Coomera. Visual inspection of aerial images shows that variety and intensity of traffic calming measures in CCDs located in the northeast of Helensvale outperform any other location in the study area. Particularly, the widespread application of roundabouts at the intersections helps to slow down traffic speed via creating a vertical diversion for vehicles. Average calming ratios for Coomera, Helensvale and Upper Coomera are 48%, 52% and 43%, respectively.

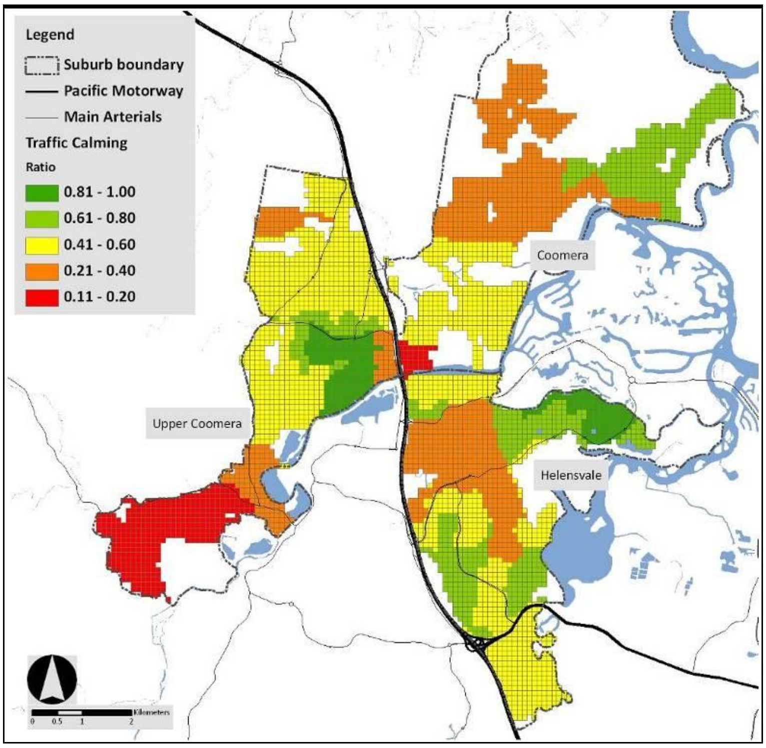


Figure 6.16 Traffic calming

As shown in Figure 6.17, three-fourths of the study area has average or above average traffic calming ratio. It could be considered as an obvious sign of the availability of safe pedestrian environments in the area. Among all suburbs, only Coomera region presents a higher 'below-average' ratio (50% of the area has a limited number calming measures on the roads).

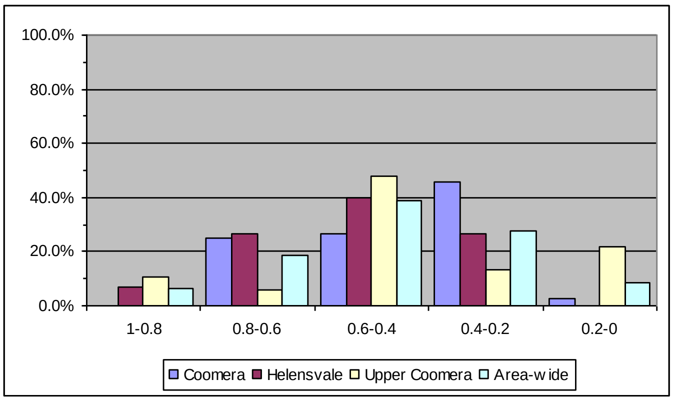


Figure 6.17 Distribution of grid cells in the study area by traffic calming

6.7 PEDESTRIAN FRIENDLINESS

In addition to good internal connectivity and traffic calming applications, existence of well-designed footpaths also motivates people to walk when reaching an urban service, or to travel actively. In terms of pedestrian friendly urban areas, the best case is the provision of pedestrian zones designated only for pedestrians' use considering the factors such as grade, directness, shade, lighting, visual amenity, safety, and so on, or, wide footpaths clearly separated from roadways considering aforementioned factors. However, predominance of the roadways, low densities and lack of demand from people for good walking infrastructure make footpath provision hard, most of the time less cost-efficient. Conversely, health benefits of an active lifestyle are becoming obvious and people's attitude has been changing in favour of walking. Because of this, provision of walking infrastructure even in the minimum level might yield great personal and social benefits in the long term.

In this analysis, similar to traffic calming ratio calculation, footpaths were marked on the map by visual inspection of the aerial images. The main difference between this and previous analysis is that footpaths were recorded as to the ratio of the double sided footpath. It means that if the footpath is only on one side of the road, this road segment yield a half mark (i.e., 0.5). If there are footpaths on both sides of the road, then a full mark is given to this road segment. Then, a walkability ratio which equals to the ratio of roads with footpaths to total length of all roads for each CCD was calculated.

Similar to traffic calming ratio evaluation, five bins were formed to assess the availability of pedestrian network. The figure belonging to normalisation thresholds for this indicator is not given here because the same normalisation thresholds, which are previously used for traffic calming and internal street connectivity, were applied and can be seen in Figure 6.13.

As shown in Figure 6.18, there are not any areas with above average walkability ratio. It is a clear indication that there is a serious lack of walking infrastructure in the study area; it is particularly obvious in the northern CCDs of Helensvale, the peripheries of Upper Coomera and for nearly the whole Coomera. As another observation from visual inspection, most of the roads in newly developing residential areas have no footpaths or only on one side, which are quite narrow.

Furthermore, footpaths end unexpectedly when they reach an intersection or a road with higher road hierarchy. Inadequate supply of walking infrastructure and continuity problems are the prevalent issues discouraging people from walking in the area. Poor walking infrastructure supply problem can be viewed from a different perspective as an extension of car dependency or car dependent urban pattern. In Figure 6.18, it can be seen that areas with average walkability ratios congregate around commercial centres where footpath is required for people who park and walk for different activities across the centres.

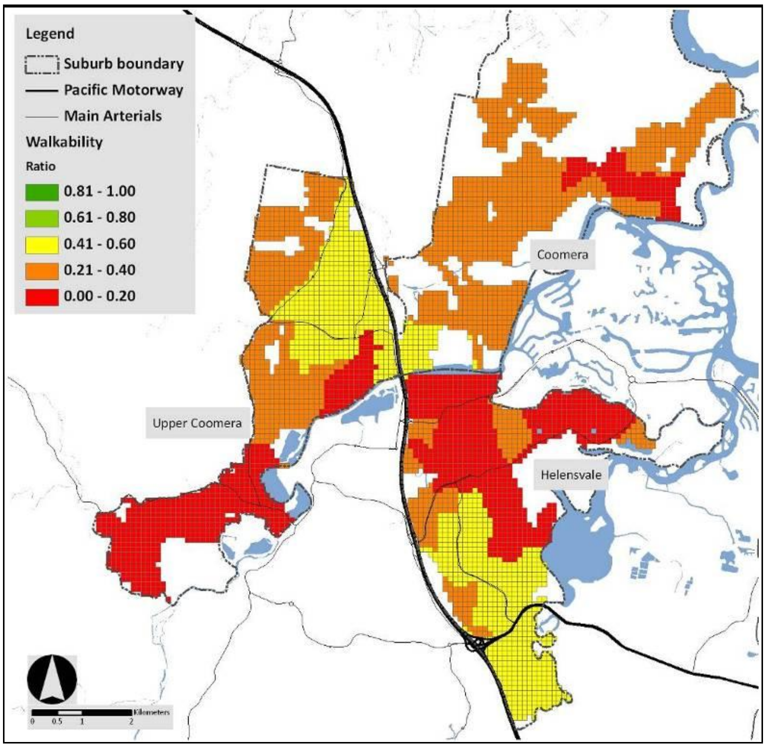


Figure 6.18 Walkability-pedestrian friendliness

The average walkability ratios for Coomera, Helensvale, Upper Coomera and area-wide are 24%, 30%, 24% and 26%, respectively. When the distribution of the walkability ratios of three suburbs is analysed (Figure 6.19), it can be seen that the distributions in Helensvale and Upper Coomera are very similar to each other and also consistent with the area-wide trend. However, a great deal of Coomera is between 20% and 40%. Even though 40% of Helensvale occupies the greatest stake in the lowest bin, it outperforms Coomera and Upper Coomera in overall assessment with an average of 30% walkability ratio. When we take into account the study area as a whole, only one-fourths of the roads have footpaths on both sides of the roadways.

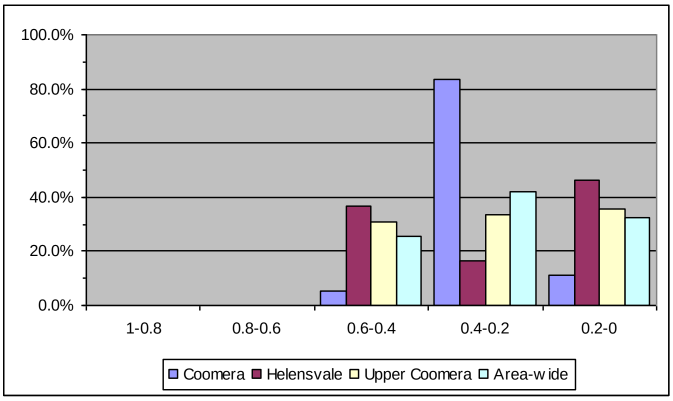


Figure 6.19 Distribution of grid cells in the study area by walkability

6.8 OPEN SPACE AVAILABILITY

In addition to the pedestrian friendliness of a neighbourhood, open spaces are considered as complementary for an active lifestyle whose aim is to enhance the physical and psychological well-being of people by allowing daily physical exercise. Moreover, these areas provide amenity for a neighbourhood and outdoor recreational activities. In this regard, adequate area for recreational activities within walking distance and connectedness of open spaces shape the use of open spaces for physical activities. These concerns can be taken into account together with walking or cycling activities. With open space provision, it is possible to design pathways with a high visual amenity and proper shading. Moreover, open spaces support the disturbed flora and fauna to a great extent depending on how much of natural vegetation is preserved.

In this analysis, available open space per capita was calculated basing on each residential lot. As the cut-off value, 1,200 m (15 minutes) walking distance was taken and accessible open spaces were designated according to the number of lots within the given cut-off value. This approach is considerably different than the classical per capita open space calculation. The usual approach is first designating an area which could be considered as a neighbourhood, and then dividing the total open space area to the total population of this neighbourhood. The main backdrop of this approach is that it is not sensitive to the location of a residential unit but how neighbourhood boundaries are drawn. It means even a park is located very close to a housing unit, say, on the other side of a road passing through in front of this housing unit, and if this road separates two neighbourhoods, then this park would not be considered as accessible for this housing unit. In order to overcome this limitation, the open space per capita was calculated as to the location of the housing unit. By this way, it is possible to detect the accessible open areas for each lot. This approach is also advised by other studies (Hewko et al., 2002; Itzhak, 2006; Smoyer-Tomic et al., 2004). To generate lot-based open space information a two-step process was followed. Firstly, per capita open space area was calculated for each open space by generating an OD matrix. In this matrix, open spaces were the origins and residential lots were the destinations. This matrix gives the number of lots that can access to the destination open spaces. By using the average household size information from the census, per capita green space was calculated for each open space. For clarification, assume that there is a park whose area is 1,000 m^2, and within 1,200 m walking distance to this park, there are 20 housing units. If the average household size is 2.5 in this CCD, per capita green area accessible would be 20 m^2 (1000/[20 x 2.5]). At the second stage, after calculating the per capita green area values for all open spaces, another OD matrix was formed but this time the origins and destinations in the previous OD matrix were inverted. This matrix showed which open spaces can be accessible for the residential lots. Since per capita area was calculated for each open space in the previous step, lot-based open space accessibility was calculated by adding these per capita green area values. For example, if there are 3 parks within 1200 m walking distance of a residential lot and per capita open space is calculated as 3 m^2/person, 6 m^2/person and 7 m^2/person, then the total open space for this unit is 16 m^2/person.

Golf courses, forests, grasslands, waterways, wetlands, grazing and agriculture uses were excluded from the analysis because of either not fitting the open space definition in terms of the designated use of the area (such as, wetlands, agriculture, grassland, grazing) or limitations imposed on their use (such as, club membership for golf clubs, safety and property ownership issues for waterways and forests). As previously done, it was assumed that there has not been a substantial change in the average household size since 2006.

Byrne and Sipe (2010) provided a detailed outlook about how green area standards are designated considering mainly the UK and Australia examples. In their review it is possible to find typologies and planning standards with respect to the best practices in Australia. Apart from this review, the local government (GCCC, 2006c) also defined the desired standards in parallel to the planning scheme. Furthermore, Standards for Urban Infrastructure of Australian Capital Territory Government (ACTG, n.d.) set standards including neighbourhood parks in Canberra territory. By using the information provided by these resources, a set of benchmark values were assigned for open space availability. As the desired case, coastal zone recreation area standards of the GCCC (2.5 ha/1,000 residents) and neighbourhood park area standards of ACTG (1 ha/1,000 people) were assigned to upper and lower limits of the medium bin. Again, northern and southern zone open space (recreation, sport, community facilities and outdoor recreation) standard of the GCCC (5 ha/1,000 residents) was considered as the upper limit for medium-high bin. Open space provision greater than this value was adopted as the best case. For the lower end of the medium range, 5 m² per capita was assigned to the lower limit of the medium-low bin. The worst case was assumed as no open space area. These ranges and respective indicator values are depicted in Figure 6.20.

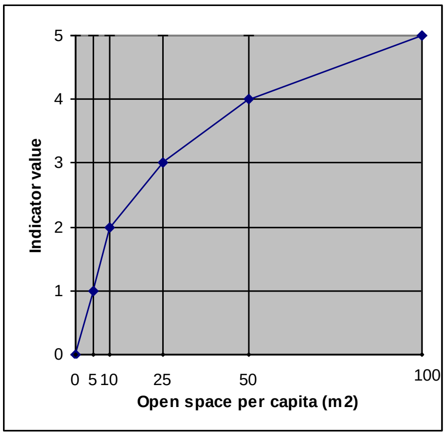


Figure 6.20 Normalisation thresholds for open space availability

As it is evident in Figure 6.21, there is no open space availability problem in the study area except in a few locations in Helensvale. These areas are generally located in a neighbourhood where there are only a few small local parks and long cul-de-sacs which make accessing to the closest open spaces hard. The averages of available open space for Coomera, Helensvale and Upper Coomera are 112, 200 and 94 m², respectively. It is 137 m² when the study area is considered as a whole.

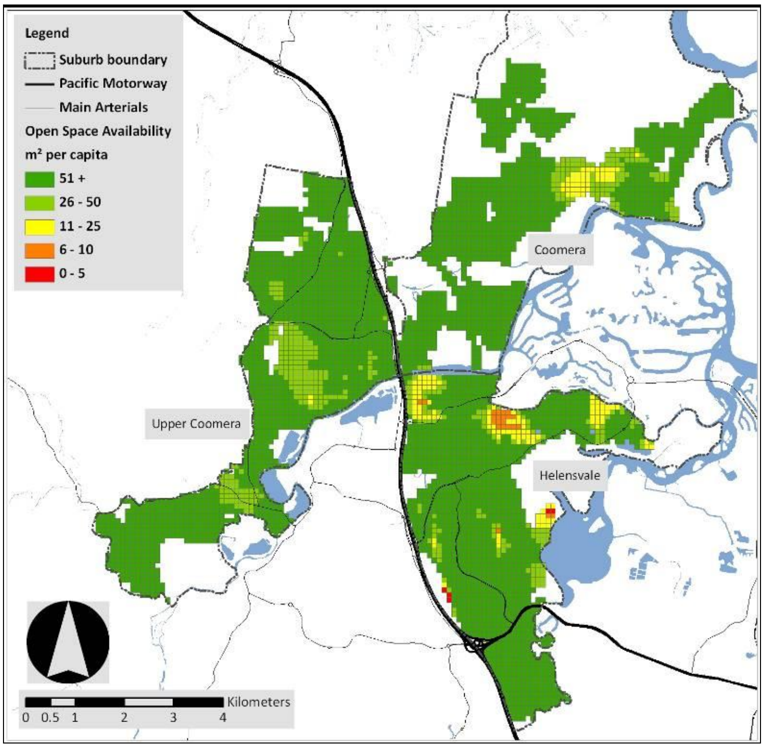


Figure 6.21 Open space availability

It is also evident that nearly 85% of the whole area has 50 m² or more open space per capita, which also conforms with the overall average value of 137 m². Only a small part of Helensvale (10%) is located in the medium and medium-low bins.

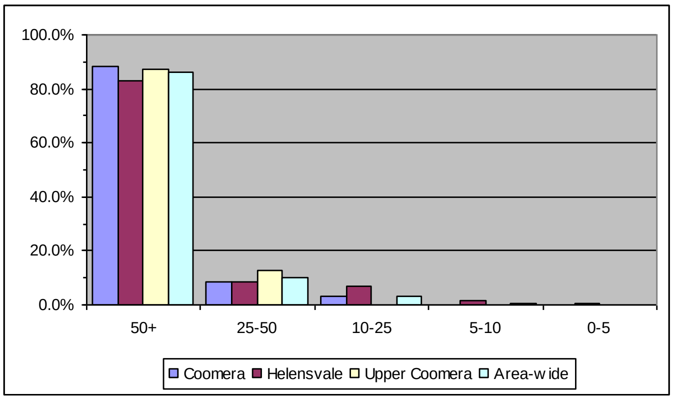


Figure 6.22 Distribution of grid cells in the study area by open space availability

6.9 SUMMARY

The most obvious observation on the urban form indicators was that there was a distinction between suburb centres and the suburb peripheries. While the former had comparatively smaller parcels and higher population density, the latter presented the opposite of the former. The same distinction was also observed in land use mix indicator. Consequently, the suburb centres had better scores than periphery areas. Housing to job ratio helped to scrutinize self-containment of job opportunities in the study area, and except a few CCDs around Helensvale and Upper Coomera suburb centres, the performance scores were below the average benchmark value. This was interpreted as a mismatch between residents' occupations and the job opportunities provided in the area. However, it was not possible to reach a conclusion whether it is related to the people's residential choice and perception of commuting time or firm's location decisions without doing further socio-economic and demographic analysis.

Design/layout indicators showed that the study area performed very well in internal connectivity, open space availability and traffic calming indicators, but it was observed that the pedestrian network was very poor and lacking mostly in the residential areas. This implies while the all prominent qualities to create a safe, convenient, connected and comfortable pedestrian network was existed, the provision of the network itself was lacking.

Another important quality of these analyses was the innovativeness in quantification of two density/diversity and design metrics. As highlighted previously, one of the objectives of this study is to show location specific urban form and transport qualities of the area, and a spatial scale close to parcel level can give the most detailed results. Accordingly, calculation of land use mix and open space availability was done on parcel level by considering the true network distances and converted to grid cells by weighted average of the parcel areas. Whilst computationally expensive, this approach has certain advantages to demarcate areas with finer details and gives more robust analysis results.

In summary, while the suburb peripheries of the study area had the characteristics similar to sprawled urban development and mobility patterns, the suburb centres had various advantages which could be exploited to create pedestrian friendly, compact and contained settlements. From design perspective, the most important shortcoming was the provision of pedestrian network. Having examined the transport and urban form related qualities of the study area, another set of indicator analyses were conducted to reveal the effects of transport and land use patterns. These –mostly negative- effects are called externalities and discussed in the next chapter.

Chapter 7: Analysis: Part III

This last analysis chapter provides an overview of mostly transport related externalities experienced in the study area. In this study, externalities refer to the external or unanticipated effects of mobility and urban form patterns which incur extra costs to public and environment, and obscure the true cost of travel and urban sprawl. The externalities are elaborated within two categories, pollution and resource consumption, following the common compartmentalisation in the literature. Accordingly, the main aim of this chapter is to show area-specific pollution and resource consumption problems considering their environmental and public costs implicitly. By definition, pollution refers to generation of a number of pollutants exceeding assimilation capability of the environment and affecting human health and residential amenity; resource consumption refers to exploitation of natural or public resources which diminishes reproduction and assimilation capacity of the environment or prevents its utilisation for other competing purposes (i.e., opportunity cost). Pollution category indicators are well-studied and easy to define by referencing the literature. In some cases, it is comparatively hard to consolidate resource consumption indicators and the definition given above can provide guidance. In order to clarify the relation of some indicators with resource consumption category, additional information is provided in the respective sections.

Similar to the previous two analysis chapters, each section starts with an explanation about the importance and meaning of the measure in terms of land use and transport sustainability, and normalisation procedures embraced. Then the analysis results, which present area specific overview of the indicator, cluster formations and a comparison of distribution of indicator scores for three suburbs and overall area, are presented.

7.1 AIR QUALITY

Increasing number of car travels and the distance travelled for daily trips are the main sources of transport related environmental externalities, such as pollution, non-renewable resource consumption, traffic congestion, and accidents and fatalities.

These externalities can be regarded as the undesired composite effects of urban form and travel patterns on neighbourhood-level sustainability. In order to provide a detailed outlook to these externalities, various indicators to analyse and portray a clear picture about the problematic areas were selected. Air quality problem is the first issue discussed in this section.

As one of the main topics of this ARC Linkage project, initially, various transport related pollutants collected from 11 sites in the study area were analysed. Particularly, concentrations of various heavy metals and polycyclic aromatic hydrocarbons were analysed due to their potential hazardous effects on the health of humans and pristine ecosystems (Gunawardena, et al., 2011). Among these pollutants, lead (Pb), which is considered as one of the prominent heavy metal pollutants, was taken as the cursor pollutant. Another important feature of lead in the air is that it exists in the air as fine particulates and can diffuse along the area depending on the atmospheric conditions.

By using transport network forecasts for 2011 provided by the GCCC (i.e., GCCC PIP traffic forecasts), a stepwise regression analysis was employed to estimate the distribution of Lead concentrations on each road segment. The regression equation is given in below:

$$Pb_{Air} = -0.124 + 6.184[INV\_SPEED] + 0.084[COR] + 0.0000027[VOL]$$
$$R^2 = 0.956\, F(3,9) = 43.136$$

where INV_SPEED is the reciprocal of operating speed (i.e., approximately 85% of the design speed) of the road, COR is the ratio of the area of commercial uses to the area of residential uses within 1 km of the observation point and VOL is the daily volume of the road. Note that the equation as a whole and all coefficients are significant at 95% level.

Lead concentration in air was estimated by using the regression equation above for each road segment. These values were then interpolated by ESRI’s ArcGIS spatial analysis tool to the whole area. Theoretically, it might not be plausible to interpolate pollution values basing on the road segment; however, as stated earlier, fine particulate nature of lead makes it possible to assume that a homogenous diffusion of lead particulates all over the area. Also, the road segments over which lead in the air regressed cover the whole study area. This helps to assume that virtual observation points are well distributed in the area, which facilitates showing short range variations. Following the interpolation, the air pollution data was aggregated into grid cells covering all urban footprints in Coomera, Helensvale and Upper Coomera.

Please note that lead concentrations for the Pacific Motorway were excluded from this analysis due to very high traffic volumes on this road, which are outside the confidence intervals of regression analysis employed.

While analysing Lead concentrations in the study area, a set of benchmark values were used in accordance with the classification and standards of air toxics from the Department of Sustainability, Environment, Water, Population and Communities (DSEWPC, 2001). For lead concentration, the exposure limits defined by National Occupational Health and Safety Commissions and National Ambient Air Quality Standards and Goals were selected to configure the pollution concentration ranges. According to this, the maximum allowable limit for lead concentration in the atmosphere is defined as 0.50 µg/m³, averaged over one year (Department of the Environment and Heritage (DEH), 2004). This value was taken as the worst case for the study area and also it was assumed that half of this limit value could be considered as the upper limit for the medium range. The rest of the benchmark values were designated by dividing this range to five bins, which are given graphically in Figure 7.1.

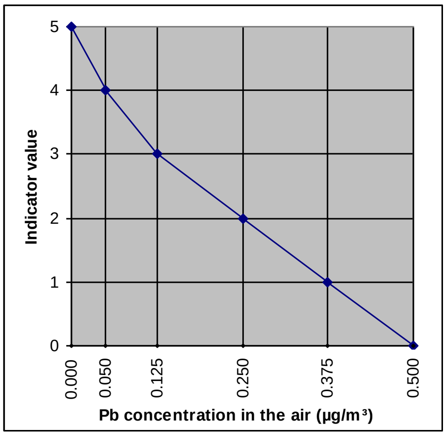


Figure 7.1 Normalisation thresholds for air quality

As it can be seen in Figure 7.2, throughout the area, there are only two spots which pose a lead exposure risk from transport, which are the either sides of the Pacific Motorway close to Exit 54. Lead pollution concentration is just above the medium range around the main arterials of the area, such as, the northern part of Upper Coomera between Abraham Road and Old Coach Road, Pacific Motorway connection of Hope Island Road and the surroundings of Helensvale Shopping Centre. Apart from these areas, lead concentration is relatively low, specifically in the peripheries of Upper Coomera and Coomera where population density and traffic volume are low. The average lead concentrations are 0.014, 0.028, 0.012 and 0.018 for Coomera, Helensvale, Upper Coomera and whole area, respectively.

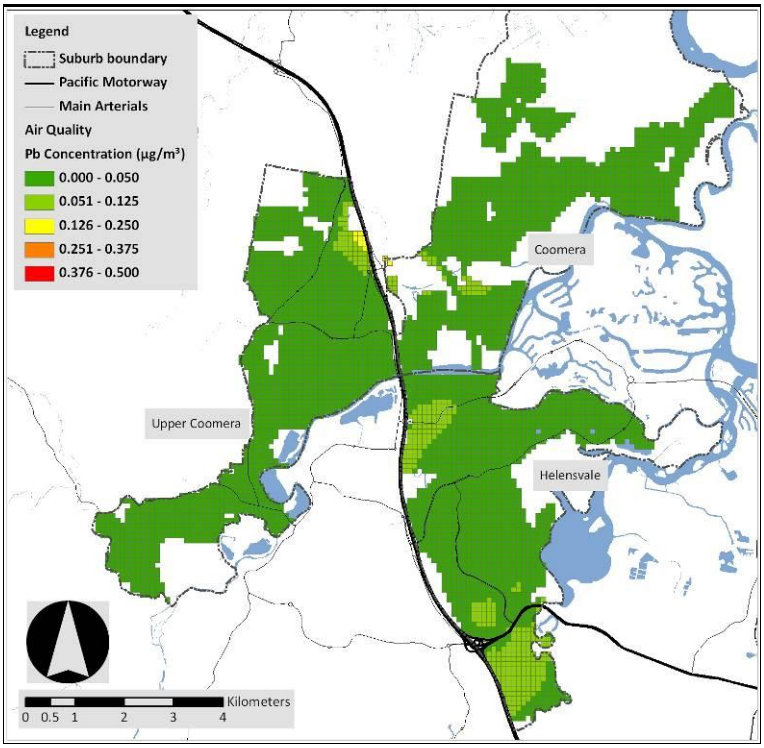


Figure 7.2 Air quality (Lead concentration)

When distribution of lead concentration is analysed in Figure 7.3, nearly the whole of Coomera and Upper Coomera take place in the first bin where concentrations are very low. Approximately 18% of Helensvale sits in the medium-low concentration bin. The only problematic location in the area is the north-east of Coomera, where the forecast concentrations are as high as the half of the ambient air quality standard.

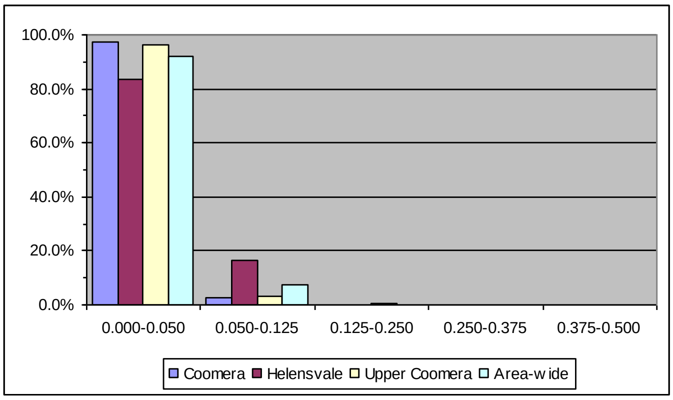


Figure 7.3 Distribution of grid cells in the study area by air quality

7.2 GHG FROM TRANSPORT ACTIVITIES

While it does not entail any direct risks for human health, the GHG are the main source of the climate change. Approximately 25% of the GHG comes from transport activities in Australia, and urban transport activities are one of the biggest contributors of GHG emissions. As a consequence of this, Australian Government has set a number of standards for each economic sector producing GHG to reduce emissions and to comply with international GHG reduction schemes, particularly Kyoto Protocol targets. In this analysis, CO2 emissions were used as the measure of the indicator and estimated for each CCD.

Since there is no data for GHG emissions for any small-scale statistical unit (no data even for Local Government Area level), traffic volume information of the GCCC transport model was considered as a good proxy for the estimation of CO2 emissions. By using average fuel consumption and emission production values advised by the DSEWPC (2008) and assuming that medium size vehicles constitute the majority of vehicle fleet and on average 2.5% of vehicles on the traffic are heavy vehicles in the Gold Coast, average CO2 emissions were estimated for each road segment on the annual basis.

As a national standard, Australian Government has targeted not to exceed 108% of 2000 CO2 (GHG in general) inventory of Australia by 2010. In 2000, the total CO2 inventory for Queensland was 2.62 tonnes per capita (Australian Greenhouse Office (AGO), 2002). To comply with this target, 108% of this figure, which is 2.83 tonnes per capita, was defined as the middle value for current GHG emission analysis. This target was embraced as the benchmark for GHG emission for this analysis. Here, while the best case for GHG is zero emission, the worst case is the mirror value of first range, which is 4.52 tonnes per capita.

Note that CO2 emissions from the Pacific Motorway and the Gold Coast highway were excluded from this analysis due to their very high traffic volumes, which possibly would give a biased outcome for the CCDs surrounding the motorway. Moreover, the residents residing in these CCDs contribute very marginally to overall CO2 emissions coming from these high-volume roads, so the exclusion of these roads would have a marginal effect on the average figures. It could be said that the exclusion of motorway causes a limited reflection of CO2 emissions for the area.

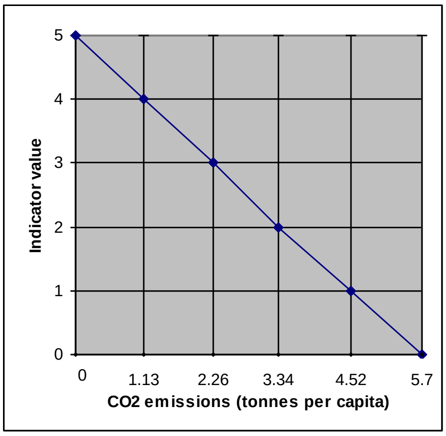


Figure 7.4 Normalisation thresholds for GHG emissions

The most prominent aspect of Figure 7.5 is that the areas with low population density, whether they are residential or commercial and industrial, have the highest CO2 emission values. It is specifically the case for the industrial region of Coomera and the northern part of it, and the periphery areas of Upper Coomera. As for Helensvale centre area, the high volumes on Discovery Drive and Lindfield Road pull up per capita emission values for the low density residential areas. Per capita CO2 emission is very high in the south of Helensvale, which consists of mainly commercial uses (low CCD population). The average CO2 emissions for Coomera, Helensvale and Upper Coomera are 4.42, 1.53 and 2.88 tonnes per capita, respectively. Interestingly, the overall average value is very close to the national target of 2.83 tonnes per capita, which is 2.86.

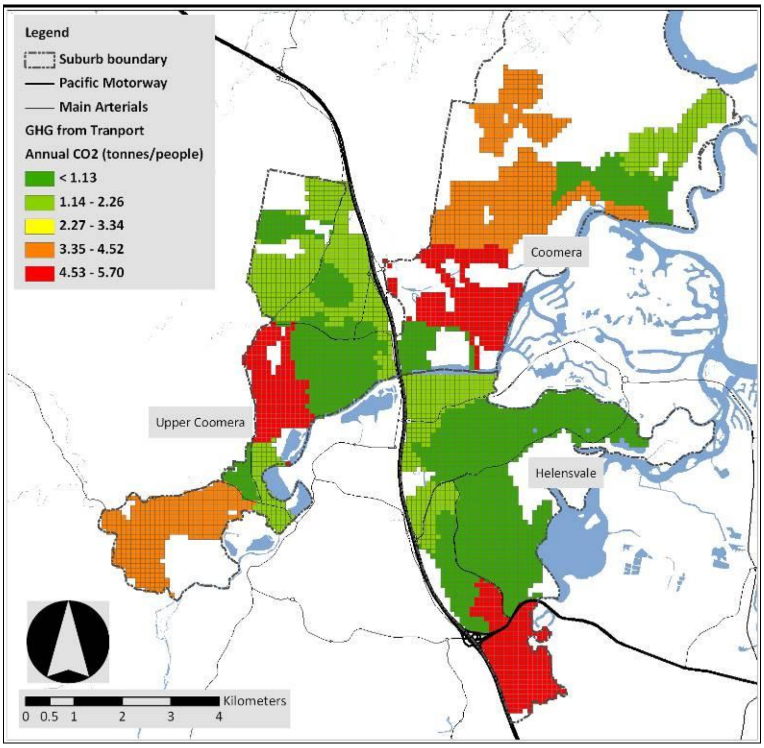


Figure 7.5 Greenhouse gases from transport activities

In Figure 7.6, Helensvale superiority in terms of CO2 emissions, which also positively contributes to the overall emission values in the area, can be easily detected. Nearly half of Coomera is situated at the below average range. On average 20% of the whole area sits in the highest emission bin and a similar distribution among suburbs in this bin can be seen in the figure. Another interesting observation is that there are not any CCDs in the area falling under the middle bin and in overall, high emission values are offset by low values.

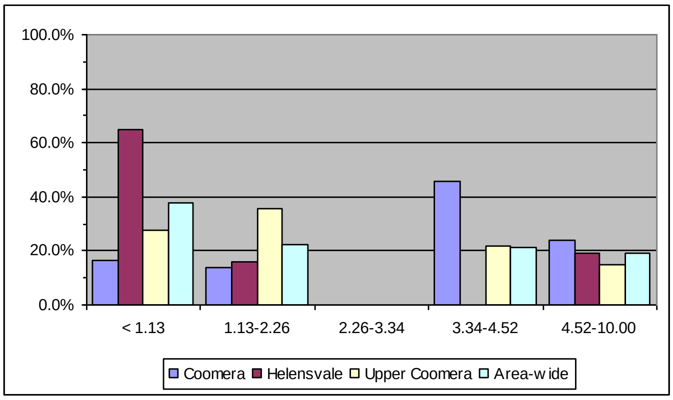


Figure 7.6 Distribution of grid cells in the study area by GHG from transport

7.3 TRAFFIC NOISE

In addition to transport activities' unfavourable effects on air quality and climate change, they also negatively affect human health and property value due to noise pollution coming from road traffic. It is particularly one of the most important problems in European cities with very high population densities, which have developed along with the road network. It is reported that exposure to a noise level higher than 65 dBA for a long time causes sleeping disorders, depression and occasionally heart diseases (Babisch, 2006). Moreover, an increase in noise level causes depreciation in property values. This is particularly the case where a highway or a main arterial is built in an area once there was no such development.

Noise pollution was estimated for an 18 hour time period (L_{18}) by employing the CoRTN (calculation of road traffic noise) procedures, which were developed for the United Kingdom (UKDOT, 1988). For computational convenience, the topographic features of the area were excluded from the analysis as well as the actual building heights by assuming the area is flat and all buildings are six metres high. Virtual receptors were designated for each building's façade facing the closest road segment. In order to estimate the noise for the interiors of the blocks, another set of receptors were designated for the centroids of each block. In most of the cases, additional receptor points were designated for the blocks to capture the physical barrier dependent variations. By using the GCCC 2011 transport model's road volume information, the noise level for each virtual receptor was calculated via an ArcGIS VBA module which was written by the author. After approximately 480 hours of computer processing, noise estimation for each receptor was completed. Then this point layer representing receptors was interpolated by ArcGIS tools to yield a continuous surface for the study area. Finally, an average noise level value was assigned to each grid cell with respect to interpolated noise pollution raster.

The GCCC has set noise exposure targets in the City Transport Plan (GCCC, 1998). According to this, while 63 dBA is the target for the local roads and the future roads, 68 dBA is the target noise level for the existing roads under state government control. Moreover, a program for noise abatement in urban areas in the EU, which is called SILENCE (Kloth, et al., n.d.), gives detailed information on noise sources, techniques to detect and analyse noise, and measures and strategies for noise abatement. In order to select reliable benchmark values for noise pollution, the information provided by these sources was synthesised. Particularly, a similar diagram which shows different noise levels with the effects of these levels on soundscape given by Kloth et al. (n.d., p.59) was used to designate benchmark values. As it can be seen in Figure 7.7, the target of 63 dBA for the Gold Coast sits in the medium range.

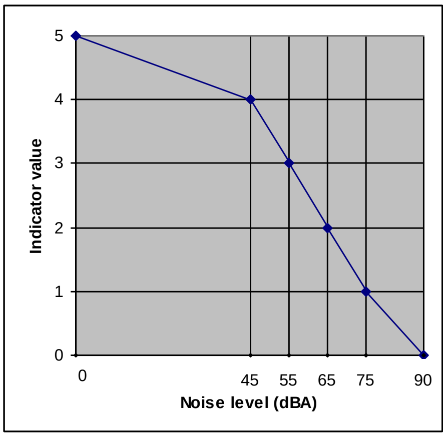


Figure 7.7 Normalisation thresholds for noise pollution

As it can be seen in Figure 7.8, high noise levels are correlated with high traffic volume on the roads. Particularly, areas surrounding the intersections of Hope Island Road, Old Coach Road and Helensvale Road with the Pacific Motorway have above average noise levels. As expected, noise is always above average level along the Pacific Motorway and the Gold Coast Highway. In a few specific locations on these roadways, noise levels increase to even over 75 dBA. However, when we look at the average noise level for three suburbs and the whole area, we see relatively low average values, which are 43.5, 48.5, 44.8 and 45.8 dBA for Coomera, Helensvale, Upper Coomera and the whole area, respectively. On average, the noise level in Helensvale is slightly over the other suburbs as it can be seen in Figure 7.9.

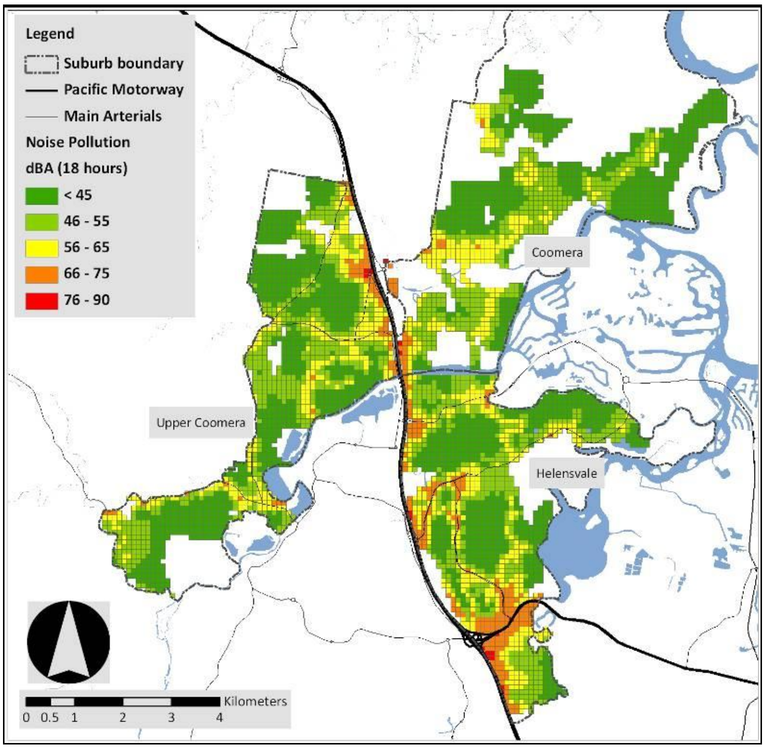


Figure 7.8 Traffic noise pollution

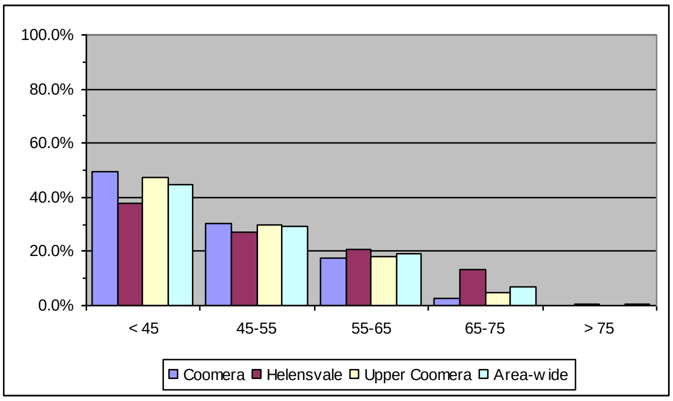


Figure 7.9 Distribution of grid cells in the study area by noise pollution

7.4 STORMWATER QUALITY

Another main aim of the ARC Linkage project is to reveal how air-borne pollutants built-up on the roads and are discharged to water bodies via stormwater runoff. By using stormwater runoff pollution values for 11 sites in the study area (Mahbub, et al., 2011), the lead concentration in stormwater was analysed by following the same methodology used for air pollution calculation. The same assumptions made for air pollution were applied for this analysis.

Lead concentration in wash-off was calculated by following similar procedures as done for air quality calculation. The only difference is the regression equation used to estimate the wash-off concentration, which is given below:

$$Pb_{Stwormwater} = 0.68 + 0.68[VOC]$$
$$R^2 = 0.483 \qquad F(1,8) = 6.528$$

where $[VOC]$ is the ratio of volume to capacity. Note that the overall equation and the coefficient of $[VOC]$ are significant at 95% level, while the equation constant is at 90% level.

The water quality standards advised by National Health and Medical Research Council (NHMRC), and the Natural Resource Management Ministerial Council (NRMMC) were used in designating benchmark values for stormwater quality. The values of 0.02, 0.1, 0.2, 0.5 and 1mg/L were adopted for drinking water, aqua-livestock and recreational water, long term irrigation water, livestock drinking water and short term irrigation water benchmark values (NHMRC, 2004; NRMMC, 2000), respectively. These values and corresponding indicator values are given in Figure 7.10.

Once more, lead concentrations for the Pacific Motorway were excluded from this analysis due to very high traffic volume on this road which might have given inconsistent results if not. Because of this, the stormwater quality figures given below reflect a partial picture of the study area. A further investigation to analyse the stormwater pollution on the Pacific Motorway would help to make more robust inferences about the overall stormwater pollution in the area.

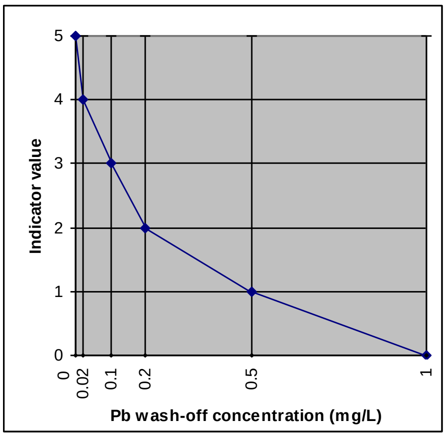


Figure 7.10 Normalisation thresholds for stormwater quality

Stormwater quality presents a relatively good picture in the study area. Average level lead pollution is evident only in the surroundings of road segments with low level of service ratio (high volume over capacity ratio). The average lead concentrations present a pretty flat distribution, which are 0.094, 0.098 and 0.096 for Coomera, Helensvale and Upper Coomera, respectively.

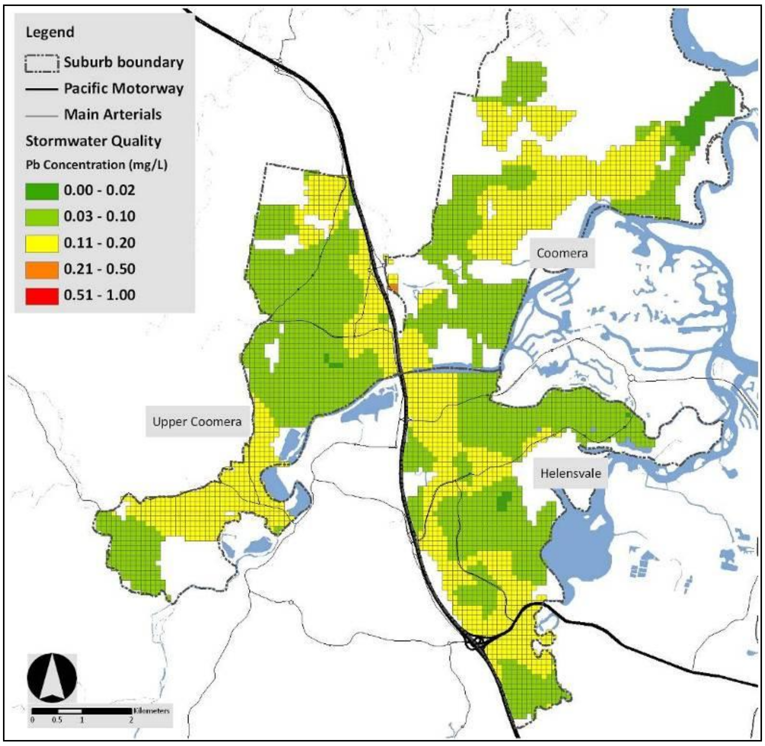


Figure 7.11 Stormwater quality (Lead concentration)

Generally, most of the area is placed in the above average or the average range as shown in Figure 7.12. Approximately 58% of the area is in the range of 0.02-0.10 mg/L, while 41% is in the middle bin. These two figures add up to 99% which also confirms the relatively good performance of the area in terms of lead pollution in stormwater.

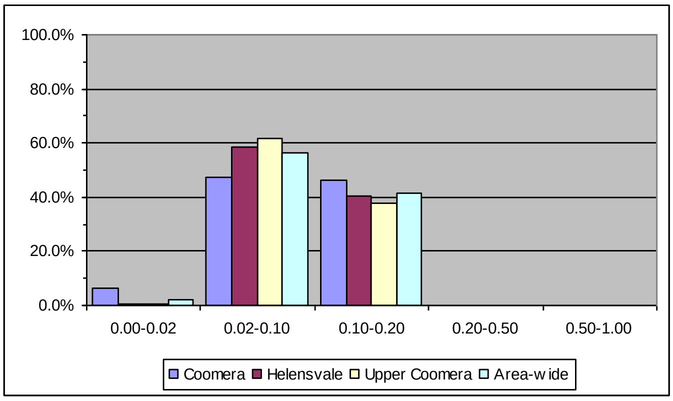


Figure 7.12 Distribution of grid cells in the study area by stormwater quality

7.5 LAND OCCUPIED BY URBAN USES

Another concern in sustainable neighbourhood design is the resource consumption. This is important because we are consuming more – generally non-renewable natural resources and energy – by urban development, at the same time producing various forms of externalities which degrade the well-being of living beings, sometimes jeopardising their existence. In terms of consumption of the natural resources, urban development taking place in the greenfield areas inherently converts a piece of land into an artificial cover for people's use. Most of the time it is an unavoidable process; however, the balance between use and conservation should be maintained as much as possible. In this analysis the urbanisation ratio of each suburb was scrutinised to evaluate land consumption for urban uses. While conducting this analysis, there were a few important concerns about how the classification of preserved and purely urban areas could be made. In general, grasslands, wetlands, forests and waterways were considered as less-disturbed natural resources and non-urban. Moreover, a few specific residential domains in the Gold Coast planning schemes were considered as non-urban, such as, park-living and rural living, because of the conservation opportunities carried out by these domains.

Initially, the total area of urban land uses was recorded separately to a field in a GIS layer by using land use information provided by the GCCC. Then the proportion of urbanised area for each CCD was calculated by dividing the urbanised area to CCD area.

Due to lack of information related to benchmark values on sustainable level of urbanisation, indicator values were assigned according to possible minimum and maximum values, which are zero, representing no urbanisation, and 1, representing fully urbanised areas. The range of 0 to 1 was divided to five equal bins as shown in Figure 7.13.

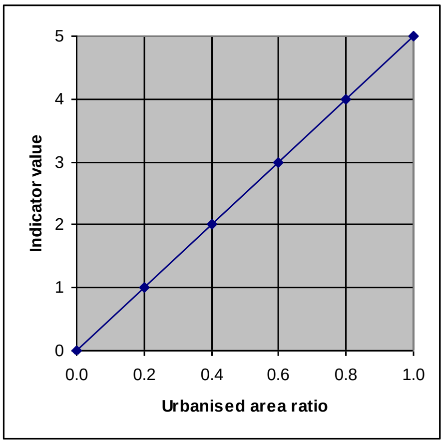


Figure 7.13 Normalisation thresholds for urban land consumption

It is found that the average urbanisation ratios for Coomera, Helensvale and Upper Coomera are 30.4%, 68.2% and 54.0%, respectively. The outcome of this analysis is given in Figure 7.14 below. The most striking observation about this figure is that once well-performing regions of the study area are now grouped under the least performing bin. It is more or less the expected result because these areas are relatively high density residential areas, and it is quite hard to find any preserved areas with these characters. On the contrary, areas encircling low performing sections have acceptable or good performance values in terms of urbanised area ratio. It is a little too late to advise remedies for low performing areas, but it would be a wise strategy to preserve existing land with natural characteristics for the areas where urban development is predicted for the near future.

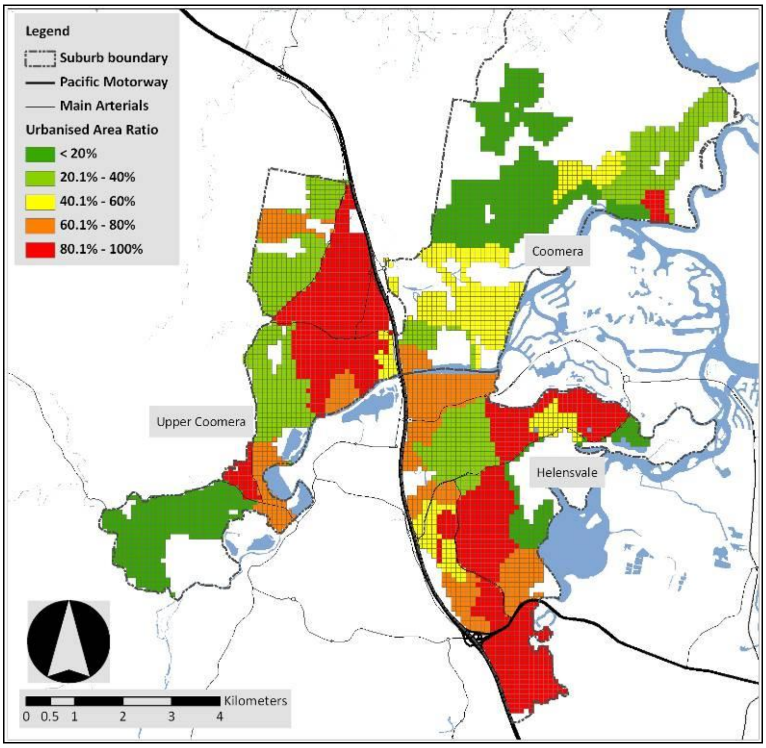


Figure 7.14 Land occupied by urban uses

There is a wide variation in the distribution of the grid cells into the urbanisation ratios as presented in Figure 7.15. Apparently, Coomera and Helensvale present a mirror image of each other. While more than 40% of Coomera has less than 20% urbanisation ratio, the opposite can be said for Helensvale's urbanisation ratio. In overall, approximately 30% of the area can be considered as fully urbanised.

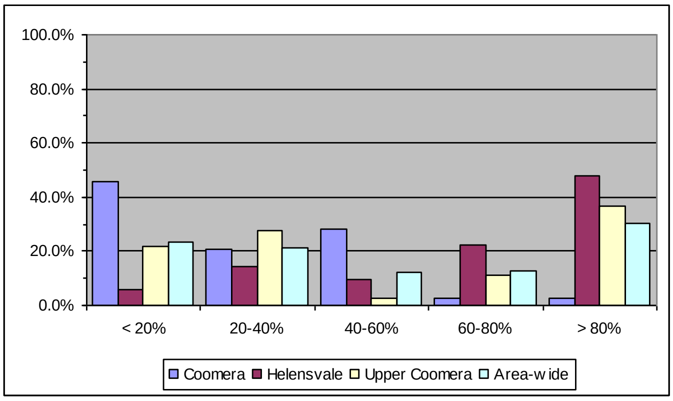


Figure 7.15 Distribution of grid cells in the study area by urbanised area ratio

7.6 LAND OCCUPIED BY ROADWAYS

When we look at the resource consumption issue from transport perspective, non-renewable fuel use or monetary resources/materials spent for transport means are the most popular indicators in similar studies. However, these indicators are highly correlated with VKT and number of vehicles, respectively. Obviously, it will be double counting to include these indicators in this study, because these two transport considerations have already been evaluated elsewhere. Here, land devoted to transport infrastructure comes forward as a clear alternative to fuel and monetary resources spent for transport activities. From another perspective, it is also a key indicator to assess the cost-effectiveness of transport investments.

All roadway areas were digitised by the help of overlay analysis tools in ArcGIS, because these areas were not recorded as polygons in land use map provided by the GCCC. After digitising, the total area of the roadways was saved for each CCD by using overlay analysis tools one more time. Then these areas were divided to CCD populations acquired from ABS. The Pacific Motorway is excluded due to its servicing population from which it is impossible to extract a subset of users corresponding to local users in the study area. Per capita roadway area figures were calculated by dividing the total road area in a CCD to CCD population.

Litman (2003) analysed different impervious surfaces in the urban areas and provided a typology for different types of residential densities. As a sub-class in his typology, per capita roadway area in different residential settings constitutes the basis of the determination of the benchmark values for this analysis. According to this, per capita roadways values of 33, 66, 133, 200 m² for low rise apartment block (4 stories), small, medium and large single family lots, respectively, were assigned to the upper limit of medium-high, medium, medium-low and low benchmark values, which are shown graphically below.

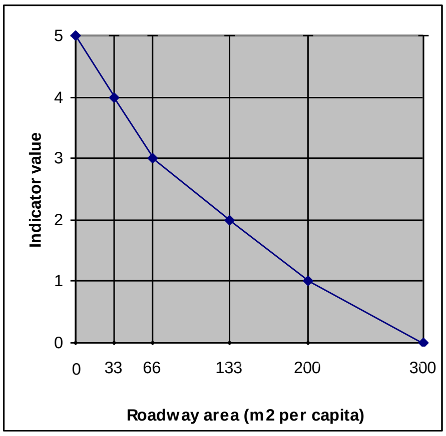


Figure 7.16 Normalisation thresholds for land occupied by roadways

Figure 7.17 shows the area-wide distribution of per capita roadways area as CCD boundaries. As expected, the residential areas with low density and commercial and industrial areas have the highest per capita road surface, so they are grouped under the low performing areas. The most outstanding observation is that medium density residential areas of Upper Coomera are also classified as low performing, unexpectedly. It might be due to the existence of wide roads passing through the neighbouring CCDs, such as, Abraham road, Old Coach road, Days road and Reserve road. There are only two CCDs performing above average in the area. Among all suburbs, Coomera stands out with its very low performance. Here, there are only a couple of CCDs with close to average values, and the rest of the area has very high values of per capita roadway area. When we analyse the average per capita road areas for Coomera, Helensvale and Upper Coomera, which are 1,011, 180 and 516, respectively, we can see that even if Coomera and Upper Coomera look similar in terms of low performance, their average values are significantly different from each other. The distribution of grid cells may provide more detailed information about this aspect.

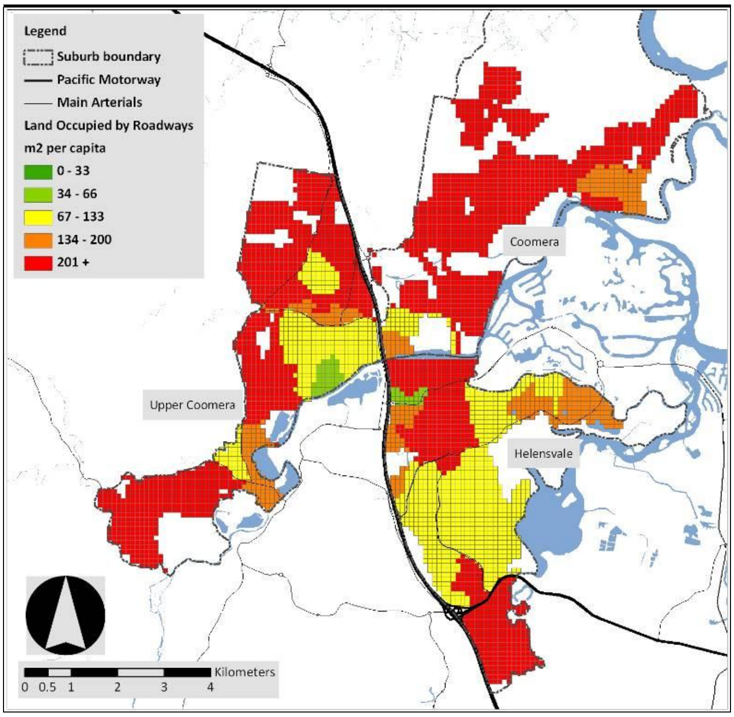


Figure 7.17 Land occupied by roadways

As it can be seen in Figure 7.18, Helensvale is relatively the best performing suburb among others (42% of Helensvale is in the range of 66-133 m^2). If we extend a bit the previous discussion about similarity of Coomera and Upper Coomera in terms of area-wide distribution of per capita road areas, we can say that nearly 88% and 70% of Coomera and Upper Coomera are placed in the last bin. Even though the percentages are close, seemingly, the average per capita road area for Coomera CCDs is nearly two times larger than the Upper Coomera average. It is very hard to convey the exact proportional difference from the figure, because the last bin consists of grid cells larger than 200 m² and gives a very general idea about the per capita roadway area.

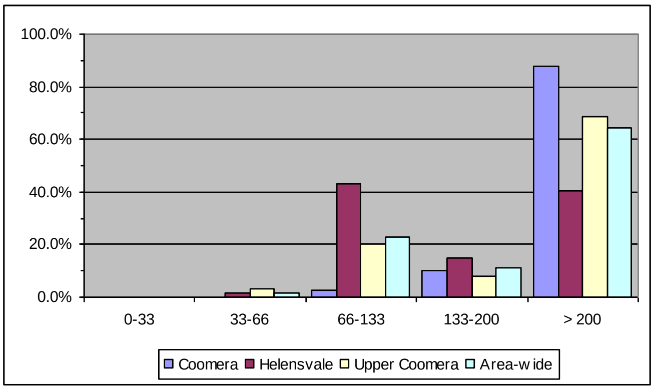


Figure 7.18 Distribution of grid cells in the study area by land occupied by roadways

7.7 TRAFFIC CONGESTION

Another transport related externality is the traffic congestion problem. Technically, traffic congestion starts to occur when the volume of the road exceeds 60% of its capacity and this is measured with the level of service (LOS) of the road segment. It crudely means when volume increases, manoeuvre opportunities and speed of the vehicles start to decrease and travel time increases. Naturally, the level of congestion changes with the saturation of volume to capacity (VC) ratio. Being directly related to the performance of the transport infrastructure, traffic congestion or VC ratio has been used as a mobility measure in city-wide or corridor level studies. The main reason behind inclusion of congestion to resource consumption category is related to a number of problems associated with it, longer travel times, high fuel consumption and high level of pollution generated by the slow moving traffic. Therefore, traffic congestion may be the most prominent one bearing both high economic and environmental costs to the public.

In this analysis, VC ratio provided by 2011 forecasts of the Gold Coast transport model was used as the LOS measure, and VC was weighted as to the length of each road segment. Then, these weighted average VC ratios were assigned to each CCD in the study area by employing overlay analysis tools of ArcGIS.

LOS classes of AUSTROAD were used to delineate benchmark values for this indicator. More specifically, the respective A, B, C and D classes of LOS were assigned as the upper limits of each indicator values. Normalisation ranges for each indicator values are shown graphically in Figure 7.19.

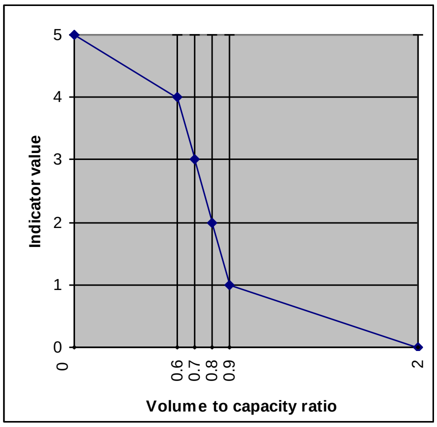


Figure 7.19 Normalisation thresholds for traffic congestion

As shown in Figure 7.20, there is no serious congestion problem except for the area encircling Exit 57 of the Pacific Motorway and the middle section of Helensvale. The average congestion figures for Coomera, Helensvale, Upper Coomera and the study area are 0.43, 0.54, 0.43 and 0.47, respectively. Due to urban form and travel characteristics in Helensvale as stated before, there is an intensification of urban activities and services, ergo a higher average congestion ratio in this area.

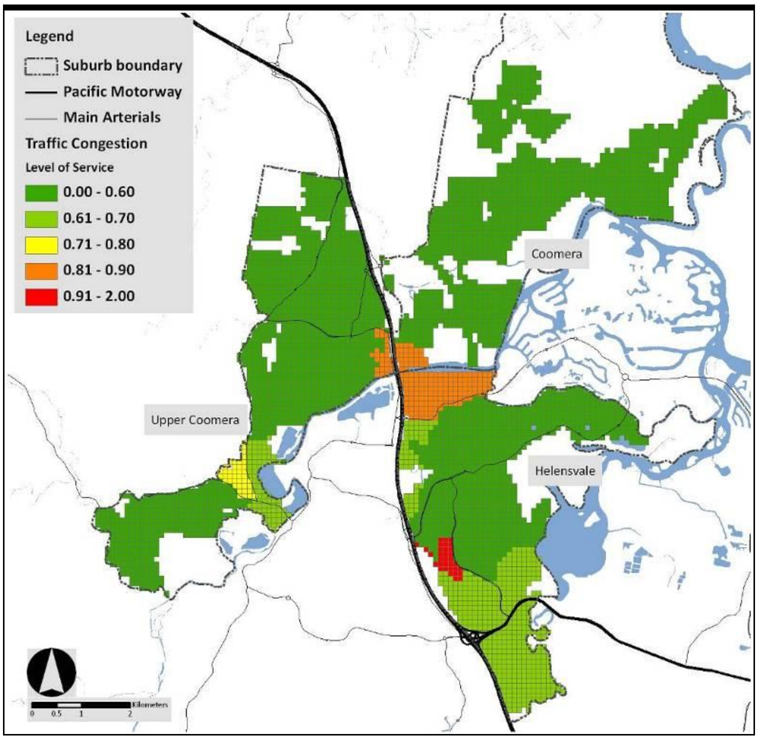


Figure 7.20 Traffic congestion

The distribution of grid cells among congestion level bins conforms with the previous figure. Approximately 91% of the area has 0.7 or less VC ratio which can be deemed as a very good outcome.

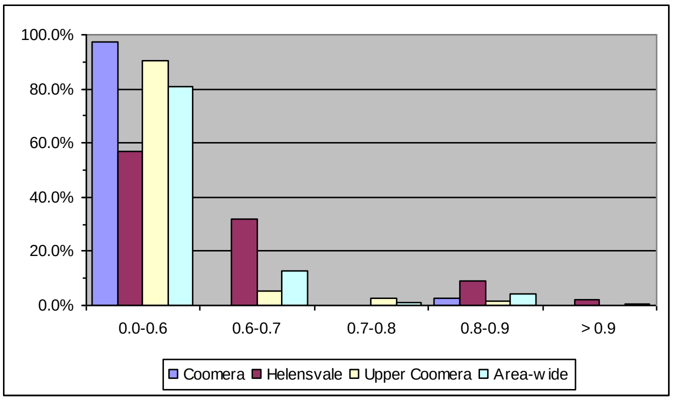


Figure 7.21 Distribution of grid cells in the study area by traffic congestion

7.8 TRAFFIC ACCIDENTS

The final indicator of the study is traffic accidents. Traffic accidents may be the most direct externality of transport activities. By the dramatic increase in the number of vehicles on the roadways for the last two decades, the number of accidents has increased significantly. Moreover, the economic, social and psychological costs of traffic accidents are becoming more serious day by day. This is the main justification of inclusion of traffic accidents under this category considering the public costs of traffic accidents occurring as in various forms, such as hospitalisation, insurance, reclamation, control systems, policing and first aid services, loss of manpower and other social costs associated with them. In this section the traffic accidents are analysed for each CCD to supply a basis to assess the ultimate objective of road safety and management endeavours, which is to diminish the traffic accidents on roadways.

There is an ongoing debate on how traffic accident statistics should be presented in academic or governmental documents. Some contend that traffic accidents should be given in a classical way, which means they should be normalised relative to the number of people or vehicles. For example, the best measure might be reporting the number of accidents per 1,000 persons if a city is the case, or reporting the number of accidents at an intersection averaged by total ingress and egress values if the case is an intersection. By this way, it is possible to compare the occurrence of the accidents with other settings using the same analysis unit. However, the opponents of this approach state that normalising the number of accidents undermines the importance of the phenomenon and may cause delays in taking necessary measures. They also assert that whenever average values are given, actual figures should be supplied as well. Following the latter approach, actual accident figures were used instead of population averages.

All traffic accidents were counted without looking at the severity, whether it is fatal or there is minor injury or property damage. Traffic accidents data was acquired from the QTMR in a tabular format which consisted of all relevant information, such as date, location, severity of accidents, and road and weather conditions. The location of each accident was converted to a point layer and by this, the number of accidents that occurred in each CCD was extracted via overlay analysis tools in ArcGIS. Then, these values were assigned to coinciding grid cell by using a join query in ArcGIS.

The ultimate intention of all road safety and management endeavours is to decrease the number of total accidents to zero, which was strongly emphasised by The Swedish Road Administration (Whitelegg & Haq, 2006) as Vision Zero programme and has been adopted by a number of EU countries. Following a similar approach, benchmark values for car accidents were designated starting from zero. Since the number of accidents is a whole number, the upper limit of the successive range was defined by adding one to the lower limit of previous range. The upper limit of the last bin corresponds to the maximum number of accidents that occurred in the study area in 2009. The normalisation thresholds are given in Figure 7.22.

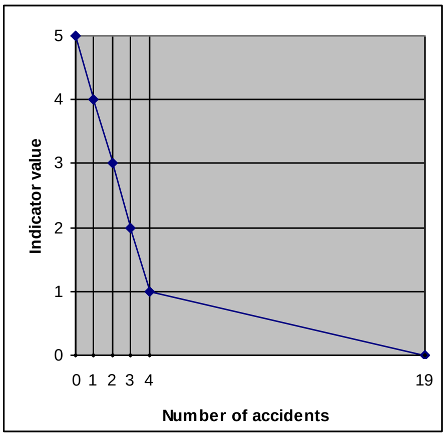


Figure 7.22 Normalisation thresholds for the number of traffic accidents

In Figure 7.23, the number of accidents that occurred in each CCD is mapped for the year of 2009. It can be easily seen in the figure that the incidents accumulate in the areas close to the major roads and commercial uses. Typically, this indicates that there is a correlation between the traffic volume and the number of accidents. As related to low densities and low traffic volumes, very low number of accidents are recorded in the peripheries of Coomera and Upper Coomera. The average number of traffic accidents that occurred in 2009 is 3.17, 4.6, 2.14 and 3.3 for Coomera, Helensvale, Upper Coomera and the whole area, respectively.

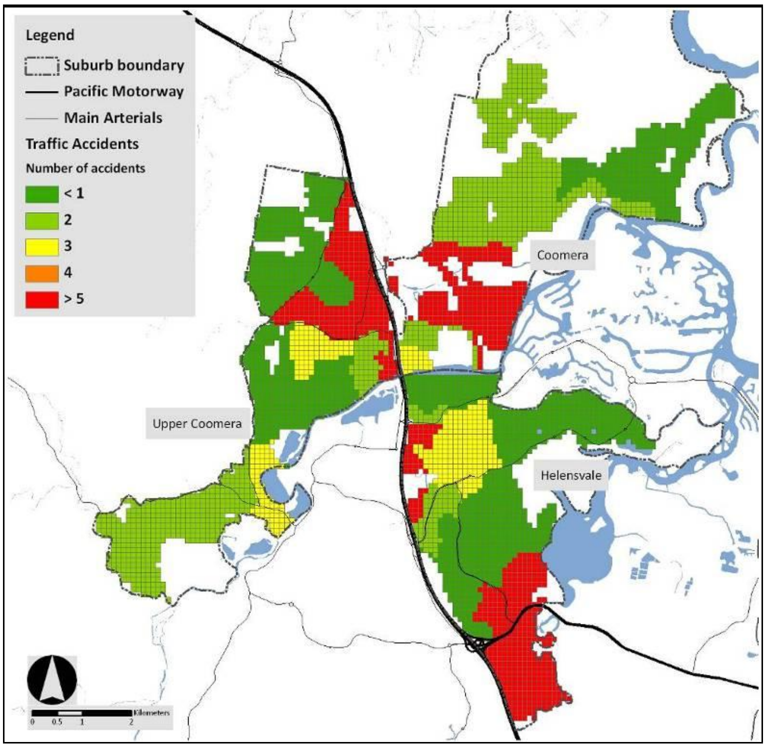


Figure 7.23 Traffic accidents

The distribution of grid cells in the area shows that one or no accidents occurred in 52% of Helensvale. Following Helensvale, Coomera shows a relatively good performance in terms of the number of accidents. In overall, nearly 20% of the area, which is also equally distributed between the suburbs, suffers from 4 or more traffic accidents. Particularly, the CCDs around Helensvale centre and the industrial zone in Coomera experienced the highest number of accidents in the area. For example, the highest number of accidents, 19 traffic accidents, occurred around Helensvale shopping centre in 2009.

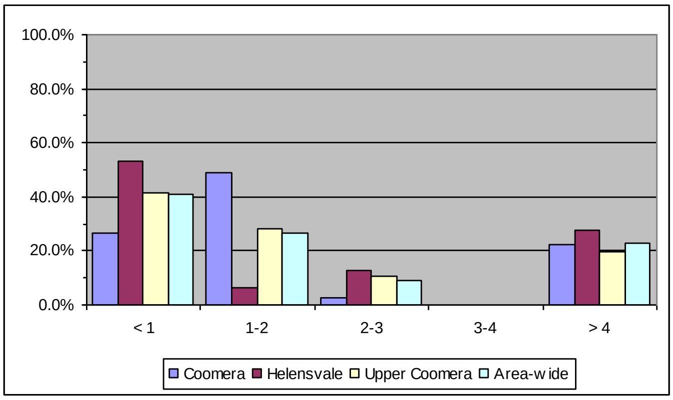


Figure 7.24 Distribution of grid cells in the study area by traffic accidents

7.9 SUMMARY

As expected, all pollution indicators were co-related with the volume of the roads, with a minor exception of GHG emissions, which also depended on the population density. While the effect of traffic volume on indicator score was the most obvious in noise pollution analysis, the other pollution indicators did not strictly correlate with the traffic volume. The benchmark values adopted and spatial interpolation methods employed were the two main reasons of the latter phenomenon. It can be said by examining the results that there were a limited number of locations where the pollution level was problematic (e.g., around Helensvale shopping centre and Coomera exit on Pacific Motorway), but in overall, there was no pollution problem in the study area.

The results of resource consumption indicators showed that urbanisation and roadway per capita indicators were closely related to the population density and tended to yield low scores in CCDs with low densities. While traffic congestion was not a serious problem, there were a few locations where the number of traffic accidents relatively high. These were located at or around the suburb centres and were due to the high vehicle circulation in these locations.

In summary, the study area had neither a serious pollution nor the resource consumption problem. The general observation about them was that the areas which performed better in previous two themes yielded low scores in these indicators. Obviously, this was a natural outcome of high vehicle and pedestrian circulation and subsequent high traffic volumes on the roads.

Chapter 8: Results and discussion

This chapter aims to report the final output of the model as to the normalisation, weighting and aggregation schemes adopted, and to discuss its utilisation for policy formulation and robustness of the composite indicator by taking into account other alternatives to its principal formulation. First the composite indicator scores for 4404 grid cells computed by following normalisation (benchmark-based normalisation), weighting (expert opinion) and aggregation (linear additive) procedures as explained in the methodology chapter are presented. After elaboration of prominent aspects and comparison of each suburb in terms of final scores, a further analysis is presented to show category level performances and possible compensation among both categories and indicators. Considering the advantages of category level analyses in detecting cluster formation in the study area, suburb clusters are further analysed and its utilisation for policy formulation is discussed. Lastly sensitivity of the composite indicator is reported to reflect on robustness of the findings and to highlight important factors to be considered if the outcomes will be used for policy formulation.

8.1 ANALYSIS OF THE COMPOSITE INDICATOR SCORES

By using benchmark-based normalisation, expert weighting and linear aggregation for 24 indicators of this study, a composite index score was generated for each grid cell in the study area. It should be noted that the linear aggregation (i.e., weighted average of the indicators) of the 5 point Likert scale used for normalisation and expert weighting, which sums up to 1, produces a range of index scores between 0 and 5, which represent the worst and best cases for a grid cell, respectively. Accordingly, all descriptive analyses in this section refer to this range. The final output of the composite indicator creation process can be seen in Figure 8.1. As a note, the composite scores change between 1.29 and 3.37, and the average of them is 2.19. That means, the performance of the study area can be regarded as medium, and there exists neither a best performing nor a worst performing area. There are only two districts where the composite score is between 3 and 3.5, Upper Coomera centre

(E5:F6 range on the map) and the northern parts of Helensvale centre (H9 and H10). The medium performing areas gather around these two locations. The peripheries of all suburbs have scores at the low end of the overall score distribution. The worst performing district is the isolated eastern parts of Upper Coomera, and this is mainly due to the low performance of this location in transport and urban form indicators.

Figure 8.2 illustrates the distribution of the composite scores for the study area. It can be roughly said by looking at Figure 8.2 that, while the half of the area is located in below average bin, the other half is in the average score bin. What is more, nearly a quarter of the cells are just around the limit of the average performance bin (the frequency bin showing values between 1.75 and 2 in the figure and labelled as 2), and they can be considered as the primary candidates for performance increase.

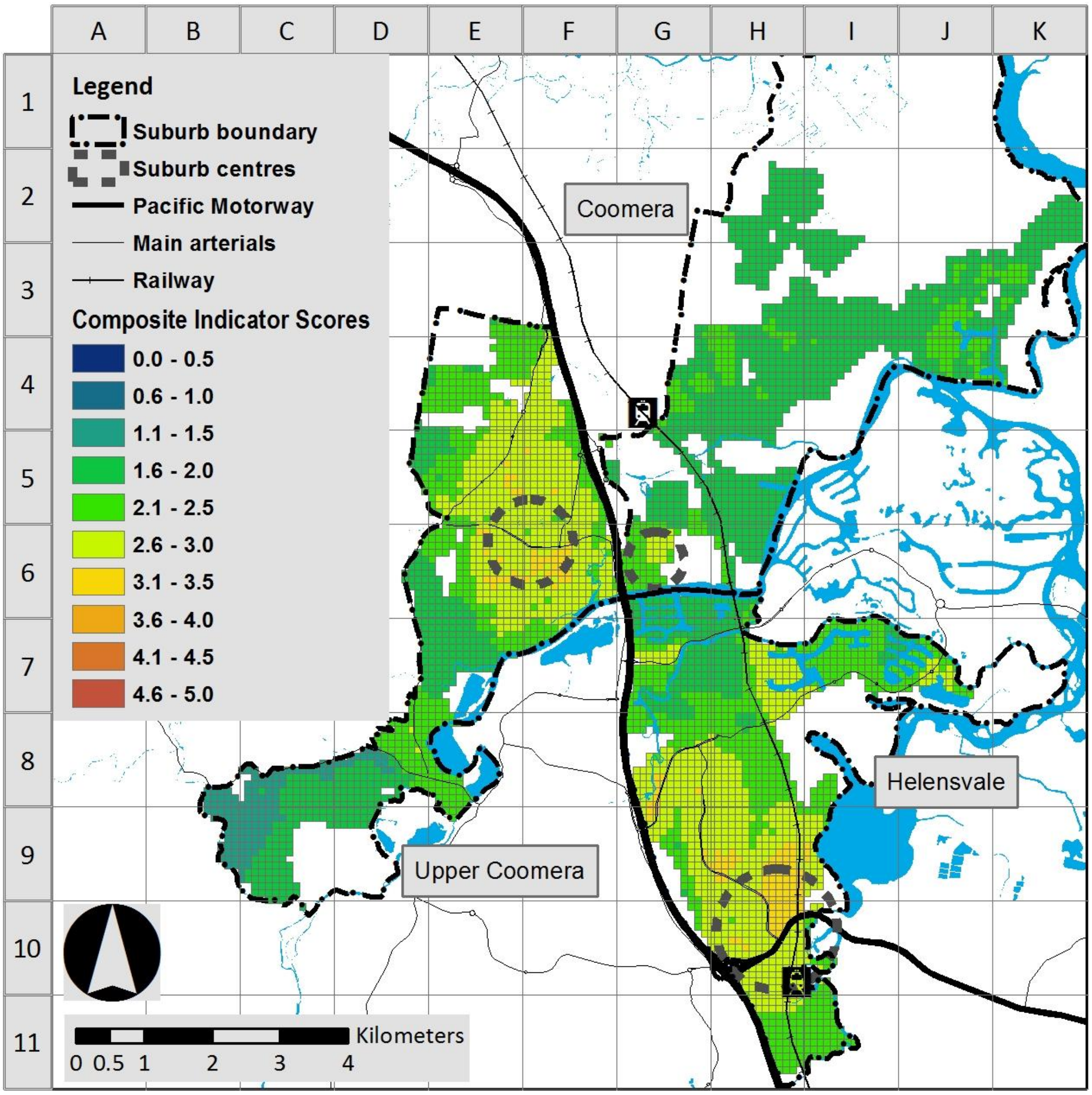


Figure 8.1 Final composite indicator scores

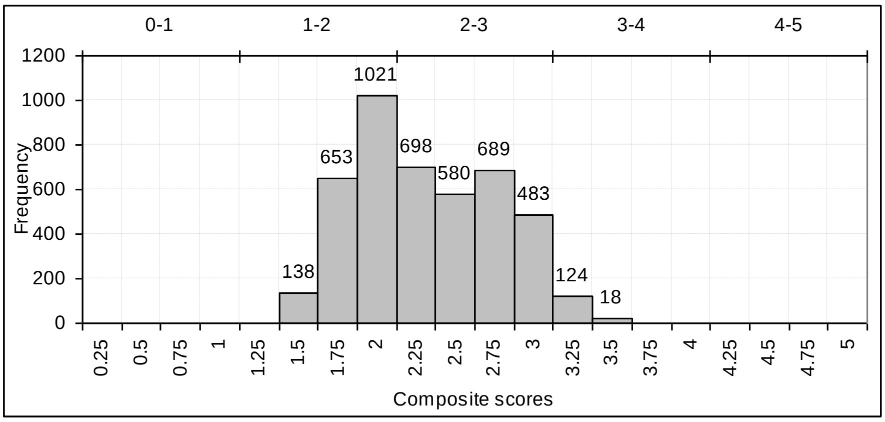


Figure 8.2 Distribution of the final scores

While Figure 8.2 depicts a general picture of the area performance, Figure 8.3 shows suburb specific details of the score distribution. The first observation about the figure is that Helensvale has the lowest and highest number of cells in 1-2 and 3-4 score bins, respectively, and shows the best performance in the study area context. It is followed by Upper Coomera and Coomera. Additionally, more than 66% of the medium-high performing cells are in Helensvale. While Upper Coomera encompasses the lowest performing area (see B8:C9 range in Figure 8.1), most of the low performing cells are located in Coomera. While only 20% of Coomera yield a medium score, the rest lies in the medium low performance bin.

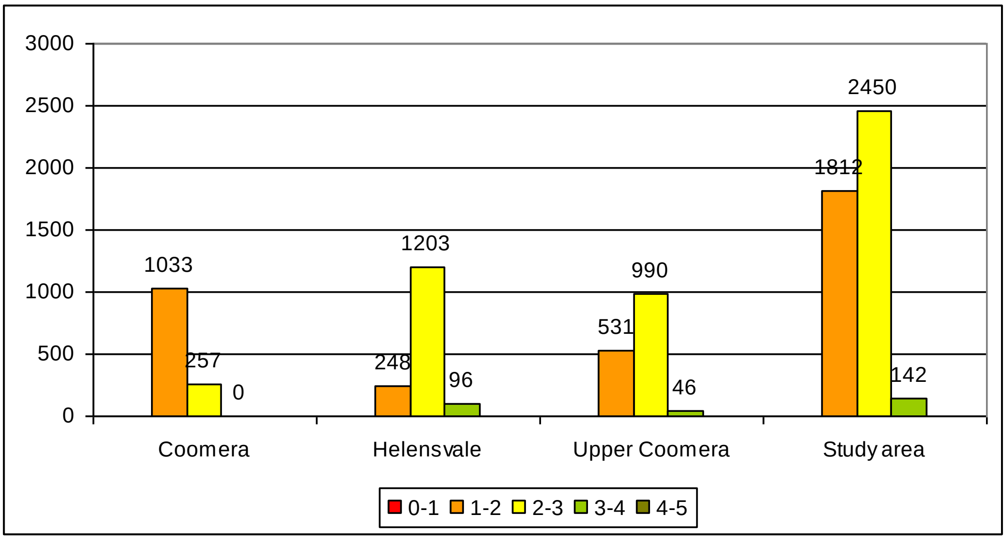


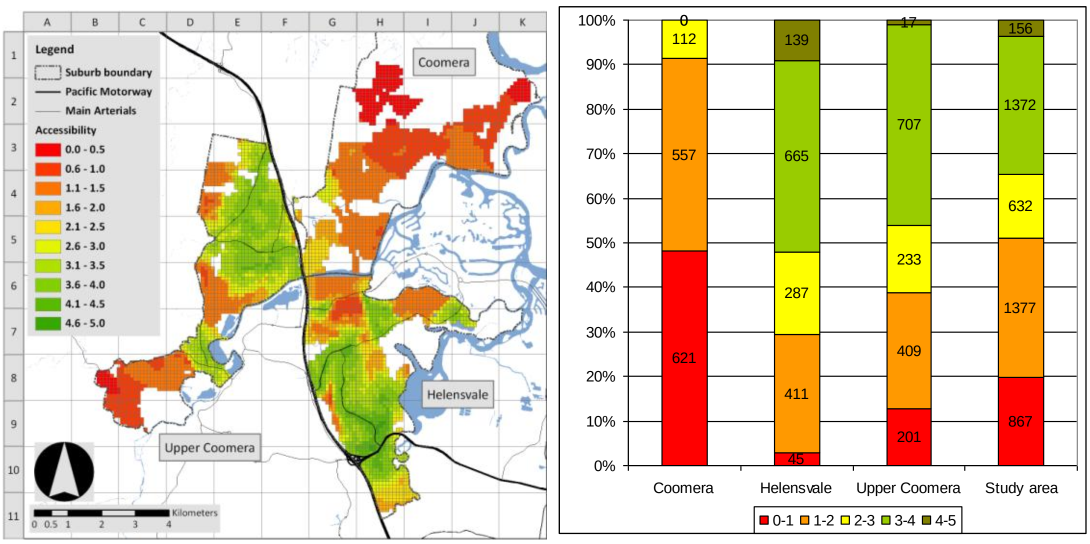
Figure 8.3 Final composite indicator scores

As stated previously, the main problem of any composite indicator exercise is the substitution between the indicators' scores as the result of arithmetic aggregation applied, which obscure the fine details of location specific performances. In order to detect this compensation effect, the category base scores were inspected. The main purpose of this was to provide a clear idea about which categories compensate each other more frequently and to what extent.

8.1.1 CATEGORY SCORES

In this section, each category score is presented by two figures, one a map showing the location specific scores, and the other a cumulative bar graph showing the distribution and ratio of the category scores. The categories are explained in the same order as given in the indicator list.

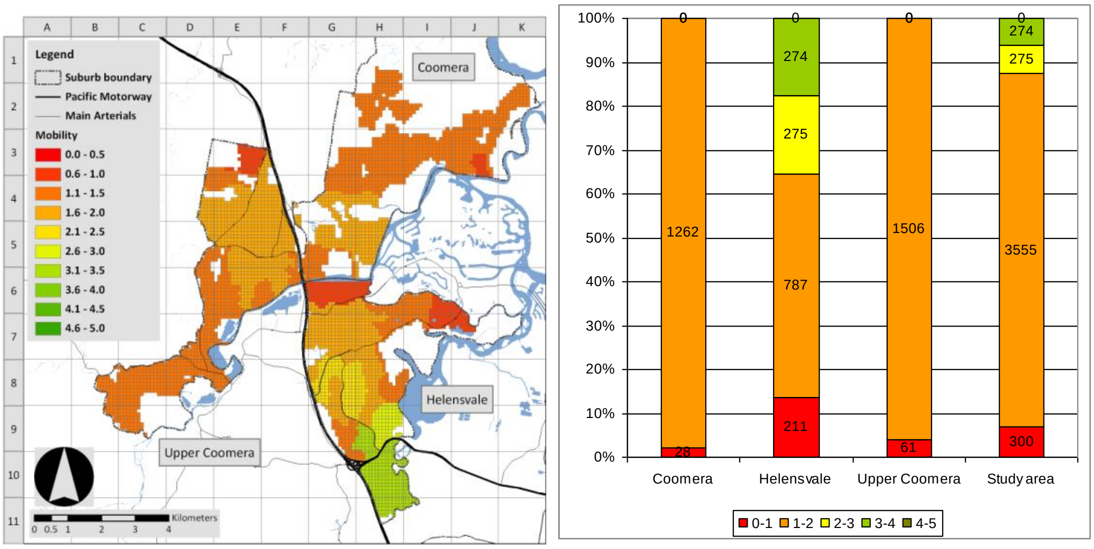
Figure 8.4 shows the accessibility category composite scores for the study area and distribution of the cell scores for the suburbs. In Figure 8.4a, in line with expectations, the areas close to the public transport routes and suburb centres, and the surroundings of main arterials yield high scores. As explained previously, Coomera is the most disadvantageous suburb mainly due to the scarcity of the urban services and public transport services. On the other hand, Helensvale is the most accessible suburb with more than half of the cells located in above medium performance (53%). While the central locations of Upper Coomera perform as well as Helensvale, the suburb peripheries of the former appear problematic. Overall, significant variation exists in the area in terms of composite scores, and nearly half of the area yields medium or better scores.



(a) **(b)**

Figure 8.4 Accessibility category composite score

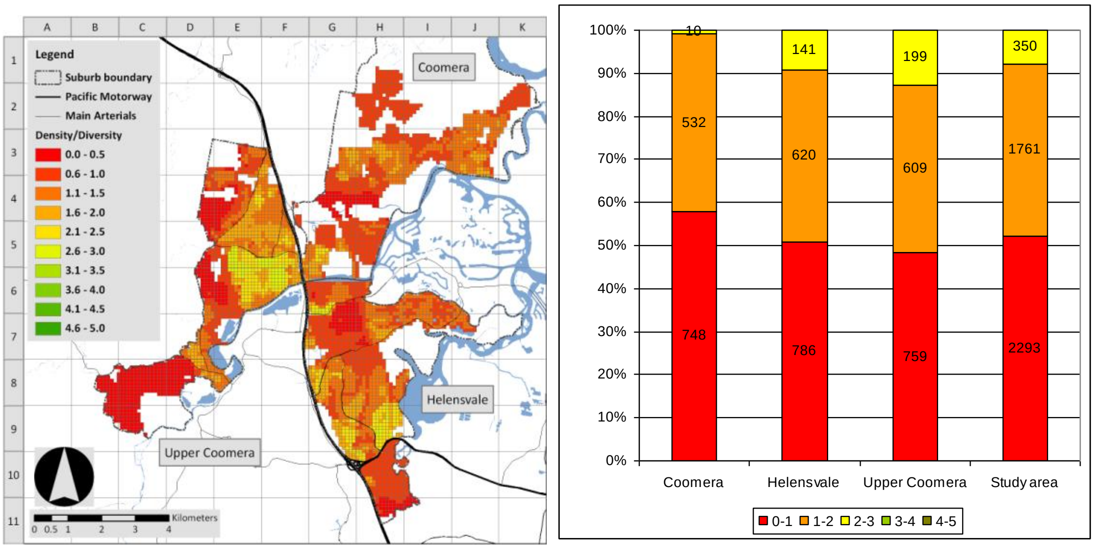
As shown in Figure 8.5a, the mobility performance of the area can be regarded as medium or medium low. There are a few locations, mostly in and around Helensvale centre, showing comparatively better performance (G9:H10 range on the map). The areas with the lowest performance are located in the northern parts of Upper Coomera (E3 on the map) and Helensvale (G6 and I6 on the map), and in general, the scores tend to diminish in the peripheries of Coomera, Upper Coomera, and the northern part of Helensvale. A general outlook of these scores can be seen in Figure 8.5b. Here, the similarity in the distribution between Coomera and Upper Coomera is obvious, and only 18% of Helensvale yields a medium-high performance. Helensvale centre is the only area that yielded the best performance in this category.



(a) (b)

Figure 8.5 Mobility category composite score

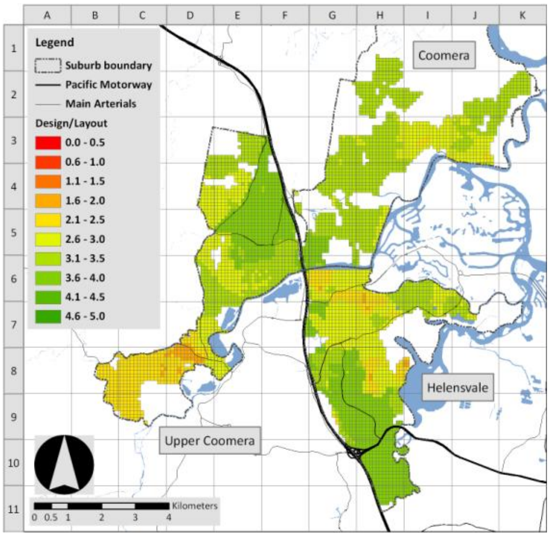
As it can be seen in Figure 8.6a, the density and diversity category is the most problematic among all categories. While the central locations of three suburbs comparatively score better, the periphery districts of suburbs have the lowest values. This is particularly so for a few CCDs of Upper Coomera in the east (B8:C9 range, E4 and E6), the northern parts of Helensvale (G6:H7) and the middle section of Coomera (G4:H4). It can also be seen that two indicator values on the parcel level, land use mix and average parcel size, are the main source of the variety in the category scores. In Figure 8.6b, it is hard to compare the performance of the suburbs due to a close resemblance in the distributions, but Upper Coomera marginally performs better than the others.

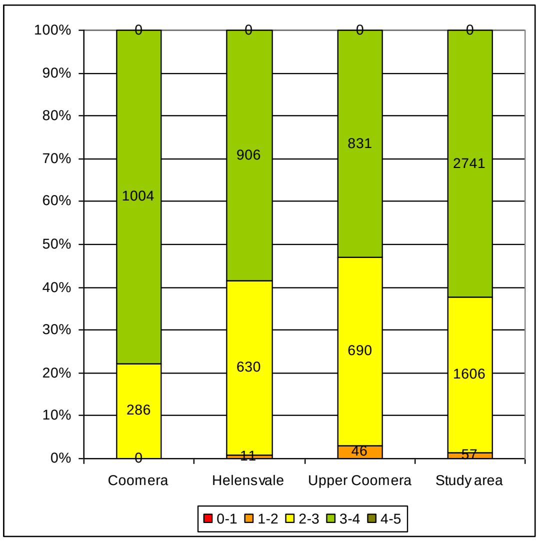


(a) (b)

Figure 8.6 Density and diversity category composite score

All suburbs perform better in the design category when compared to the transport and urban form categories as shown in Figure 8.7a. Particularly, Helensvale and Upper Coomera centres embody highly scored cells. The most problematic region in the area is the western periphery of Upper Coomera (D8 on the map). This figure reflects CCD level performance mostly, and the small variations in scores are the result of open space per capita indicator, which was calculated at the parcel level. It can be easily seen in the Figure 8.7a that the areas in the north and middle parts of Helensvale (G6, H6 and H8) show medium-low performance due to the low accessibility to open spaces. Figure 8.7b shows that nearly 80% of Coomera yields medium-high score. Overall, while a little more than 35% of the area is located in the medium score range, approximately the 62% of the area shows medium-high performance.

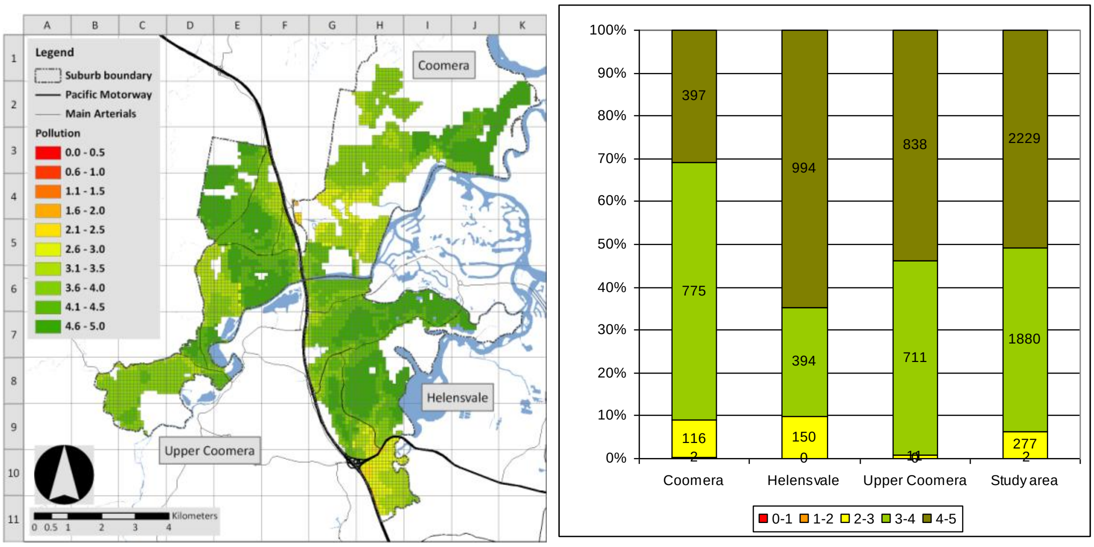




(a) **(b)**

Figure 8.7 Design category composite score

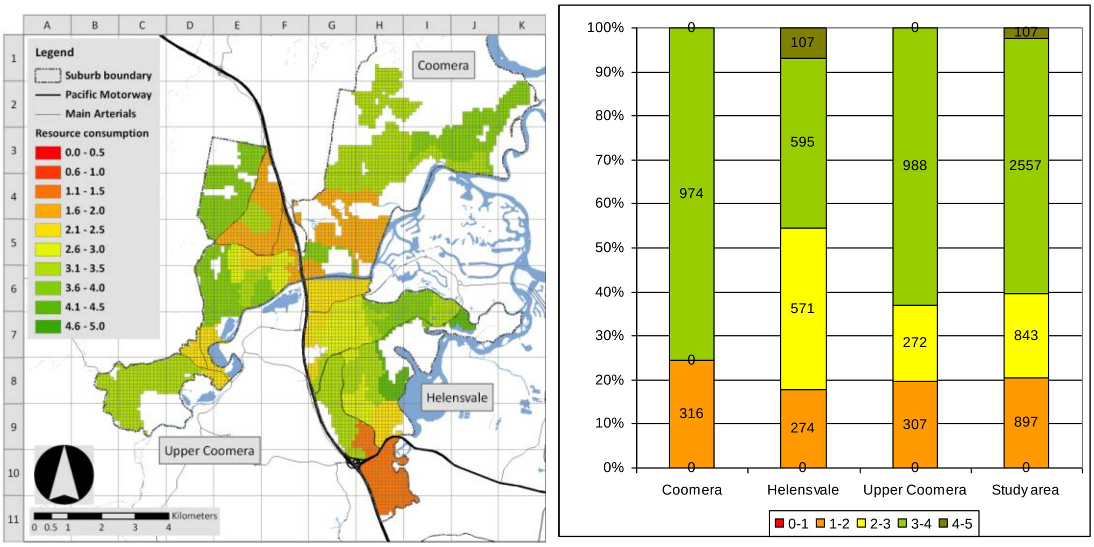
The composite of the pollution category indicators is given in Figure 8.8a and b. Contrary to higher performances in accessibility category, the areas close to the arterial roads show relatively lower performance than the inner parts of the area mainly because of the correlation between high traffic volume and the pollution emitted. The most striking observation is that in previous analyses the centres of Upper Coomera and Helensvale yielded a similar performance, but in terms of pollution, Helensvale centre is the most problematic district in the area as opposed to Upper Coomera centre. Moreover, the areas performing relatively poorly in the transport and urban form categories now perform better. This is the most remarkable indication of the compensation effect between transport and pollution indicators. Figure 8.8a can be generalised as the higher the traffic volume, the more the pollution in the surrounding areas. Figure 8.8b shows that a little more than 50% of the area scores between 4 and 5, and Helensvale is the suburb where most of the highest as well as the lowest performing cells are located. Even though the study area performs remarkably well in this category, lower weights assigned to these indicators reduce the overall contribution of them.



(a) **(b)**

Figure 8.8 Pollution category composite score

A general observation about Figure 8.9is that the category scores a perfect fit in the CCD boundaries because all indicator data in this category was gathered at the CCD level. Interestingly, the figure closely resembles the results of traffic accidents indicator analysis. The main reason behind this could be the higher weight of the traffic accidents indicators and the similar performance of the areas in terms of other resource consumption indicators. Furthermore, highly urbanised areas perform below the average, while periphery regions appear more advantageous. There are a couple of CCDs which perform very well in this category in Helensvale. Very similar to the previous figures, Helensvale embodies most of the highest performing cells, as it can be seen in Figure 8.9b. In overall, nearly 80% of the area performs medium or above medium scores (19% medium and %61 above the medium score).



(a) **(b)**

Figure 8.9 Resource consumption category composite score

Previous analyses indicated that the study area performs at or below average in transport and urban form domains, but performs better in the externalities category. In order to clarify how this relationship between categories compensate each other and in some sense normalise the final score, all the category scores are summarised in Figure 8.10. When we look at the distribution of the final composite values for each category, it is easy to see the accumulation in the second and third bins. It can also clearly be seen in the figure that the low index values of the transport and urban form categories are compensated by the high index scores of the externalities category. It is a clear indication of over-normalisation due to the substitution between the category scores. Additionally, relatively higher weights of the transport and urban form categories and the great number of the design category cells grouped in 0-1 score bin shift the composite scores to the average and below average performance bins.

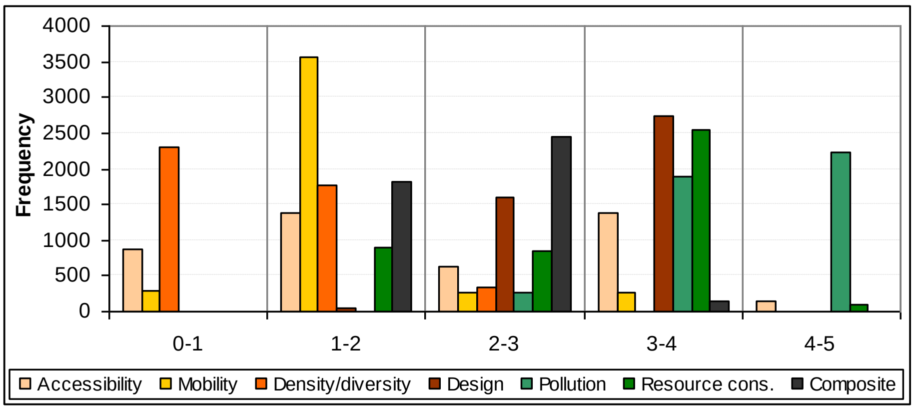


Figure 8.10 Distribution of final scores as to each category and composite

The findings of this section confirm that there is compensation between indicators, and this information can be utilised to extract practical consequences, which can help to support planning decision making. In order to reach this end, there needs to be a further clarification on the clustering of the category scores in the study area. Therefore, extra analysis was performed to show the prominent cluster formations in the area according to the category scores, which are summarised in the next section.

8.1.2 SUBURB CLUSTERS

Having revealed the category-based and composite indicator scores, another analysis was conducted to provide extra information on the clustering. For this, each category was separated into three clusters, which represent low, medium and high performance according to the relative category-based composite scores. By using k-mean cluster analysis via the Statistical Package for the Social Sciences (SPSS), each cell was assigned a cluster identifier. It should be noted that the range of the final category scores were used in this analysis. Next, this information was dissolved by GIS tools to show the clusters on the map. The results of k-mean cluster analysis are given in appendices (see Table 9.12 on p.304), while the map showing the clusters can be seen in Figure 8.11. Basically, Figure 8.11 shows the agglomeration of similar category attributes geographically. In this map the clusters greater than 10 Ha are shown for visual convenience. Each cluster is shown according to the relative cluster classification and the weight of each category. For simplicity, each performance identifier (i.e., H for high, M for medium and L for low) were assigned a pseudo score (i.e., 3 for H, 2 for M and 1 for L) and this was linearly aggregated (i.e. weighted average of category scores) with each category weight (see p.114 for category weights). The total score for each cell was listed in ascending order together with the category identifier. Following this, cells with the same category identifiers were dissolved by using GIS to reveal the clusters and by using the ranking list in the previous step, remaining identifiers (i.e., clusters greater than 10 Ha) were listed as seen in the legend of Figure 8.11.

According to this figure, there are good and poor performing clusters of each suburb. For example, while the clusters located in G9:H9 range, D5 and E5, and F5 on the map are the best performing clusters for Helensvale, Upper Coomera and

Coomera, the clusters in G7, A8:C9 range and F4:G5 range are the poor performers, respectively. As the best case is HHHHHL, the worst case is LLLMLL (see the map key for the description of labels). In addition to this, the distribution of these clusters is given in Figure 8.12.

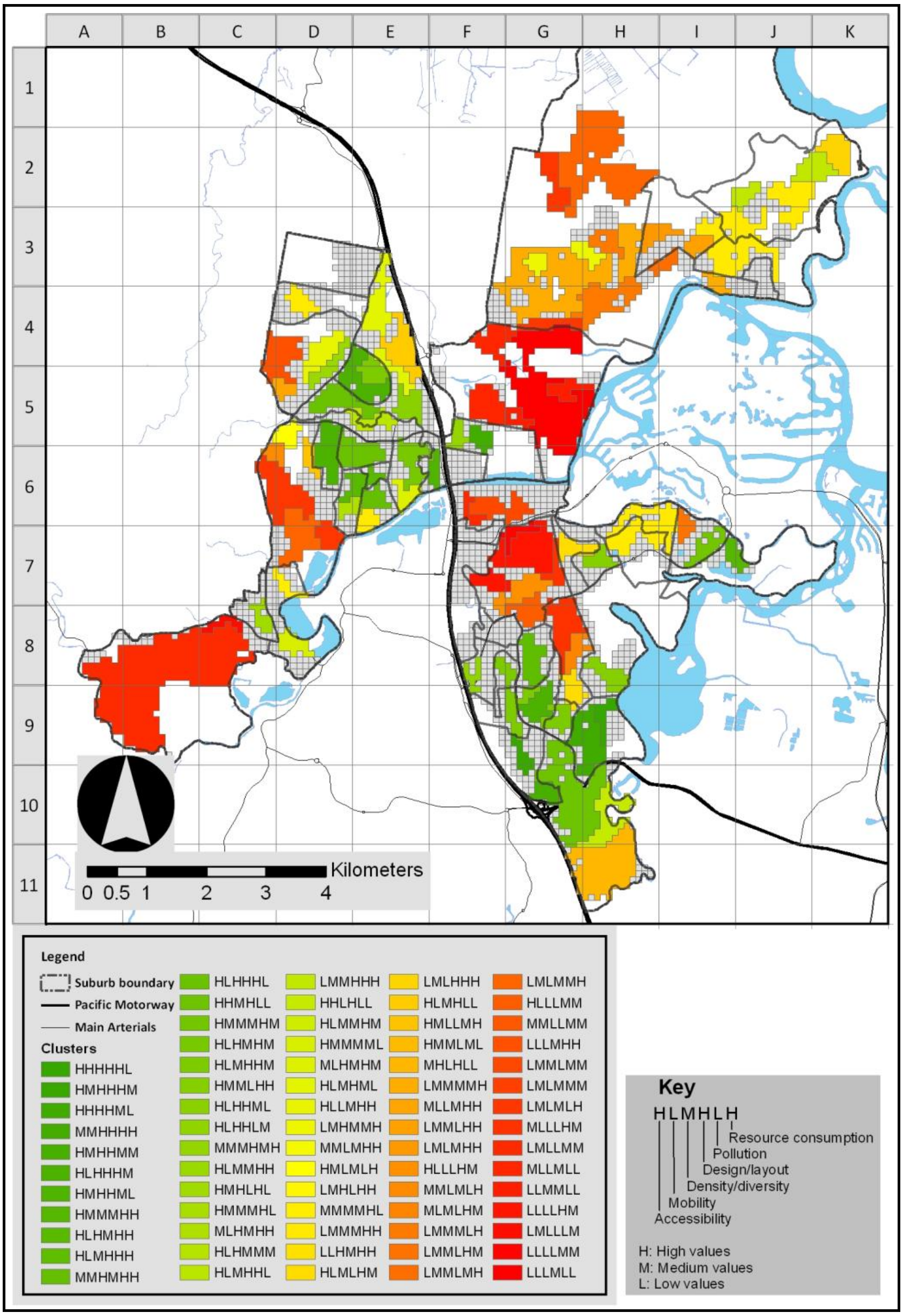


Figure 8.11 Clusters for the study area

Figure 8.12 clearly shows that the most frequent cluster in the area is LMLLMM cluster (the 7% of the study area). This represents the cells which are located in low clusters for the accessibility, density/diversity and design categories, but perform medium for the mobility, pollution and resource consumption categories, respectively. Actually, the first 31 items in the cluster list given in Figure 8.12 cover 66% of the study area, while 37% of the study area is covered by cells which perform medium or mostly low in the transport and urban form categories, but yield mostly high performance in the externalities categories. The opposite phenomenon (i.e., medium or mostly low in externalities but medium or mostly high in the transport and urban form categories) is evident only for the 7% of the study area. This information does not only confirm the existence of the compensation between categories, but also gives an idea about the direction of this compensation.

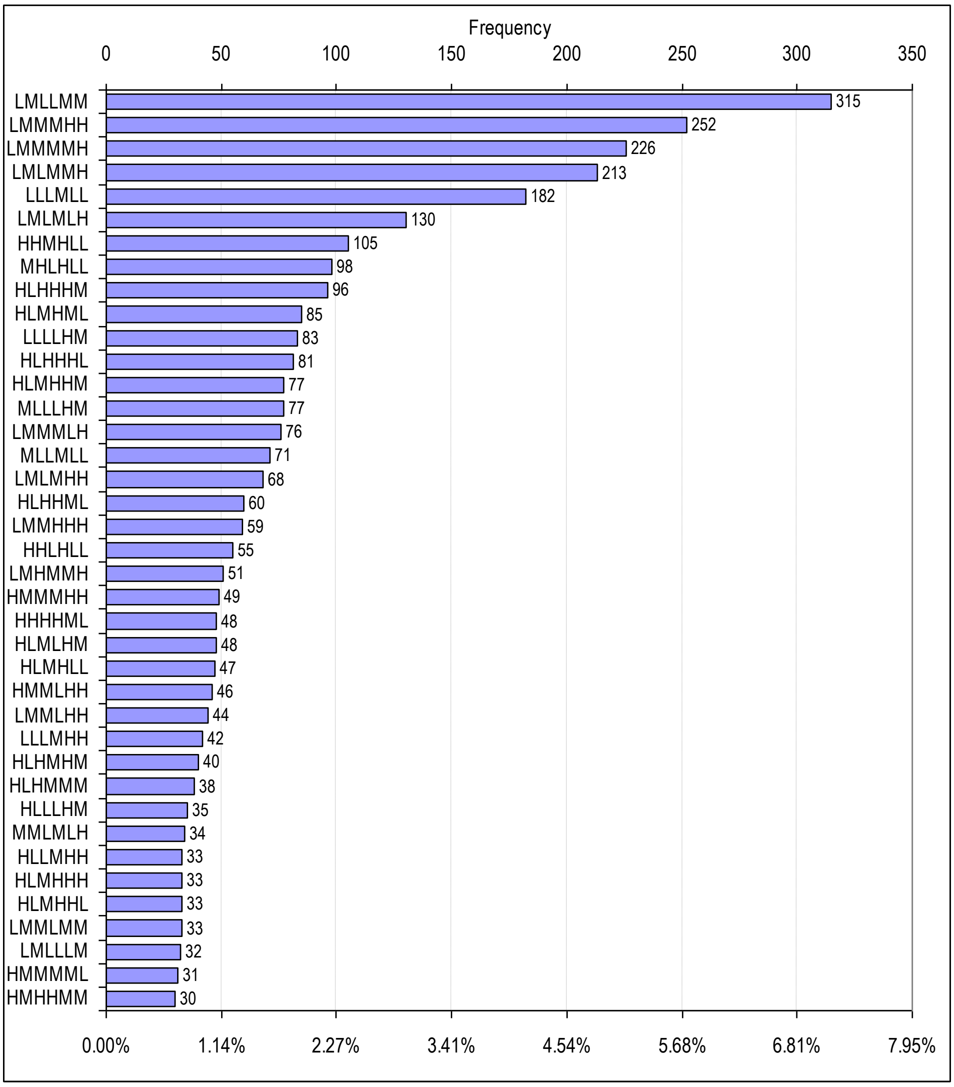


Figure 8.12 Frequency of the clusters (greater than 30 occurrences)

In order to show how this information can be utilised for planning policy formulation, a more general clustering formation is used for each suburb. For this, maps showing clusters greater than 10 Ha for each suburb were prepared and are given below.

Figure 8.13 shows clusters in Coomera. A general property of the strings used to define the clusters shows that this area particularly performs low and medium in the transport and urban form categories respectively, but performs medium or high in the externalities category. Depending on the locational advantages and the close proximity to the emerging Coomera centre, the areas located on the lower left part of the map are the best candidates for accessibility and mobility interventions. It is expected that this suburb will accommodate most of the population growth in the Gold Coast during the next 10 years to 2020. Accordingly, the number of urban and public transport services will increase parallel to the new urban development. When the available land stock in the area is taken into account, this suburb can be considered as the best candidate for transit oriented urban development. One important note here is that a special attention should be paid while designing the future development here not to diminish the advantages in the pollution and resource consumption categories.

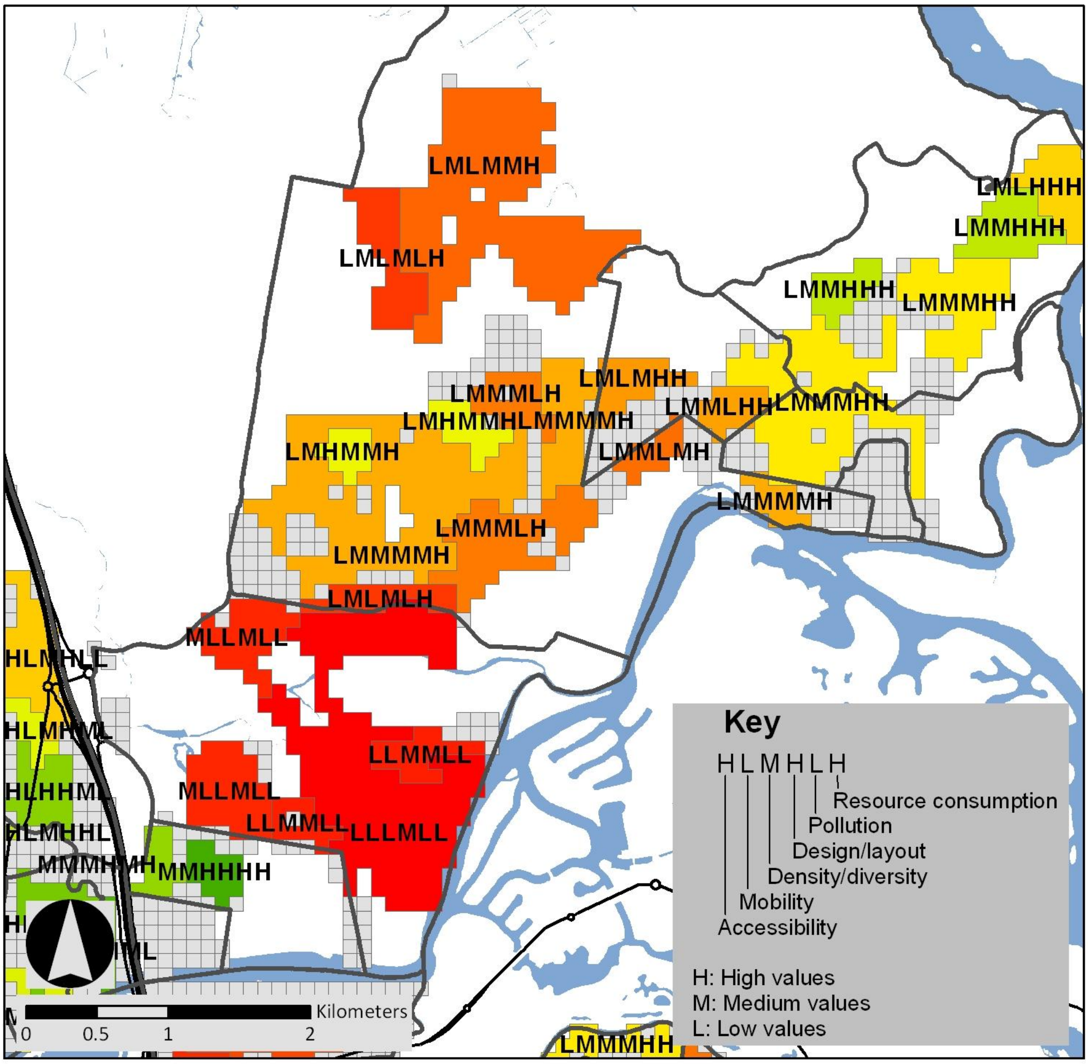


Figure 8.13 Coomera clusters

The clusters defined in Helensvale can be grouped into three classes. As can be seen in Figure 8.14, the clusters located on the upper half of the map have the same qualities as the other periphery clusters, low performance in the transport and urban form but high in the externalities categories. Another class can be seen on the lower part of the map labelled as MHLHLL and HHLHLL. This area covers the Helensvale shopping centre and reflects the opposite of periphery area performance. These areas can be the best candidates for WSUD applications, and environmental monitoring is required here to ensure that air and stormwater benchmarks are not exceeded. Furthermore, the available land in the southernmost cluster, which is close to various urban services and public transport interchange, can be planned for residential development, and this may also lead to a better land use mix and job to housing ratio. Between these two classes, the best cases take place in this study area context, which is the last class for Helensvale. These areas can provide inspiration for the intervention options applicable for the whole study area.

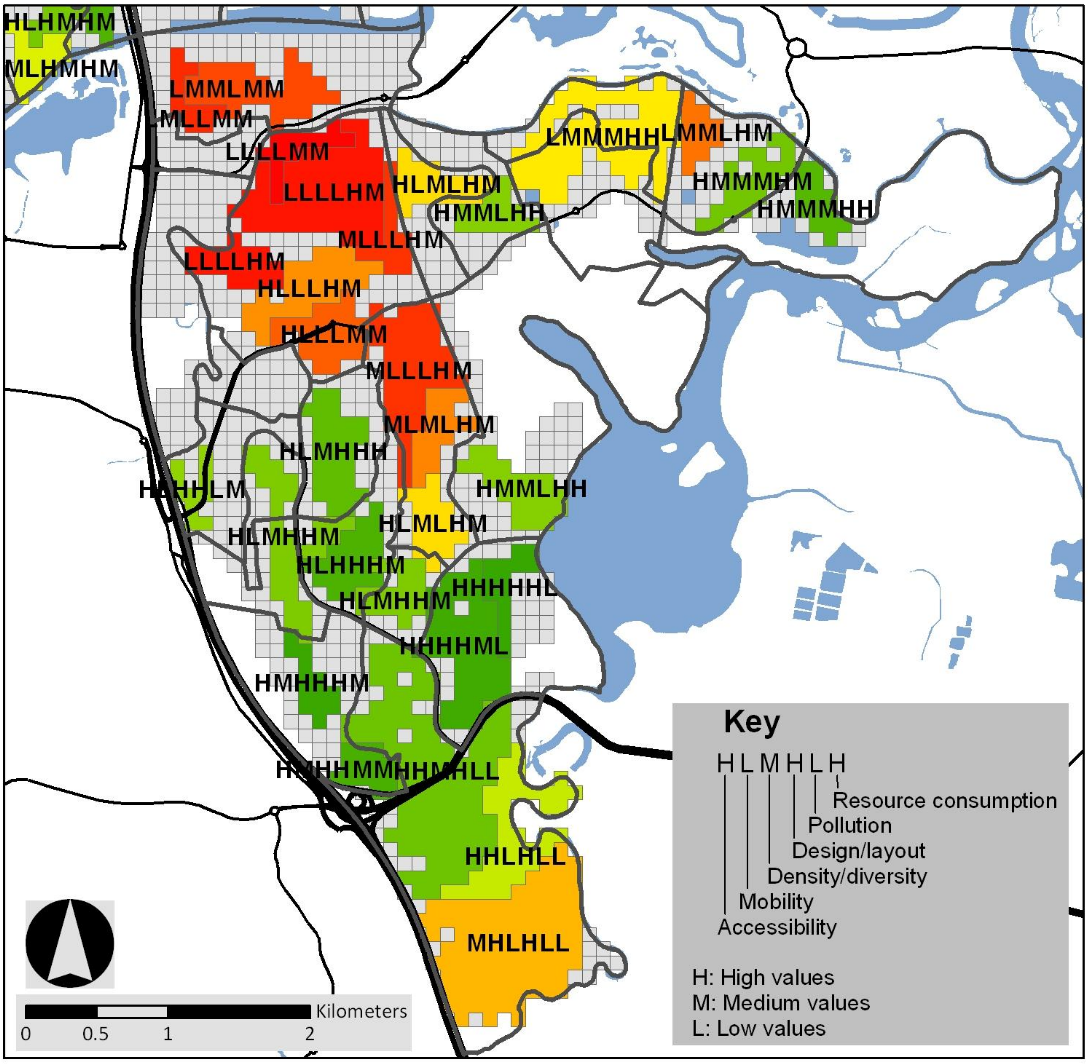


Figure 8.14 Helensvale clusters

Figure 8.15 shows the clusters in Upper Coomera, which can be easily grouped into two. While the areas saturated around the upper right corner cover good performing areas in the study area context, the clusters around the southwest extension of Upper Coomera have similar qualities to that of other periphery clusters. As mentioned previously, the southernmost cluster is the lowest performing area in the study area. Accessibility and mobility improvement can be advised for this district, but the locational disadvantages (e.g., long distance to the central locations, very low population density, and high auto dependency) will make it hard to apply these interventions effectively. Upper Coomera is the second best suburb in terms of overall performance, and a couple of clusters exist around Upper Coomera centre (coloured with darker green), which can be considered as the best cases according to the indicators defined by this study.

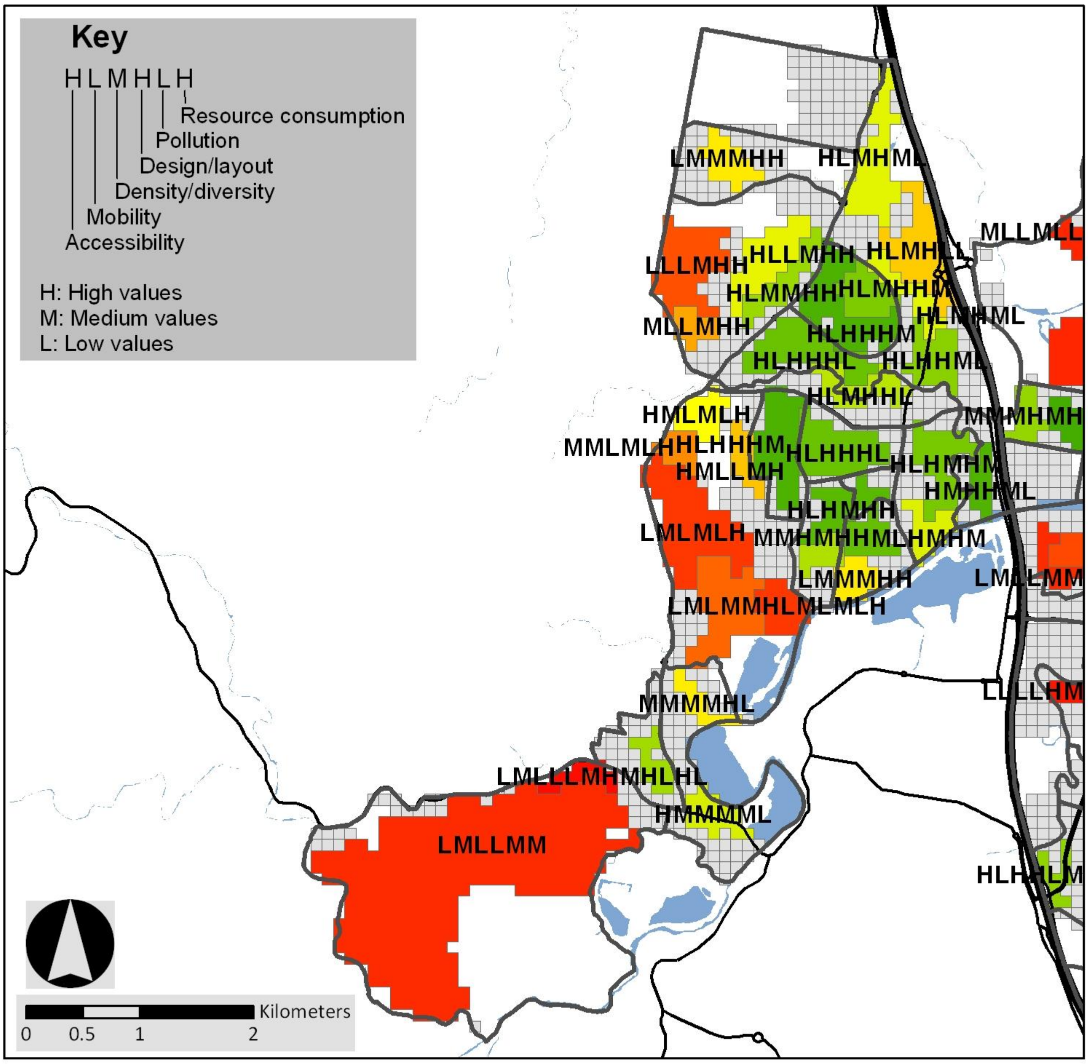


Figure 8.15 Upper Coomera clusters

8.2 SENSITIVITY ANALYSIS

The main aim of this section is to answer the question ‘How much change may occur in the final model results if we adopt different normalisation, weighting and aggregation schemes?’ Accordingly, the results of a number of analyses, which were conducted to show robustness, stability and parsimony of the model, are presented in this chapter. Firstly, the structure of the sensitivity analysis is given to provide a general idea about which alternatives are evaluated. Following this, the specific details of normalisation, weighting and aggregation alternatives are explained by referring to the approaches advised by similar studies. Then, the results of these analyses are discussed in terms of the robustness of the model.

The main aim of this sensitivity analysis is to reflect on the validity and reliability of the model result by testing the alternatives to the decisions made on the previous stages of composite indicator creation. In this sense, there are three subjects which require revaluation. These are normalisation, weighting and aggregation methods as the given order in the composite indicator creation process. Originally, the model was formed by using benchmark-based normalisation, expert opinion weighting and linear additive aggregation. The alternatives to these methods, which are analysed here, are two normalisation (min-max and z-score) and weighting (equal and factor analysis) schemes, and one aggregation (geometric) approach.

8.2.1 ALTERNATIVES TO NORMALISATION SCEHEMES

Normalisation is employed to omit scale and magnitude effects of the units of each indicator to make any arithmetic operation viable. There are two considerations requiring special attention to yield a valid normalisation output. They are the scale of measurement (categorical, ordinal, interval and ratio) and the existence of outliers. While it is not possible to normalise categorical (nominal) data, there are a number of alternatives to other data scales with changing resolutions and accuracies. As a rule of thumb, the ratio and interval scales provide more accurate results than the ordinal scale. Here, another issue related to the interval and ratio scales is that some normalisation schemes basing on a value or limit can generate variations in the normalised values. The well-known examples of this issue are measurement taken in different units of temperature (Celsius and Fahrenheit degrees in interval scale) and length (metric and imperial unit in ratio scale). More clearly, the measurement of the same case using different units can give different values when normalised according to the best performer. Because of this, invariability of the scale should be checked and necessary transformation should be applied (Nardo, et al., 2008).

Since this is the starting point of the arithmetic operations in composite indicator creation procedure, the existence of the outliers in the dataset should be taken into consideration before normalisation. In some cases, the outliers may lead to serious biases in the results depending on their magnitude. This is particularly the case when the central tendency measures (i.e., arithmetic mean, standard deviation) are used. The most preferred method to diminish the effects of outliers is data winsorising. It is principally a data transformation technique by rounding-up or -down the outliers to the closest limit value adopted (Esty et al., 2005). In this study, the outliers are winsorised to the 2.5% percentile values at each tail of the distribution. After this, two normalisation schemes, min-max and z-score normalisations, are explored and reported in this chapter.

Min-max normalisation

Min-max normalisation is the simplest and most widely employed normalisation technique by similar studies. It involves scaling the values to the minimum and maximum data range. More specifically, it can be presented as follows:

$$I_{new} = \frac{I_{raw} - I_{\min}}{I_{\max} - I_{\min}}$$

where *I* corresponds to the indicator value(s), *new*, *raw*, *min* and *max* subscripts denote transformed and original indicator value, and minimum and maximum range of the indicator values, respectively. Since the transformed indicator value can vary between 0 and 1, a further scaling was used to transform values in a range between 0 and 5 by multiplying normalised value by 5.

z-score normalisation

This involves scaling the data to zero mean and unity variance, which is also known as standardisation. More specifically, it can be presented as follows:

$$I_{new} = \frac{I_{raw} - \mu}{\sigma}$$

where *I* is the indicator value(s), *new* and *raw* subscripts denote standardised and original indicator value, μ and σ correspond to mean and standard deviation of indicator value distribution, respectively. There is one more step to transform new values to the desired indicator score range which is 0-5. For this, the mean value was taken as the medium performance value.

The rest of the values were transformed by using cumulative distribution values. The normalisation was made according to the definition of high or low performance for each indicator. For example, if the case was ‘the higher the value, the better the indicator performance’ for an indicator, then higher cumulative distribution values were multiplied by 5 and assigned to the respective cell, or vice versa.

8.2.2 ALTERNATIVES TO WEIGHTING SCHEMES

The weight of an indicator basically reflects its relative importance and acts as the substitution rate when the indicators are aggregated. In sensitivity analysis, testing different weighting schemes may be the most important stage because the adopted weighting scheme can change the final index value considerably. In practice, there are a few general approaches mostly employed by other studies as mentioned by Nardo et al. (2008) and Kondyli (2010):

- Adopting weights resulting from a participatory method;
- Assigning equal weights; and
- Using a statistical model of weights.

The weighting scheme formed according to a participatory process (i.e., the expert opinions) was presented in the previous chapter, and this is the principal weighting scheme of this model. The remaining weighting schemes, equal weighting and statistical model weighting, were trialled as suggested. Factor analysis was selected as the statistical method due to its common use by similar studies, simplicity and useful properties in forming an alternative indicator categorisation, and the results of factor analysis (FA) is discussed at the end of this chapter.

Equal weighting scheme

The use of equal weighting for composite indicator creation has been one of the most common approaches due to mainly two reasons, its simplicity and the practicality in overcoming the issues of “insufficient knowledge of causal relationships or a lack of consensus on the alternative.”(Nardo, et al., 2008, p.31). For example, Esty et al. (2005) argued the use of equal weights for sustainability indicator studies as “no objective mechanism exists to determine the relative importance of the different aspects of environmental sustainability.” (p.66). This statement also implies that if there is no prior information related to the importance of the indicators, the best option could be to use equal weighting. For this study, equal weighting means that the reciprocal of total number of indicators (1/24 ~ 4.17%) and categories (1/6 ~ 16.67%) is to be assigned to each indicator and category, respectively.

Factor analysis weighting scheme

The main question which FA tries to answer is "do the individual variables co-vary because they have underlying factors in common?' (de Vaus, 2002). In order to extract the underlying factors, two decisions are necessary. The first is to decide on which factor extraction method is to be used. The second decision is to work out how many factors to extract. De Vaus (2002) explains the main steps in forming 'scales' using factor analysis as follows:

- Selecting the variables to be analysed;
- Extracting an initial set of factors;
- Extracting a final set of factors by 'rotation';
- Constructing scales based on the results at step 3, and using these in further analysis.

In the context of this study, the methodological details of these steps can be further explained according to the order given above as follows:

- Correlation analysis and the Kaiser-Meyer-Olkin (KMO) test were used to select relevant variables (see Table 9.13 and Table 9.15);
- The number of factors were decided by Eigenvalues threshold (i.e., greater than 1) and inspecting the change in scree plot. The variation explained by entered variables were extracted from the sums of squared loadings (see Table 9.14 and Figure 9.5);
- Principal component analysis and Varimax with Kaiser normalisation were used for the extraction and rotation of the components, respectively (see Table 9.16);

- A weight for each variable was calculated by dividing the square of rotated variable loading to the variance explained by this factor in which this variable was placed considering the high loading value in a previous step.

The only problem related to the applicability of FA was the existence of five highly correlated indicator pairs as shown in Table 8.1. A correlation coefficient ratio 0.7 was taken as the benchmark value as suggested (de Sá, 2003; Lang & Secic, 2006). While the high correlation was particularly problematic with the pairs of 'population density', the others were just above the given threshold. As mentioned in the chapters where the indicator analysis results were given (see Chapters 6 and 7), this was an expected result and was mainly due to the calculation method using the CCD population as denominator for greenhouse gas and roadway area calculations. It should be noted that this analysis was conducted with 'normalised' indicator values. Consequently, the selected benchmarks generated new data scales and generally narrowed the data range, which led to a decrease in standard deviations and increased the correlation coefficient. The correlation coefficient dropped to -0.67 when raw data was used for this analysis. Moreover, it can be said that high correlation between population density and roadway area per capita will not be necessarily the case for the other settings. For the given 47 CCDs, this correlation exists, but it also depends on various other qualities of the transport network and settlement pattern (e.g., width of the roads, parcel size, dwelling density, timing of the road provision, and so on) which could be different for the other settings. The same assertion can be made for the rest of the highly correlated pairs. Therefore, inclusion of these pairs to the analysis, specifically the 'land area occupied by roadways-population density' pair, will not cause a considerable bias. Furthermore, the KMO measure of 0.727 (see Table 9.15) is an indication of small partial correlations among variables and the sample is adequate to conduct the FA.

Table 8.1 Correlation analysis results

Highly correlated indicators	**Correlation coefficient**
Access to LUDs by walking – Access to public transport stops	0.717
Access to LUDs by cycling- Access to LUDs by walking	0.728
Greenhouse gases from transport – Population density	0.799
Land area occupied by roadways - Population density	0.914
Land area occupied by roadways - Greenhouse gases from transport	0.704

The resulting weighting scheme is given in Table 8.2, and the details of the factor analysis with respect to the aforementioned procedures are given in the appendices (see p.305).

Table 8.2 Category and indicator weights extracted from factor analysis

Category/Indicator	Weight	Weight rank
Accessibility	**0.18**	**2**
Access to public transport (PT) stops	0.036	17
Access to land use destinations (LUDs) by PT	0.054	5
Access to LUDs by walking	0.040	14
Access to LUDs by cycling	0.047	8
Mobility	**0.17**	**3-4**
Number of car trips	0.014	24
Commuting distance	0.046	10
Parking supply in employment centres	0.062	1
PT service and frequency	0.047	9
Density and diversity	**0.19**	**1**
Parcel size	0.035	18
Population density	0.040	15
Land use mix	0.060	3
Housing and jobs proximity	0.058	4
Design and layout	**0.14**	**6**
Street connectivity	0.038	16
Traffic calming	0.032	20
Pedestrian friendliness	0.045	11
Open space availability	0.022	22
Pollution	**0.17**	**3-4**
Air quality	0.041	12
Greenhouse gases from transport	0.048	7
Traffic noise	0.019	23
Stormwater quality	0.061	2
Resource consumption	**0.16**	**5**
Land area occupied by urban uses	0.034	19
Land area occupied by roadways	0.041	13
Traffic congestion	0.049	6
Traffic accidents	0.032	21

A close examination of the table above reveals that the 'category' weights given in Table 8.2 are not so different than the equal weighting scheme where the expected category weight is 16.6%. Moreover, the weights assigned by factor analysis to a number of indicators are very close to the equal weighting values (4.2%). When ranked according to the last column of Table 8.2, the weights of the first and last five indicators are comparatively higher and lower, respectively, than the equal weighting scheme. Considering this, it can be said that the first five and last five indicators will determine the differences between factor analysis and equal weighting schemes.

8.2.3 ALTERNATIVE TO AGGREGATION

As stated previously, the fundamental question of aggregation is whether the compensation between indicators is allowable. Since aggregation by using addition and multiplication allows compensation between indicators, there are two practical approaches to detect the compensation problem. In the previous chapter, the discussion on category scores and intervention clusters showed that the compensation between the transport-urban form and externalities categories in both directions is significant. As an extension of this discussion, the changes in the final composite scores were analysed. In addition to the linear addition of the indicator scores, which is the principal aggregation method in this study, geometric (multiplicative) aggregation was trialled as an alternative to this method. The results of both linear and geometric aggregation are reported.

8.2.4 RESULTS OF THE SENSITIVITY ANALYSIS

It should be noted that 18 possible different indexing schemes exist (i.e., multiplication of 3 normalisation schemes, 3 weighting schemes and 2 aggregation schemes) applicable to the indicator data. In this section, comparison of 17 alternatives with the principal indexing construct is reported. The results of this analysis are presented in four main groups. Firstly, the changes in the composite score are given for each suburb considering the values of the cells with the lowest and the highest scores assigned by the alternative indexing schemes. Following this, the overall distribution of differences from the final scores for 17 alternative schemes is presented and discussed. Next, an analysis of which alternative schemes yielded the most negative and positive scores is provided to describe how different normalisation, weighting and aggregation schemes produce varying outputs. Lastly, the range of the final score changes is mapped for the study area.

Figure 8.16 shows the range of changes in the final scores produced by different indexing schemes for Coomera. The x-axis of the figure corresponds to the individual grid cells when they are sorted in ascending order according to the composite indicator score. Accordingly, the smallest case number (i.e., 1) corresponds to the smallest composite value, or vice versa. While the red dots represent the final composite score of this study, the gray spikes correspond to the range of negative and positive differences from the final scores. It can be seen in Figure 8.16 that the final scores change between 1.56 and 2.64. The range of differences is as high as -0.71 and +0.99, and the greatest range of difference is 1.43. As marked by the blue ellipsis on the figure, values between 1.7 and 2.2 have the highest fluctuation in the final scores. As a general observation, while the negative differences do not show a considerable variation, the positive differences vary significantly, particularly on the right hand side of the figure.

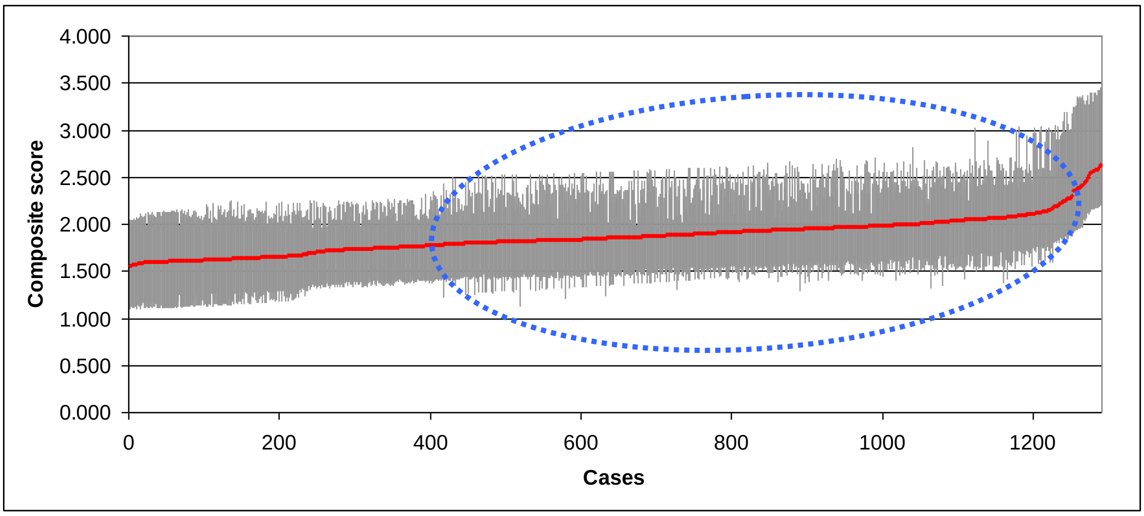


Figure 8.16 Range of changes in the final scores for Coomera

As can be seen in Figure 8.17, the final scores change between 1.51 and 3.37 for Helensvale. This suburb is the best performing locality as stated previously, and performed well particularly in the indicators of transport and urban form categories. The range of differences is as high as -0.8 and +0.98, and the greatest range of difference is 1.65. The blue ellipsis in Figure 8.17 shows the values where there is a comparatively large fluctuation in the differences. Similar to Coomera, this fluctuation is situated between 2.1 and 2.6 final indicator score range. The fluctuation in negative values is relatively large and the most significant for Helensvale when compared to the other suburbs.

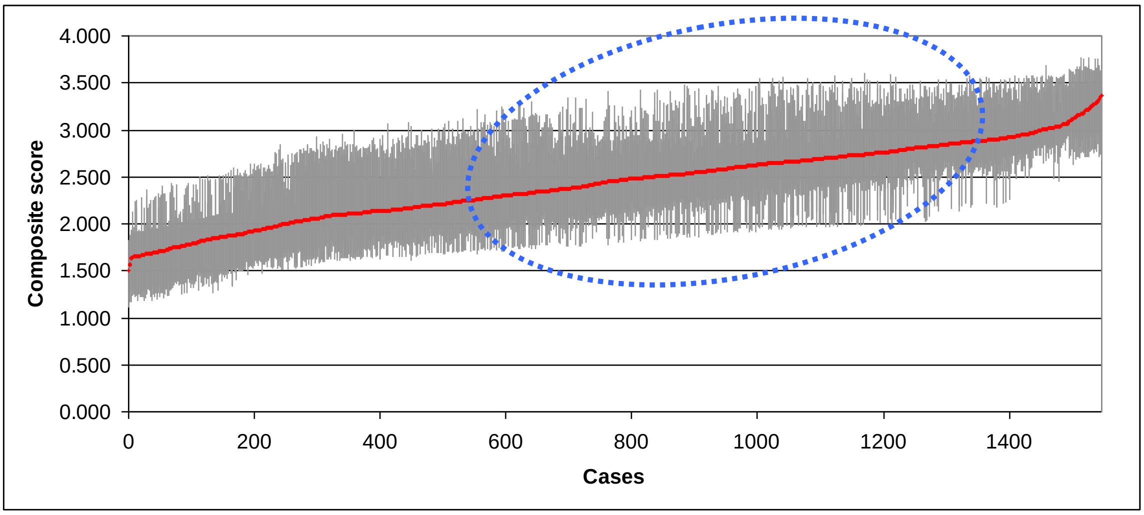


Figure 8.17 Range of changes in the final scores for Helensvale

Figure 8.18 shows that the final scores change between 1.29 and 3.2, and the range of differences is as high as -0.76 and +0.92 in Upper Coomera. The greatest range of difference is 1.38. The blue ellipsis in Figure 8.18 marks the range where the fluctuation in the final scores is significant and is located between 1.9 and 2.6 final score range. The range of values smaller than 1.9 form a nearly perfect buffer around the final scores. The differences are minimal in the rightmost end of the figure.

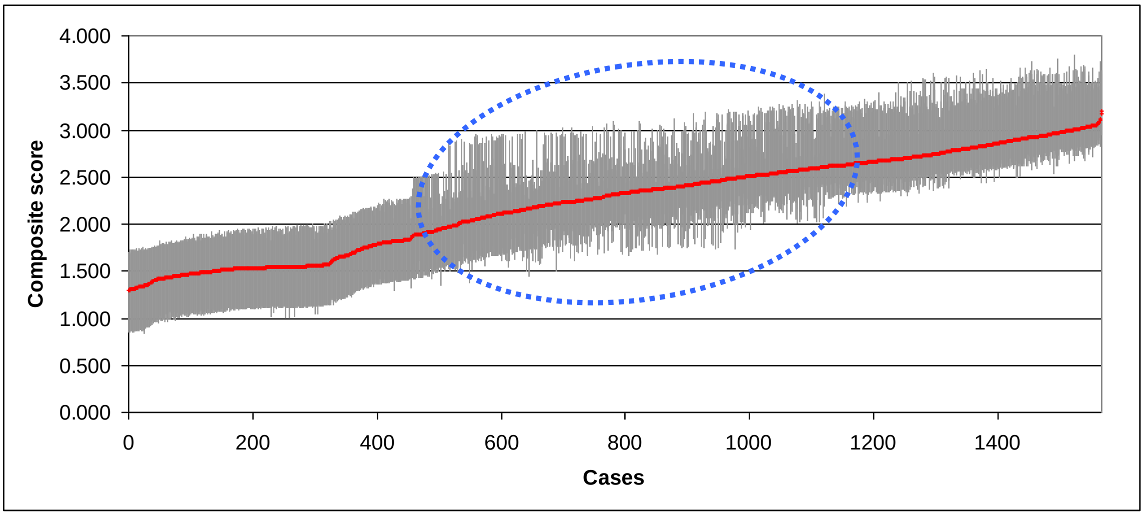


Figure 8.18 Range of changes in the final scores for Upper Coomera

Figure 8.19 depicts all the differences from principal indexing construct once 17 alternative schemes were compared. Obviously, the total number of differences equals to 74,868 (i.e., 4404 cells x 17 alternative indexing schemes). Figure 8.19 clearly shows that the principal indexing scheme reports a final score smaller than the overall average of the alternative constructs. This is a result of the selected normalisation, weighting and aggregation methods, and the implications are discussed below. On average, alternative indexing schemes produce a final score 0.08 greater than the principal scheme. The two red lines on both sides of the average value in the figure correspond to ± 1 standard deviations from 0.08. The distribution of the differences is similar to the negatively skewed normal distribution, and this is the expected result of the greater values of positive differences.

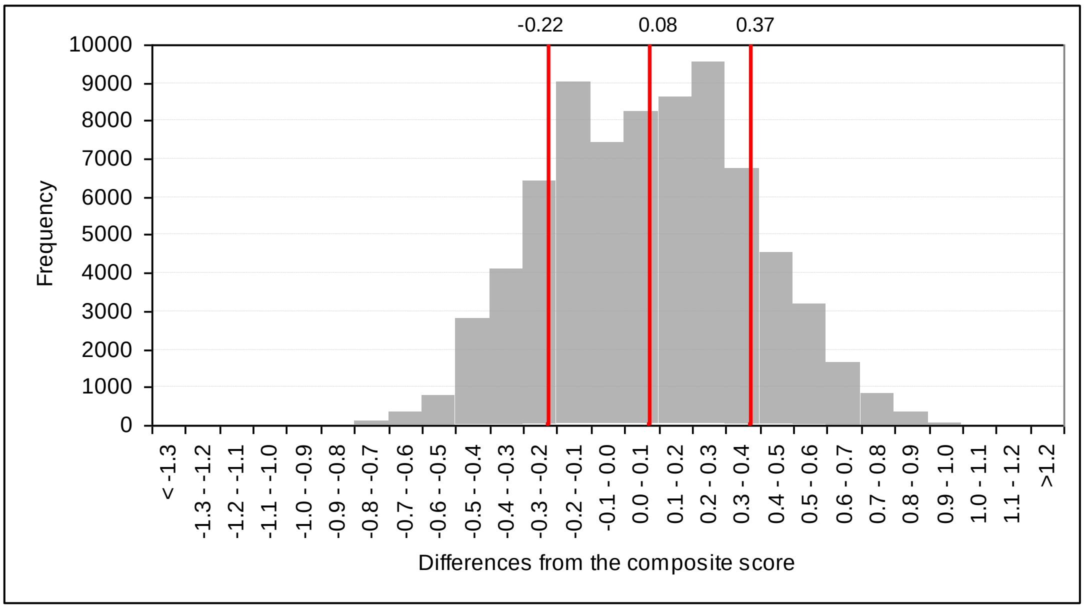


Figure 8.19 Distribution of the differences for all indexing schemes

Figure 8.20 summarises the information given in the figures 8.16 – 8.18. Here, the average scores of alternative schemes are depicted against the averages of final composite scores in terms of percentiles. Accordingly, each percentile contains the scores of 44 grid cells (i.e., 1% of total 4404 cases) and they were averaged for each percentile. The error bars attached to the alternative scheme averages shows the 95% confidence intervals of these alternative scheme scores (i.e., ±2 standard deviations of the scores in each percentile). The approach employed here is very similar to 'one-at-a-time sensitivity measures' used by similar studies, and it is stated that it perform as well as other complex measures (Hamby, 1994; Pannell, 1997; Hamby, 1998). As can be seen in Figure 8.20, the averages of final scores of principal construct well-conform with the averages of alternatives when the final scores are small, but they start to lag behind after the composite score of 2. In some instances, these lags become as large as 0.3 between 2.2 and 3 score range, but then the differences follow a stable trajectory for the rest of the short score range (i.e., between 3 and 3.5). The most important observation about this figure is that the scores of principal scheme always fall inside the 95% confidence interval and it can be interpreted as, while tending to report smaller final scores when compared to the alternative schemes, the final indicator scores are consistent with respect to the analysed alternatives.

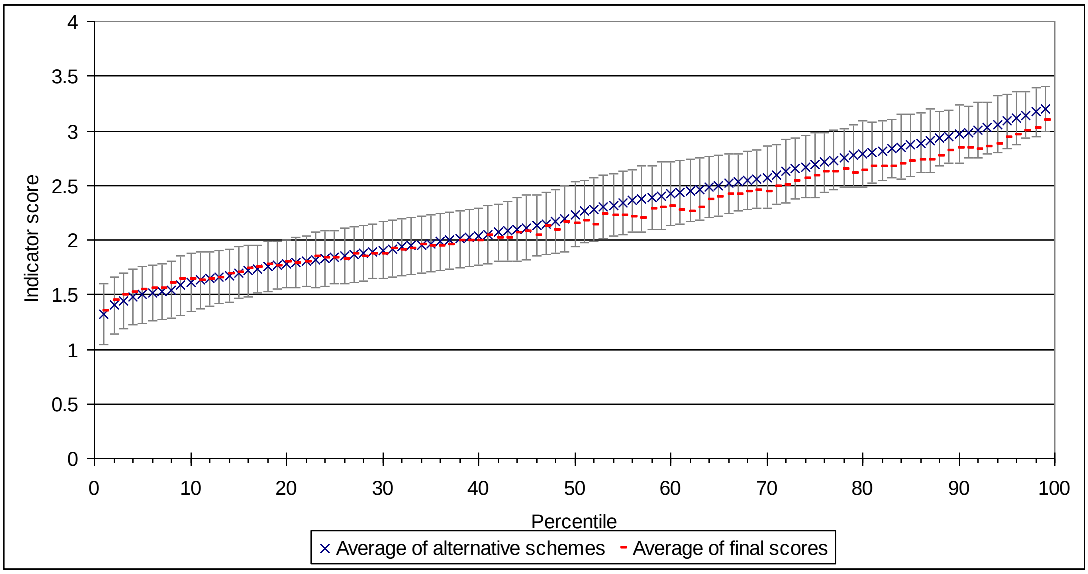


Figure 8.20 Comparison of average scores of alternative schemes with the principal construct

Having determined the tendency of alternative schemes to report greater positive differences, further investigation was conducted to answer why this was the case. For this, the distribution of all indexing schemes according to the reported minimum and maximum values for each cell was determined. For each indexing scheme an abbreviation was used, as given in Table 8.3. For example, the principal indexing scheme of this study is shown as n1w3a1, which corresponds to benchmark-based normalisation, expert weighting and additive aggregation.

Table 8.3 Descriptions of abbreviations used for indexing schemes

Abbreviation	Description
n1	Benchmark-based normalisation
n2	min-max normalisation
n3	z-score normalisation
w1	Equal weighting
w2	Factor analysis weighting
w3	Expert opinion weighting
a1	Additive aggregation
a2	Geometric aggregation

Figure 8.21 shows the frequency of the positive differences for each grid cell. The most striking observation about Figure 8.21 is that all indexing schemes in the figure are additive aggregation schemes. This is due to the fact that geometric aggregation always gives equal or smaller values than linear aggregation. This is also the reason why the greatest minimum differences were assigned by the geometric aggregation (see Figure 8.22). Another important observation about the figure is that benchmark-based normalisation has a tendency to yield less positive differences. There are only 174 grid cells which yielded the positive difference with benchmark-based normalisation, which is the case for the cells performing better in all indicators when evaluated by the equal weighting scheme (i.e., n1w1a1). The other six bars in the figure correspond to the combinations of two normalisation and three weighting schemes. It can be said in crude terms that while the equal weighting yielded more positive differences, it is hard to distinguish which one of the two normalisation schemes yielded more positive differences.

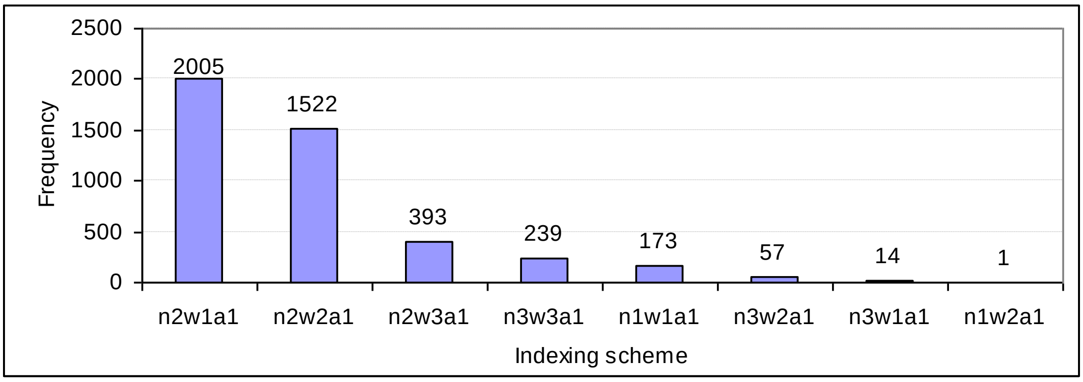


Figure 8.21 Distribution of indexing schemes that gave positive differences

Figure 8.22 portrays the opposite phenomenon of Figure 8.21. It can be clearly seen that all bars belong to the geometric aggregation, and n1w3a2 (i.e., benchmark-based normalisation, expert weighting and geometric aggregation) is the dominant scheme in terms of yielding negative differences. This confirmed that benchmark-based normalisation tends to understate overall composite indicator score. The 'strictness' of this scheme in assigning normalised indicator values, which is particularly the case for how zero performance is evaluated (i.e., assigning zero scores to the raw indicator values which are outbound of the defined zero benchmark), is the main reason behind this finding. In contrast, it is possible for the grid cells to be assigned an indicator score greater than zero (if they are marginally far away from the limit values corresponding to the zero score) in other alternative normalisation schemes.

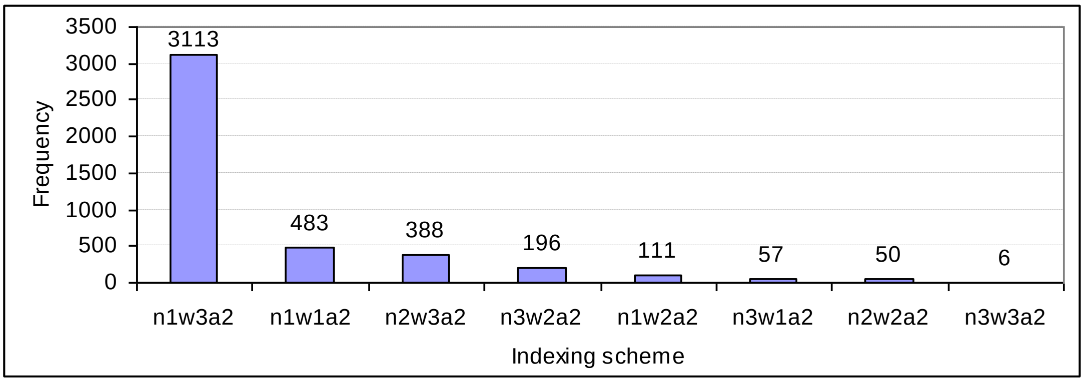


Figure 8.22 Distribution of indexing schemes that gave negative differences

Lastly, a summary of the figures 8.16 – 8.18 are mapped in Figure 8.23. The main purpose of this map is to show the differences which result from the alternative indexing schemes, geographically. As remarked in the key of the map, the header row of the legend shows the negative differences, and these negative differences are coloured differently. Additionally, the column labels under each row heading correspond to the ranges of the positive differences and are coloured in a scale for each negative difference. While the lighter chroma corresponds to smaller positive differences, the darker chroma reflects greater differences. At first glance the figure is dominated by the negative difference values between -0.2 and -0.5 (i.e., red, umber and green colours). These differences tend to have greater positive difference values in central locations of the suburbs. In Helensvale, negative differences are greater than -0.5. In particular, the grid cells yielded medium or marginally medium-high final scores in Upper Coomera and Helensvale (i.e., surroundings of the suburb's central locations) having a tendency to be stable in terms of negative differences but with a fluctuation in positive differences. These cells tend to be greater in positive differences. Coomera, in general, portrays a stable picture in the middle sections, but the suburb central location and the northeast corner have greater positive differences. The negative differences in the latter area tend to be greater as well.

It should be noted that the differences shown in Figure 8.23 are computed for the indexing scheme, which gives the minimum and maximum differences for the respective grid cell. Because of this, this figure should not be confused with the distribution of all differences given in Figure 8.19.

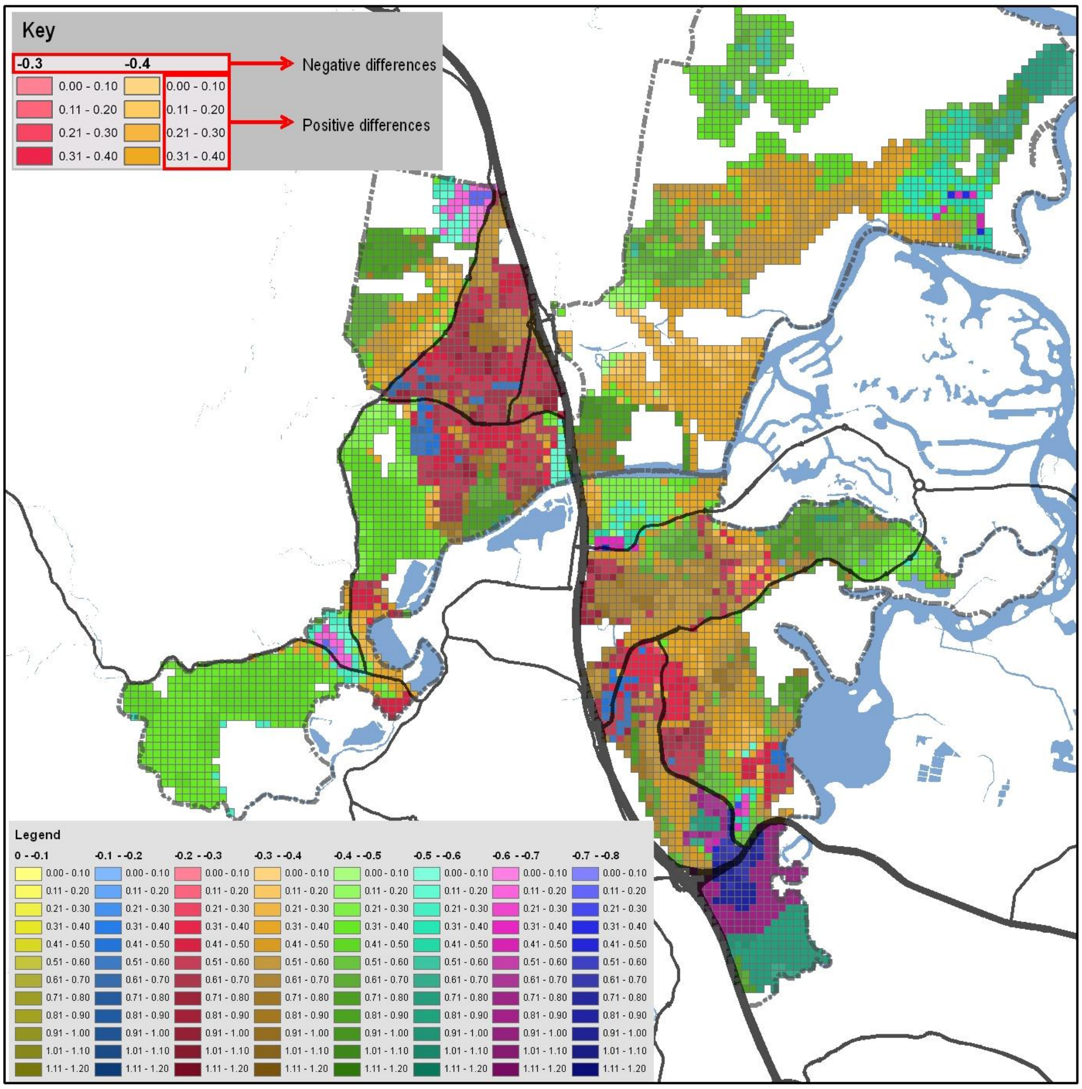


Figure 8.23 Positive and negative differences for the grid cells

8.3 SUMMARY

This chapter summarised the performance of the study area via the synthetic composite indicator formed by using the benchmark-based normalisation, expert weighting and linear additive aggregation. Starting from the results of the composite indicator generated, the composite scores were discussed in depth with reference to the category performances. This analysis showed that the area performed medium-low in overall (i.e., 2.19) 1.29 and 3.37 being the lowest and highest grid cell scores, respectively. While suburb centres yielded high scores due to higher weights assigned to transport and urban form indicators, the suburb peripheries yielded medium-low or low scores in general. When compared Helensvale performed better than the other two suburbs, followed by Upper Coomera and Coomera. Additionally, category level analyses showed that there was a rather serious compensation effect between the indicators and it was particularly the case between transport-urban form and externalities categories. While this is unavoidable if the simple arithmetic aggregation schemes are adopted, the detection of the cases where the compensation is most frequent can provide insights about area specific intervention options. To inspect this, an extra cluster analysis was conducted considering the category level composite score for the study area and each suburb. Finally, the outcomes of this analysis enabled to delineate action areas with the possible planning intervention options, such as suitable locations for sub-centre development, walkable neighbourhoods, transit oriented development, WSUD implementation and environmental monitoring.

The sensitivity analysis results showed that the principal indexing construct tended to understate the final scores when compared to the alternative schemes. The main reasons behind this were, firstly, the 'strictness' of the benchmark-based normalisation and secondly, the peculiarity (i.e., non-uniformity) of the expert weighting schemes. In general, equal weighting scheme with additive aggregation yielded the most positive differences. On the other hand, benchmark-based normalisation and expert weighting schemes gave the most of the negative differences when aggregated geometrically. The magnitude of positive differences was greater than the negative ones, and as a result of this, the average of the differences of alternative indexing constructs was 0.08 greater than the principal construct. The distribution of the negative differences was more stable than the positive ones, and the differences were comparatively volatile in the range of final scores between 1.7 and 2.8. Due to the wide range of final composite indicator scores, the range of differences was greatest in Helensvale. When these deviations were mapped, the distinction between the suburb centres and suburb peripheries was obvious one more time. Moreover, the suburb centres tend to yield high positive and negative differences. The highest deviations were the case for Helensvale central area and its surroundings.

In summary, the range of the differences was negatively skewed if zero deviation was accepted as the central measure. However, the final composite scores were buffered by negative and positive differences, and it was observed that the final values were inside the 95% confidence intervals. This could be shown as the evidence for the stability of final scores. The positive average of differences, 0.08, was relatively close to the zero difference value, but the large number of cases (i.e., 4404 grid cells) made it hard to state that they were not different.

Chapter 9: Conclusion

This study devised a decision support tool which can be used to evaluate the performance of urban settings from land use and transport integration perspectives at the neighbourhood level. Furthermore, it specifies a set of indicators to reflect on the land use and transport interrelation and externalities, and a composite index to measure performance and to formulate strategies to ameliorate the effects of these externalities. It also provides a coherent and systematic standpoint to consolidate land use and transport integration objectives via a set of indicators and a composite index. These are the prominent qualities of this study that contribute to the current urban sustainability debate and open new avenues for further investigations. It does not provide all remedies for the problems resulting from unsustainable mobility patterns and urban form characteristics coupled with the mobility patterns (i.e., the qualities leading to long trip distances and automobile dependent travel patterns); however, it does shed light on a number of the current urban sustainability problems to demarcate problematic areas, which can be intervened by planning tools.

This chapter reviews the extent that the research questions are addressed, and the conclusions that can be drawn from the investigation on indicator based elaboration of land use and transport integration in the confinement of urban sustainability concept. Accordingly, the chapter is structured on three discussions: (1) The findings on forming urban form, transport and externalities indicator system and composite indicator; (2) The implications of the proposed model in formulating urban sustainability policies; and (3) The robustness of the proposed model. This chapter ends with the limitations of the study and suggestions for further research.

9.1 INDICATOR SYSTEM AND COMPOSITE INDICATOR FINDINGS

In Chapter 2, the definition and implications of the urban sustainability concept were reviewed. This showed that urban sustainability is not exempt from the critiques inherent to the conceptualisation of sustainability (e.g., its wide scope, value-laden nature and local context). Even though it was not addressed literally as ‘urban sustainability’ in previous planning endeavours, there exists a long tradition in planning of balancing the three tiers of sustainability in devising urban development directions. After its inclusion in the policy documents as one of the key considerations for the planning of existing urban areas and future urban development, a number of subjects have been defined as the components of urban sustainability. They are urban form, infrastructure, urban economy, community and urban ecology.

Urban sustainability is chiefly important for two reasons, the trajectory of rapid urbanisation process in global scale and the social and environmental burdens as a result of the contemporary production and consumption choices of people. Among all the subjects covered in urban sustainability, sustainability of mobility patterns and their relation to the urban form are two prominent topics, which also overlap with the reasons given above. That is to say, population, automobile ownership, travel demand, and time spent and distance travelled for daily trips are steadily increasing, and the literature provides evidence that these phenomena are related to a great extent to the urban form (i.e., distribution of land use destinations, density of the settlement and urban design qualities). This is the main reason behind the conceptualisation of land use and transport integration.

As summarised in Chapter 2, integration of land use and transport is generally taken into account from a computational (casual relationship) and policy direction perspectives in practice. It is evident that in Australia the latter approach is preferred over the former in guiding the local planning agencies. Accordingly, there are a number of principles which outline the planning objectives on local level. These mainly focus on the compactness of the settlement, planning new developments in close proximity to the existing urban services, enhancing public transport service and quality, infill development, encouraging active transport via design features, changing travel behaviour, balancing the travel costs of automobile and alternative modes, enhancing the character and amenity of the urban areas, and provision of affordable housing and accessibility to urban services.

Another issue is to determine the optimal spatial scale to achieve the objectives of land use and transport integration. The literature clearly proves that the neighbourhood level is the most practical scale to understand the nature of urban form and mobility patterns as well as to decide on relevant planning interventions. Even though the sustainability of mobility patterns and urban form is covered by the neighbourhood sustainability concept, it has a much wider scope than defined by these considerations. In the Australian context, neighbourhood sustainability is defined by referring to the economic vitality, community well-being and cohesion, affordable living, safe, connected and convenient settlement atmosphere, and environment-friendly life style considerations as summarised in Chapter 2.

The discussion to this point clarifies the considerations related to the first part of the first research question: how is land use and transport integration conceptualised in local scale, and what is the most practical spatial scale to elaborate integration principles? This review showed that sustainable urban form and mobility discussions in the literature clearly overlap with the issues raised by policy documents in Australia; a considerable effort has been spent to frame the extent of land use and transport integration idea and to guide implementation by general principles in the South East Queensland regional plan, the Gold Coast City transport plan and local council's current planning scheme; there is a tendency to measure urban sustainability performance with indicators; and neighbourhood scale provides the most effective tools to reach many of the integration principles. By this review, the first objective of this research, defining the principles of land use and transport integration from a holistic perspective to consolidate a valid and reliable monitoring and assessment method, was achieved. These findings then were used to deepen literature review to address the second objective and the second part of the research question.

In order to address the second part of the question, the assessment methods were reviewed. In Chapter 3, a list of available assessment tools was given according to their temporal scale, and advantages of indicator-based assessment were discussed with regard to the similar endeavours in the literature. The main considerations of the indicator theory, which is a sub-domain in the evaluation theory, were revealed and used as the framework for the indicator system of this study. The indicator theory mainly involves the selection of the framework to be used to demarcate the key domains, types of indicators, criteria for the selection and the number of indicators.

Maybe the most important steps in this list are to decide on the framework and the criteria to be used to formulate an indicator system.

There are three frameworks preferred to depict the compartments and interrelationship of sustainability issues. The starting point of most of the sustainability endeavours is to state that sustainable development should be conceived from a holistic perspective, and this can be done by taking into account the three E's of sustainability (i.e., environment, economy and equity). However, this approach also leaves too many gaps to fill in terms of delineating the boundaries of a system which will be conceived in a holistic manner. In order to overcome this problem, the use of the intersections of three domains and employment of casual frameworks (e.g., driving force-pressure-state-impact-response framework of the OECD) are two alternatives which give a clearer understanding about the extent of the sustainability considerations. While the former, though more specific than three-tiered framework, still lacks in clearly defining action domains, the latter requires considerable effort to formulate all of the connections between categories and indicators and demand extensive data collection effort for the indicators. When these issues are considered, a third type of framework, policy-derived frameworks (i.e., goal-based, sectoral and issue-based), emerges as the mostly preferred approach in planning problems. The main advantage of this approach is that it allows using the existing policy headings as the indicator categories and formulating the indicators by referencing the three tiers of the sustainability. A natural tendency here is to select the indicators from state and response domains of the casual framework (e.g., driving force-pressure-state-impact-response framework). This way, it is possible to formulate strategies considering the clear correspondence between the policy targets and the indicators.

As the types and the number of indicators by and large depend on the nature of the study, there is an emerging consensus on using a set of indicator selection criteria. As reported in Chapter 3, the criteria mostly employed by similar studies can be listed as relevance to issues and target audience, relevance to management, analytical soundness, sensitivity to change, measurability, and data requirements and availability. These criteria clearly reflect that indicators should be related to the institutional duties and capabilities, scientifically valid, flexible to fit in changing conditions and be measurable with the data available.

Having defined the main qualities of an indicator system, the indicator candidates related to land use and transport integration were extracted via an extensive literature review. As summarised in Chapter 3, this process yielded three main themes of land use and transport integration (i.e., transport, urban form and externalities) and six categories corresponding to the specific concerns of each theme (i.e., accessibility and mobility for transport, density/diversity and design for urban form, and pollution and resource consumption for externalities categories). Furthermore, a number of indicators were grouped under these categories and presented to the industry partners of this project for their review. As a result of a number of workshops and meetings held with the industry partners, an indicator list consisting of 24 indicators, which reflects strategic and local level sustainability considerations and satisfies the selection criteria adopted, was prepared. This was the second objective of this research, producing a set of land use and transport indicators which are comprehensive and relevant to local sustainability concerns for performance monitoring, and it was achieved by this literature review and the inputs of the officers from industry partners.

In order to investigate available tools to measure the overall performance of the urban settings, another review was conducted on the composite indicator creation procedures. This review showed that even though it is hard to prove the validity of composite indicators on theoretical grounds, their practical value is the main motivation for a number of other studies in the literature. The procedures of composite indicator are straightforward and clear, but it has been advised as a rule of thumb that the computational choices made on each step should be reported with whys, and the overall robustness of the model should be discussed with reference to these choices for the legitimacy of the proposed method. Having noted these considerations, another review was carried out to show the general tendencies of the studies involving spatial indices in Chapter 3. This provided an overlook on the practical qualities of the spatial dimension of the indexing methodology. The main function of the discussion on the composite indicator was to delineate the main parameters of the third objective and second research question.

The second research question was about the measurement of the sustainability performance in integrated manner considering the urban form and transport related qualities of the case study area. After selecting the indicators, relevant data items were collected from various governmental agencies and local government, and a number of data items were produced by using geographic information system tools on parcel level. Due to confidentiality concerns of the local government, parcel level data was not used for the analyses. Instead unit of analysis was selected as 100 metre grid cell with regard to its clear advantage in representing urban areas at a finer detail. This data was used to map each indicator measure for the study area, which provided a general outlook of the performance of the area by indicators and helped to detect spatial patterns visually. However, it was not possible to have a general idea about the overall performance of the area by examining each indicator analysis individually, and there were considerable differences among indicators in terms of their comparative importance. The same issues have been the main inquiry of the multi-attribute decision analysis and it was possible to adopt approaches in this area. However, multi-attribute decision analysis aims to find the best alternative considering the decision objectives and variables, which was not the case in this study. Instead of creating a ranking among alternatives (i.e., unit of analysis, such as, suburb, census collection district or parcel), this study aimed to find a metric that can be used for overall performance evaluation. Therefore composite indicator creation procedures were adopted as the main measurement strategy. A composite indicator was formed in accordance with the standard procedure and was trialled in the case study area.

9.2 IMPLICATIONS OF THE MODEL OUTCOMES FOR CASE STUDY

Following the generic methodology advised for composite indicator creation, all indicators were first normalised according to the benchmark values defined, were then assigned a weight according to the opinions of an expert panel, and finally aggregated by using linear addition.. The major findings of the proposed methods are given in two groups, overall and category-based performance of the study area, as follows:

Overall performance of the study area:

- The overall performance of the three case study suburbs is ranked from the highest to lowest as Helensvale, Upper Coomera and Coomera. The minimum and maximum composite scores were 1.29 and 3.37, respectively, and the average of them was 2.19. This implied that the performance of the study area was at medium level on average;
- There were no cells which had the best or worst composite indicator values (i.e., 5 for the best and 0 for the worst). There were only two best performing clusters in the study area, one in Upper Coomera centre and the other in the northern parts of Helensvale centre whose composite indicator values were between 3 and 3.5. The lowest composite scores were in the western CCDs of Upper Coomera (see Figure 8.3 on p. 219 for more detail);
- As a general remark, the suburb centres and their close surroundings performed better than the periphery areas mostly due to the higher weights given to the transport and urban form category indicators;
- Once the contrast in the performances of Coomera and Helensvale-Upper Coomera is closely analysed, it can be said that the age of the settlement is positively correlated with the variety and number of urban services available. This is the main reason of the low performance of Coomera where there are a limited number of urban services provided since it is in the beginning of the urban development process.

Category-based performance of the study area:

- Nearly 5% of the study area had the highest scores (i.e., range of 4-5) in accessibility category, and a great variety in composite values was evident. This is a result of both the spatial unit of the indicators (i.e., individual parcels) and the apparent advantage of the suburb centres in terms of accessibility to various land use destinations. The superiority of Helensvale in this category, which is followed by Upper Coomera and Coomera, and the accessibility disadvantages of the suburb peripheries were noticeable.

- Approximately 93% of the study area performed medium (25%) or lower (68%) in the mobility category, which can be seen as an indication of automobile dependent travel patterns and long distances for the daily travels for the area. Only 25% of Helensvale was in medium-high score band, which is mostly due to the existence of the public transport interchange in the central of Helensvale.
- Density/diversity category is the most problematic category and maybe the best candidate for planning interventions. Densification together with the ideal land use mix in accordance with the local employment characteristics can yield an increase in not only this category, but also in accessibility and mobility categories. Another observation was that it was not possible to distinguish a better performing suburb in the area due to the very low indicator scores area-wide. But it could be said that Upper Coomera performed marginally better than others.
- Design category scores showed that the study area performed medium or better overall. The lowest scores belonged to the western end of Upper Coomera, which presented poor performances in the previously-mentioned categories. Helensvale was the best performer on average. This category essentially encompasses the urban design qualities of the neighbourhood which makes pedestrian movements easier. When the result of this category was analysed, it was possible to contend that there was a general correlation between accessibility and design categories, which implied that suburb centres had better pedestrian networks due to the high automobile and pedestrian circulation.
- Pollution category scores were negatively correlated with the volume of the roads in the specific locations, as expected. As a result of this, the areas performing better in the previous analyses yielded below average scores in this category. The only exceptions here were the centre of Upper Coomera (i.e., less polluted than expected) and the industrial zone in the middle of Coomera (i.e., more polluted than expected). A close examination of these exceptions proved nothing new; the existence of the high volume road was the main determinant of the lower performance in this category.

- Resource consumption category scores were perfectly fit in the CCD boundaries due to the spatial units of the indicators encompassed. A striking observation was the close resemblance between the car accidents indicator results and the composite category scores of resource consumption. The main reason for this was the relatively higher weight and the variety in the values of traffic accidents indicator. Similar to the pollution category scores, the suburb centres performed poorly when compared to the periphery areas of suburbs. It can be explained by the high urbanisation ratio of these areas and the high traffic circulation, which results in traffic congestion and traffic accidents. Even though Helensvale had most of the lower performing grid cells, approximately 7% of the same suburb yielded the highest scores. Unlike the previous category analyses, Coomera performed better than the other suburbs.

These analyses showed that there was compensation between urban form-transport and externalities categories. More specifically, the areas that performed better in either transport or urban form yielded low scores in externalities categories. This created a clear distinction between the suburb centres and peripheries. However, revealing this distinction did not provide any useful information to help to designate policy options. What is more, looking at the six category scores every time to see what was problematic or not was not that practical. To overcome this problem, all information extracted from category analyses were combined in clusters.

As an extension of the second research question, in the next step, the clusters corresponding to comparatively high, medium and low performances in each category were defined by the cluster analysis method. In Chapter 8, these clusters were presented as intervention areas with a label corresponding to the category-based performance of the cluster. While the previous observation was easily confirmed (i.e., the substitution between transport-urban form and externalities categories) by this cluster analysis, these clusters were also particularly helpful to detect which cluster was weak or strong category-wise. Moreover, these did not only point out the problematic areas where planning intervention can be applicable, but also showed the best cluster candidates for soft or participatory measures (e.g., neighbourhood information meetings, smart or active travel campaigns, travel demand management incentives, and so on).

Overall, the compensation between the indicators included in a composite indicator model, which results in overly-normalised final values, was one of the serious problems experienced in this study. This was still the problem when theme composite scores were considered. However, the category-based scores helped to detect this compensation by category-based comparisons and to assess the urban areas considering contextually similar measures (i.e., indicators grouped in a category). It can be said that while overall composite scores can be useful to consult with public without delving into the specific details of each indicator and to portray the overall performance of an urban setting, category scores can be instrumental for planning offices to formulate policies and planning tools for a specific location. These implications were indirectly presented in this study, but a greater focus was placed on the validity and reliability of the composite indicator methodology and the interpretation of the outputs from a technical perspective.

The discussion in this section addresses the third objective and the second part of the research question, which is generating an indicator-based evaluation method in integrated manner to portray sustainability level by land use and transport integration principles and trialling its potential in policy formulation and assessment of urban development scenarios. More specifically, a composite indicator was developed and its implication was discussed together with its utilisation for demarcating problematic areas and devising urban development strategies. However, it was not possible to discuss how it can be used for scenario development and assessment due to the static nature of the method. While its practical use is explained in below, the issues related to the static nature of the model and how to improve this in the future are given in limitations and future research sections.

There are two important considerations which should be reflected on in terms of the applicability of the model in other settings for decision making purposes. This model was formulated on a set of indicators which correspond to the land use and transport integration principles in South East Queensland. From this perspective, the same indicators can be used by other local authorities in Queensland with small modifications on the indicator measures (i.e., according to the data availability) and their relative weights (i.e., according to the relative priority of the indicators for the given locality). They can provide a unified assessment method for land use and transport integration and make comparisons between settings viable. This can also help to identify the best cases and integration policies which might inspire other localities. This model can be used by other local authorities internationally as well, where the land use and transport integration is a part of the overall urban sustainability objective, because there is a refinement on the land use and transport integration issues as discussed in the literature review. Again, a modification in indicators and measures, and their weights may be required to reflect the local considerations better.

In terms of the utilisation of the model outputs, category level outcomes can be incorporated with the planning scheme objectives of the GCCC when updating the city plans. These outcomes can help to demarcate areas according to their performance and to decide on the best option satisfying a number of planning objectives, such as interconnected walkable neighbourhoods, a good mix of urban uses and services, densification around employment centres, and so on. Additionally, a number of indicators of this model rely on the traffic estimates and provide benchmarks related to these estimates. Once available, the outputs of similar travel demand models can be easily incorporated to measure the category-based performance. From this perspective, this model provides further insights about better utilisation of traffic estimates.

9.3 SENSITIVITY OF THE MODEL

In order demonstrate the robustness of the final composite indicator results, a sensitivity analysis was applied with the alternatives of normalisation, weighting and aggregation schemes in the last step. In this analysis, min-max and z-score normalisation, equal and FA weighting and geometric aggregation schemes were tested against the principal model construct.

The most important finding of this analysis was that the principal indexing construct tended to understate the final scores when compared to the alternative schemes. The main reason behind this was the normalisation and weighting schemes adopted. As shown in Chapter 8, the benchmark-based normalisation scheme tended to give lower composite indicator scores. However, from another perspective, the benchmark-based normalisation has strong bearings in defining the performance of an area by indicators, and in the context of this study, it was the most plausible option to underpin a generalising urban sustainability performance discussion considering transport and urban form integration. Therefore, its employment was fundamental for the validity of the study. Instead of judging the final construct for yielding lower scores, it could be helpful to scrutinise the validity of min-max and z-score normalisation schemes together with the relative contribution of the defined categories to the overall sustainability performance (i.e., assigning more weight to the most important ones vs. treating all of them equally). In this sense, responses to the questions below would clarify how a normalisation and weighting construct can be selected:

- Is it legitimate to assume that the range of indicator values of an area is the best reflection of the indicator performance? To what extent can one setting's indicator value range be generalised for the other settings? What would be the implications of using a normalisation scheme with a different reference point (e.g., minimum, maximum and mean values of the data distribution) for each unique setting in terms of comparability of the urban areas within the given value range?
- Is there a difference in approaching the local sustainability issues relative to their severity or priority? From a decision making perspective, what could be the implications of giving equal weights to all of the considerations defined according to the policy objectives and local needs?

In order to devise a generalising indicator-based assessment, the use of benchmark values extracted from the literature and local policy documents was the most rational option. In fact, without thresholds, it is not possible to place an urban area in a comparable scale with other cities, or to see the attainment of sustainability targets. What is more, this can be regarded as one of the requirements of the policy relevance criterion for the indicators. Even more, an indicator framework should reflect how the urban form and transport issues are considered on a local level. Consequently, the consultation with the local experts on the relative importance of these subjects is the most viable alternative in this sense.

Another important remark was that geometric aggregation schemes gave greater negative differences, unlike the additive scheme, which yielded greater positive differences in all cases. This was an expected result due to the mathematical definitions of these aggregation methods (i.e., geometric aggregation always gives equal or smaller results than that of its additive alternative).

Overall, as the composite indicator values got smaller or greater, they tended to fluctuate less. The distribution of the negative differences was more stable than the positive ones, because one of the indexing schemes formulated by using the geometric aggregation was overwhelmingly dominant in producing negative differences. The range of composite indicator scores of 1.7 and 2.5 was the least stable because of the high sensitivity of these values to normalisation and weighting schemes adopted.

When these differences were mapped, it was obvious that the suburb centres tend to yield higher positive and negative differences than the suburb peripheries. The highest deviations were the case for Helensvale central area and its surroundings mainly due to the weighting scheme adopted.

Despite the wide range of differences in some parts of the study area, the final composite scores of the principal indexing construct followed a consistent trajectory between the ranges of positive and negative differences.

9.4 LIMITATIONS

This method gave a momentary picture of neighbourhood level sustainability considering land use and transport related indicators, and in this sense, can be considered as static. The most important improvement in the model's usefulness would be the inclusion of 'scenario evaluation capability' to provide a dynamic picture of the study area taking into account the changes in the indicator values. More clearly, inclusion of a module can answer the question of what type of urban development alternative may create the best outcomes in terms of urban form and mobility patterns. However, the evaluation of development alternatives can be viable only if the relationship between population growth and land use destination supply, public transport service and travel demand are known. Obviously, the inclusion of these capabilities to this model requires more data and analysis capabilities, and this defines a far wider scope for a PhD study.

The elaboration of land use and transport integration as a planning objective is a sub-domain in urban sustainability debate and inherently, it has value-laden and context-dependent qualities. In this study, the principles of integration were derived from the policy documents of South East Queensland, and they were used as the basis for an indicator system. These indicators were aggregated to form a composite indicator according to their relative importance derived from an expert survey. Throughout this process, the subjectivity of the political nature of land use and transport integration prevailed. This also means that another set of indicators and measures could be selected for the same purpose and aggregated by using other options available. However, from another perspective directly related to the political content of the issue, a decision support tool cannot be formulated without the inputs of the stakeholders and users. In this sense, this model offers a unified method for assessment of land use and transport integration and, in overall, aims to diminish the subjectivity, theoretically and practically. That is to say, while the indicators presented provide a comprehensive list applicable in the Queensland context, which can be used as a checklist for planning documents, the composite indicator method offers an alternative for measuring the success in reaching integration objectives. While the former quality gives a clear understanding about the integration and the prominent issues of this subject, the latter delineates how integration objective can be achieved by implementing right policies.

It should be noted that the indicators of this model were extracted by taking into account the neighbourhood scale considerations. However, land use and transport integration have also been scrutinised at regional or strategic scales by other researchers. These analyses have provided a wider perspective on solution of land use and transport sustainability related problems and a more comprehensive approach to coordination of land use and transport systems (i.e., seamless flow of passengers, multimodal travel patterns, macroform-dependent planning decisions, and so on). As mentioned previously, the spatial scale determined the framework of the model and the content of variables to be included to a great extent. If land use and transport integration is to be analysed at the regional or city scale, the indicators should be refined accordingly to better reflect the specific issues as disclosed in the literature review part. In this case, indicators can be more generic in terms of definition and unit of analysis, but can encompass a broad range of considerations.

Considering the previous limitation, not all land use and transport integration principles could be covered in this study, such as provision of a range of housing options (i.e., affordable housing), designation of high capacity public transport system, soft measures to manage travel demand. These issues can be best discussed at regional or strategic level, and this inherently leads to preference of a coarser spatial analysis unit which makes it hard to discuss urban form and accessibility variables in finer detail. This can be regarded as a trade off between comprehensiveness of the issues to be covered and the spatial detail of the analysis.

It should be underlined that there are two strong assumptions in forming a composite indicator by using the same steps in this study, linearity and additivity of indicators. While the linearity means that an addition to indicator value is regarded as the same in given normalisation benchmark range, the additivity implies disregarding interaction between indicators and allows full compensation among indicators. As highlighted in the “spatial indices” section, these assumptions and limitations of spatial indices should be addressed before their utilisation for policy formulation.

When we look at the data used for indicator analyses, it can be seen that they are dated to 2008-2009, except the census data dating to 2006. During the calculation of indicator analyses based on the census data, it was assumed that there has not been any considerable change in the demographics of the area between 2006 and 2008-2009. This was the most critical assumption of this study. On the one hand, it was permissible for the areas where limited or no urban development took place (e.g., Upper Coomera and Helensvale) due to the unavailable land stock. On the other hand, it was critical for the newly developing suburbs. Because of this, the performance of Coomera could be a little bit understated for the reference dates. However, this assumption was unavoidable with regard to the large data requirement of this study. Collecting this data from other sources or producing the first hand data was not possible because either there was no alternative data source, or the time and monetary costs would exceed the budget of this study. Moreover, finding a number of data items belonging to the same period has been one of the pressing problems for similar indicator studies.

In this study, another critical assumption was about the type, engine size and fuel of the current vehicle fleet. At the moment, the number of vehicles operating with renewable fuel in the study region is very limited, so all calculations were made according to classical vehicle fleet characteristics by using average fuel consumption and CO2 production ratios. In the future, the number of more efficient and less polluting vehicles will increase, and this would result in betterment in a number of indicators. Therefore, for future application of this model, the change in characteristics of vehicle fleet should be taken into account, particularly while estimating GHG emissions and air pollution indicators.

When calculating accessibility to LUDs by cycling and walking, a number of factors, such as grade, shading, safety and design of the infrastructure, affecting the preference towards the use of these transport modes were excluded from the analysis for the sake of simplicity. Moreover, since there was no observed data on the volume, capacity and average speed of these types of infrastructure, average values were used as the proxies.

Lead was used as a cursor pollutant for air and stormwater pollution calculation in this study. Even though its use in petroleum had phased out by 2002 in Australia, the analyses showed that there is still lead in the air and stormwater owing to the re-suspension of previous build-up and industrial activities. Lead concentration might change depending on the atmospheric conditions (e.g., wind speed, humidity, temperature, and so on), which were not included in the analysis. However, the method used in the indicator calculation section was generally in concordance with the theoretical debate over the air pollution phenomenon. As a further refinement, another air pollutant can be used as cursor pollutant according to the air quality targets of the other localities. This flexibility is one of the main advantages of indicator-based assessment, providing elasticity to the indicator system to fit in the local political context.

Even though it was mentioned in the integrated transport plans, freight transport was excluded from this study owing to the residential characteristics of the area and limited number of destinations in the area which can potentially produce or attract freight trips (such as industrial or commercial zones, ports, terminals or warehouses, and so on). In addition, the city transport plan addressed the tourism related traffic problems in the Gold Coast, which were excluded from this study. The main reason for this was again the mostly residential characteristics of the study area. It is an absolute necessity to include considerations related to freight transport and tourism trips if this model is applied to areas which have the potential for producing or attracting these trips.

As explained in “unit of analysis” section, any aggregation operation on a spatial unit causes modifiable areal unit problem (MAUP). Further analysis without taking into account MAUP can give biased results in descriptive and explanatory studies (Openshaw, 1984). Due to the time limitations it was not possible to fully analyse the effect of MAUP for the composite index and the clusters formulated for the suburbs. Even though it may not cause serious problems for exploratory studies, MAUP should be addressed if the outputs of this model are to be used for descriptive or explanatory purposes.

While conducting the expert surveys, the participants were also asked for their opinions about the scope and the potential use of the model. These informal conversations helped to address a few limitations of this study. For example, one expert objected to the top-down approach of this study and stated that it was very hard to validate the judgments related to the performance of these areas by setting a number of criteria (i.e., indicators), which were defined by a panel of professionals. Actually the preference of people in selecting a place to live either in suburb centres or periphery locations (i.e., the self-selection phenomena) may depend on a number of factors, and they cannot be necessarily regarded as unsustainable (see the definition of urban village in Chapter 4 on p.97). Another study addressing urban sustainability considering the effects of self-selection phenomenon on neighbourhood selection could provide more hints about the neighbourhood level sustainability. This objection mainly originated from the ideological standpoint of the participant and has strong roots in procedural debates of planning theory. However, there is no right response to this objection due to its ideological content. It can be said that this study devises a planning support tool, and the planning traditions and regulations determine the content and the scope of this model. Besides, one of the Gold Coast City Council transport planning officers advised that the results of transport indicator could possibly be used as an appendix to the city transport plan for the public consultation. Overall, this is a rather greater debate than this study can contribute to.

Another participant contributed to this objection from another perspective by way of an example. He stated that Coomera Waters project, located in the north-east end of Coomera, was considered as one of the best practices of water sensitive urban design in SEQ. However, when these analyses results were considered, one could see that this area performed very poorly in terms of urban form and transport characteristics. This was a contradiction as the area was regarded as sustainable in terms of household level renewable resource use, but unsustainable from an urban form and transport perspective. It was generally observed that the peripheries of suburbs benefited from less pollution and consumed relatively less resource; however, in the context of urban form and mobility patterns, they were problematic. This contradiction leads us to another debate, management of a measurement method considering households or dwellings as the unit of analysis. While household level analyses can provide the finest details of sustainability evaluation, the data required to conduct this analyses and the confidentiality matters can make their application hard.

Another participant underlined that this study used the same indicators and benchmarks for all types of land uses. He asked how this method could be refined to take into account each land use in the context of their characteristics. For example, housing and job proximity might not be of interest for grids covering the commercial uses, as traffic congestion or parking space availability might not be that important for the residential grids. If the unit of analysis of this study was the parcel, this would be one of the most important issues when formulating the calculation procedures of the indicators. It could be necessary to calculate and map each land use separately before giving composite indicator scores. However, the use of grids as the spatial unit and transformation of the relevant data to this scale led us to make inferences on neighbourhood level, not on parcel level.

Lastly, the normalised indicator values of 'population density' and 'land area occupied by roadways' were strongly correlated due to the benchmark values and the calculation method embraced (i.e., the population of the census collection district was used as the nominator for population density and denominator for roadway area per capita calculations). This inherently brought to mind the double counting problem which occurs when highly correlated indicators are included in a model. Possible outcomes of this problem were investigated, and the problem was interpreted as a consequence of the new measurement scale formed by benchmark-based normalisation, and the similarities between urban form and traffic patterns in the study area. The Pearson correlation coefficient was calculated for raw data and found as -0.67, which clearly showed the effect of the normalisation process on the resulting high correlation. Moreover, depending on the built environment characteristics (e.g., dwelling type and density, parcel size, road width, and so on), the same indicator pair might yield a lower correlation coefficient. Because of these, highly correlated indicators were not omitted from the model.

9.5 FUTURE RESEARCH DIRECTIONS

As stated previously, adding a 'policy evaluation module' to the model could be the most remarkable contribution. The main function of this module is to assess the effect of a change in one indicator or category composite on other indicators and categories. By this way, it is possible to assess which implementation strategy contributes more to the overall area performance. Furthermore, it can be combined with a scenario analysis module which helps formulating and testing different urban development scenarios in order to select the best option. For this, there are a number of parameters that should be estimated for the given setting, such as the type and number of land use destinations with respect to their site selection tendencies (i.e., residential density and vehicle circulation, price of land, and land use pattern), determinants of public transport patronage and service provision, relationships between density/diversity indicators and determinants of traffic accidents. These considerations point out a need for explanatory approach which takes into account the dynamic relationships between the indicators with respect to their statistical properties. Considering these, the model can be reformulated with the structural equations modelling, system dynamics method and genetic algorithms.

With a number of modifications in indicator framework, this model can be incorporated with an existing model to measure neighbourhood sustainability from a holistic perspective similar to Leadership in Energy and Environmental Design's (LEED) neighbourhood development rating tools. In this sense, VicUrban's sustainable community rating can be the best option, which requires the inclusion of the indicators of community well-being, environmental leadership, urban design excellence, affordable housing and commercial success into this model. Considering the experience in housing and urban development issues, the findings of the studies of Australian Housing and Urban Research Institute can be incorporated with this model to develop a new assessment tool. This tool can particularly be useful to reflect on housing development, social well-being, accessibility and environmental externalities.

As an immediate refinement, the model can be run one more time with the 2011 census data when released. It could then be possible to test the validity of the assumptions and make a performance comparison between periods of 2008-2009 and 2011. This comparison can provide invaluable information related to the robustness and usefulness of the model. Furthermore, the model can be tested for the whole Gold Coast city with the available data, and this can provide a benchmark for the findings of the model.

9.6 SUMMARY

In this chapter, the findings of the proposed method were discussed referring to the research questions and implications for the case study area. Moreover, the robustness of the model was discussed by the result of the sensitivity analysis. Finally, the originalities and contributions of this research were summarised as follows:

- The land use and transport indicators were encompassed as a constituent of urban sustainability together with the pollution and resource consumption in the previous studies, but the indicator list of this study, which chiefly covers the indicators of land use and transport integration, is one originality of this study. In this sense, this list can be considered as a practical contribution to the literature and urban planning practice. It can be used as a checklist for the content of planning documents, help to define benchmarks for performance evaluation and make comparisons between different settings viable.

- There are various examples of spatial indexing with different spatial scales and topics in the literature. Generally, the spatial scales of these examples are close to the strategic scale, and this has not been that helpful in detecting problematic areas and analysing the components of the problems. The spatial scale of this study enables demarcatation of the areas according to their performance in the confinement of the indicator system devised, for formulation of deliberate policies. More clearly, it helps to prioritise planning decisions by showing what to do and where. The spatial indexing approach adopted in this study is also original in this sense.
- This study also contributes to specific areas in neighbourhood sustainability concept. The results of this study are compatible with other neighbourhood sustainability endeavours in Australia, and with a number of modifications in the indicator list, can be modified into a new tool to measure neighbourhood sustainability from a holistic perspective.

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Appendices

APPENDIX A: SPATIAL INDEXING STUDIES

Table 9.1 Details of spatial indexing studies reviewed

Name	Indicator selection	No of indicators/ parameters	Normalisation	Weighting	Aggregation	Presentation
Land Use Sustainability Index (LUSI) [1]	Author(s)	6	Linear (0.5-1)	Expert consultation	Functional	Maps of sub-domains and composite
Sustainable Mobility Index	Author(s)	26	Linear (min-max)	AHP	Linear	No output
Sustainable mobility indicators	Author(s)	22	-	-	-	Tables and bar graphs
Composite Sustainability Index	Author(s)	15	-	-	Linear	Tables and radar diagrams
An Index of Regional Sustainability (AIRS) for south west Victoria [2]	Regional stakeholders	13	Sustainability Impact Ranking *	AHP	Linear	Maps of sub-domains and composite
A composite indicator for North Aegean islands [3]	Author(s)	20	Linear (min-max)	Equal	Linear	Radar diagrams of sub-domains and composite
Urban compactness indices	Author(s)	41	z-scores	Equal	Linear	Tables showing compactness of the cases
Urban Sustainability Index	Expert consultation	22	-	AHP	-	Tables comparing performance of the cities
The Dashboard of Sustainability for Padua	PadovA21 Consortium	60	Linear (min-max)	Equal	Linear	Dashboard graphics for different years
Taipei sustainability index	Taipei City government	51	z-scores and linear (min-max)	Equal	Linear	Trend graph for four sub-category and bar chart for overall index

Name	Indicator selection	No of indicators/ parameters	Normalisation	Weighting	Aggregation	Presentation
Spatial network analysis for multimodal urban transport systems (SNAMUTS)	Author(s)	14	Conversion formula for each sub-index	Equal	Linear	Stylised public transport route maps for different scenarios
Index of Sustainable Urban Mobility (I_SUM)	Author(s)	19	-	-	-	A map presenting sub-division indices
Housing Sprawl Measure	Author(s)	8	z-scores	Equal	Linear	Tables showing rank of each city
Sustainability Synthetic Index (ISS)	Author(s)	42	Linear (min-max)	Equal	Linear	Maps showing clusterings of index values and locations
Neighbourhood Accessibility Index [4]	Author(s)	17	None	Factor analysis	Linear	A value for each neighbourhood in a tabular format
Pedestrian Environment Factor (PEF)	Project team and stakeholders	4	Expert evaluation	Equal	Linear	Maps and photographic evidencing
Land Use and Public Transport Accessibility Index (LUPTAI)	Author(s)	1	Benchmark values	Equal	Not applicable	Accessibility maps
NewHeartlands Sustainability Index 2006 [5]	Project team	10	-	Factor analysis	Linear	Maps showing four sub-domains
Neighbourhood Destination Accessibility Index (NDAI)	Author(s)	8	-	Expert consultation	-	Tables and maps of accessibility scores
Building earthquake risk index	Author(s)	11	Linear (min-max)	Author(s)	Linear	Maps showing earthquake risk of the buildings and possible retrofitting
Office location sustainability index	Author(s)	8	-	Expert consultation	Linear	Maps showing the sustainability level with regard to locational advantages
TxDOT Sustainability Enhancement Tool (SET)	TxDOT	13	Linear (min-max)	MAUT**	Multiple Criteria	Tables and bar graphs

Notes:
* See Richards, et al., 2007
** Multiple attribute utility theory
[1] Multivariate analysis: Pearson Correlation Coefficient
[2] Multivariate analysis: Spearman's correlation coefficient; Robustness analysis: Changing the weight of each indicator by ±0.005
[3] Imputation: A simple imputation technique (replacement with the mean)
[4] Multivariate analysis: Pearson Correlation Coefficient; Robustness analysis: Comparison of final index values with expert evaluations
[5] Multivariate analysis: Principal component analysis; Imputation: Use of averages or re-valuing to zero, where applicable; Robustness analysis: Kaiser's measure of sampling adequacy and sample splitting

APPENDIX B. INITIAL INDICATOR LIST

GCCC Workshop – ILTIM initial indicator list – Ranking Sheet – 02 October 2009

Name/Department:..

Categories	R1	Indicator Set	R2	Indicators	Assessment (*)			R3	Comment/Data Source/Contacts
Demographics		Resident characteristics		Labor force participation	I	M	S		
				Population density	I	M	S		
				Car ownership	I	M	S		
		Employment characteristics		Jobs to housing balance	I	M	S		
				Employment density	I	M	S		
Urban Form		Housing Compactness		Use mix ratio	I	M	S		
				Dwelling density	I	M	S		
				Single-family parcel size	I	M	S		
				Single-family dwelling density	I	M	S		
				Multifamily dwelling density	I	M	S		
		Residential resource consumption		Wastewater generation	I	M	S		
				Solid waste generation	I	M	S		
				Energy use	I	M	S		
				Residential water consumption	I	M	S		
		Local amenities		Recreation/social/cultural facility supply	I	M	S		
		Transit orientation		Transit adjacency to residents, services and recreation	I	M	S		
Transportation		Non-auto travel pattern		Transit adjacency to employment	I	M	S		
				Transit proximity to employment	I	M	S		
				Pedestrian network coverage	I	M	S		
				Bicycle network coverage	I	M	S		
		Auto travel pattern		Home-based vehicle kms traveled	I	M	S		
				Nonhome-based vehicle kms traveled	I	M	S		
				Number of home-based vehicle trips	I	M	S		
				Number of nonhome-based vehicle trips	I	M	S		
				Parking supply in employment centres	I	M	S		
		Pollution generated		Emissions of CO2, SO2, heavy metals and polyaromatic hydrocarbons	I	M	S		

(*) **I**: Irrelevant (theoretically and/or practically), **M**: Merge (it is overly specific and/or could be merged with another indicator), **S**: Separate (it is so general and needs to be more specific)

Please indicate other indicator set(s) or indicator(s) that should be included in the indicator list

....

....

....

Figure 9.1 Sample indicator list of GCCC workshop

APPENDIX C. LAND USE PLANS AND DEMOGRAPHICS OF THE STUDY AREA

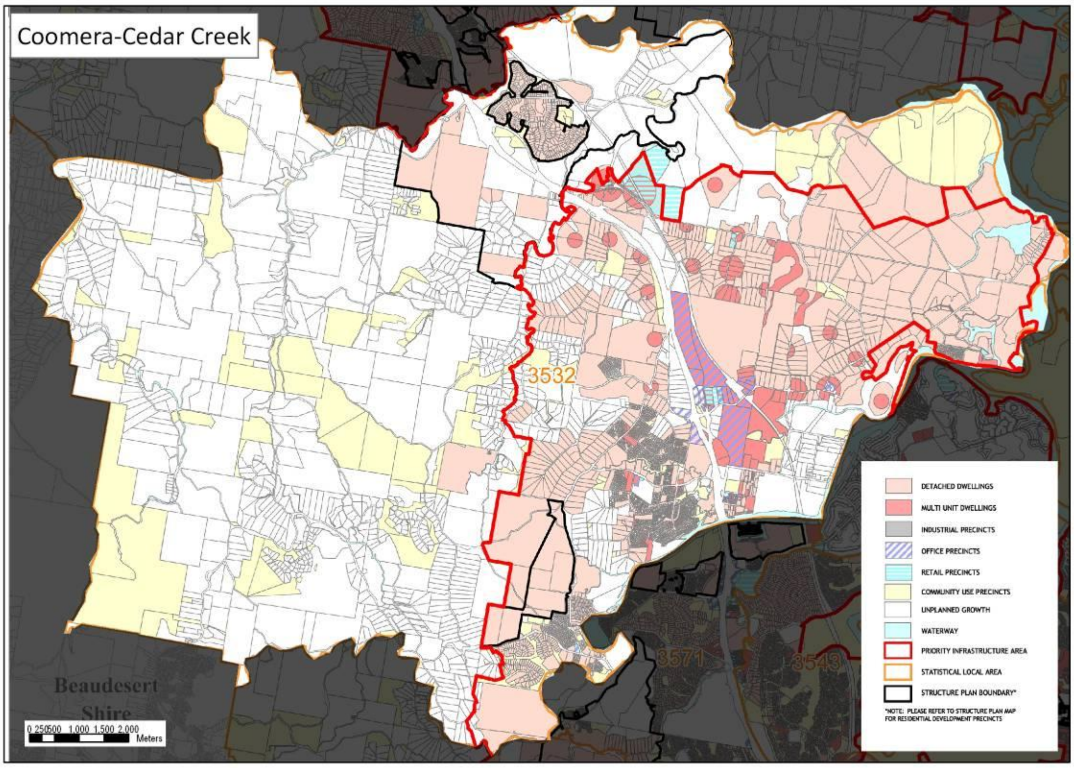


Figure 9.2 Land use plan for Coomera and Cedar Creek

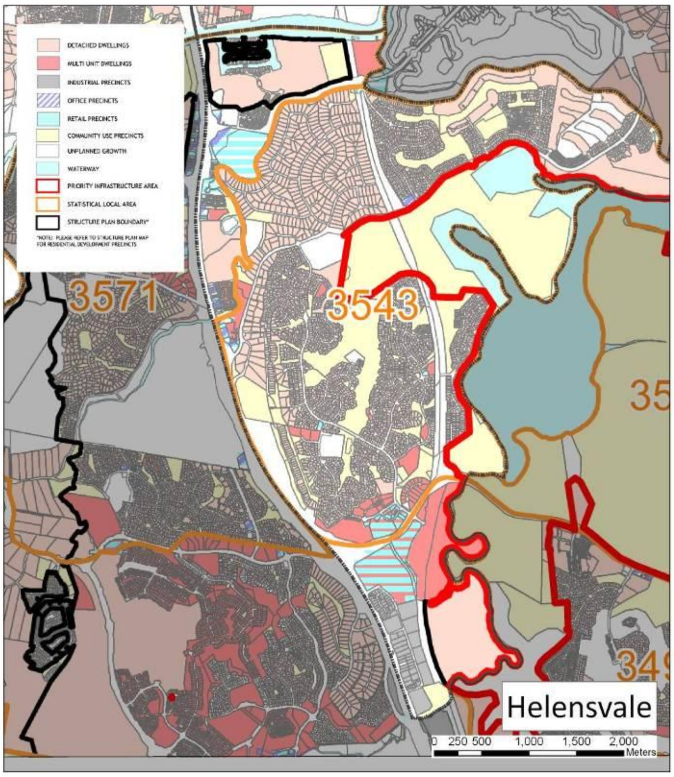


Figure 9.3 Land use plan for Helensvale

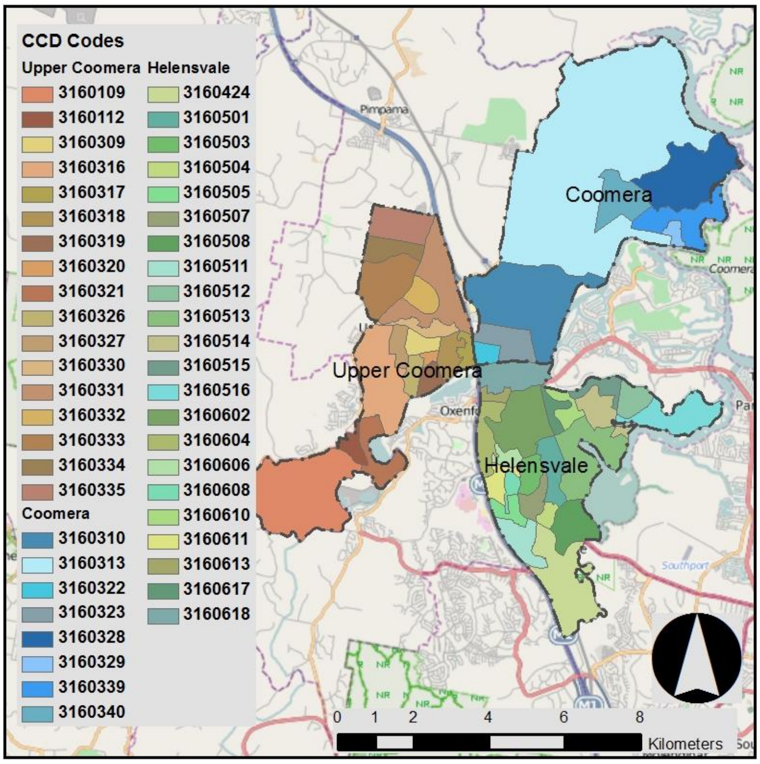


Figure 9.4 Case study CCDs

Table 9.2 Population and household structure of the study area

Suburb	CCD No	Population			Household structure			
		Male	**Female**	**Total**	**Total families**	**Average family size**	**Equalised weekly family income**	**Average number of vehicles per family**
Coomera	3160310	189	161	350	157	2.23	988.44	1.55
	3160313	303	286	589	223	2.64	845.53	1.68
	3160322	212	237	449	212	2.12	762.19	1.34
	3160323	473	496	969	471	2.06	813.43	1.25
	3160328	130	147	277	98	2.83	1251.84	1.73
	3160329	123	133	256	98	2.61	1437.75	1.61
	3160339	339	357	696	220	3.16	1119.30	1.84
	3160340	232	231	463	156	2.97	1196.59	1.79
	Average	*250*	*256*	*506*	*204*	*2.48*	*969.38*	*1.53*
	Total	*2001*	*2048*	*4049*	*1635*	-	-	-
Helensvale	3160424	445	494	939	369	2.54	849.43	1.43
	3160501	484	503	987	362	2.73	885.77	1.73
	3160503	331	313	644	252	2.56	890.14	1.71
	3160504	215	222	437	166	2.63	912.27	1.60
	3160505	224	240	464	211	2.20	980.66	1.56
	3160507	288	304	592	228	2.60	823.95	1.81
	3160508	539	640	1179	490	2.41	940.32	1.48
	3160511	466	483	949	373	2.54	886.51	1.51
	3160512	352	355	707	259	2.73	1261.61	1.67
	3160513	443	454	897	356	2.52	926.01	1.66

Suburb	CCD No	Population: Male	Female	Total	Household structure: Total families	Average family size	Equalised weekly family income	Average number of vehicles per family
	3160514	355	341	696	250	2.78	1100.78	1.83
	3160515	297	331	628	218	2.88	1210.80	1.99
	3160516	149	166	315	103	3.06	938.95	1.66
	3160602	559	516	1075	358	3.00	1083.24	2.25
	3160604	250	238	488	297	1.64	780.13	1.43
	3160606	282	254	536	179	2.99	955.31	1.92
	3160608	225	223	448	167	2.68	996.88	1.68
	3160610	372	380	752	281	2.68	1060.13	1.78
	3160611	249	315	564	215	2.62	827.96	1.44
	3160613	260	288	548	230	2.38	737.67	1.45
	3160617	298	296	594	213	2.79	895.22	1.81
	3160618	168	168	336	108	3.11	1242.85	2.26
	Average	*330*	*342*	*672*	*258*	*2.60*	*952.64*	*1.69*
	Total	*7251*	*7524*	*14775*	*5685*	-	-	-
Upper Coomera	3160109	278	263	541	190	2.85	1000.64	2.32
	3160112	451	470	921	315	2.92	1025.08	1.78
	3160309	434	464	898	321	2.80	764.87	1.47
	3160316	55	48	103	40	2.58	746.84	2.43
	3160317	171	223	394	181	2.18	831.07	1.28
	3160318	594	583	1177	389	3.03	834.13	1.72
	3160319	335	328	663	237	2.80	788.98	1.69
	3160320	271	264	535	194	2.76	824.76	1.33
	3160321	326	307	633	227	2.79	849.00	1.88
	3160326	430	459	889	284	3.13	832.00	1.63
	3160327	391	365	756	273	2.77	895.52	1.40
	3160330	326	404	730	248	2.94	818.10	1.27
	3160331	827	881	1708	587	2.91	792.82	1.47
	3160332	653	638	1291	469	2.75	812.12	1.56
	3160333	144	145	289	103	2.81	1005.45	1.57
	3160334	272	257	529	169	3.13	1112.10	1.91
	3160335	38	37	75	24	3.13	883.88	2.00
	Average	*353*	*361*	*714*	*250*	*2.85*	*857.60*	*1.61*
	Total	*5996*	*6136*	*12132*	*4251*	-	-	-
Study area	*Average*	*492*	*507*	*999*	*379*	*2.68*	*920.09*	*1.64*
	Total	*15248*	*15708*	*30956*	*11571*	-	-	-

Table 9.3 Employment and SEIFA indices of the study area

		Employment						SEIFA Indices			
Suburb	**CCD No**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**A**	**B**	**C**	**D**
Coomera	3160310	138	45	9	16	6	46	1003	1014	945	943
	3160313	178	89	16	5	11	112	1021	1034	1058	956
	3160322	146	77	12	7	6	106	940	962	973	913
	3160323	393	137	28	24	19	123	954	967	901	935
	3160328	110	33	9	7	0	33	1170	1142	1204	1042
	3160329	82	35	4	0	6	45	1204	1146	1205	1110
	3160339	233	80	16	10	5	103	1177	1142	1190	1061

		Employment						SEIFA Indices			
Suburb	**CCD No**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**A**	**B**	**C**	**D**
	3160340	161	68	13	5	0	55	1196	1145	1204	1080
	Average	*180*	*71*	*13*	*9*	*7*	*78*	*1063*	*1054*	*1060*	*993*
	Total	*1441*	*564*	*107*	*74*	*53*	*623*	-	-	-	-
Helensvale	3160424	274	161	26	20	6	207	1005	1018	1006	966
	3160501	302	178	24	8	9	220	1035	1055	1082	957
	3160503	200	93	22	6	4	160	1025	1046	1063	955
	3160504	137	73	15	8	0	116	1043	1064	1072	981
	3160505	157	74	18	6	5	103	1012	1011	998	985
	3160507	182	88	17	6	6	151	1053	1070	1082	972
	3160508	326	161	32	13	13	375	1008	1015	1037	953
	3160511	232	134	16	10	9	319	1042	1042	1053	988
	3160512	203	99	22	10	4	141	1188	1137	1207	1084
	3160513	298	153	16	9	6	209	1030	1046	1080	969
	3160514	240	102	24	6	11	156	1144	1122	1183	1024
	3160515	210	100	14	0	5	138	1146	1127	1200	1039
	3160516	82	61	5	4	3	42	1149	1119	1173	1032
	3160602	339	169	31	12	13	216	1124	1109	1172	1028
	3160604	131	58	15	6	3	176	895	900	926	876
	3160606	183	80	15	13	13	92	1056	1059	1085	961
	3160608	138	70	22	7	6	85	1047	1068	1099	948
	3160610	231	105	20	10	3	188	1117	1100	1164	1018
	3160611	146	72	11	20	3	218	976	988	986	949
	3160613	172	82	20	16	8	105	947	959	936	908
	3160617	184	107	15	8	0	127	1086	1091	1157	961
	3160618	127	49	14	4	4	48	1157	1131	1240	1011
	Average	*204*	*103*	*19*	*9*	*6*	*163*	*1057*	*1057*	*1089*	*981*
	Total	*4494*	*2269*	*414*	*202*	*134*	*3592*	-	-	-	-
Upper Coomera	3160109	192	102	16	6	0	105	1066	1078	1119	1007
	3160112	325	134	24	5	6	135	1071	1074	1159	959
	3160309	275	128	32	19	9	135	1002	999	1007	937
	3160316	33	17	0	3	0	21	1058	1066	1164	972
	3160317	140	52	13	6	3	60	1003	984	927	1009
	3160318	379	157	35	25	12	157	1023	1031	1068	933
	3160319	213	101	13	14	9	126	1011	1036	1036	948
	3160320	158	60	17	13	10	74	986	997	990	937
	3160321	205	99	25	9	8	134	1029	1034	1087	943
	3160326	271	102	16	18	9	130	1088	1066	1112	972
	3160327	245	87	6	18	13	99	1028	1003	1022	944
	3160330	190	72	14	12	10	199	991	976	959	959
	3160331	490	191	43	34	22	271	1031	1011	1062	932
	3160332	428	146	33	40	15	175	1048	1020	1044	955
	3160333	113	40	3	7	0	34	1087	1046	1116	975
	3160334	204	60	8	4	11	49	1145	1103	1190	1012
	3160335	36	11	0	0	0	6	1140	1127	1188	945
	Average	*229*	*92*	*18*	*14*	*8*	*112*	*1039*	*1029*	*1062*	*955*
	Total	*3897*	*1559*	*298*	*233*	*137*	*1910*	-	-	-	-
Study area	*Average*	*209*	*93*	*17*	*11*	*7*	*130*	*1051*	*1046*	*1075*	*972*
	Total	*9832*	*4392*	*819*	*509*	*324*	*6125*	-	-	-	-

Notes: E1: Employed, full-time; E2: Employed, part-time; E3: Employed, away from work; E4: Unemployed, looking for full-time work; E5: Unemployed, looking for part-time work; E6: Not in the labour force; A: Index of Relative Socio-economic Advantage and Disadvantage; B: Index of Relative Socio-economic Disadvantage; C: Index of Economic Resources; D: Index of Education and Occupation

Table 9.4 Dwelling structure of the study area

		Dwelling structure						
Suburb	**CCD No**	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**Total**
Coomera	3160310	16	23	114	3	9	3	168
	3160313	214	0	3	0	0	3	220
	3160322	50	92	60	0	0	0	202
	3160323	57	93	316	0	0	0	466
	3160328	94	0	0	0	0	0	94
	3160329	93	0	5	0	0	0	98
	3160339	220	0	0	0	0	0	220
	3160340	177	0	0	0	0	0	177
	Average	*115*	*26*	*62*	*0*	*1*	*1*	*206*
	Total	*921*	*208*	*498*	*3*	*9*	*6*	*1,645*
Helensvale	3160424	224	42	81	3	0	0	350
	3160501	333	3	0	0	0	0	336
	3160503	210	25	0	0	0	0	235
	3160504	155	0	16	0	0	0	171
	3160505	116	84	0	0	0	4	204
	3160507	221	0	0	0	0	0	221
	3160508	339	0	0	147	0	3	489
	3160511	240	3	115	0	0	0	358
	3160512	279	0	0	0	0	0	279
	3160513	283	31	5	26	0	0	345
	3160514	248	0	0	0	3	0	251
	3160515	223	0	0	0	0	0	223
	3160516	99	0	0	0	0	0	99
	3160602	323	0	0	0	0	3	326
	3160604	74	89	0	0	128	3	294
	3160606	161	0	0	0	0	0	161
	3160608	146	4	0	0	0	0	150
	3160610	289	0	0	0	0	0	289
	3160611	103	112	0	0	0	0	215
	3160613	197	6	17	0	0	0	220
	3160617	209	0	0	0	0	0	209
	3160618	113	0	0	0	0	0	113
	Average	*208*	*18*	*11*	*8*	*6*	*1*	*252*
	Total	*4,585*	*399*	*234*	*176*	*131*	*13*	*5,538*
Upper Coomera	3160109	178	0	0	0	0	0	178
	3160112	289	0	0	0	0	0	289
	3160309	211	0	93	0	0	0	304
	3160316	36	0	0	0	0	0	36
	3160317	0	10	231	0	0	0	241
	3160318	379	0	0	0	0	0	379
	3160319	232	0	0	0	0	0	232
	3160320	190	0	0	0	0	0	190
	3160321	201	5	0	11	0	3	220
	3160326	0	277	7	0	0	0	284
	3160327	148	29	84	0	0	7	268
	3160330	111	88	61	0	0	0	260

Suburb	CCD No	Dwelling structure (a)	(b)	(c)	(d)	(e)	(f)	Total
	3160331	504	83	15	0	47	0	649
	3160332	344	108	3	0	0	0	455
	3160333	127	0	0	0	0	0	127
	3160334	175	0	0	0	0	0	175
	3160335	72	0	0	0	0	0	72
	Average	*188*	*35*	*29*	*1*	*3*	*1*	*256*
	Total	*3,197*	*600*	*494*	*11*	*47*	*10*	*4,359*
Study area	*Average*	*185*	*26*	*26*	*4*	*4*	*1*	*246*
	Total	*8,703*	*1,207*	*1,226*	*190*	*187*	*29*	*11,542*

Notes: (a). Separate house; (b). Semi-detached, row or terrace house, townhouse etc with one storey; (c). Semi-detached, row or terrace house, townhouse etc with two or more storeys; (d)Flat, unit or apartment in a one or two storey block; (e) Caravan, cabin, houseboat; (f) Other types

Table 9.5 Land use distribution of the study area

Suburb	CCD No	Urban Residential	Commercial	Industrial	Rural Residential	Open Ground	Recreation (facilities & sub/urban parks)	School	Mining	Tourism	Agriculture	Forest, Grazing and Grassland	Vacant Land	Wetlands	Utilities and Infrastructure	Grand Total
		Land-use distribution (in ha, 2006)														
Coomera	3160310	5.3	6.1	56.6	50.1	0.9	27.2	-	-	69.4	23.3	142.8	34.6	5.0	-	421.4
	3160313	39.7	0.6	0.9	263.6	7.6	5.2	-	-	-	359.8	815.2	93.4	209.7	-	1,795.6
	3160322	12.4	2.0	-	1.1	0.9	-	-	-	-	-	4.7	0.3	-	0.9	22.3
	3160323	15.7	0.4	-	0.4	0.8	6.6	6.7	-	-	59.1	-	-	-	-	89.7
	3160328	24.0	-	0.5	22.9	4.4	-	-	-	-	-	103.9	46.1	56.0	-	257.8
	3160329	8.6	1.2	0.5	-	2.6	2.9	-	-	-	-	-	1.7	-	0.0	17.6
	3160339	23.1	-	-	-	0.9	1.1	-	-	-	-	4.8	10.2	46.3	-	86.3
	3160340	23.6	-	-	0.1	2.3	7.6	-	-	-	-	17.0	15.9	52.8	0.1	119.4
	Average	*19.0*	*2.1*	*14.6*	*56.4*	*2.5*	*8.4*	*6.7*	-	*69.4*	*147.4*	*181.4*	*28.9*	*74.0*	*0.3*	*351.3*
	Total	*152.3*	*10.3*	*58.6*	*338.1*	*20.4*	*50.6*	*6.7*	-	*69.4*	*442.2*	*1,088.5*	*202.2*	*369.9*	*1.0*	*2,810.1*
Helensvale	3160424	23.7	35.4	20.8	0.6	2.6	94.7	-	-	-	-	6.7	15.2	-	0.3	199.9
	3160501	27.7	-	-	-	3.8	45.7	-	-	-	-	-	-	2.0	-	79.3
	3160503	18.9	-	-	-	2.5	25.6	-	-	-	-	-	-	-	-	47.0
	3160504	13.4	-	-	-	0.2	7.5	-	-	-	-	-	-	-	-	21.1
	3160505	12.8	0.5	-	4.6	0.8	-	-	-	-	-	17.1	1.6	-	-	37.4
	3160507	19.1	1.0	-	-	0.6	23.7	-	-	-	-	-	-	-	-	44.4
	3160508	34.9	0.3	-	3.3	6.8	8.7	-	-	-	-	32.2	0.8	-	0.9	87.9
	3160511	34.0	-	-	-	1.2	5.4	5.7	-	-	-	7.7	-	-	0.8	54.9
	3160512	26.1	-	-	-	2.5	-	-	-	-	-	-	2.3	-	-	31.0
	3160513	24.0	0.3	-	-	1.7	2.8	-	-	-	-	140.3	-	12.0	-	181.1
	3160514	19.6	-	-	-	0.8	8.6	-	-	-	-	4.4	0.3	0.1	0.0	33.8
	3160515	19.0	-	-	-	11.7	0.4	-	-	-	-	-	0.2	-	-	31.3
	3160516	8.9	-	-	-	0.8	0.6	-	-	-	-	-	2.8	75.1	-	88.3
	3160602	4.2	0.4	-	140.9	0.6	17.5	-	-	-	-	0.9	0.9	-	3.9	169.2
	3160604	6.7	27.9	0.4	-	1.6	3.0	-	-	12.8	-	9.3	0.8	1.8	-	64.3
	3160606	12.9	-	-	6.5	1.6	1.9	-	-	0.0	-	-	-	-	2.0	25.0
	3160608	16.3	-	-	-	1.1	2.1	-	-	-	-	2.2	-	-	0.7	22.4
	3160610	24.9	-	-	-	0.4	-	-	-	-	-	-	0.3	-	-	25.5

Suburb	CCD No	Land-use distribution (in ha, 2006)														
		Urban Residential	**Commercial**	**Industrial**	**Rural Residential**	**Open Ground**	**Recreation (facilities & sub/urban parks)**	**School**	**Mining**	**Tourism**	**Agriculture**	**Forest, Grazing and Grassland**	**Vacant Land**	**Wetlands**	**Utilities and Infrastructure**	**Grand Total**
	3160611	12.2	3.2	-	17.4	1.0	0.1	-	-	-	-	0.4	2.8	-	-	37.1
	3160613	8.6	3.3	-	-	0.6	0.5	-	-	-	-	-	-	-	-	12.9
	3160617	17.6	1.0	-	-	10.2	0.3	-	-	-	-	-	-	-	-	29.0
	3160618	26.8	-	-	1.0	7.5	15.6	-	-	-	-	-	12.5	-	-	63.4
	Average	*18.7*	*7.3*	*10.6*	*24.9*	*2.8*	*13.9*	*5.7*	-	*6.4*	-	*22.1*	*3.4*	*18.2*	*1.2*	*63.0*
	Total	*412.3*	*73.3*	*21.2*	*174.4*	*60.7*	*264.5*	*5.7*	-	*12.8*	-	*221.2*	*40.4*	*91.0*	*8.7*	*1,386.3*
Upper Coomera	3160109	-	-	-	215.7	13.3	33.3	-	0.1	-	179.2	5.2	13.7	-	-	460.6
	3160112	22.8	2.7	-	-	0.2	0.3	-	-	-	-	1.2	2.2	-	-	29.4
	3160309	15.7	2.4	-	-	1.9	1.1	13.1	-	-	0.5	-	-	-	-	34.7
	3160316	12.6	-	-	124.7	15.0	-	-	17.8	-	27.0	13.2	11.5	-	-	221.7
	3160317	13.6	0.5	-	2.6	0.1	0.9	0.9	-	-	-	-	-	-	-	18.6
	3160318	24.4	-	-	0.1	6.8	2.7	12.7	-	-	-	-	0.2	-	-	46.9
	3160319	26.7	-	-	4.1	2.7	-	-	-	-	-	0.0	0.1	-	-	33.7
	3160320	9.5	-	-	-	0.3	-	-	-	-	-	-	-	-	-	9.7
	3160321	25.8	0.1	-	11.6	3.2	9.4	-	3.9	-	-	-	4.4	-	0.3	58.6
	3160326	22.1	-	-	6.3	3.0	1.0	-	-	-	-	-	0.1	-	-	32.4
	3160327	18.0	0.4	-	8.5	2.5	0.8	-	-	-	-	-	6.3	-	-	36.5
	3160330	15.1	3.5	4.0	2.8	9.7	2.7	-	-	-	-	0.1	0.1	-	-	37.9
	3160331	56.8	31.9	10.9	3.5	15.3	8.6	10.6	-	3.0	6.1	8.6	20.3	-	0.0	175.7
	3160332	28.1	-	-	-	0.3	4.7	7.9	-	-	-	-	6.5	-	-	47.6
	3160333	24.8	-	-	75.7	6.6	0.7	-	-	-	-	42.5	12.0	-	1.6	163.9
	3160334	30.6	-	-	-	5.2	-	-	-	-	-	27.5	0.6	-	-	63.8
	3160335	17.6	0.1	-	-	-	2.7	11.9	-	-	-	82.8	0.3	-	-	115.4
	Average	*22.8*	*5.2*	*7.5*	*41.4*	*5.4*	*5.3*	*9.5*	*7.3*	*3.0*	*53.2*	*20.1*	*5.6*	-	*0.6*	*93.4*
	Total	*364.2*	*41.7*	*14.9*	*455.6*	*85.9*	*68.8*	*57.3*	*21.8*	*3.0*	*212.7*	*181.0*	*78.3*	-	*1.9*	*1,587.1*
Study area	*Average*	*19.8*	*2.7*	*2.0*	*20.6*	*3.6*	*8.2*	*1.5*	*0.5*	*1.8*	*13.9*	*31.7*	*6.8*	*9.8*	*0.2*	*123.1*
	Total	*928.7*	*125.3*	*94.7*	*968.1*	*167.0*	*384.0*	*69.7*	*21.8*	*85.2*	*654.9*	*1,490.7*	*320.9*	*460.9*	*11.6*	*5,783.5*

APPENDIX D. SUMMARY OF AIR AND STORMWATER POLLUTION REGRESSIONS

Table 9.6 Summary of air quality regression analysis

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.978[a]	.956	.934	.00960346

a. Predictors: (Constant), VOL_8HOURS, Com divided by res, INV_Speed85
b. Dependent Variable: lead

Table 9.7 ANOVA of air quality regression analysis

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.012	3	.004	43.136	.000[a]
	Residual	.001	6	.000		
	Total	.012	9			

a. Predictors: (Constant), VOL_8HOURS, Com divided by res, INV_Speed85
b. Dependent Variable: lead

Table 9.8 Coeffcients of air quality regression analysis

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.124	.022		-5.551	.001
	INV_Speed85	6.184	.975	.699	6.340	.001
	Com divided by res	.084	.008	1.052	10.963	.000
	VOL_8HOURS	2.702E-6	.000	.324	3.011	.024

a. Dependent Variable: lead

Table 9.9 Summary of stromwater quality regression analysis

Model Summary[c,d]

Model	R		R Square	Adjusted R Square	Std. Error of the Estimate
	VAR00003 = 1.00 (Selected)	VAR00003 ~= 1.00 (Unselected)			
1	.735[a]		.540	.387	.03575663
2	.695[b]	.	.483	.409	.03511249

a. Predictors: (Constant), V/C2, V_Actual
b. Predictors: (Constant), V/C2
c. Unless noted otherwise, statistics are based only on cases for which VAR00003 = 1.00.
d. Dependent Variable: Lead

Table 9.10 ANOVA of stromwater quality regression analysis

ANOVA[c,d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.009	2	.005	3.522	.097[a]
	Residual	.008	6	.001		
	Total	.017	8			
2	Regression	.008	1	.008	6.528	.038[b]
	Residual	.009	7	.001		
	Total	.017	8			

a. Predictors: (Constant), V/C2, V_Actual
b. Predictors: (Constant), V/C2
c. Dependent Variable: Lead
d. Selecting only cases for which VAR00003 = 1.00

Table 9.11 Coeffcients of stromwater quality regression analysis

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.072	.033		2.198	.070
	V_Actual	-1.587E-6	.000	-.256	-.866	.420
	V/C2	.077	.029	.785	2.653	.038
2	(Constant)	.068	.032		2.144	.069
	V/C2	.068	.027	.695	2.555	.038

a. Dependent Variable: Lead
b. Selecting only cases for which VAR00003 = 1.00

APPENDIX E. SUMMARY OF CLUSTER ANALYSIS

Table 9.12 The results of k-mean cluster analysis for categories

	Final cluster centres			**Number of cases in each cluster**		
	1	2	3	1	2	3
Accessibility	3.522	0.998	2.280	1638	2041	725
Mobility	3.112	1.125	1.865	365	2367	1672
Density/diversity	2.017	0.541	1.166	788	1845	1771
Design/layout	3.709	2.391	3.074	1290	1071	2043
Pollution	3.142	3.883	4.606	981	1596	1827
Resource consumption	1.775	3.543	3.021	1212	1872	1320

APPENDIX F. FACTOR ANALYSIS DETAILS

Table 9.13 Correlation between indicators

	PT_STOP	NDAI_PT	NDAI_WALK	NDAI_CYCLE	NUM_OF_TRIPS	COMMUT_DIST	PARKING	PT_SERVICE	PARCEL_SIZE	POP_DENSITY	LU_MIX	HOUSE_JOB	INT_CONN	CALMING	WALKABILITY	OPEN_SPACE	AIR_QUAL	GHG	NOISE	STORMWATER	URBANISED	ROAD_AREA	CONGESTION	ACCIDENTS
PT_STOP	1.000	.493	.717	.558	.025	.323	-.117	.352	.297	.504	.347	.090	.133	.208	.410	-.010	-.118	.383	-.331	-.102	-.521	.474	-.130	-.084
NDAI_PT	.493	1.000	.514	.473	.098	.436	.049	.322	.102	.407	.075	-.057	-.060	.087	.130	-.006	-.160	.270	-.212	-.161	-.387	.497	-.257	-.014
NDAI_WALK	.717	.514	1.000	.728	.159	.438	.024	.624	.255	.496	.596	-.005	.311	.220	.579	.076	-.446	.247	-.408	-.208	-.640	.456	-.260	-.318
NDAI_CYCLE	.558	.473	.728	1.000	.170	.597	-.102	.571	.215	.506	.347	-.182	.140	.193	.472	.044	-.440	.294	-.320	-.189	-.622	.527	-.314	-.219
NUM_OF_TRIPS	.025	.098	.159	.170	1.000	.356	-.073	.277	-.056	-.027	.307	-.035	.310	-.014	.402	.182	-.251	-.375	-.285	-.138	-.077	.111	-.185	-.396
COMMUT_DIST	.323	.436	.438	.597	.356	1.000	.074	.438	.010	.299	.075	.082	.259	-.088	.395	.128	-.294	.018	-.277	-.204	-.232	.333	-.195	-.295
PARKING	-.117	.049	.024	-.102	-.073	.074	1.000	.198	-.094	.061	-.063	.047	.018	-.087	-.016	.120	-.176	.113	-.037	.108	-.061	.106	.046	-.192
PT_SERVICE	.352	.322	.624	.571	.277	.438	.198	1.000	-.042	.119	.346	-.154	.357	.097	.610	.257	-.558	-.123	-.355	-.199	-.486	.145	-.287	-.598
PARCEL_SIZE	.297	.102	.255	.215	-.056	.010	-.094	-.042	1.000	.409	.211	.109	.118	.247	.151	-.224	.005	.359	.027	-.001	-.274	.329	-.106	.131
POP_DENSITY	.504	.407	.496	.506	-.027	.299	.061	.119	.409	1.000	.216	.112	.155	.450	.292	-.215	-.112	.799	-.084	.007	-.654	.914	-.188	.133
LU_MIX	.347	.075	.596	.347	.307	.075	-.063	.346	.211	.216	1.000	-.003	.346	.237	.424	.118	-.416	.018	-.343	-.172	-.418	.162	-.194	-.359
HOUSE_JOB	.090	-.057	-.005	-.182	-.035	.082	.047	-.154	.109	.112	-.003	1.000	.209	.277	.166	-.110	.119	.088	.032	.138	.075	.051	.158	.017
INT_CONN	.133	-.060	.311	.140	.310	.259	.018	.357	.118	.155	.346	.209	1.000	.076	.609	.163	-.247	-.076	-.229	-.108	-.204	-.049	-.147	-.332
CALMING	.208	.087	.220	.193	-.014	-.088	-.087	.097	.247	.450	.237	.277	.076	1.000	.351	-.206	.002	.409	.029	.280	-.503	.398	.134	.229
WALKABILITY	.410	.130	.579	.472	.402	.395	-.016	.610	.151	.292	.424	.166	.609	.351	1.000	.160	-.349	.046	-.293	-.098	-.488	.197	-.271	-.333
OPEN_SPACE	-.010	-.006	.076	.044	.182	.128	.120	.257	-.224	-.215	.118	-.110	.163	-.206	.160	1.000	-.213	-.232	-.167	-.037	.056	-.190	-.066	-.323
AIR_QUAL	-.118	-.160	-.446	-.440	-.251	-.294	-.176	-.558	.005	-.112	-.416	.119	-.247	.002	-.349	-.213	1.000	.032	.295	.167	.292	-.099	.404	.568
GHG	.383	.270	.247	.294	-.375	.018	.113	-.123	.359	.799	.018	.088	-.076	.409	.046	-.232	.032	1.000	.121	.184	-.449	.704	-.035	.424
NOISE	-.331	-.212	-.408	-.320	-.285	-.277	-.037	-.355	.027	-.084	-.343	.032	-.229	.029	-.293	-.167	.295	.121	1.000	.362	.223	-.076	.295	.398
STORMWATER	-.102	-.161	-.208	-.189	-.138	-.204	.108	-.199	-.001	.007	-.172	.138	-.108	.280	-.098	-.037	.167	.184	.362	1.000	-.006	.044	.354	.260
URBANISED	-.521	-.387	-.640	-.622	-.077	-.232	-.061	-.486	-.274	-.654	-.418	.075	-.204	-.503	-.488	.056	.292	-.449	.223	-.006	1.000	-.655	.168	.158
ROAD_AREA	.474	.497	.456	.527	.111	.333	.106	.145	.329	.914	.162	.051	-.049	.398	.197	-.190	-.099	.704	-.076	.044	-.655	1.000	-.126	.135
CONGESTION	-.130	-.257	-.260	-.314	-.185	-.195	.046	-.287	-.106	-.188	-.194	.158	-.147	.134	-.271	-.066	.404	-.035	.295	.354	.168	-.126	1.000	.290
ACCIDENTS	-.084	-.014	-.318	-.219	-.396	-.295	-.192	-.598	.131	.133	-.359	.017	-.332	.229	-.333	-.323	.568	.424	.398	.260	.158	.135	.290	1.000

Note: Correlations greater than 0.7 are highlighted

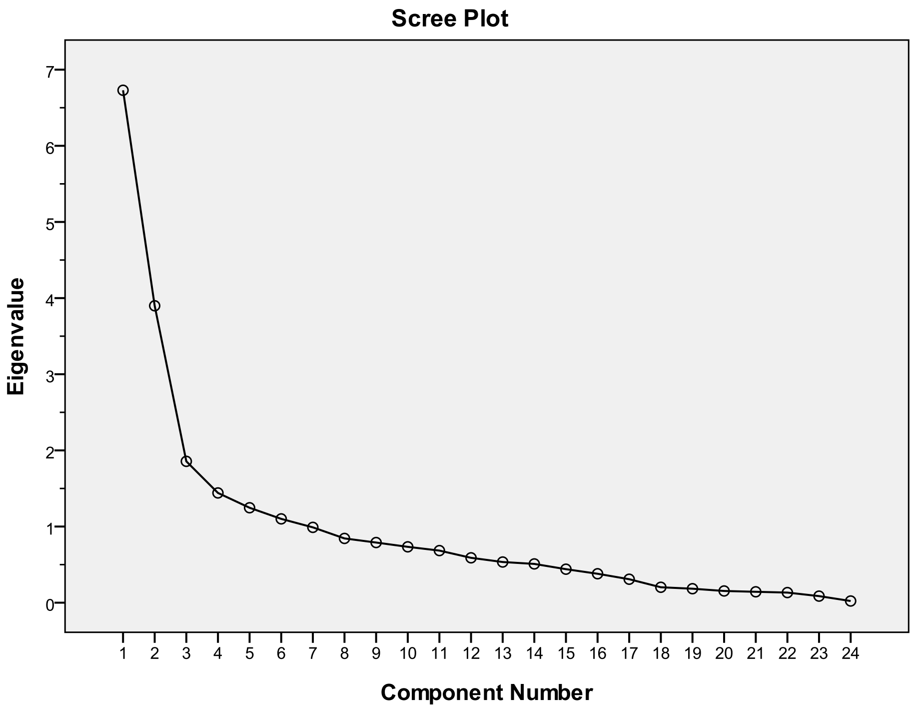


Figure 9.5 Scree plot of Eigenvalues

Table 9.14 Extraction and rotation of loadings, and total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.729	28.038	28.038	6.729	28.038	28.038	4.036	16.818	16.818
2	3.899	16.246	44.285	3.899	16.246	44.285	4.027	16.781	33.599
3	1.856	7.735	52.020	1.856	7.735	52.020	3.146	13.110	46.709
4	1.441	6.005	58.025	1.441	6.005	58.025	2.072	8.635	55.344
5	1.247	5.194	63.219	1.247	5.194	63.219	1.617	6.738	62.082
6	**1.101**	**4.586**	**67.805**	**1.101**	**4.586**	**67.805**	**1.374**	**5.723**	**67.805**
7	.989	4.122	71.927						
8	.844	3.517	75.444						
9	.790	3.291	78.735						
10	.734	3.056	81.791						
11	.684	2.851	84.642						
12	.589	2.455	87.097						
13	.534	2.226	89.323						
14	.509	2.122	91.445						
15	.440	1.834	93.279						
16	.380	1.583	94.862						
17	.308	1.284	96.147						
18	.203	.844	96.991						
19	.184	.765	97.756						
20	.154	.641	98.398						
21	.143	.596	98.994						
22	.133	.553	99.548						
23	.086	.360	99.908						
24	.022	.092	100.000						

Notes: Extraction based on Eigenvalue and only values greater than 1.0 are reported. Extraction method is Principal Component Analysis.

Table 9.15 KMO and Barlett's sphericity tests results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.727
Bartlett's Test of Sphericity	Approx. Chi-Square	73459.801
	df	276
	Sig.	.000

Table 9.16 Rotated component matrix

	Component					
	1	2	3	4	5	6
LU_MIX	**.769**					
PT_SERVICE	**.676**	.413				
WALKABILITY	**.667**				.462	
AIR_QUAL	**-.636**					-.357
NDAI_WALK	**.622**	.602				
URBANISED	**-.580**	-.509	-.377			
ACCIDENTS	**-.561**		.423	.359		
NDAI_PT		**.784**				
NDAI_CYCLE	.448	**.727**				
COMMUT_DIST		**.724**			.360	
ROAD_AREA		**.679**	.562			
PT_STOP	.304	**.639**				
GHG		.361	**.775**			
POP_DENSITY		.568	**.703**			
PARCEL_SIZE			**.657**			
OPEN_SPACE			**-.524**			
STORMWATER				**.767**		
CONGESTION				**.685**		
CALMING	.336		.458	**.553**		
NOISE	-.367			**.428**		
HOUSE_JOB					**.771**	
INT_CONN	.491				**.623**	
NUM_OF_TRIPS	.304		-.370		**.376**	
PARKING						**.883**

Notes: Component values greater than 0.3 are reported.
Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 20 iterations.

Calculation of the weights according to factor analysis

By following the procedure given in Nardo et al. (2008), the weight of each indicator was calculated according of the formulas given below:

$$C_j = \frac{\sum L_{ij}^2}{V_j}, \text{ and } i \in j;$$

$$W_{ij} = \frac{L_{ij}^2}{\sum V_j} \frac{C_j}{\sum C_j} \sum \frac{1}{C_j} \text{ and } i \in j$$

where i represents indicators (i=1,2,3,…,24) and j represents factors (j=1,2,3,…,6, see the columns of Table 9.16). L_{ij} and V_j correspond to factor loadings and variance explained by the specific factor. C_j is a correction array which consists of square of the loading of each indicator in factor j divided to the variance explained by the given factor (see column 8 in Table 9.14 for explained variances after rotation). For example, if we want to calculate the weight of land use mix indicator (i.e., labelled as LU_MIX in Table 9.16), first we need to produce C_j array. In this exercise, C_j = [0.73, 0.63, 0.57, 0.75, 0.70, 0.57]. Here, for example, the first item in the array, 0.73, is a product of the operation, $[(.769)^2 + (.676)^2 + (.667)^2 + (-.636)^2 + (.622)^2 + (-.580)^2 + (-.561)^2)]/4.036$ (see Table 9.16 for factor loadings of the first factor). After this, it is possible to calculate the weight for this indicator, such as $W_{11} = \frac{0.769^2}{16.273} * \frac{0.73}{3.94} * 9.251 = 0.061$. It should be noted that land use mix is the first indicator in the list (i.e., i=1) and grouped under the first factor (i.e., j=1)

APPENDIX G: SELECTION OF SURVEY SNAPSHOTS

Firstly, by using SPSS's K-means cluster analysis, clustering of transport, built environment and externalities categories was analysed. After trial and error, analyses with three-means value gave a good separation between possible cluster means, which resulted in well-separated clusters (see Figure 9.6). For three categories (transport, urban form and externalities) and three cluster means, the expected number of clusters was 27 (namely, 3^3=27). However, K-means cluster analysis gave 25 actual clusters for given data set as it can be seen in Figure 9.6. In the figure, black squares show the locations of snapshots with corresponding cluster values and are given here for the convenience. The selection criteria of these sites will be explained together with the spatial cluster analysis.

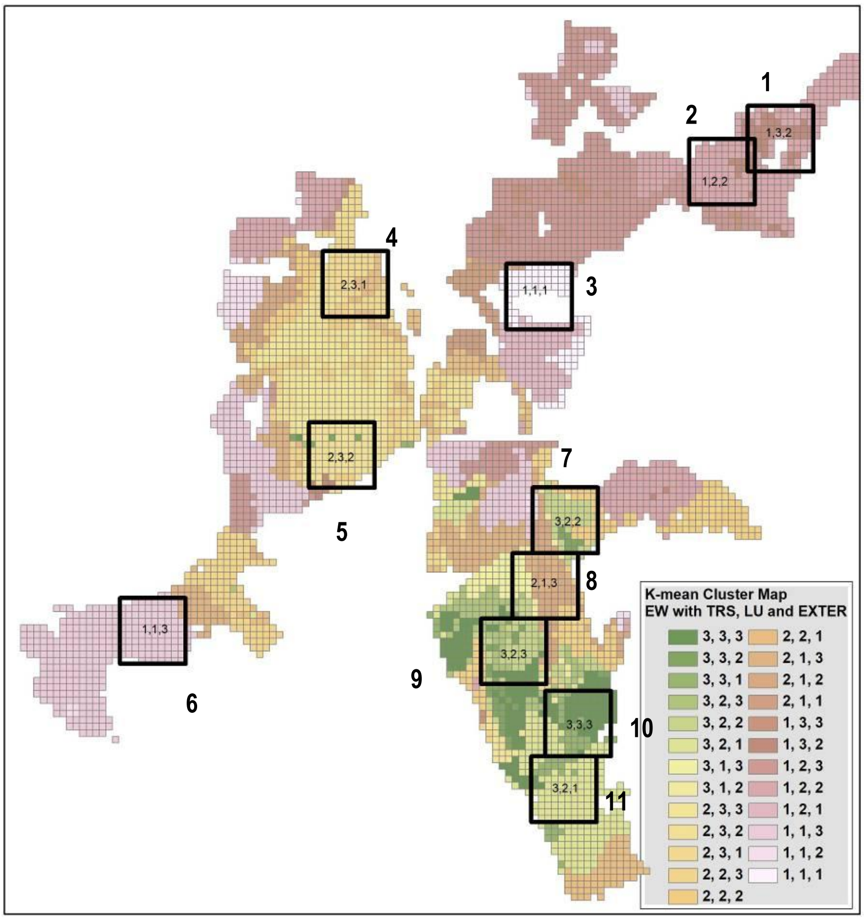


Figure 9.6. k-means cluster analysis results

To further clarification, statistical properties of each cluster were given in Table 9.17 below. As it can be seen in the table, nearly half of the index values are clustered around the values of 1.19, 2.01 and 3.02 for transport, built environment and externalities categories, respectively. This distribution table also gives interesting hints about the spatial clustering of the index values in the area. In Figure 9.6, it is easy to see that the northern section of Coomera shows low transport index performance but has good values for built environment and externalities categories; on the other hand the opposite can be said for the middle part of Helensvale. The southern part of Coomera and the northern section of Helensvale present low transport and built environment index scores but they have good scores for externalities category. As for Upper Coomera, central locations are grouped in the clusters with average index values. However, the peripheries of Upper Coomera have similar clusters as the southern part of Coomera.

Table 9.17. K-means cluster analysis summary

	Final Cluster Centres			**Number of Cases in each Cluster**			
Categories	**1**	**2**	**3**	**1**	**2**	**3**	**Total**
Transport	1.19	2.07	3.04	2009	1628	767	4404
Built Environment	1.44	2.01	2.66	1166	2287	951	4404
Externalities	2.17	3.54	3.02	884	1352	2168	4404

After analysing statistical clusters in the area, secondly, cluster and outlier analysis tool (Local Moran I) of ArcGIS, which uses local spatial autocorrelation statistics to detect spatial clusters, was employed. This tool was particularly helpful in revealing regions with similar features (for example, regions where statistically significant [p value<0.05] high or low values were clustered with high or low values, respectively) taking into account distance between spatial entities. In this study each grid cell was taken as analysis unit and three analyses conducted for each indicator category. For each cell, Euclidian distance of 499 metre was taken threshold value where the similar index values were searched to form the clusters. Selection of 499 metres as threshold value was basing on the size of the snapshot which is a 1 x 1 km square (100 hectares). The Figure 9.7 below shows an overlay analysis where how many times each cell is clustered in either high or low values. More specifically, a cell with the value of 3 in the figure represents that this cell yield a high or low value three times for each equally weighted index scores of three categories, which are transport, built environment and externalities.

Spatial clusters for the study area were extracted mainly inspecting Figure 9.7 visually. Two-step visual inspection was conducted for this purpose. Firstly, the areas where two or more spatial clusters exist were selected in Figure 9.7, and then these areas were compared with the k-means analysis results to finalise snapshot selection. If there were two sites with the same k-means cluster values, only one of them was added to the final set. In this selection process, representation of each suburb with the equal number of snapshots and minimising overlaps between snapshots were the main criteria adopted. According to these, three snapshots each from Coomera and Upper Coomera, and five from Helensvale were selected. As shown in the figure, snapshots cover nearly all areas where maximum number of spatial clustering occurs. Also, respective k-means cluster analysis values are given inside the squares representing snapshot locations. After selection of spatially and statistically similar areas, 11 snapshots were prepared for expert survey. A copy of expert survey is given in the following pages (pp. 313-318).

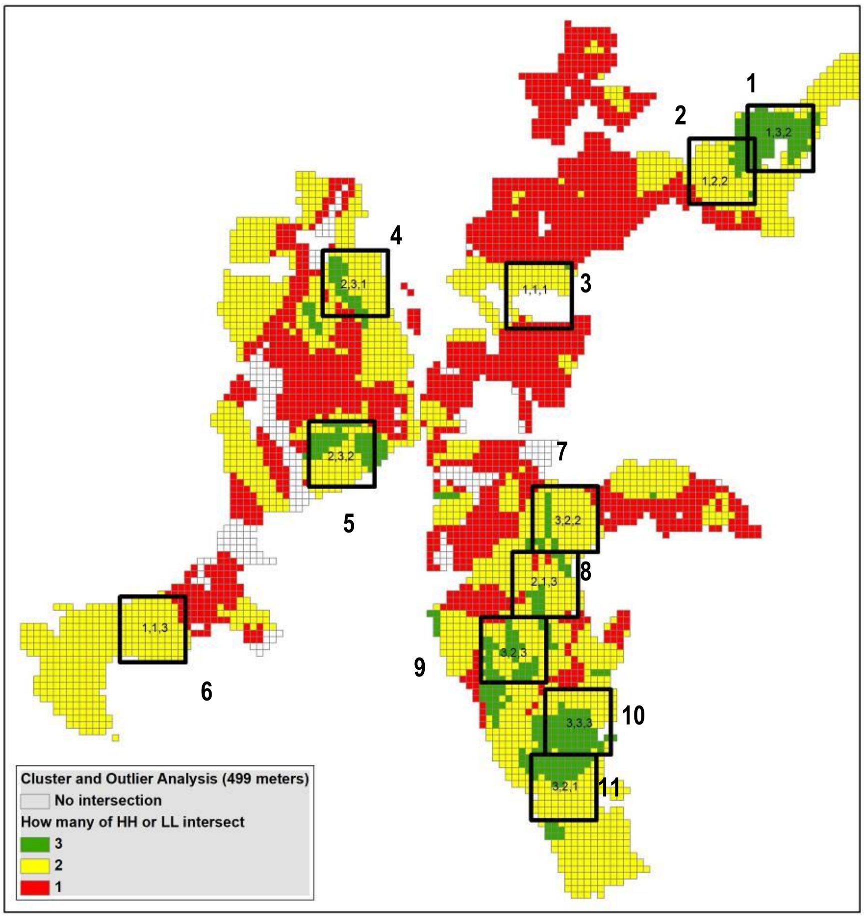
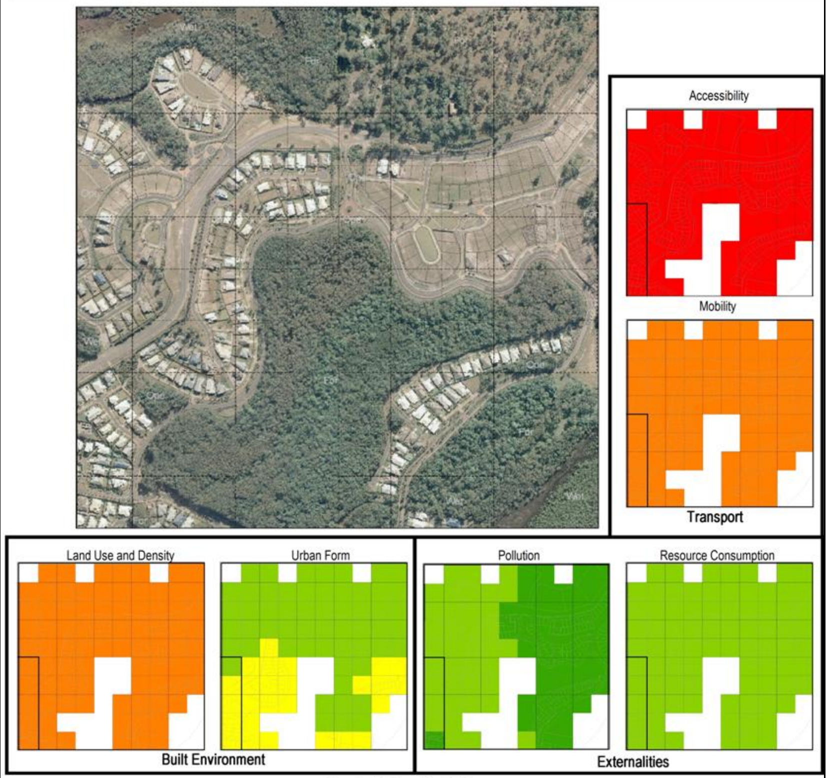


Figure 9.7.Anselin Local Moran I analysis results

APPENDIX H: SAMPLE OF SURVEY

Site 1. Upper Coomera - Colman Rd



Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	6403	0.66	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	0		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	14		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	28		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.1	1.33	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	29.9		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	3%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	0		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	2,275	1.62	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	2.29		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.30		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	1.89		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.62	3.02	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	79%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	24%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	89		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.01	4.02	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	1.40		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	38		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.06		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	31%	3.2	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	874		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.19		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	1		16	4	3	2	1	0	0	18	3

* EW: Equal weighting

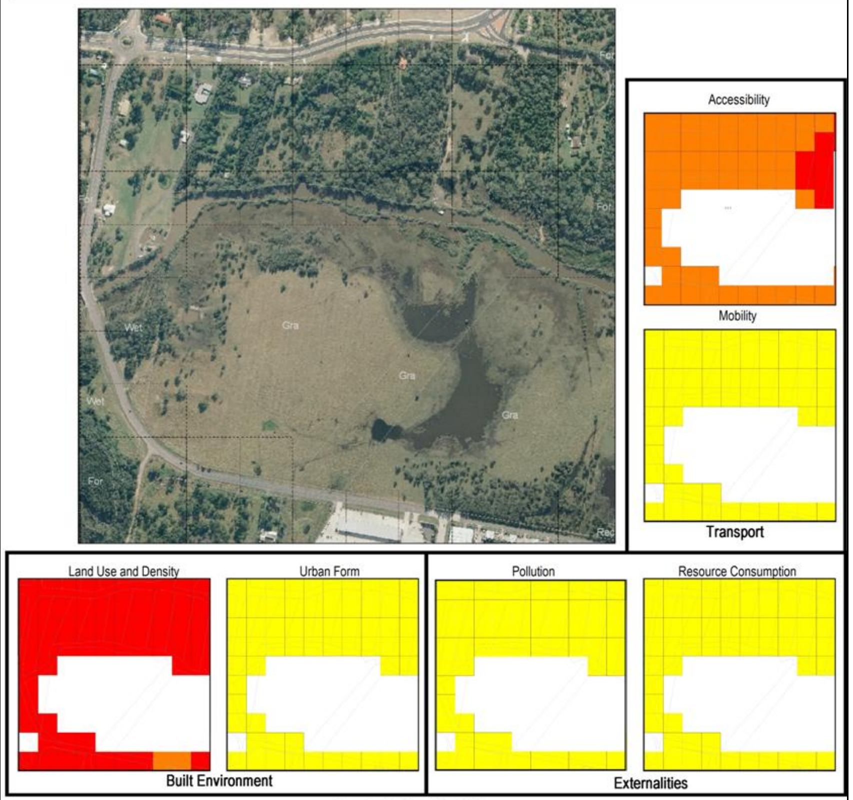
Site 2. Upper Coomera - Ragamuffin Dr

Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	5421	0.77	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	0		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	19		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	30		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.6	1.22	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	28.2		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	0		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	1,302	1.41	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	7.95		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.31		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	0.61		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.63	2.77	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	74%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	19%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	47		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.01	4	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	0.87		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	40		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.10		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	36%	3.26	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	478		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.45		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	0		16	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 3. Upper Coomera - Beattie Rd



Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	1792	1.11	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	0		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	13		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	82		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	6.9	2.04	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	22.9		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	5%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	41		0	20	40	60	90	150	0	189	29
Average parcel size	m^2/lot	28,964	0.58	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	1.19		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.24		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	17.34		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.61	2.64	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	49%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	21%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m^2/person	163		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m^3	0.03	2.58	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	9.37		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	57		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.11		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	50%	2.09	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m^2/person	678		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.49		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	8		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 4. Coomera - Abraham Rd

Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	547	2.4	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	0		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	70		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	103		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.1	1.85	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	20.8		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	38		0	20	40	60	90	150	0	189	29
Average parcel size	m^2/lot	13,127	1.83	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	9.81		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.50		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	2.15		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.74	3.05	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	54%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	43%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m^2/person	74		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m^3	0.06	3.26	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	1.67		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	59		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.10		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	83%	1.88	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m^2/person	229		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.53		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	4		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

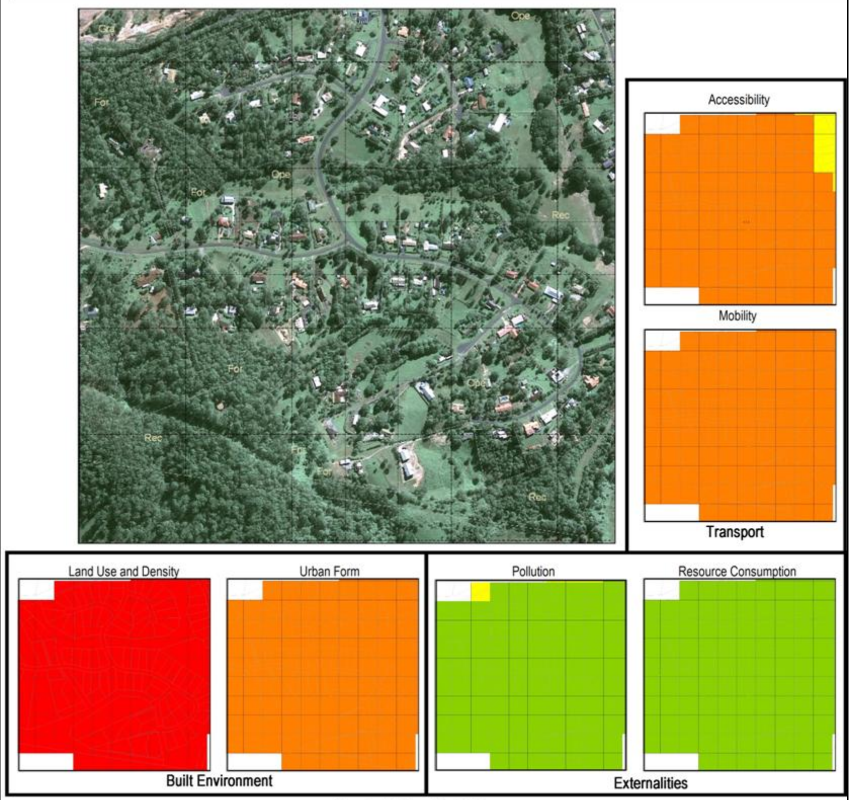
Site 5. Coomera - Diamond Sand Dr

Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	760	2.84	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	96		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	40		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	103		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.2	1.48	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	20.1		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	5%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	15		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	712	2.49	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	20.99		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.32		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	1.52		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.66	2.95	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	83%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	17%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	59		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	µg/m³	0.01	4.21	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	0.24		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	41		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.08		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	85%	3.11	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	76		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.24		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	1		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 6. Coomera - Glenview Rd



Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	2178	1.21	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	20		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	14		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	53		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.2	1.32	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	26.9		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	0		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	8,092	0.53	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	1.82		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.17		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	0.00		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.50	1.7	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	11%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	0%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	82		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	µg/m³	0.01	3.4	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	3.66		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	33		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.11		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	17%	3.07	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	403		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.47		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	2		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

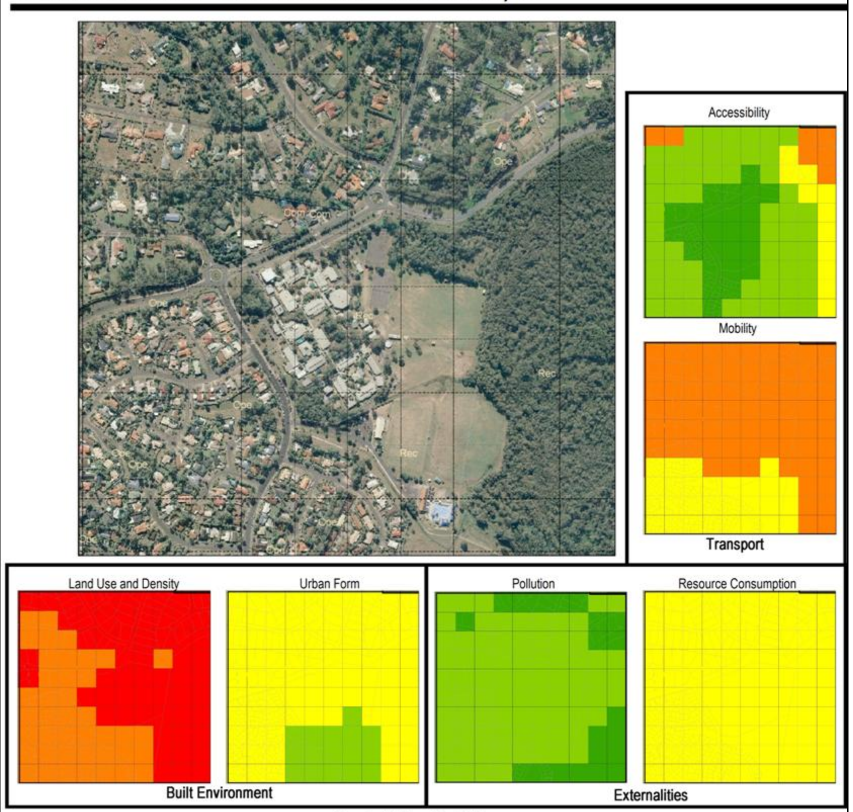
Site 7. Helensvale - Monterey Keys Dr

Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	492	3.34	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	110		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	45		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	103		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	8.9	1.63	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	19.4		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	5%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	24		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	1,572	1.38	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	13.41		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.20		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	0.16		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.57	2.37	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	52%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	18%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	106		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.00	4.02	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	0.50		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	48		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.09		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	71%	3.02	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	126		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.30		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	1		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 8. Helensvale - Helensvale Rd and Discovery Dr

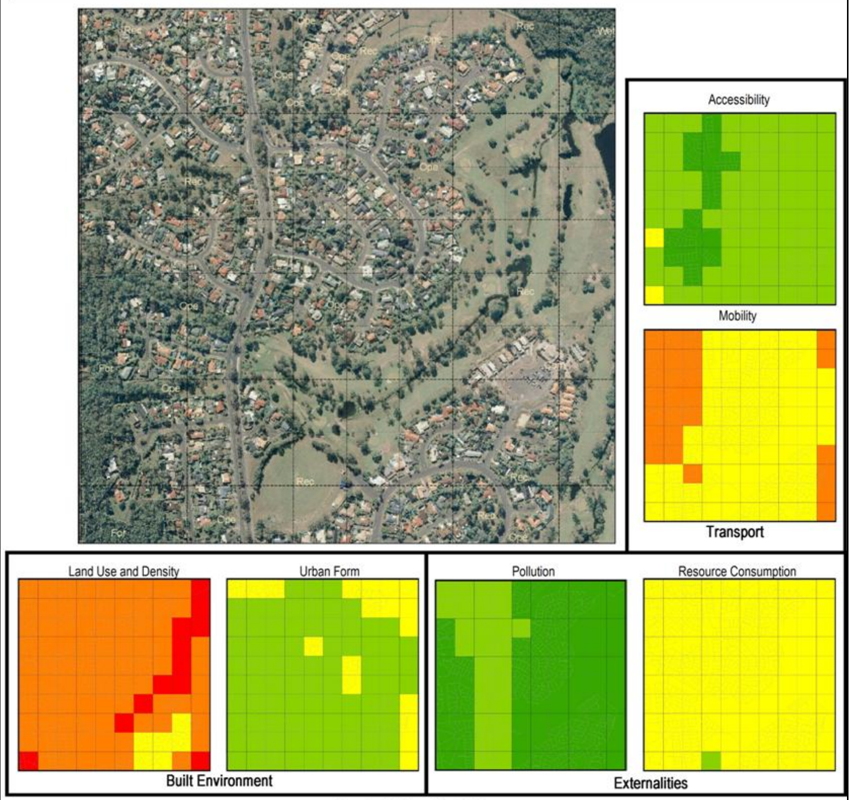


Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	414	3.53	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	114		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	44		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	115		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	9.2	1.89	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	16.7		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	32		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	4,713	1.06	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	9.40		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.22		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	0.11		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.58	2.42	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	33%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	19%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	337		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.02	3.81	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	0.68		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	51		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.10		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	56%	2.75	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	154		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.50		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	2		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 9. Helensvale - Discovery Dr



Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	456	3.59	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	132		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	39		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	119		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	8.1	2.1	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	17.5		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	40		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	1,493	1.4	160,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	13.89		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.29		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	1.07		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.59	3.11	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	64%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	47%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	150		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.02	4.05	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	0.44		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	39		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.09		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	93%	2.81	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	96		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.52		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	1		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

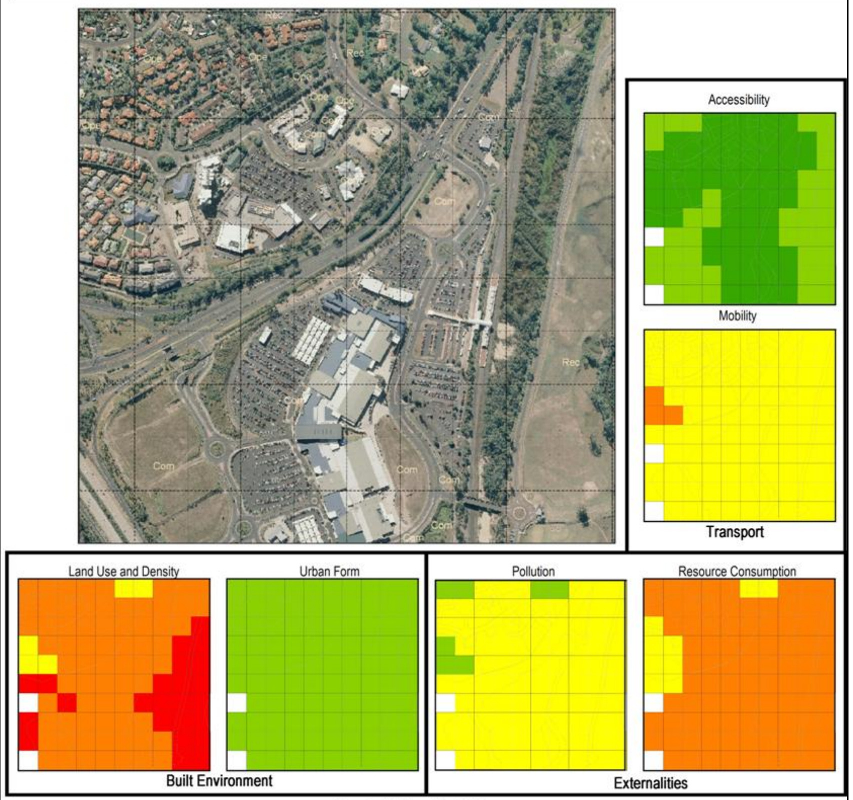
Site 10. Helensvale - Discovery and Mildura Dr

Snapshot Information Table

Indicators	Units	Average Values For: Indicator	Average Values For: Index (EW)*	Benchmark Values: Zero	Low	ML	Med	MH	High	Study Area Information: Min	Max	Average
Access to public transport stops	m	444	4.02	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	135		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	81		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	124		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	7.7	2.59	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	17.2		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	106		0	20	40	60	90	150	0	189	29
Average parcel size	m²/lot	1,143	2.23	160,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	13.37		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.41		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	2.09		0|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.64	3.14	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	59%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	49%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m²/person	213		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	μg/m³	0.04	3.37	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	1.72		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	54		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.11		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	73%	1.97	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m²/person	154		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.67		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	7		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Site 11. Helensvale - Westfield Helensvale



Snapshot Information Table

Indicators	Units	Average Values For		Benchmark Values						Study Area Information		
		Indicator	Index (EW)*	Zero	Low	ML	Med	MH	High	Min	Max	Average
Access to public transport stops	m	481	4.09	1200	800	600	400	200	0	15	8070	1841
Access to land use destinations (LUDs) by public transport	NDAI Score	135		0	14	34	68	95	135	0	135	40
Access to LUDs by walking	NDAI Score	97		0	14	34	68	95	135	0	113	33
Access to LUDs by cycling	NDAI Score	125		0	14	34	68	95	135	14	125	83
Average number of trips made by car per household	car trips/HH	7.9	2.86	11	9	7	5	3	0	4.8	10.2	8.5
Average commuting distance to work for per employee	km/employee	17.4		35	30	15	10	1.6	0	12.9	32.6	21.5
Off-street parking spaces per employee in employment centres	probability	4%		10%	8%	6%	4%	2%	0%	3%	11%	5%
Public transport service and frequency	services/day	181		0	20	40	60	90	150	0	189	29
Average parcel size	m^2/lot	54,566	1.27	180,000	5,000	1,000	800	400	0	84	1,600,050	46,316
Population density	people/ha	4.52		0	5	15	30	50	100	0.53	40.34	7.57
Land use mix ratio	ratio	0.60		0	0.2	0.4	0.6	0.8	1	0.00	0.83	0.31
Housing to jobs ratio	ratio	4.52		8|2.5	2|2.3	4|2.1	6|1.9	8|1.7	1-1.5	0.00	31.66	3.15
Internal street connectivity	ratio	0.75	3.2	0	0.2	0.4	0.6	0.8	1	0.46	0.84	0.63
Traffic calming	ratio	49%		0%	20%	40%	60%	80%	100%	11%	100%	48%
Walkability, pedestrian friendliness	ratio	50%		0%	20%	40%	60%	80%	100%	0%	57%	26%
Open space availability	m^2/person	241		0	5	10	25	100	1600	3	866	137
Air quality (Lead concentration)	$\mu g/m^3$	0.05	2.46	0.5	0.375	0.25	0.125	0.05	0	0.00	0.27	0.02
CO2 emissions from transport activities	tonnes	4.60		10	4.52	3.34	2.26	1.13	0	0.04	9.37	2.86
Exposure to traffic noise	dBa	66		90	75	65	55	45	0	8	79	46
Stormwater quality (Lead concentration)	mg/lt	0.12		1	0.5	0.2	0.1	0.02	0	0.02	0.21	0.10
Land area occupied by urban uses	ratio	84%	1.38	100%	80%	60%	40%	20%	0%	12%	100%	52%
Roadway area per capita	m^2/person	312		2000	200	133	66	33	0	61	1967	543
Traffic congestion	LOS	0.67		2	0.9	0.8	0.7	0.6	0	0.00	0.91	0.47
Traffic accidents	count	16		15	4	3	2	1	0	0	18	3

* EW: Equal weighting

Expert questionnaire for The Integrated Land Use and Transportation Indexing Model: Assessing the Sustainability of Gold Coast, Australia

Name: ……………………………………………….. Date: ……………………………………………………………

Profession: ……………………………………….. Department: ……………………………………………….

1 Evaluation of standard snapshots of the area

How do you evaluate these sites' *neighbourhood level sustainability performance*?

Site	Low		Med-Low		Medium		Med-High		High
Site 1	○	○	○	○	○	○	○	○	○
Site 2	○	○	○	○	○	○	○	○	○
Site 3	○	○	○	○	○	○	○	○	○
Site 4	○	○	○	○	○	○	○	○	○
Site 5	○	○	○	○	○	○	○	○	○
Site 6	○	○	○	○	○	○	○	○	○
Site 7	○	○	○	○	○	○	○	○	○
Site 8	○	○	○	○	○	○	○	○	○
Site 9	○	○	○	○	○	○	○	○	○
Site 10	○	○	○	○	○	○	○	○	○
Site 11	○	○	○	○	○	○	○	○	○