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A METHODOLOGICAL APPROACH FOR
INDICATOR-BASED SUSTAINABLE TRANSPORT
ASSESSMENT

by

Nicodemus Herb Castillo

A dissertation thesis submitted in partial fulfilment of the requirements
for the award of the degree of Doctor of Philosophy at Loughborough
University

October 2004

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Abstract

Sustainable transport is now a popular goal of transport planning. As with any aspiration, systems and mechanisms are required to assess and gauge success in achieving this policy goal. There is increasing reliance on sustainable transport indicators as appropriate tools for this purpose. The usefulness and credibility of any indicator-based assessment will undoubtedly depend on the specific indicators utilised. As such, indicators must be selected carefully to maximise their contribution to the sustainable transport decision making process. A review of current applications of sustainable transport indicators has revealed however, that they are typically selected in an \textit{ad hoc} and arbitrary fashion. Development of a framework that facilitates transparent and systematic indicator selection would therefore represent a significant advance in transport research. In that regard, this thesis presents the \textbf{E}valuative \textbf{a}nd \textbf{L}ogical \textbf{A}pproach to \textbf{S}ustainable \textbf{T}ransport \textbf{I}ndicator \textbf{C}ompilation (ELASTIC), a methodological framework which provides a flexible, participatory and systematic mechanism for identifying and selecting key sustainable transport indicators. The output of ELASTIC is the Transport Sustainability Profile (TSP), a small un-aggregated suite of sustainable transport indicators which together can provide a snapshot of the sustainability of a transport system. Using various multi-criteria and statistical techniques, ELASTIC applies a robust process to evaluate and select indicators based on their analytical soundness and their relevance to key objectives of sustainable transport. A generic and transferable tool, ELASTIC is capable of application at different geographical scales as well as to non-transport sustainability assessment. For the purpose of this research, the framework is demonstrated through application to England, UK where the judgements of relevant Academics and Transport Planners are elicited and entered into the ELASTIC framework to systematically select a subset of 15 indicators from an initial set of 200. By disaggregating the sample of stakeholders into regional groupings, different context-specific suites of indicators for the regional groupings were also derived. The demonstration confirms ELASTIC to be an inclusive and practical approach to compiling a suite of sustainable transport indicators specific to context and which reflects the unique values of key stakeholders.

\textbf{Key Words:} sustainable transport, sustainability assessment, indicators, multi-criteria decision analysis, analytic hierarchy process, participatory transport planning.
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CHAPTER ONE: Introduction

1.0 Overview

This chapter describes the background to the research and briefly discusses how the pertinent issues contributed to the development of the aims and the work presented in this thesis. The original contributions of the research are then presented and the scope of the thesis defined. Finally, the chapter concludes with a description of the structure of the thesis and a brief outline of each component chapter.

1.1 Research background

The physical movement of humans and commodities over space and time, provided by an efficient transport system, is essential for the functioning of societies and economies. There is no debating the fact that over the years, transport has enriched and shaped society. It is becoming increasingly clear however, that the benefits provided by transport have come at a cost. The improvement in the mobility of both people and goods, while contributing to tremendous social and economic advances, has also had various adverse effects on society, the environment and some sectors of the economy.

Since the popularisation of the concept of 'sustainable development' by the Brundtland Commission (WCED 1987) and its emphasis on minimising the negative impacts of development, the adverse impacts of transport have become of increasing concern to the general public, policy-makers, and planners alike. There is now general consensus that current transport trends cannot continue, and that fundamental changes in the planning, design, and operation of transport systems are needed (Banister and Button 1993, Whitelegg 1993, Nijkamp 1994, Black 1996, Greene and Wegener 1997, DETR 1998, May et al 2003). These concerns have converged to form an interest in the concept of sustainable transport and over the past decade, numerous strategies, policies, Green Papers, White Papers and academic research articles have been published by international

1.2 Sustainable transport and the need for assessment

Given that sustainable transport has become a popular goal of transport planning, tools are necessarily required to enable policy makers and decision makers to assess and monitor whether transport systems are indeed progressing towards this goal. Sustainable transport is a broad, complex and multidimensional concept however, the assessment of which poses numerous challenges. A major problem is the sheer vastness of the data that would have to be considered to comprehensively assess the myriad of issues relevant to the concept. The fact that transport’s impacts are measured in different units is an additional problem. To be effective therefore, tools and mechanisms to assess sustainable transport must be capable of capturing the key dimensions of the concept and at the same must enable easy interpretation of the resultant information and data.

Increasingly, sustainable transport indicators are proving useful for this purpose and have seen wide application both in the academic literature and in practice (see for example, Kupiszewska 1997, European Environmental Agency and Eurostat 1999, OECD 1999, Lautso and Toivanen 1999, Ricci 2000, Gilbert et al 2002, Black et al 2002, Borken 2003, Gudmundson 2003 a, Imran and Low 2003, Minken et al 2003, Jones et al 2003, Nicholas et al 2003, etc.). The attractiveness of indicators is largely due to their ability to provide informative signals for the multiplicity of issues inherent in considerations of sustainability. Logically, the indicators utilised in any given context will determine the types of decisions taken based on the issues they illuminate and the information they provide. Therefore, indicators must be selected carefully so that they illuminate only those issues that are key to sustainable transport and relevant to the context. Over the years, numerous sustainable transport indicators have been proposed. Consequently,
when seeking to apply indicator-based assessment processes to monitor, gauge and communicate transport sustainability, policy makers and transport practitioners are faced with an endless choice of possible sustainable transport indicators. This poses a difficult problem for practitioners as selection of poor performance measures can lead to poor decisions and outcomes. There is therefore a significant need for a systematic approach to facilitate the identification of appropriate indicators and performance measures to guide sustainable transport assessment in any given context (Pratt and Lomax 1996).

1.3 Statement of the problem

While the verbiage and literature on sustainable transport is plentiful, and the use and application of sustainable transport indicators is widespread, examination of the literature and past work has revealed an absence of any robust, comprehensive and easy-to-use framework that enables the selection of appropriate sustainable transport indicators.

Identifying high quality and appropriate sustainable transport indicators, like most decision making scenarios in transport planning, is a complex process which requires the balancing of multiple, and often conflicting objectives. Key considerations include ensuring their highest possible relevance to key principles of sustainable transport, as well as maximising their analytical soundness and practical applicability. Moreover, a key requirement in sustainability analysis is that the values of relevant stake-holders must be incorporated into the decision making process and that assessment must be inherently flexible to enable adequate recognition of the requirements and peculiarities specific to the context in which the indicators are applied.

An analytical framework is therefore needed that provides a simplified, comprehensible and systematic process to aid the selection of key sustainable transport indicators in a way that assures accordance with relevant sustainability principles. Once the appropriate simplifications and assumptions to guide indicator selection are defined, such a framework can serve as a valuable operational tool for sustainable transport planning as it would facilitate an important, but currently lacking process (Van den Bergh 1996).
1.4 Research aims and objectives

This research is based on the premise that for progress to be made towards sustainable transport, systems and mechanisms are required that will enable its operationalisation and assessment so that movement towards or away from sustainability can be ascertained and appropriate decisions taken.

1.4.1 Overall aim

Based on the above premise, the primary aim of this research is to develop and apply a generic and transferable methodological framework that will facilitate the selection of key indicators which can then guide the assessment and monitoring of the sustainability of a given transport system.

The specific objectives of the research are as follows;

1. To specify a vision for sustainable transport and draw on the literature and current practice to decompose the vision into generic objectives;

2. To establish the role of assessment in sustainable transport planning and examine the adequacy of indicators as sustainable transport assessment tools;

3. To identify key desirable characteristics of sustainable transport indicators and indicator-based sustainability assessment frameworks;

4. To conduct an extensive critical examination of current approaches to selecting and identifying sustainable transport indicators in the literature and in practice;

5. To devise a participatory framework for assessing and selecting key sustainable transport indicators in a way that maximises their desirable attributes;

6. To demonstrate the framework with a practical application to England, UK.
1.5 Original contributions of the research

Indicators and performance measures for sustainable transport up to now have largely been selected in an arbitrary manner. Even where formal frameworks are purported, these have lacked the ability to adequately incorporate the views of stakeholders or the flexibility to take consideration of the context to which the indicators are to be applied.

The main output of this research is the Evaluative and Logical Approach to Sustainable Transport Indicator Compilation (ELASTIC), a methodological framework which provides a flexible, inclusive and systematic approach for selecting a suite of sustainable transport indicators for assessing the sustainability of a given transport system.

The following are individual contributions of the research.

1. A review of the various definitions of sustainable transport and identification from the literature of the key attributes of a sustainable transport system;
2. Clear illumination of the importance of assessment in sustainable transport planning, and the adequacy of sustainable transport indicators as assessment tools;
3. Specifications of gaps and needs in current research based on an extensive international review of approaches to sustainable transport indicator selection;
4. A validated participatory, systematic and transferable methodological framework for identifying and selecting key sustainable transport indicators.

1.6 Scope of the research

The research presented in this thesis is primarily concerned with the assessment of sustainability within the road transport sector. Consequently, the formulation as well as the demonstration of the framework that makes up the main output of this thesis, are to road transport. However, ELASTIC is transferable and is capable of application at any spatial or geographical level. Moreover, while the application in this thesis is to road transport, the framework, with appropriate modifications, can also be applied for selecting sustainability indicators in any context.
Chapter One: Introduction

1.7 Outline of the thesis

The thesis is comprised of eight chapters including this introduction. All chapters follow a similar format. Each begins with a brief overview, followed by an introduction and detailed discussion of the topic that the chapter addresses. Each chapter culminates with a summary and review of the key points.

The remaining seven chapters of the thesis are organised as follows:

Chapter Two provides an introduction to the concept of sustainable transport. It commences with a brief discussion of sustainable development, in which sustainable transport has its roots. This is followed by a focused discussion of the concept of sustainable transport and examination of the various suggested definitions and interpretations. These are then used to derive a broad vision of sustainable transport for the purposes of this thesis. A similar review of the suggested objectives of sustainable transport is undertaken, resulting in them being clustered into five broad categories.

Chapter Three examines the need for assessment and monitoring mechanisms in sustainable transport planning. The roles of indicators as monitoring tools and the importance of systematic frameworks to aid their selection is then discussed. The desirable attributes and qualities of good indicators as well as good indicator-based sustainability assessment frameworks are also established.

Chapter Four presents a critical review of past applications of sustainability indicators. First, a brief review is undertaken of the application of indicator-based frameworks to assessment of the broader concept of sustainable development. This was necessary partly because sustainable transport has its origins in this broader concept, but also because a greater volume of work on sustainability indicators has been undertaken in this wider context. Following this broad review, a critical sector-specific examination is conducted of the application of indicators within sustainable transport planning. To draw together the key findings of the review, a Strengths-Weakness-Opportunities-Challenges (SWOC) analysis is conducted to illuminate the gaps and opportunities from the past applications.
Chapter Five presents the key contribution of the thesis, namely the Evaluative and Logical Approach to Sustainable Transport Indicator Compilation (ELASTIC), a methodological framework for systematically selecting and compiling a suite of indicators for assessing and monitoring the sustainability of transport systems. The principles underlying the ELASTIC framework and the inherent processes are described in detail. The various theoretical and methodological underpinnings of the framework, primarily multi-criteria decision analysis and monte carlo simulation, are also presented.

Chapter Six describes the application of the ELASTIC framework to selection of suitable sustainable transport indicators for England, UK and its regions. To provide some background and to establish the suitability of ELASTIC for the application, the UK’s sustainability and planning policy contexts are first discussed. Once the pertinence of the ELASTIC framework is established, the application is described in detail. This commences with a description of the initial large set of indicators entered into the process. Following this, the criteria against which the indicators are evaluated, as well as the surveys conducted to derived the necessary weightings, are discussed.

Chapter Seven presents the results of the application of ELASTIC to England and describes the attendant analyses and the subsequent indicator selection process. The results of the surveys conducted to elicit stakeholder judgements are first described and multi-criteria decision analysis subsequently applied to derive numeric weights for the ELASTIC criteria and sub-goals. Once the indicators in the initial long list are evaluated against these weighted criteria, the Transport Sustainability Profile (TSP) - a small suite of the best performing sustainable transport indicators, is then derived for England. To further demonstrate the robustness and flexibility of the ELASTIC framework, the stakeholders surveyed are disaggregated into three broad spatial groupings and their values are used to derive TSPs specific to these broad regional groupings.

Chapter Eight presents a summary of the research and describes the contribution of ELASTIC to current sustainable transport planning. Future work to enhance ELASTIC and sustainable transport assessment generally are also proposed.
1.7.1 Appendices to the thesis

To support the content and the work presented in the thesis, 11 supporting documentations are appended to the thesis. These are as follows:

Appendix A1: The pre-notification letter sent out to prospective survey participants informing them of the impending (first) questionnaire survey.

Appendix A2: The ‘Guide to Completing the Questionnaire’ sent out with questionnaires in the first stage of the survey process.

Appendix A3: Generic version of the Cover Letter sent with questionnaires in the first stage of the survey process.

Appendix A4: The actual questionnaire sent out to Transport Planners in the first survey.

Appendix A5: The actual questionnaire sent out to Academics in the first survey stage.

Appendix B1: The pre-notification letter sent out to prospective survey participants informing them of the impending (second) questionnaire survey.

Appendix B2: The ‘Guide to Completing the Questionnaire’ sent out with questionnaires in the second survey stage.

Appendix B3: Generic version of the Cover Letter sent with questionnaires in the second survey stage.

Appendix B4: The questionnaire sent out to Transport Planners in the second survey.

Appendix B5: The questionnaire sent out to Academics in the second survey stage.

Appendix C1: Normalised outcome scores assigned to indicators in the initial long list.
CHAPTER TWO: The concept of sustainable transport

2.0 Overview

The concept of sustainable transport has its origins in the wider concept of sustainable development. Consequently, this chapter commences with a discussion of sustainable development in the broader sense. This is then followed by a sector-specific and more focused discussion of sustainable transport. Among other things, a broad vision for sustainable transport is established and the key objectives of the concept ascertained.

2.1 The concept of sustainable development

The expression ‘sustainable development’ was first used in its current context in 1980 by the International Union for the Conservation of Nature and Natural Resources (IUCN), in a publication titled 'World Conservation Strategy' (IUCN 1980). Among other things, the strategy stated that; ‘for development to be sustainable it must take account of social and ecological factors, as well as economic ones; of the living and non-living resource base; and of the long term as well as the short term advantages and disadvantages of alternative actions’ (IUCN 1980, p. 23).

Current understanding and popularity of the concept of sustainable development however, can be attributed directly to the United Nations' World Commission on Environmental Development (WCED) report, Our Common Future (WCED 1987)

1, which spawned the oft-quoted definition of sustainable development as ‘development that meets the needs of the present without compromising the ability of future generations to meet their own needs’ (WCED 1987, p.23). Central to the WCED’s definition was an emphasis on the integration of economic, environmental and social goals, and a requirement that they be addressed equally, both for present and future generations.

1This report is also popularly known as the ‘Brundtland Commission report’ after former Norwegian Prime Minister Dr Gro Harlem Brundtland, who was chair of WCED at the time of publication.
The underlying tenet is that there are social and physical/ecological limits to economic growth and that patterns of consumption, growth and development must be held within what is ecologically and socially feasible, so that future generations are bequeathed adequate resources to enable them to continually enhance their quality of life.

In 1992, nearly 180 countries met at the 'Earth Summit' in Rio de Janeiro to discuss how to achieve sustainable development. The key outcome of this meeting was the 'Rio Declaration' subsequently elaborated through *Agenda 21* (United Nations 1992), which identified the various issues and areas that have to be addressed for progress to be made towards sustainable development. While it does not specify how to bring about sustainable development, *Agenda 21* suggests several key principles that are integral to achieving the policy goal. Some of the most often quoted principles are shown in Box 2-1 below.

<table>
<thead>
<tr>
<th>Equity</th>
<th>The right to development must be fulfilled in a way that equitably meets the developmental and environmental needs of present and future generations.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation</td>
<td>Sustainable development issues are best addressed with the participation of all concerned citizens, at the relevant level.</td>
</tr>
<tr>
<td>Specificity of context</td>
<td>Legislation, standards, management objectives and priorities should reflect the specific developmental context to which they apply. Standards applied in some areas may be inappropriate and unwarranted in others.</td>
</tr>
<tr>
<td>Polluter pays</td>
<td>External costs should be internalised through the use of economic instruments, with a view to ensuring that the polluter bears the cost of pollution, with due regard to the public interest and without distorting international trade and investment.</td>
</tr>
</tbody>
</table>

**Box 2-1: Select principles of sustainable development as stated in Agenda 21**
Chapter Two: The concept of sustainable transport

In 2002, representatives of the world assembled again at the Rio + 10 World Summit on Sustainable Development in Johannesburg, South Africa, at which they reaffirmed the commitment to sustainable development and the associated principles previously agreed at the 1992 Rio Summit (United Nations 2002).

2.1.1 An abundance of definitions of sustainable development

Since the WCED's definition, numerous other definitions of sustainable development have been proposed. Moffatt et al (2001) estimate that the definitions number in the hundreds. Some of them are simple, such as the UK government's assertion that sustainable development is 'development that ensures a better quality of life for everyone, now and for generations to come' (DETR 1999 a). Goodland (1995) on the other hand, distinguished between 'environmental sustainability', 'economic sustainability', 'social sustainability' and 'sustainable development'. He defined environmental sustainability as the maintenance of life-support systems (both sinks and resources), economic sustainability as the economic tantamount of environmental sustainability, being defined as the maintenance of economic capital, and social sustainability as the maintenance of social capital. Sustainable Development is then taken to be the integration of all three dimensions of sustainability. The integration of the different dimensions of sustainability in a way that does not reduce their total sum is a popular interpretation of sustainable development among Ecological Economists (see for example Pearce and Atkinson 1993, Pezzey 1996, Pearce and Barbier 2000, etc.). This interpretation of sustainability has its theoretical roots in the Hicksian definition of income (Hicks 1939), that is, 'the amount of income that can be spent without reducing real consumption in the future'. Using this general ideology, interpretations based on the Hicksian definition of income take development to be sustainable when the combined levels of social, environmental and economic sustainability are such that the sum of all three is not reduced.

Some writers however, unwittingly limit the concept of sustainability to the environmental aspects. Hawken (1993) for example suggested that sustainability is achieved when 'the demands placed on the environment by people and commerce can be met without reducing the capacity of the environment to provide for future generations'.
Despite their multiplicity, the various definitions of sustainable development are fundamentally similar in that they all tend to be based on the underlying premise that 'a sustainable system is one which survives or persists' (Costanza and Patten 1995). Moreover, there are several common themes that run through the many definitions. These themes include enhanced equality of opportunity, inter and intra generational equity, respecting ecological limits and minimising environmental damage, improvements in societal welfare and health and the maximisation of economic growth.

2.1.2 Achieving the goal of sustainable development

Promulgation of sustainable development as a policy goal, can give the impression that it is an ideal and definitive end state. There is increasing consensus in the modern sustainable development literature however, that sustainable development is not a 'fixed end state of harmony' (see for example, Shearman 1990, Shriberg 2002). Rather, as described by Hodge and Hardi (1997), 'it is an ongoing process of evolution in which people take actions leading to development that meets their current needs without compromising the ability of future generations to meet their own needs'.

2.2 Transport in the context of sustainable development

There is increasing recognition that the transport sector has an important role in determining progress towards sustainable development (Gudmundsson and Höjer 1996, OECD 1997, Banister 2000, Geerlings 2003, Bayliss 2004). Transport's importance in this context stems from the fact that it permeates a vast number of human activities and therefore has implications on a number of processes and issues that are key to sustainable development. As previously stated, sustainable development is often interpreted as the integration of environmental, social and economic concerns (Pope et al 2004). In order to briefly highlight the importance of transport within the context of sustainable development, a summary overview of the implications of transport on each of these three dimensions is presented below. It should be noted however that this review is by no means comprehensive and is intended only to provide a general insight into the wide variety of transport impacts that exist.
2.2.1 Environmental impacts of transport

The impacts of road transport on the environment are well documented (see for example, Royal Commission on Environmental Pollution 1994, Hensher and Button 2003, Safonov 2003). For ease of discussion, the various impacts of road transport on the environment are classified here into two categories, namely resource use and environmental pollution.

2.2.1.1 Resource use

Road transport is a significant consumer of natural resources, some of which are non-renewable. Since non-renewable natural resources have no regeneration capacity, their use is inherently unsustainable. However, the rate of use can, in theory, be controlled to accommodate developments of substitutes and alternatives or more efficient technologies. As discussed in the sub-sections below, the non-renewable resources whose consumption for transport purposes is of most concern are land and fossil fuel.

Land use

Road transport is a major consumer of land, which is required to meet spatial needs for roads, parking spaces, etc. (Akinyemi and Zuidegeest 2002). The Royal Commission on Environmental Pollution (1994) estimates that roads alone take up a fifth of the surface of urban areas in the UK. Within urban areas, high proportions of land are devoted to transport that could be used for other development or be kept intact for aesthetic and other purposes. Outside urban areas, transport infrastructure can destroy or disrupt natural habitats and adversely affect ecological balance, as well as take up arable land that could be used for agricultural purposes.

The problem can become cyclic. The provision of roads, by attracting and accommodating induced traffic, can encourage low-density developments and consequent urban sprawl which in turn creates more demand for new land and resources (Newman and Kenworthy 1989, Kenworthy and Laube 1999, Noland 2001). Similarly, where infrastructure takes up agricultural land, importation of agricultural produce from other regions is necessitated, thus creating further demand for transport infrastructure.
Fossil fuel Use
Road transport is a significant consumer of energy, the predominant source of which is fossil fuels (Browning et al 1998). Cooper et al (2001) have shown that urban sprawl and current transport patterns are exacerbating such consumption, an inherently unsustainable phenomenon since fossil fuels are essentially non-renewable. Indeed, alternatives to fossil fuels are emerging, but fossil fuels continue to be used more quickly than renewable substitutes are being developed and adopted (Daly 1990, OECD 1996).

2.2.1.2 Environmental pollution
The combustion of fossil fuels to provide energy for propulsion of motor vehicles results in several kinds of emissions into the atmosphere. These include Carbon Monoxide (CO), Nitrogen Oxides (NO\textsubscript{x}), Volatile Organic Compounds (VOCs), Particulates (PM\textsubscript{10}), Sulphur Oxides (SO\textsubscript{x}) and Carbon Dioxide (CO\textsubscript{2}). Many of the emissions from road transport have direct impacts on human health as well as various global and local effects on the environment (for a more detailed discussion of these impacts see Moon 1994, Poulton 1994, Bechtold 1997, Leiby 2001, Beer et al 2002, Mediavilla-Sahagún and ApSimon 2003, Parkhurst 2004, etc.).

Global Impacts
The release of carbon dioxide (CO\textsubscript{2}) into the atmosphere - an almost inevitable consequence of the combustion of fossil fuels has important global implications. Carbon dioxide is the principal anthropogenic ‘greenhouse gas’, a family of pollutants that absorb and trap heat from the earth’s surface that would otherwise have been radiated into space. Recent analyses suggest that the earth’s temperature is currently rising at a rate of up to 3° C per 100 years (Karl et al 2000). The Intergovernmental Panel on Climate Change (2001) reports that CO\textsubscript{2} alone is responsible for two-thirds of current enhancements in the greenhouse effect. Among other things, global warming causes increased variability and extremity in weather patterns, raised sea levels, expansion of deserts, spread of vector-borne diseases, and widespread destruction of plants, animals and ecosystems (OECD 1997).
The concept of sustainable transport

2.2 Social impacts of transport

While the environmental effects of transport highlighted in the previous section are for the most part negative, the social impacts are more of a mixed nature – having a combination of positive and negative effects. This subsection proceeds by first examining the social benefits, followed by a similar exposition of the socially detrimental effects.

2.2.1 Social benefits of transport

Transport is a 'means to an end' and as such serves a valuable role in providing society and individuals with the spatial access necessary to meet their social and economic goals. The list of services and societal needs to which transport enables access is inexhaustible. Among the primary examples however, are housing, education, leisure activities and employment. Transport also enables participation in the political and economic processes and provides access to essential services such as medical care (Friedmann et al 2001). An additional social benefit of transport is the 'personal independence' that it endows. Transport allows people to venture into places and do things that they would otherwise be unable to do. It has been especially pivotal in cementing the woman’s role in society (Pazyllan and Pintzov 1996, Bravo 2002).

2.2.2 Adverse social impacts of transport

Despite its fundamental importance in providing an essential service to society, transport, unfortunately, also has various adverse effects on the very society it often serves so well (Lyons 2004). Some of these negative impacts are examined below.

Perpetuation of inequity

Given the generally perceived positive contribution to economic growth, transport improvements should theoretically make everyone collectively 'better-off'. However, this is not always the case. In most of the world, the road transport sector has been narrowly focused on providing roads and attendant infrastructure for motorised traffic. This has been a cause and an effect of increased car dependence, which in turn tends to displace non-motorised transport modes such as walking and cycling, and their users. The narrow
focus on car users has also reduced the viability and therefore the levels of service and availability of public transport for those requiring it most, who invariably tend to be the poor, disabled, children and others who are unable to manoeuvre or afford a car. The consequent inadequate mobility suffered by non-drivers and the poor manifests itself in reduced access among these groups to education, employment, income security and other necessary services and processes (Cervero 1999, Waldorf 2003).

Furthermore, the various positive and adverse impacts of transport (be it environmental, social or economic) are not equally or randomly distributed throughout society, but follow the well established lines of structural social inequality (Hamilton and Jenkins 1992). It is often the poor, for example, who are displaced by the expansion of right-of-way for transport infrastructure and also the poor who are less able to afford increased prices as public transport struggles to provide services due to decreased demand and profits. Cyclic poverty is therefore perpetuated as the poor are unable to access job locations because of transport deficiencies which they cannot overcome because of their lack of income (World Bank 1996 a).

Social disruption and exclusion
Transport infrastructure frequently creates physical and psychological barriers which divide communities (Egan et al 2003). Additionally, high speeds and volumes of traffic can inhibit pedestrians and cyclists from crossing or travelling alongside roads, and the noise, pollution and danger associated with heavy traffic can discourage people from using local facilities or visiting each other. Such ‘severance’ caused by road traffic and related infrastructure therefore disrupts the life of communities. Additionally, the attendant decrease in pedestrian activity that it causes, has an adverse impact on cohesion and solidarity in communities and therefore reduces social capital (Appleyard et al 1972, Leyden 2003).

A related impact of current transport systems is social exclusion, defined by Walker and Walker (1997) as the ‘dynamic process of being shut out, fully or partially, from any of the social, economic, political and cultural systems which determine the social integration
of a person in society'. Invariably caused by the marginalisation of certain sections of society, this phenomenon is exacerbated by the decreased availability and accessibility, inadequate safety and security, high costs and poor information that are pervasive features of current transport systems (Social Exclusion Unit 2003).

**Excessive number of fatalities and adverse effects of human health**

Road traffic accidents are the cause of numerous deaths and fatalities globally. Of great concern is the fact that current trends do not portend for amelioration of this phenomenon. Recent studies by Pucher and Dijkstra (2003) for example, have shown that greater motorisation results in greater risks to users of non-motorised modes such as walking and cycling. Moreover, Ewing et al (2003) have shown a strong correlation between urban sprawl and the incidence of traffic accidents.

As has been alluded to previously, emissions from transport have direct consequences on human health (Dora and Phillips 2000, Haines et al 2000). Traffic noise and dependence on motorised transport also result in various other ailments, such as insomnia, obesity and deterioration of mental health (Frumkin 2002, Egan et al 2003, Saelens et al 2003).

### 2.2.3 Economic impacts of transport

Transport delivers access, services and goods that enable economies to function. Transport is therefore of key importance to the growth and maintenance of a vibrant economy. Some of the various economic benefits of transport are described below.

**Employment benefits**

Transport provides access to work and as such, has considerable impact on the employment growth value and the total earnings growth value (Ozbay et al 2003). Road transport as a sector also provides direct employment in vehicle manufacturing, driving and logistics. The economic benefits of road transport employment are further enhanced by the knock-on effect that occurs when individuals directly employed in transport spend and invest their earnings within the local, and national economies (Keane 1996).
Growth of the local economy
Road transport facilitates the import and export of goods, a role that is essential for the survival of any economy. A large proportion of 20th century industrial growth for example, can be directly attributed to the flexibility of road transport (Tolley 1996). Moreover, transport provides high quality access to labour, suppliers and customers, and enables firms to save inventory costs by using just-in-time delivery techniques, which are based on minimising inventory while maximising the use of efficient and timely delivery. As such, good dependable transport services allow businesses to receive inputs to production facilities and to transport finished goods to their markets in an efficient manner. It is therefore of no surprise that the existence of adequate transport infrastructure is a key determinant of industry location (Leitham et al 2000). Forkenbrock and Foster (1990) have also shown that because investment in transport infrastructure lowers transport costs, the existence of adequate transport facilities can serve to attract economic activity from competing regions.

2.2.3.1 Adverse economic impacts of transport
Despite its importance for economic growth, transport does have some adverse economic effects. The two most important are the massive financial costs that it necessitates and the pervasive non-payment of full costs by transport users.

Cost of transport investment
Transport investment accrue huge financial costs to tax payers, which are often exacerbated by poor forecasts and planning, and thus high levels of inefficiencies (Skamris and Flybjerg 1997, Odeck 2004). In addition to the real financial costs to tax payers, transport also incurs high ‘opportunity costs’, that is, the monies invested in transport that could be spent on other activities beneficial to society such as the reduction of pollution and the education of citizens. The incurrence of ‘opportunity costs’ is especially pertinent within the context of transport as transport investments account for a major percentage of governments’ expenditure worldwide. Such funds could be invested in other areas and programmes where there may be a more dire need.
Non-payment of full costs of transport use

Transport users do not currently bear the full costs of their transport activities. Road transport incurs various external costs on society that are not accounted for by individuals benefiting from such transport use (Schipper and Sperling 1994, Pearce et al 1996, Mayeres et al 1996, Forkenbrock 2001). Such external costs are caused by the combination of the various adverse environmental, social and economic impacts of transport which represent costs to third parties and natural entities that suffer as a consequence. It is these costs that should be borne by individuals benefiting from the transport activity. Typically however, transport users only pay the private costs of vehicle use, totally ignoring the other costs. Such non-payment of full social costs results in pareto inefficiency in transport markets (Pigou 1920). As the perpetrators of transport externalities need not pay the full costs, ‘the invisible hand’ that maintains market equilibrium based on the relationship between price, demand and supply cannot function in the true sense. Since there is no economic incentive to take into account the negative effect of their transport decisions on others, there is an excessive demand and supply of transport activities that cause negative externalities such as pollution, and an under-supply and lack of demand for activities that create positive externalities, such as cycling, or those that minimise externalities, such as public transport.

2.3 The concept of sustainable transport

As demonstrated in the previous sections, transport has significant implications on the environment, society and the economy, and as such is important to achieving the wider goal of sustainable development. Current and forecasted transport trends are incompatible with the underlying tenets of sustainable development however, as the negative impacts of transport present significant environmental, economic and social threats to present and future generations. Over the past two decades, these many adverse effects of transport have been widely recognised and there is now general consensus that current transport trends cannot continue and that fundamental changes in the planning, design, and operation of transport systems are needed (Banister and Button 1993, Whitelegg 1993, Nijkamp 1994, Black 1996, Greene and Wegener 1997, DETR 1998, May et al 2003).
The popularity of sustainable development as a policy goal and the increasingly recognised need for curtailing and managing transport’s adverse impacts, have converged to form a wide interest in the concept of ‘sustainable transport’. The emergence of this concept has had profound implications on transport planning, and sustainable transport is now a ubiquitous expressed and fundamental goal of transport planning globally.

The popularity and significance of the concept of sustainable transport in the current planning context is reflected, *inter alia*, by the plethora of strategies, policies, Green Papers, White Papers, research articles and theses that have been published by international organisations, governments, academics and practitioners, all advocating a shift towards the new paradigm of sustainable transport and proposing measures through which it can be achieved (see for example, European Commission 1992, World Bank Group 1996, Reinsra *et al* 1996, OECD 1997, Banister 2000, European Commission 2001, Roth and Kåberger 2002, Schipper 2002, Low and Gleeson 2003, etc.).

### 2.3.1 An abundance of definitions of sustainable transport

While generally taken to be the expression of sustainable development in the transport sector, there is currently no consensus on a specific and single definition of sustainable transport. As with its predecessor - the broader concept of ‘sustainable development’, numerous definitions of sustainable transport appear in the literature and in practice.

As was similarly the case with the broader concept of sustainable development, early definitions of the concept (for example, Nijkamp 1994, Greene and Wegener 1997) placed an emphasis on the environmental dimensions and impacts of transport. Generally however, more recently proposed definitions of sustainable transport tend to take due consideration of the environmental, social and environmental dimensions.

A typology of some proposed definitions of sustainable transport are shown in Box 2-2 below.
Chapter Two: The concept of sustainable transport

'Mobility or traffic movement that enables transport to fulfil its important economic and social functions while at the same time limiting its detrimental effect on the environment.'

(European Commission 1992)

'Satisfies current transport and mobility needs without jeopardising the ability of future generations to meet these needs.'

(Black 1996)

'A sustainable transport system is one that:
- allows the basic access needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy;
- limits emissions and wastes within the planet’s ability to absorb them, minimises consumption of non-renewable resources, reuses and recycles its component, and minimises the use of land and the production of noise.

(Centre for Sustainable Transport 2002)

'A transport system through which people's needs and desires for access to jobs, commerce, recreation, culture and home are accommodated using a minimum of resources.'

(Sustainable San Francisco 1997)

'A sustainable urban transport and land use system provides access to goods and services in an efficient way for all inhabitants of the urban area, protects the environment, cultural heritage and ecosystems for the present generation, and does not endanger the opportunities of future generations to reach at least the same welfare level as those living now, including the welfare they derive from their natural environment and cultural heritage.'

(May et al 2001)

'A transport system and transport patterns that can provide the means and opportunities to meet economic, environmental and social needs efficiently and equitably, while minimising avoidable or unnecessary adverse impacts and their associated costs, over relevant space and time scales.'

(EXTRA Project 2001)

Box 2-2: A typology of proposed definitions for sustainable transport
2.3.1.1 The vision of sustainable transport for the purposes of the research

The absence of a single unambiguous definition of sustainable development, and by extension sustainable transport, has been bemoaned by some authors (see for example, Lélé 1991, Costanza and Patten 1995, Fortune and Hughes 1997). The lack of a single and unambiguous definition is not viewed as a major deterrent in the context of this research however. A key tenet of sustainable development and sustainability analysis – as shown in Box 2-1, is that it must reflect context and as such, interpretations will be dependent on time and place. Different individuals will interpret sustainability differently, based on their specific circumstances (Mitchell 1996). Consequently, Kidd (1992) argues that ‘there is not, and should not be, any single definition of sustainability that is more logical and productive than other definitions’.

What is therefore needed is a non-rigid, guiding ‘vision’ that clearly states a desired general direction for sustainable transport, but falls short of specifying how such movement will be achieved, and which allows adequate flexibility to accommodate contextual customisation. Indeed, the susceptibility of Brundtland’s definition of sustainable development (WCED 1987) to a variety of definitions, has been criticised over the years. Due to the afore mentioned context-specificity of sustainability however, and the desirability of place and time-specific interpretations, the spirit of Brundtland’s definition is viewed to form an adequate basis for formulation of a vision of sustainable transport to guide this research. Among other things, the utility and resilience of Brundtland’s definition is evident by the fact that although coined in the 1980’s, it is still by far, the most popular interpretation of sustainable development.

Given the obvious strengths WCED’s broad definition, the vision for sustainable transport presented in this thesis is an interpolation of Brundtland’s definition to the transport context. Stated formally, the vision for sustainable transport is to achieve...

‘an ongoing process which enhances the ability of transport systems to meet the transport and mobility needs of the present generation without jeopardising the ability of future generations to meet their own mobility (and other) needs.’
2.4 Objectives of sustainable transport

Given the deliberate and inherent vagueness of the vision of sustainable transport specified above, the key task then becomes to operationalise it in a way that is clear, meaningful and which can guide policies and decisions. The approach in this thesis is to operationalise and elucidate the vision by decomposing it into key objectives of sustainable transport. For sustainable transport to be achieved, transport patterns and trends would then have to be moving in a way conducive to the objectives being met.

To ascertain the types of objectives that have been proposed for sustainable transport in the literature and in practice, an intensive review of the academic literature and sustainable transport plans was undertaken (Table 2-1 highlights some of the sources reviewed). While indeed the resultant set of objectives were numerous, there were clearly some common themes running through them which could aid in their classification.

The PROSPECTS Project (May et al 2001) had previously suggested six overarching objectives for sustainable transport as shown in Box 2-3 below.

<table>
<thead>
<tr>
<th></th>
<th>Economic efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Livable streets and neighbourhoods</td>
</tr>
<tr>
<td>3</td>
<td>Protection of the environment</td>
</tr>
<tr>
<td>4</td>
<td>Equity and social inclusion</td>
</tr>
<tr>
<td>5</td>
<td>Safety</td>
</tr>
<tr>
<td>6</td>
<td>Support of economic growth</td>
</tr>
</tbody>
</table>

Box 2-3: Objectives for Sustainable Transport proposed by the PROSPECTS project

When the PROSPECTS objectives were reduced to five by combining the objectives Economic Efficiency and Support of economic growth into a single objective - Support of a vibrant and efficient economy, and Safety expanded to Health and Safety, it was found that they could serve useful as overarching objectives under which the myriad objectives suggested in the literature and practice can be neatly categorised as shown in Table 2-1 below.
<table>
<thead>
<tr>
<th>Source</th>
<th>Livable Streets &amp; Neighbourhood</th>
<th>Protection of the Environment</th>
<th>Equity and Social Inclusion</th>
<th>Health &amp; Safety</th>
<th>Support of a vibrant &amp; efficient economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gilbert and Tanguay (2000)</td>
<td>-Minimise noise</td>
<td>-Limits emissions within planets ability to absorb them -Minimise consumption of non-renewable resources -Reuses and recycles components -Minimises use of land -Consistent with Ecosystem health</td>
<td>-Meets basic needs of individuals -Meets basic needs of society -Consistent with human health -Access is met equitably -Is affordable -Operates efficiently -Offers a choice of transport modes</td>
<td>-Access needs are met safely</td>
<td>-Supports a vibrant Economy</td>
</tr>
<tr>
<td>Shiftan et al (2003)</td>
<td></td>
<td>-Energy Savings -Reduction of air pollution from road transport -Protection of wildlife and natural habitats</td>
<td>-Improvement of accessibility to employment, activities etc. -Maximising the availability of public transport to population</td>
<td>-Decreasing road transport accidents and their severity</td>
<td></td>
</tr>
<tr>
<td>Lautso and Toivanen (1999)</td>
<td>-Congestion</td>
<td>-Consumption of Natural resources -Pollution</td>
<td>-Health -Equity -Opportunities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black (2000)</td>
<td></td>
<td>-Use of finite resources -Atmospheric pollution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gudmundsson and Hojer (1996)</td>
<td></td>
<td>-Safeguarding natural resource base within critical loads, levels and usage patterns</td>
<td>-To maintain the option value of a productive capital base for future generations -To improve the quality of life for individuals -To secure an equitable distribution of life quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Croydon Borough Council (2004)</td>
<td></td>
<td>-Encourage use of environmentally friendly modes -Reduce levels of noise and air pollution from transport</td>
<td>-Reduce dependency on car travel -Improve accessibility</td>
<td>-Reduce danger and perception of risk from transport</td>
<td>-Promoting economic growth and planning</td>
</tr>
</tbody>
</table>

Table 2-1: Examples and classifications of objectives and principles of sustainable transport proposed in the literature and practice
2.4.1 Generic objectives of sustainable transport used in this research

Given the reasonable fit of the various objectives of sustainable transport within the taxonomy above, the overarching objectives shown in Table 2-1 are used in this research as the key generic objectives for operationalisation of the broad vision of sustainable transport proposed in section 2.3.1.1 above.

In order to adequately reflect the numerous other objectives that they are taken to incorporate, the five overarching objectives are defined as shown in Box 2-4 below.

| i) Livable Streets and Neighbourhoods: A sustainable transport system should be designed and operated in a way that enhances the physical, aesthetic and other special characteristics of the area, such that it supports community identity and comfort and encourages social, cultural and recreational activity within the community. |
| ii) Protection of the Environment: A sustainable transport system should minimise natural resource consumption, ensure the preservation of vital habitats and reduce transport-related emissions and wastes that affect the global climate, biological diversity and the integrity of essential ecological processes. |
| iii) Equity and Social Inclusion: A sustainable transport system should contribute to both social and spatial equity by meeting the basic mobility needs of all social, economic and geographical groups, and providing them with access to a full range of facilities, services and activities. |
| iv) Health and Safety: A sustainable transport system should be designed and operated in a way that minimises hazards to health, the incidence and fear of transport-related crime, and the numbers, severity and risks of traffic accidents to all transport users. |
| v) Support of a Vibrant and Efficient Economy: A sustainable transport system should support a vibrant economy and contribute to economic growth while simultaneously supporting market mechanisms that promote fuller cost accounting which reflect the true social, economic and environmental costs of activities. |

Box 2-4: Overarching objectives of sustainable transport for purposes of this thesis
2.5 Summary

Sustainable development, now a fundamental policy goal of governments, planners and policy makers worldwide, is concerned with minimising the adverse impacts of development with a view to ensuring that an adequate quality of life and resources can be bequeathed to future generations. Transport has major implications on the environment, society and economy, and as such has important implications on the wider concept of sustainable development. It is now very clear that recent and current transport trends, characterised by increasing motorised traffic, are incompatible with the principles of sustainable development. Recognition of this problem, combined with a desire to redress these patterns, have converged into the new paradigm of sustainable transport. As with the its predecessor, sustainable development, there is currently no consensus on the definition of the concept, and indeed, numerous suggestions have been proposed. To operationalise the concept of sustainable transport therefore, many authors and organisations have decomposed it into key objectives. A review of the many suggested objectives showed that they can be classified under five generic overarching themes, namely Livable streets and neighbourhoods, Protection of the environment, Equity and social inclusion, Health and safety, and Support of a vibrant and efficient economy. These are therefore taken to be the generic objectives of sustainable transport for the purposes of this research. However, as sustainable transport is time and place dependent, their applicability, relative importance and specific interpretations, will depend on the context in which the given transport system is placed.
CHAPTER THREE: Indicator-based assessment of sustainable transport

3.0 Overview

The aims of the research were presented in Chapter one and the concept of sustainable transport introduced in Chapter two. This chapter builds on both by discussing the need for assessment in sustainable transport planning and the roles that indicators can play in facilitating such assessment. The need for systematic and robust frameworks for assessment and indicator selection are also discussed and desirable characteristics of such frameworks established.

3.1 Introduction

Chapter two has shown that sustainable transport is now a popular goal of transport planning globally and has become the key aspiration of many recent transport strategies and policies. As with any goal or aspiration, it is imperative that systems exist to measure, assess and monitor trends towards sustainability, so that decision makers and policy makers can be regularly informed of their success towards achieving this stated goal (Mitchell et al 1995, Lombardi and Brandon 1997, Foxon et al 1999, Hardi and DeSouza-Huletrey 2000, Tweed and Jones 2000, Brunner and Stark 2004, Pope et al 2004). To echo Roberts (1995), 'if you cannot measure it, you cannot manage it'. Assessment is especially imperative in the context of sustainability as it is an inherently very complex and broad concept and as such requires consistent and clear mechanisms to aid decision makers and planners' in gathering, compiling and analysing the extensive data in a way that clarifies and supports sustainable planning and strategy design (United Nations 2001). The need for information to guide decision making at all levels of sustainability management and planning was recognised by the WCED (1987) as well as the Rio Summit (United Nations 1992), and has been reaffirmed by the ‘Rio +10’ conference held in Johannesburg, South Africa, 2002, which called for ‘specific activities, tools, policies, measures and monitoring and assessment mechanisms’, to aid sustainable decision making and to gauge progress towards sustainability (United Nations 2002).
Corollary to the increased importance and popularity of the concept of sustainable transport therefore, is a critical need for appropriate approaches for assessing progress towards the goal, in a way that is practical, transparent, systematic and which takes into account the various objectives of sustainable transport, as well as the trade-offs and potential synergies between them.

### 3.2 Benefits of sustainable transport assessment

Assessment can be predictive, real-time, or retrospective. Predictive assessment may be undertaken at the early stages of the transport planning process in order to ascertain the future impacts that a package of policies or measures will have on transport sustainability. Similarly, during actual implementation of the policies and measures, assessment can provide valuable feedback and information for monitoring their impacts on issues and factors relevant to transport sustainability. Retrospective assessment on the other hand, is the post-evaluation of the sustainability performance of a transport system over a defined time period or subsequent to the implementation of a package of measures or policies. Adequately conducted assessment can therefore serve useful in guiding decisions at all levels of sustainable transport decision-making and planning as shown in Figure 3-1 below.

**Figure 3-1: Roles of assessment at different stages of sustainable transport planning**
Some of the specific benefits that assessment can provide for sustainable transport planning are as follows:

- **Illuminating progress towards sustainable transport**

  The primary goal of sustainable transport assessment is to enable decision makers to monitor and evaluate performance in achieving objectives and targets. While it is not necessary to know an exact end point for sustainability, an essential condition for assessment is to establish a desirable direction for change (Hodge and Hardi 1997). Once the issues and components that are essential to the viability and sustainability of the system are identified, assessment provides a frame of reference to identify if change has occurred and sets a context for judging whether the change is good or bad.

- **Operationalising the concept of sustainable transport**

  Sustainable transport is a fuzzy concept and a relatively new policy goal. As such, if its attendant challenges and key ingredients are not fully explored and clearly defined, there is a risk that the goal will remain nothing more than a bland set of exhortations unconnected to realities. Sustainable transport must therefore be operationalised in order to provide policy-makers with useful and practical information which can then guide their decisions (European Commission 2001). The outputs of appropriately conducted assessment will necessarily be linked to key elements of sustainable transport. By illuminating the key aspects of the concept, assessment can therefore aid in enhancing stakeholders' understanding of sustainable transport in operational and practical terms.

- **Guiding sustainable transport planning, policy-making and benchmarking**

  Assessment enables trends in the problems, and in overall performance sustainable transport strategies, to be determined (May et al 2003). As such, it can help to inform policy choices and illuminate the necessary corrections needed in response to identified trends (Kelly 1997). Furthermore, assessment provides an empirical and quantitative basis for benchmarking and evaluating the performance of alternative policy options and facilitates comparisons over time and across space (Gudmundsson 2003 b). Such information can provide a sense of direction for decision makers when selecting or ranking policy alternatives.
Chapter Three: Indicator-based assessment of sustainable transport

- Facilitating communication and stakeholder participation

By providing clear measures, the outputs from sustainable transport assessment can prove useful for communicating to stakeholders the sustainability performance of a transport system. Moreover, adequately conducted assessment can enhance the transparency of decisions and facilitate participation (Hardi and DeSouza-Huletey 2000). When used to decide on alternatives for example, robust assessment will provide an auditable trail which clearly shows how a choice is reached, enables pros and cons to be viewed, and facilitates open negotiation and debate (Bentivegna 1997).

- Provides a perspective of the transport system within the broader context

The transport system is only one of many sub-systems within the broader context of sustainable development. By assessing the sustainability of the transport system therefore, a sense of the magnitude of transport’s impacts on broader sustainable development, relative to other sectors, can be ascertained.

3.3 Challenges to transport sustainability assessment

Assessing the sustainability of sustainable transport is a challenging task. A key issue is the ambiguity of the concept of sustainability and the fact that it incorporates multiple and often conflicting objectives. The multiplicity of issues and impacts, the differing contexts and the diversity of values and view points that have to be considered also pose formidable challenges. Sustainability measurement mechanisms are required to not only capture and reflect the key features of the system but also the interactions among the social, economic, and environmental dimensions. Moreover, they are required to present the different types of information, with differing measurement units in a way that provides a coherent and balanced message.

Given all the foregoing, it is clear that assessing the sustainability of transport systems in a way that ensures that the pre-requisites of practicality, acceptability, accuracy, soundness of logical base and completeness are met is an immensely difficult task (Bentivegna 1997). It is a challenge that must be met however, as assessment is sine qua non for improving the quality, credibility and direction of sustainability decisions (Spellerberg 1991, Lombardi and Brandon 1997).
3.4 Indicators as sustainable transport assessment tools

Determining whether a transport system is on a desired course to sustainability requires an assessment process facilitated by tools that can adequately supply decision makers with informative signals on the multiplicity of inherent issues.

Indicators have been advanced by many authors as being appropriate tools for monitoring and assessing sustainability (see for example, Kuik and Verbruggen 1991, Opschoor and Reinjnders 1991, Reid 1995, Mitchell 1996, Farrel et al 1998, Bell and Morse 2000, Valentin and Spangenberg 2000, Abolina and Zilans 2002, Hens and De Wit 2003, Zhang et al 2003, etc.).

Also worthy of note is the fact that Agenda 21 specifically placed a requirement on signatory states to develop ‘indicators of sustainable development ...to provide solid bases for decision making at all levels’ (Chapter 40 of Agenda 21, UN 1992). Since the implementation of Agenda 21, numerous countries, organisations and municipal governments have developed indicator sets (NTREE 2003, UK DETR 1999, UK DEFRA 2004). Indicators have also been applied to the assessment of sustainability in specific sectors, including Agriculture (Pacini et al 2003, Piorr 2003), Urban Planning (Alberti 1996, Huang et al 1998, Foxon et al 1999, Lindsey 2003), Land Use Management (Cornforth 1999, Haberl et al 2004), Mining and Minerals Industry (Azapagic 2004), Forestry Management (Karjala et al 2004, McDonald and Lane 2004), Water Resources Management (Kondratyev et al 2002, Giupponi et al 2004), Tourism Management (Miller 2001), and Production Industries (Velava 2001).


The popular application of indicators reflects their global attractiveness as suitable tools for assessing and monitoring sustainability trends and for ascertaining the effectiveness of policies, decision and actions geared at enhancing sustainability.
3.4.1 Definition of indicators

The term ‘indicator’ has its origins in the Latin verb *indicare*, which means ‘to disclose or point out, to announce or make publicly known, or to estimate or put a price on’ (Hammond *et al* 1995). In modern days however, numerous definitions of indicators have been proposed. Four examples reflective of the many definitions are shown in Box 3-1 below.

**Box 3-1: Examples of definitions of ‘indicators’ in the literature**

- ‘a measure, index of measures or models that characterize or simplify information about complex systems or phenomena. The primary uses of an indicator are to characterize current status and to track or predict significant change.’ (Jackson *et al* 2000)

- ‘a parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon with a significance extending beyond that directly associated with the parameter value.’ (OECD 1994)

- ‘something that represents a particular attribute, characteristic or property of a system.’ (Gallopin 1997)

- ‘a policy-relevant variable that is specified and defined in such a way as to be measurable over time and/or space. It need not be quantified. Measurement can be on the basis of qualitative scales.’ (Pastille Consortium 2002)

Irrespective of the definition adopted, it is clear that indicators provide small windows that provide insight into the big picture and convey information about complex systems in a way that makes those systems easier understood (Mitchell *et al* 1995).

It is also clear that indicators can take many forms. An indicator may, for example, be a qualitative variable, a ranking variable or a quantitative variable.
3.4.2 Taxonomies and types of indicators

Given the multiplicity of indicators and numbers that may be used in any given application, there is a need to classify them in some way to facilitate, among other things, ease of viewing and interpretation. An approach to classification that has proven popular in the literature is to categorise them into 'input', 'process', 'outcome' and 'output' indicators, or a variation of these (See, Moxey et al 1998, Villareal 2004, Audit Commission 2000 a, HM Treasury et al 2001, etc.). Under this system, indicators are classified as follows:

- **Input Indicators** measure the resources that are provided to contribute to, or facilitate, policy and behavioural changes.

- **Process Indicators** show whether the activities planned are actually being carried out and carried out effectively. They indicate what is being done, and how it is being done. A process indicator takes due consideration of the fact that end state outcomes, intermediate outcomes and policy outputs are arrived at via some process and may thus enhance the ability to monitor and predict system changes.

- **Output Indicators** are based on the recognition that due to time lags in the system between changing inputs and discernible changes, there are needs for measures to inform decision makers of progress. Consequently, rather than focusing on ultimate outcomes, 'output indicators' reports on an observable event, from which an outcome may then be inferred. In this respect, 'output indicators' act as proxies for ultimate outcomes.

- **Outcome Indicators** measure the achievement of specified objectives. They report on the impacts or consequences of activities and therefore measure how well policies have achieved what they had set out to achieve.

Among other things, the National Audit Office *et al* (2001) argues that this approach to classifying indicators clarifies the relationships between inputs, outputs and outcomes which serves to reveal how inputs, outputs lead to outcomes. Evidence about these links can then help in identifying which inputs and outputs are most important to measure.
3.4.3 Composite indices

A specific type of indicator, presenting highly condensed information obtained by aggregating different data, is called a composite index. Composite indices are obtained by combining individual indicator values, by adding and weighing, to derive a single new figure. The idea of a single, composite index of sustainability has been of considerable interest especially in the field of Ecological Economics (see for example Van Den Bergh 1996, Lawn 2003, Díaz-Balteiro and Romero 2004, etc.). Some of the various composite indices of sustainability that have been proposed in the literature over the years are shown in Table 3-1 below.

<table>
<thead>
<tr>
<th>Index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmentally Adjusted Net National Product (Hartwick 1990)</td>
<td>Adjusts traditional measures of economic performance, such as Gross domestic Product (GDP) and Net National Product (NNP) to take consideration of the impacts of economic growth on the environment and takes cognisance of environmental constraints on the economy.</td>
</tr>
<tr>
<td>Genuine Savings (Pearce and Atkinson 1993, Pearce and Atkinson 1995, Pearce and Barbier 2000)</td>
<td>This approach takes sustainable development as having been achieved when ‘Total Capital Stock’ (TCS) is maintained or enhanced. TCS, in turn, is taken as being made up of three types of capital, i.e., Physical capital (K_p), Natural Capital (K_n) and Human Capital (K_h). The requirement is that the value of the net change in the total capital stock (TCS) must be equal to or greater than zero.</td>
</tr>
<tr>
<td>Index of Sustainable Economic Welfare (Daly and Cobb 1989)</td>
<td>Adjusts elements of conventional national accounts to reflect wider determinants of welfare. The adjustments include an estimate for non-monetised contributions to welfare (e.g., the services derived from unpaid household labour), and deducting funds spent to offset environmental degradation etc.</td>
</tr>
<tr>
<td>Ecological Footprint (Rees and Wackernagel 1994, Wackernagel and Rees 1996)</td>
<td>A land-based measure that compares human demands in country i, in terms of consumption, with the extent to which those demands can be met by the land area in country i. A positive footprint is an indication of an unsustainable system; i.e., that a country’s natural capital is being depleted, or that it is imposing part of its footprint on other countries.</td>
</tr>
<tr>
<td>Environmental Space (Opschoor, L. Reijnders 1991)</td>
<td>This measure compares global mean use of a given resource, expressed in per capita units, with a country’s per capita consumption of that resource. The environmental space measure $i$ is then the percentage reduction (or increase) in the use of that resource in country $j$, necessary to reduce (increase) per capita consumption in country $j$ to the global per capita average for resource $i$.</td>
</tr>
<tr>
<td>Human Development Index (United Nations Development Programme 1990)</td>
<td>Derived by standardising and then averaging three perceived quality of life determinants, namely; a measure of life expectancy (taken to be a proxy for health); a measure of education (taken to be a proxy for opportunity); a measure of income (GDP per capita).</td>
</tr>
<tr>
<td>The World Bank’s Measure of the Wealth of Nations (World Bank 1995, 1996b)</td>
<td>The approach uses aggregation and monetisation techniques to compare data and rank nations according to the cumulative value of their capitals. Capitals are measured through a selected number of perceived key environmental and social issues to which monetary values are attached. Summing the monetary values for all key issues result in a single overall monetary value which is taken to reflect the true wealth of the given nation.</td>
</tr>
</tbody>
</table>

Table 3-1: Suggested composite indices of sustainable development
3.4.4 Criticisms of composite indices as measures of sustainability

Undoubtedly, a single composite index for measuring sustainability would have numerous advantages. Among other things, Commentators and decision makers are more likely to refer to a single number than to an array of statistics. Moreover, a single number makes comparisons easy, and can be shown adjacent to the well established single measure of economic performance, the GDP, to give a more balanced picture of the state of a country or region. However, existing composite indices have been criticised by numerous authors on many fronts. Some of the criticisms are detailed below.

Composite indices may conceal important issues

Given the multiplicity of issues inherent in the concept, aggregation to a single index (or even a few indices) will fail to capture the wide spectrum of information relevant to sustainable development (Mitchell 1996). The use of composite indices to reflect sustainability will therefore inevitably conceal key issues, some of which may potentially be very important to overall system performance (Bossel 1999, Foxon et al 1999, Morse 2004). Economically based indices such as the Environmentally Adjusted Net National Product (EANNP) for example, tend to ignore key environmental and social issues. Similarly, the Human Development Index (HDI) accounts for some social aspects, but fails to consider economic and environmental dimensions. Composite indices therefore over-simplify the inherent complexity of sustainability, and may consequently provide misleading signals. A common example is the use of the Ecological Footprint to measure overall sustainability when it actually only measures efficiency and fairness in consumption based on land area.

Components of indices are often arbitrarily chosen

As insinuated above, single composite indices are limited in the number of issues that they can incorporate. Therefore, only a small subset of issues will be included from the multitude of sustainability-related issues that exist. However, the issues that tend to be chosen for inclusion in sustainability indices often lack any clear basis. In the case of the Index of Sustainable Economic Welfare (ISEW) for example, the specification of what deductions and additions to consumption should be made is essentially arbitrary (Neumayer 1999). A similar problem exist with specification of the resources for derivation of the Environmental Space Index (Hanley et al 1999).
Composite indices are difficult to interpret

While theoretically, a good index may produce a strikingly clear picture of overall system performance, it will not reveal so clearly the main constituents of that performance. Consequently, single indices and their components are difficult to interpret (Morse 2004). Aggregate indicators become even more questionable when they require the combination of 'apples and oranges' (as in the case of the HDI). An attendant adverse effect of the difficulty of interpretation is that opportunities for broad stakeholder participation are minimised (Hass et al 2002).

Problem of weighting

The value of a single component index will depend on the factors included in its derivation, and how these separate components are 'weighted' relative to each other. In the case of GDP, the common weighting mechanism is the monetary value of the goods produced. However, when considering environmental and social issues this becomes a major problem as no common measure exist to translate such factors into agreeable units. To overcome this problem, many of the proposed indices, such as the EANNP, Genuine Savings and ISEW, attempt to attach financial values to environmental and social endowments. As these endowments have no market value however, their conversions to monetary units often require assumptions and extrapolations that distort reality and are therefore imperfect at best (Bossel 1999).

3.5 Characteristics of good sustainable transport indicators

It is partly due to the aforementioned problems of composite indices that indicators have seen popular application in sustainability assessment. Logically, the usefulness of any indicator for sustainability decision making and assessment will depend on its quality and characteristics. Numerous desirable characteristics of sustainability indicators have been proposed, the key ones of which are shown in Table 3-2 below (see for example, Anderson 1991, Environmental Protection Agency 1996, Meadows 1998, Sustainable Seattle 1998, Audit Commission 2000a, Audit Commission 2000b, Jackson et al 2000, HM Treasury et al 2001, UNCSD 2001, Pastille Project 2002, Dhakal and Imura 2003, etc.). A key benefit of such a list of desirable characteristics, as will be shown in the latter chapters of this thesis, is that they can be used to assess the quality of a selected suite of indicators.
### Measurable
An indicator should be easy to measure and record with standard, reliable and scientifically defensible methods. Rigorous measurement increases credibility.

### Significance
The indicator should measure something believed to be important, or should reflect or represent something of significance to the sustainability of the area over generations.

### Logically or scientifically defensible
The indicator should be scientifically valid, transparent and analytically sound. It should be responsive and understandable rationales should exist for its use and drawing of conclusions.

### Interpretable
The indicator should be understandable, shown in units that make sense and be accepted by stakeholders as a valid sign of sustainability. Even complex issues and calculations should eventually yield clearly presentable and understandable information.

### Policy-relevant
An indicator should be associated with relevant policy goals and attendant issues around which key policies are formulated. Unless the indicators are linked to critical decisions and policies, it is unlikely to motivate action and be integrated into decision-making processes.

### Clarity in value/direction
Improvements or degradations in levels of sustainability should be clearly conveyed by the assembled set of adopted indicators. The individual component indicators should therefore be unambiguous, with no uncertainty about what direction is good or bad.

### Speed of availability/ (timeliness)
There should be little delay between the element being measured and the provision of data on it.

### Ease of Data Availability
Data and statistics relevant to the geographic area and, preferably, comparable to other cities, counties, or communities must be easily available and at an affordable and reasonable cost. If data are not readily available, a practical method of data collection or calculation should exist.

### Isolatable
The indicator should be able to accurately reflect the share of impact attributable to transport.

**Box 3-2: Key suggested desirable characteristics of sustainability indicators**
### 3.6 Roles of indicators in sustainable transport assessment

Indicators can ascertain current system performance and track or predict significant changes. When chosen well and used appropriately therefore, a suite of indicators are powerful evaluative and decision aid tools. Some of the specific roles that indicators can play in sustainable transport assessment are listed below (Environmental Protection Agency 1996, DETR 2001, United Nations 2001, Pastille Project 2002).

#### Captures the multidimensionality of sustainable transport
Comprised of multiple indicators, an indicator-based assessment framework will typically be broad enough to represent the wide array of sustainable transport issues. The resultant comprehensive and consistent coverage, together with systematic organisation of issues, enable priority issues and strengths and weaknesses of the performance of the transport system to be clearly identified.

#### Highlights problems and set priorities for action
Sustainable transport strategies and policies will have greatest impacts when they are focused on the most significant problems. As they enable review of the full range of transport impacts, indicators are useful for setting key priorities for action. Given their comprehensive coverage, indicators are also capable of identifying 'sleeper' issues, i.e., problems that may have otherwise been overlooked or neglected.

#### Breaks down complex problems
By reflecting relatively narrow issues, indicators can translate the broad and complex concept of sustainability into small manageable units of information.

#### Well suited for feeding into policy analysis
Indicators report on overall system performance as well as performance of sub-components, which are easier fed into the policy process so adjustments can be made.

#### Amenable to comparison and benchmarking
Indicators enable transport's impacts on issues relevant to sustainability to be viewed relative to other sectors, and also enable geographical comparisons among cities etc.

#### Educating the public
Indicators provide a simple and piece-meal overview of the complex issue of sustainable transport. Indicators can therefore be useful for educating the public about the range of inherent issues, the performance of measures, and any required changes to policies.

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**Box 3-3: Roles of indicators in assessing sustainable transport**

38
It would be expected that a well chosen suite of sustainability indicators will be capable of performing the above roles, which will be manifested in how well they collectively guide and communicate sustainable decision making and planning. As will be shown in latter chapters therefore, the ability of a given set of indicators to perform the above roles can serve useful in assessing their quality and suitability.

3.7 Selecting appropriate sustainable transport indicators

Appropriately applied sustainability indicators are powerful instruments for assessing sustainable transport, identifying the optimal course of action and generally supporting structured and coherent decision making in sustainable transport planning. However, indicators have to be carefully selected to maximise their desirable characteristics and their applicability, as inappropriately chosen indicators will inevitably result in misleading conclusions (Tam 2002).

The importance of careful choice of indicators for effective indicator-based sustainable transport assessment cannot be overstated. Decision makers cannot respond to information that they do not have nor can they react effectively to information that is inadequate. Similarly, they cannot devise policies and strategies to achieve goals or targets of which they are not aware. If the indicators are poorly chosen, inaccurately measured, delayed or biased, decisions made on that basis will not be effective. Among other things, misleading indicators will cause over or under-reactions and result in policy changes that are too weak or too strong.

3.7.1 Challenges to effective indicator choice

Due to the nature of indicators and sustainability, selection of effective indicators to guide sustainability assessment presents a number of challenges. Two key challenges to effective selection of sustainable transport indicators are examined below.

A large number of indicators are possible and available
Sustainability is a holistic policy goal, encompassing a complex mix of issues. Indicator-based assessment mechanisms are required to address these myriad issues as well as presenting the results in an informative and coordinated manner. This is an
ambitious and difficult task (Pastille project 2001). The broadness of sustainability means that numerous potential indicators exist, and indeed, may be available. However, large indicator sets may give rise to confusing messages to the public and to decision makers as it is difficult to view numerous indicators in a coherent manner (Gustavson et al. 1999, Ronchi et al. 2002). Therefore a small, manageable and useful subset of indicators is necessary. Selecting a subset from the many potential indicators that exist however, can prove a challenging task.

**Indicators are not perfect measures**

Indicators are designed only to *indicate* and to tell a partial story. Because they are abstractions of the system, no indicator or set of indicators will perfectly represent the real system. This problem is further exacerbated by the fact that the concept of sustainability is concerned with a hugely complex system, and as such information about this system will be imperfect as well. Consequently, when indicators are used for assessment and monitoring, the price to pay may be a possible distortion of the information obtained (Mitchell 1996). It is important to minimise such uncertainty however and in that regard, indicators must be selected with care so that only those with most potential usefulness for decision making are selected (Meadows 1998).

### 3.8 The need for systematic indicator selection frameworks

Uncertainty in indicator choice can be minimised by undertaking the selection within the context of a systematic framework with clearly defined processes and criteria (Dalal-Clayton and Bass 2002, Hezri and Hasan 2004). A systematic framework in this context is defined as a standardised set of procedures, devices or techniques, with specified steps within a structured process. A framework specifies the key parts (components, dimensions, elements, themes, etc.) that must be measured to get a clear and accurate reading of the state of that system and also clearly defines the aims (goals, objectives, principles, criteria, etc.) of the process, and combines these into a coherent set of procedures to facilitate indicator selection. Among other things, selection within a robust framework ensures that indicators emerge more naturally. A framework is also more amenable to transfers and adjustments to suit the needs of a given locale or set of decision makers. Other advantages of systematic indicator selection frameworks are discussed below.
Frameworks alleviate 'bounded rationality' and 'satisficing' tendencies

Like all individuals, decision makers and policy-makers concerned with sustainable transport are affected by the 'bounded rationality' complex. Originally introduced by March and Simon (1958) and Simon (1978), bounded rationality refers to the fact that decision makers have a limited ability to process information and comprehend all endogenous and exogenous factors relevant to the decision. Individuals can therefore only be expected to operate rationally within a frame of reference determined by the limits of their knowledge and information processing capabilities (Wright 1984). In order to act within the constraints of such limited knowledge, decision makers often have no choice but to simplify the dimensions of the problem and the possible alternatives. A characteristic of bounded rationality is therefore satisficing, where the decision-maker does not evaluate all possible alternatives but only searches until an adequate one is found which minimally meets the standard of acceptability (from his 'limited' perspective). Individuals therefore tend to choose the most self-satisfactory and not the optimal alternative. As the decisions and choices become increasingly complex, the limitations of bounded rationality are reached with increased rapidity.

In making a decision, such as selecting a useful set of sustainability indicators, there are various limitations to the decision maker's ability to do so effectively. These include the fact that he or she will be unaware, inter alia, of all possible indicators, the relative utility of the indicators and the consequences of these indicators for sustainability. Systematic frameworks are therefore required to support the decision-making process by providing a frame to guide indicator choice. Once the appropriate simplifications and assumptions that render effective indicator selection are determined, a systematic framework can therefore serve as a valuable tool for sustainability assessment (Van den Bergh 1996).

Systematic frameworks provide a structure for the indicator selection process

As already alluded, systematic frameworks can aid in structuring the requisite analyses and setting priorities for indicator selection. By providing a clear process and structure, systematic frameworks lay bare the selection and arrangement of issues covered by the assessment as well as the values involved, and therefore assist in making the indicator-based assessment process more open and transparent. Similarly, by ensuring that all relevant criteria and determinants of indicator choice are explicitly
set down and defined, systematic frameworks also ensure that all alternative indicators are assessed against the same set of criteria and factors (Minken et al 2002). A systematic framework would therefore simplify and validate the difficult task of selecting indicators.

**Frameworks add transparency and credibility to the indicators selected**

Due to the complexity of the concept of sustainability and the large number of potential indicators that exist, sustainable transport indicator selection can be a contentious process and there is always the potential for disagreements about specific indicator choice. A systematic indicator selection mechanism lends greater credibility to the specific indicators selected, and as such, debate can be kept focused on issues and policy, rather than on the mechanics of selection (Mitchell et al 1995).

In the event of disagreements about selection however, systematic frameworks will also provide an auditable trail which can clearly show how the choice of indicators is reached, enables pros and cons to be ascertained and discussed, and allows open negotiation (Bentivegna 1997). A related benefit of the perceived transparency and credibility of indicator selection is that it can positively influence public support for the indicators and their resulting assessment of system performance (Van Esch 1997).

### 3.9 Characteristics of indicator-based assessment frameworks

Previous sections of this chapter have shown that indicator-based assessment frameworks based on a systematic indicator selection process can play a valuable role in the sustainable transport planning process. Logically, indicator-based sustainability assessment frameworks must be compatible with key principles of sustainability and in that regard may differ, in some respects, to assessment frameworks in other policy settings. Several key characteristics and desirable features of indicator-based sustainability assessment frameworks have been suggested in the literature (see for example, Carew-Reid et al 1994, Harger and Meyer 1996, Hardi and Zdan 1997, Meadows 1998, Bossel 1999, Valentin and Spangenberg 2000, Meyer 2001, Dalal-Clayton and Bass 2002, Mendoza and Prabu 2003, etc.). Some of the key desirable characteristics of indicator-based sustainability assessment frameworks that have been proposed in the literature are shown in Box 3-4 below.
Chapter Three: Indicator-based assessment of sustainable transport

Guided by clear vision and goals
The vision of sustainability should be clearly stated and attendant goals specified to elucidate that vision. Indicators should then be selected to represent the goals and vision.

Holistic and comprehensive in scope
To adequately gauge sustainability performance, the assessment must be comprehensive and able to encompass relevant system-wide elements. Therefore indicators selected within an indicator-based assessment framework must together represent all key concerns.

Systematic and robust
Sustainability assessment should be undertaken within a structured framework that clearly incorporates processes and criteria for identifying an adequate set of indicators. Such a framework should link vision and goals to indicators and the assessment criteria and processes inherent in indicator selection must be clearly defined, reproducible, unambiguous, understandable and practical.

A minimal number of Indicators
Assessment must be based on the measurement of a limited number of indicators. The more indicators used, the more likely that their interpretation for decision making will be confusing and ineffective. The number of indicators should therefore be as small as possible, but as large as is essential to capture the holistic nature of sustainability.

Amenable to continuous assessment
Frameworks for assessment progress toward sustainable development should incorporate capacities for repeated measurement to determine trends. Such frameworks must therefore be iterative, adaptive and responsive to changes and uncertainties since systems relevant to sustainability are complex and can change frequently. They must also be capable of adjusting the inherent vision and goals as new insights are gained.

Provides adequate insight into sustainability
From examination of the selected indicators, it should be possible to deduce the viability and sustainability of the system under consideration and to compare the performance with alternative development paths. The combined suite of selected indicators should also provide adequate signals to enable stakeholders to understand the directional movement of the system under consideration towards sustainability.

Box 3-4: Desirable features of indicator-based sustainability assessment frameworks
3.10 The need for participatory assessment frameworks

There is now general consensus that participation and involvement of key stakeholders is fundamental to sustainability assessment (see for example, Edelman 1988, Holland 1997, Levett 1998, Innes and Booher 2000, Reed and Dougill 2002, Szyliowicz 2003, etc.). Therefore, in applying an indicator-based sustainability assessment, it is necessary to involve relevant stakeholders in the indicator selection and compilation process. Such participation and involvement of key stakeholders is important for a number of reasons, some of which are discussed below.

Empowerment of citizens is key to the concept of sustainability

Among other things, the WCED report advocated *political systems that secure effective citizen participation in decision making* (WCED 1987, p. 8). This emphasis on citizen empowerment was re-affirmed at the Rio Earth Summit (United Nations 1992, Voisey et al 1996). In order to facilitate the stakeholder participation that is key to citizen empowerment, decision making mechanisms for sustainable development must systematically seek to build on a wide range of interests, needs and perspectives, and include those groups in society that are not generally considered within orthodox planning processes.

The broad issue of sustainability cannot be addressed by one group

Sustainability analysis requires consideration and prioritisation of a large number of interacting and sometimes conflicting issues. Given the scale and complexity of these issues, resolution is beyond the capacity of a single sector or a single group of actors. Ultimately, the choice of indicators will require the integration of value judgements, and as such, involvement of the various stakeholders is necessary to ensure that multiple perspectives are considered (Reed and Dougill 2002). Without such participation, it is impossible to reflect the diverse and changing nature of the values held across society, and chosen courses of action will respond only to short term needs of a particular interest group rather than being founded on the aspirations of a cross-section of society (Hodge and Hardi 1997). The specification of indicators for use in indicator-based assessment must therefore be undertaken within a participatory process to ensure it represents the vision and values of the community for which they are developed.
Sustainable choices are only possible through informed choices

Taking the actions necessary to ensure progress towards sustainable transport is clearly a matter of social choice. Choice on the part of individuals and families, of communities, of the many organisations of civil society, and of government (Hodge and Hardi 1997). In recognition of this fact, the WCED (1987) observed that ‘making the difficult choices involved in achieving the aims of sustainable development will depend on the widespread support and involvement of an informed public, the scientific community, and industry’. The general public can only be expected to adjust behaviour in a way supportive of sustainability by making ‘informed choices’, that is, they must be aware and involved in planning for sustainable development (Aguilera-Klink and Sánchez-García 2002). Without such widespread support and involvement, decisions and policies for sustainability will not be legitimated and the necessary level of societal change will not be attained (Irwin et al 1994). Indicators must therefore be derived through participatory processes which ensure that indicators chosen are meaningful to the public and adequately reflect their values and objectives (Shields et al 2002). Only in this way can stakeholders be expected to support the recommendations and policies that may be formulated as a result.

3.11 The need for flexible assessment frameworks

Sustainable development and sustainable transport are ambiguous policy goals (Lélé 1991). Both are comprised of environmental, social and economic criteria, the thresholds for which are uncertain. The ambiguity of sustainability necessitates that its evaluation is undertaken within a flexible process which cannot be based on precise or dogmatic models set in time or space (Abolina and Zilans 2002).

There is no single ideal set of sustainability indicators that would be capable of universal application in all contexts, municipalities, cities, counties and countries (Mitchell 1996, Dhakal and Imura 2003). As such, indicator-based assessment frameworks must be flexible enough to enable selection of a set of indicators that are suited to the particular context to which they are being applied. Some of the various reasons why frameworks designed to select sustainability indicators should be capable of selecting indicators suited to the specific contexts are discussed below.
Circumstances and needs will differ depending on context

The specific circumstances of cities, regions and spatial boundaries will differ. Factors such as the political, administrative and cultural conditions, as well as the methods of decision-making, organisational structures, knowledge available and working practices of local institutions, will differ from city to city and will all have an impact on indicator needs and applicability (Astleithner et al 2004). Therefore, indicators applicable in one area may not be applicable in another. As such, each community and region will require an indicator-based framework capable of selecting indicators suited to its specific circumstances and needs (Innes and Booher 2000, Valentin and Spangenberg 2000). Indicator-based assessment frameworks should therefore be flexible enough to allow for adjustments and applicability to such diverse contexts.

Interpretations of sustainability will differ

The inherent ambiguity and broadness of the concept of sustainability makes it susceptible to numerous (legitimate) interpretations that will differ depending on context (Schleicher-Tappeser and Strati 1999, Gudmundsson 2003 a). An indicator is only useful however, if it has adequate resonance with the target audience. Since indicator choices should be shaped by sustainability goals (see Box 3-4), which are in turn reflective of specific interpretations of sustainability, indicators requirements will necessarily differ among communities and regions (Maclaren 1996). Indicator-based assessment frameworks must therefore be flexible enough to capture the differences in perceptions of sustainability that will be shaped by culture and demography, and which will vary across communities and spatial boundaries.

3.12 Summary

It is now clear that sustainable transport is a key policy goal and aspiration of transport planning globally. As with any goal or aspiration, it is imperative that systems exist to measure, assess and monitor trends towards sustainability. By providing a sense of direction for decision makers and stakeholders, assessment can provide a clear basis for planning future actions and for formulating sustainable transport policies. Additionally, assessment can play a useful role in operationalising the complex concept of sustainable transport as well as enhancing the transparency of decisions and communicating performance to key stakeholders.
Due largely to their ability to reflect the multiplicity of issues relevant to sustainability, indicators are now popular tools for assessing sustainability in transport and other contexts. Because of the uncertainty surrounding their relevance to sustainability and the plethora of indicators that may be applicable in any given assessment context, careful selection of indicators is key to effective indicator-based sustainability assessment. To enable appropriate selection of key indicators therefore, systematic frameworks are required. Among other things, such frameworks should seek to maximise the quality and transparency of indicator choice while adhering to key principles of sustainability such as maximisation of stakeholder participation and recognition of context.
4.0 Overview

The previous chapters have set the background and sought to justify the research by introducing the concept of sustainable transport, examining the roles for indicator-based assessment in sustainable transport planning and highlighting the need for systematic indicator selection frameworks. This chapter seeks to further justify the aims and objectives of the thesis by examining previous sustainability indicator-based assessments and identifying resultant gaps and opportunities for research.

4.1 Introduction

When examining previous work and literature relevant to indicator-based sustainable transport assessment, it is necessary to also examine past work that have been undertaken in assessing the broader concept of sustainable development. This is necessary for two main reasons which are enumerated below.

i. The concept of sustainable development, which sets the overarching framework and context for system-specific applications of sustainability, has naturally been around much longer than sectoral applications such as 'sustainable transport'. As a consequence, more work has been undertaken in assessing sustainable development, from which much could be learned and possibly transferred to the narrower sustainable transport context.

ii. As a consequence of the fact that sustainable transport is a sub-component and important determinant of the wider concept of sustainable development, indicators relevant to transport are often represented within indicator sets used for assessing sustainability in the wider context. Figure 4-1 below, adopted from Gudmundson (2003 a), shows the variety of broader planning frameworks within which sustainable transport indicators can typically be found.
Chapter Four: Review of the literature and previous research

In recognition of the above factors, this chapter proceeds by first reviewing indicator frameworks within the broad context of sustainable development. This is then followed by a more focused examination of indicators and their applications within the specific context of sustainable transport. To bring together these largely descriptive reviews, this chapter concludes with a Strengths, Weaknesses, Opportunities and Challenges (SWOC) analysis, which provides an overall critical synopsis of existing sustainability and sustainable transport indicator-based assessment frameworks, and illuminates their strengths, shortcomings and the consequent opportunities for research and further work.

4.2 General sustainable development indicator frameworks

Since the Brundtland and Rio reports (WCED 1987, United Nations 1992), there have been numerous development and applications of sustainability indicators worldwide (Hodge and Hardi 1997, Dhakal and Imura 2003). While many such indicators are selected in a completely arbitrary and ad hoc manner, some indicator-based assessments are undertaken within given frameworks or conceptual models largely intended to organise and classify indicators. Very often however, the selection of
component indicators within the categories often remains, for the most part, arbitrary and *ad hoc*. Over the years, three types of models have emerged as the most influential in forming the basis for identification and classification of sustainability indicators. Shown in Figure 4-2 below, these are *Stress-response models*, various forms of the *Multidimensional* (social-economic-environmental) model, and *Theme and Objectives based models*. As suggested by the double arrows in the figure below, the above taxonomies are not rigid, and various combinations of the approaches are often applied to indicator identification and classification.

![Diagram](image)

*Figure 4-2: The most influential models for indicator identification and classification*

### 4.2.1 Stress-response models

Stress-response models are based on the concept of causality. They take as their starting point that human activities exert 'stresses' on systems and elements relevant to sustainability, which in turn necessitate various ameliorating 'responses' from society and policy makers. By linking responses to these stresses through indicators therefore, stress-response models seek to aid decision making by illuminating clearly the effects of remedial action on sustainability as well as identifying the need for remedial action, based on the levels of stress being endured by the attendant sustainability-relevant systems and elements.
4.2.1.1 Pressure-State-Response framework

The earliest manifestation of the stress-response indicator classification approach was in the form of the Pressure-State-Response (PSR) framework developed by the Organisation for Economic Co-operation and Development (OECD) to derive a core set of indicators for monitoring environmental performance (OECD 1993). Since then, various attempts have been made to transfer application of the PSR framework to sustainability indicator-based analysis (see for example, Diamantini and Zanon 2000).

The premise of the PSR framework is that human activities exert ‘Pressures’ on the environment (such as pollution and resource depletion). These pressures induce change in the ‘State’ of the environment and alter the quality and the quantity of natural resources (for example, changes in air quality, fossil fuels stocks etc.). Society then ‘Responds’ to these changes through environmental, economic and sectoral policies with the intent to prevent, reduce or mitigate the environmental damages. A conceptual diagram of the PSR framework is shown in Figure 4-3 below.

**Figure 4-3**: Conceptual diagram of the Pressure-State-Response indicator framework
The PSR framework therefore sets the platform for identification of three broad types of indicators, namely:

- **Indicators of Environmental Pressures**: Corresponding to the 'Pressure' box in the diagrammatic representation of the PSR framework, these indicators describe pressures on the environment caused by human activities.

- **Indicators of Environmental Conditions**: Corresponding to the 'State' box of the PSR framework above, these are indicators of environmental quality and aspects of quantity and quality of natural resources.

- **Response Indicators**: Corresponding to the 'Response' box, these indicators show the degree to which society is responding to environmental changes and concerns.

4.2.1.2 **Criticisms of the PSR framework**

The PSR framework has been widely criticised as being an inappropriate model on which to base sustainability indicators. The main criticism of the PSR framework stems from the fact that it was originally formulated to analyse the interactions between environmental pressures, the state of the environment and environmental responses, and as such inadequately addresses the socio-economic factors inherent in considerations of sustainable development. At best therefore, the PSR framework will only provide a partial picture of sustainability. Consequently, authors such as Dalal-Clayton and Bass (2002) argue that the limits of the environmentally-focused PSR framework are being stretched with its recent application to the more complex concept of sustainable development.

Another basis on which the PSR framework has been criticised is due to the inherent negative causality assumed in the framework. It is assumed that all human and economic activities have adverse effects which then necessitate corrective responses. No consideration is taken of the positive effects that some human activities may have on some dimensions and issues relevant to sustainability.
4.2.1.3 The Driving force-State-Response framework

Developed and popularised by the United Nations Division for Sustainable Development, the Driving force-State-Response (DSR) framework is a modified form of the pressure-state-response (PSR) framework, which seeks to allow better inclusion of non-environmental variables (United Nations 1996). A key difference between the DSR and the PSR frameworks, is that the term 'Pressure' is replaced by 'Driving force' in order to facilitate inclusion of social, economic and institutional indicators. The use of the term 'Driving-force' is also intended to recognise that the impacts of human activities on sustainable development may be either positive or negative.

The DSR framework enables classification of three types of indicators, namely:

- **Driving forces**: These indicators represent human activities, processes, and patterns that can have negative or positive effects on sustainable development.

- **State indicators**: These indicators provide information on the condition and status of sustainable development.

- **Response indicators**: These indicators represent corrective societal actions (for example policy measures) in response to changes in the 'state' of sustainable development.

The United Nations applied the DSR framework for derivation of a set of 134 sustainable development indicators (United Nations 1996). The usefulness of these indicators was then tested in 22 countries representing all regions of the world. Feedback obtained at the end of the testing period highlighted the fact that because the DSR framework is simply a modification of the PSR framework which in turn is based on an environmental (policy) cycle, i.e., problem perception, policy formulation, monitoring and policy evaluation, it also inadequately addresses the social, economic, and institutional dimensions of sustainable development. It is not surprising therefore, that most recent applications of the DSR framework, have only been concerned with environmental issues (see for example, World Bank 1995, Barrera-Roldán and Saldívar-Valdés 2002, Kondratyev et al 2002).
4.2.1.4 Driving force-Pressure-State-Impact-Response framework

Yet another version of stress-response models and again based on the PSR framework, is the Driving force-Pressure-State-Impact-Response framework (DPSIR) developed by the European Commission (Eurostat 1999).

According to this model shown diagrammatically in Figure 4-4 below, social and economic growth, that is, ‘Driving forces’, exert ‘Pressure’ on the environment and as a consequence, the ‘State’ of the environment changes. This then leads to ‘Impacts’ on human health, ecosystems and materials that then necessitate a societal ‘Response’ that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative policy action.

As with the PSR and DSR frameworks, the DPSIR too was developed primarily to aid understanding of environmental processes, and as such, does not readily accommodate the social and economic issues inherent in the broader concept of sustainable development. In an application to measuring sustainability of water catchment systems by Walmseley (2002) for example, the under-representation of...
social and economic indicators was conspicuous. Moreover, like all other forms of the stress-response approach, the DPSIR framework neglects the systematic and dynamic nature of the processes of cause and effects. Real world sustainability 'effect' and 'impact' mechanisms are complex and cannot be isolated into a single chain of cause and effect. To do so is to make a very simplistic assumption, and as such ignore the broadness and complexity of sustainability (Dhakal and Imura 2003).

4.2.2 Multidimensional indicator frameworks

Despite the contested nature of the concept of sustainability and its many definitions, there is agreement that it is a multi-faceted concept requiring simultaneous consideration of several dimensions (Milne 1996). A popular alternative to the cyclic stress-response approaches suggested above therefore, is to classify indicators based on variations of the generally accepted pillars of sustainable development.

4.2.2.1 The Triple-Bottom-Line model

The most popular and common interpretation of the multidimensionality of sustainable development is to view it as being comprised of economic, social and environmental dimensions. Popularly known as the Triple-Bottom-Line model, this view takes the position that to be sustainable, development should not be confined to any single dimension, but instead the economic, social and environmental systems must be given equitable consideration and must be simultaneously sustainable in and of themselves. A common approach in practice and in the literature therefore, is to compile and classify indicators by attaching them to each of these three dimensions with the intent of ensuring that the state of each is appropriately reflected.

Azapagic and Perdan (2000) and Azapagic (2004) used the three categorisations to develop and classify sustainability indicators for the chemical and mining industries respectively. The categorisations were also used to derive a set of national sustainability indicators for the United States (U.S. Interagency Working Group on Sustainable Development Indicators 1998) and for Australia (Australian Bureau of Statistics 2002), as well as for the derivation of a suite of regional indicators for the state of Oregon, USA (Schlossberg and Zimmerman 2003).
4.2.2.2 Variants of the traditional multidimensional approach

Increasingly, there has been a shift from the traditional triple-bottom-line classification of sustainability indicators, to more novel and experimental forms. These are often determined by context, to which sometimes the triple-bottom-line approach may not be ideal (see for example Nijkamp and Vreeker 2000). Typical of these variants is the indicator framework applied by the Canadian Government’s National Round Table on the Environment and the Economy (NRTEE), which classified its indicators to adequately reflect the four ‘key’ capitals described below (Smith 2002, NRTEE 2003).

i. **Produced Capital**: These are produced goods, such as buildings and machinery, that provide benefits to their owners by helping to produce other goods and services.

ii. **Natural Capital**: Made up of the various environmental stocks and systems that provide the natural materials and services required to sustain livelihoods.

iii. **Human Capital**: The knowledge, skills, competencies and other attributes embodied in individuals that facilitate the creation of personal, social and economic well-being.

iv. **Social Capital**: The relationships, networks and norms that facilitate collective action, which facilitate the human interactions necessary for a healthy society.

4.2.2.3 Limitations of multidimensional frameworks

An obvious shortcoming of multidimensional models is the limit to current capabilities of analysts to comprehensively measure and report on all sustainability dimensions. Moreover, while indicators are often proposed to represent sub-elements within each dimension, many of these issues are vague and the general ‘fit’ of indicators into categories tends to be poor. It is difficult to categorise sustainability indicators into definitive categories or capitals, since a given indicator will often have implications on multiple dimensions. Rather inefficiently, some reporting mechanisms show an indicator twice if it impacts more than one dimension.
4.2.3 Theme and objectives based frameworks

In an effort to overcome the vagueness and 'poor fit' of broad multidimensional models, some indicator applications have shifted away from such high-level categorisations, to frameworks that relate the indicators to narrower and more specific themes or objectives. Typically, these themes and objectives tend to be chosen to provide more precise interpretations of sustainable development.

There has been wide application of these theme and objective lead indicator frameworks both in the literature and in practice. In the formulation of the PICABUE framework for example, Mitchell et al (1995) suggested a classification of indicators based on of six thematic categories. The City of Seattle on the other hand classified its indicator set around five themes (Sustainable Seattle 1998), while the UK sustainable development indicator framework is guided by four thematic objectives (DETR 1999 b, DEFRA and ONS 2004). On the other hand, the European Common Indicators Initiative (European Commission 2000, Tarzia 2003) based its sustainability indicator set around seven thematic objectives.

The specific themes and objectives around which indicators are classified in the above mentioned studies are shown in Table 4-1 below.

<table>
<thead>
<tr>
<th>PICABUE</th>
<th>Sustainable Seattle</th>
<th>UK Quality of life counts</th>
<th>European Common indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health</td>
<td>Environment</td>
<td>Economic growth and employment</td>
<td></td>
</tr>
<tr>
<td>Security</td>
<td>Population and resources</td>
<td>Social progress which recognises the needs of everyone</td>
<td></td>
</tr>
<tr>
<td>Personal development</td>
<td>Economy</td>
<td>Effective protection of the environment</td>
<td></td>
</tr>
<tr>
<td>Community development</td>
<td>Youth and Education</td>
<td>Prudent use of natural resources</td>
<td></td>
</tr>
<tr>
<td>Physical environment and natural resources</td>
<td>Health and Community</td>
<td>- Equality and social inclusion</td>
<td></td>
</tr>
<tr>
<td>Goods and services</td>
<td></td>
<td>- Local governance and empowerment</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Local and global relationship</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Local economy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Environmental protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cultural heritage</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Quality of the built environment</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1: Themes and objectives for classifying indicators in select applications
Theme-based approaches as described above were used by Hellström et al. (2000) in proposing 41 indicators for sustainable urban water and wastewater systems monitoring based around five themes. Similarly, Statistics Sweden and Swedish Environmental Protection Agency (2001) classified 30 national indicators of sustainable development for Sweden by relating them to four key themes, while Huang et al. (1998) derived 80 indicators for assessing the sustainability of Taipei, the capital city of Taiwan, classified around ten key themes.

4.3 Reflections on broad sustainability indicator frameworks

While an effort has been made in the above sections to categorise the various approaches to indicator classification under overarching frameworks, it will be clear by now that the models do not differ significantly to each other. Very often, the differences are only in the terminology used to describe what are essentially similar issues and approaches. For example, the stresses and pressures reflected in stress-response frameworks are mixed into some theme classifications; and themes and objectives based frameworks are themselves subsets of multidimensional models. Given the clear similarities and overlaps, the different models should not be seen as being mutually exclusive as they are often applied together.

It is also clear from the foregoing discussions that although often promoted as indicator selection models, the various sustainable development indicator frameworks examined in the previous sections are in reality only frameworks for classifying indicators. Undoubtedly, these are improvements over arbitrary approaches where long lists of indicators were simply derived with no structure or framework to organise them (Mitchell 1996). However, without a clear selection mechanism, Bossel (1999) has criticised such approaches to developing indicators as still being fundamentally 'ad hoc and arbitrary'. Similarly, Hens and De wit (2003) have observed that indicators proposed under themes and dimensions, in the absence of systematic selection mechanisms, tend to reflect the research interests and the biases of the analysts and still often result in long arbitrary lists of indicators. There is still clearly a need therefore, for the development of systematic processes and methods for identifying and selecting indicators to assess sustainability in a way that is credible, robust, informative and non-arbitrary.
4.4 Sustainable transport indicator frameworks

From examination of the literature and previous work, the indicator frameworks that have been proposed and applied specifically to sustainable transport assessment can be divided into two broad groups, namely;

i. Those with emphasis on a single dimension of sustainable transport;

ii. Those that seek to address the multiple dimensions of sustainable transport.

4.4.1 Unidimensional sustainable transport indicator frameworks

Indicator sets that focus on only a single dimension of sustainable transport tend to concentrate on the environmental dimension. Indeed many such indicators compiled to illuminate the environmental impacts of transport, have been proposed for various countries as part of normal national statistical reporting (see for example, New Zealand Ministry of the Environment 1999, United States Environmental Protection Agency 1996, 1999). However, these traditional environmentally-focused indicator sets often do not purport to have been developed to support sustainable transport decision making.

Of interest to this review are those unidimensional indicator frameworks that were designed with the expressed intent of aiding sustainable transport assessment. Two such frameworks are the Transport and Environment Reporting Mechanism (TERM) developed jointly by the European Environmental Agency (EEA) and the European Commission, and the set of indicators for the ‘integration of environmental concerns into transport policies’ developed by the Organisation for Economic Co-operation and Development (OECD). Each of these indicator frameworks are discussed below.

4.4.1.1 Transport and Environment Reporting Mechanism (TERM)

The stated aim of TERM is to provide a comprehensive reporting system that will enable the monitoring of progress of transport towards sustainability in a way that is ‘tailored to the specific needs of EU transport policy-making’ (EEA and Eurostat 1999). In this regard, the main outputs of TERM is an annual report on transport and
environment in the EU (published by EEA) which sets out indicators that seek to measure the degree of environmental integration in the transport sector. Additionally, the report and attendant indicators also seek to evaluate whether European transport is progressing in line with the objectives of sustainability (EEA 2000, EEA 2001, EEA 2002).

The TERM indicators are based around seven policy areas where it is believed that the integration of the environment and transport should take place. The issue of interest in each policy area is formulated in the form of a key question as shown in Table 4-2 below. Indicators deemed to be appropriate are then grouped in such a way as to answer each question as shown in the extreme right column.

<table>
<thead>
<tr>
<th>Key questions</th>
<th>Indicator groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Is the environmental performance of the transport sector improving?</td>
<td>Group 1: Environmental consequences of transport</td>
</tr>
<tr>
<td>2 Are we getting better at managing transport growth and improving the modal split?</td>
<td>Group 2: Transport demand and intensity</td>
</tr>
<tr>
<td>3 Are spatial and transport planning becoming better coordinated so as to match transport demand to access needs?</td>
<td>Group 3: Spatial planning and accessibility</td>
</tr>
<tr>
<td>4 Are we improving the use of transport infrastructure capacity and moving towards a better-balanced intermodal transport system?</td>
<td>Group 4: Transport supply</td>
</tr>
<tr>
<td>5 Are we moving towards a more fair and efficient pricing system, which ensures that external costs are recovered?</td>
<td>Group 5: Pricing signals</td>
</tr>
<tr>
<td>6 How rapidly are improved technologies being implemented and how efficiently are vehicles being used?</td>
<td>Group 6: Technology and utilisation efficiency</td>
</tr>
<tr>
<td>7 How effectively are environmental management and monitoring tools being used to support policy and decision-making?</td>
<td>Group 7: Management integration</td>
</tr>
</tbody>
</table>

Table 4-2: Policy questions guiding indicator identification and classification in TERM

To answer the seven questions above, 31 sustainable transport indicators were proposed by TERM after consultations with various European Commission services, national experts, other international organisations and researchers (EEA 2000).
4.4.1.2 OECD: Indicators for integrating environmental concerns into transport

As part of its work programme on environmental indicators, the OECD Working Group on Environment developed a range of indicators to monitor the integration of environmental concerns into transport policies (OECD 1999). The intent was that when interpreted in their context, the set of indicators should contribute to measuring countries' progress towards more sustainable transport patterns. The indicators were developed as a sectoral supplement to the OECD's core set of environmental indicators, and as such the framework used in their development was adopted from the overarching conceptual framework that was used for derivation of all OECD sectoral indicators within the environmental indicators programme. OECD's indicators were structured around three themes based on adjustments of the Pressure-State-Response (PSR) model. These themes are shown below.

i. **Transport trends and patterns of environmental significance:** Major driving forces and indirect pressures caused by transport.

ii. **Interactions with the environment:** Direct pressures on the environment and on natural resources and their related impacts.

iii. **Economic and policy aspects of the transport and environmental interface:** Economic aspects of environmental impacts, key policies, trade aspects and other societal instruments.

Indicators were selected for each theme based on their performance on several criteria. Using the scoring system shown in Table 4-3 below, a suite of 33 sustainable transport indicators were identified and classified by OECD.

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>Evaluation (Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy relevance, i.e. relevance to transport and environmental policies</td>
<td>High</td>
</tr>
<tr>
<td>Analytical soundness</td>
<td>good</td>
</tr>
<tr>
<td>Measurability, taking into account:</td>
<td>Short term</td>
</tr>
<tr>
<td>- data availability</td>
<td>Good</td>
</tr>
<tr>
<td>- data quality including international comparability</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-3: OECD's scoring system for evaluating the suitability of indicators
4.4.2 Multidimensional sustainable transport indicator sets

Frameworks to guide identification and classification of sustainable transport indicators that take consideration of only a single dimension of sustainable transport are inherently weak approaches to assessment as they will inevitably neglect issues that are fundamental to the concept. Consequently, approaches that enable consideration of the multiple dimensions of sustainable transport are intuitively more useful for assessing sustainable transport.

There have been various applications of indicator-based sustainable transport assessments that have sought to derive and utilise such broader sets of indicators. These have generally tended to be based on theme and multidimensional classification frameworks, which have then guided the identification and compilation of sustainable transport indicators.

Examples of sustainable transport indicator-based assessments that have utilised variations and combinations of theme and multidimensional classification approaches are discussed in the sub-sections below.

4.4.2.1 Civilising Cities Initiative

As part of a wider project to demonstrate practical examples of the contribution that the transport sector can make to improving quality of life in urban areas, the 'Civilising Cities Initiative' project team developed an indicator framework to assess the relationship between transport provision and the broader objectives of sustainability and quality of life (Jones and Lucas 2000, Jones et al 2003).

Guided by a review of existing and past frameworks, Civilising Cities Initiative’s ‘quality of life indicator framework’ was formulated around eight themes on which it was expected that transport could have impacts. The themes specified to guide the framework were; Neighbourhood, Environment, Traffic, Health, Education, Economy, Crime, and Participation.

In addition to being classified under themes, the indicators in the Civilising Cities Initiative’s framework were also grouped by data type, as shown in Table 4-4 below.
Chapter Four: Review of the literature and previous research

<table>
<thead>
<tr>
<th>Indicator Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counts</td>
<td>'Hard' measurable indicators, which can be determined directly from observation and existing data sources.</td>
</tr>
<tr>
<td>Attitudes</td>
<td>'Soft' survey indicators which rely on local attitudinal surveys that collect data on the satisfaction of local stakeholder groups.</td>
</tr>
<tr>
<td>Insights</td>
<td>Focuses group data, used to obtain qualitative insights into local problems and perceptions and factors that influence changes in attitudes and behaviour.</td>
</tr>
</tbody>
</table>

Table 4-4: Indicator classification in the Civilising Cities Initiative

Using this approach, 56 sustainable transport indicators were proposed and included in the Civilising Cities’ quality of life indicator framework (Jones et al 2003).

4.4.2.2 PROSPECTS: Indicators for sustainable urban land-use and transport

Funded by the EU, the aim of the Procedures for Recommending Sustainable Planning of European City Transport Systems (PROSPECTS) project was to provide cities with the guidance needed to generate optimal land use and transport strategies to meet the challenge of sustainability in their particular circumstances (May et al 2001). Among other things, PROSPECTS had a dedicated work package the specific aim of which was to set out objectives for sustainable urban transport and land use planning and develop appropriate indicators to measure their achievement (Minken et al 2003). Based on the research conducted in this Work Package, PROSPECTS proposed the six objectives for sustainable transport shown in Box 4-1 below:

- Economic Efficiency
- Livable Streets and neighbourhoods
- Protection of the environment
- Equity and social inclusion
- Traffic safety
- Support of economic growth
- Inter-generational equity

Box 4-1: Objectives of sustainable transport as proposed by PROSPECTS

Performance indicators relevant to each objective, with the exception of 'intergenerational equity', were proposed to facilitate assessment of whether or not
Chapter Four: Review of the literature and previous research

the objectives are being achieved and to enable regular monitoring. In specifying the indicators, a key requirement of PROSPECTS was that they were as far as possible directly related to the objectives that they were intended to illuminate. Additionally, indicators were required to be measurable, analytically sound, and policy relevant.

A total of 52 indicators were proposed in the PROSPECTS assessment framework. From this set, a subset of 19 were identified as being the most relevant and most likely to be applied in planning exercises.

4.4.2.3 Sustainable Transportation Indicators Project (CST, Canada)

The Centre for Sustainable Transportation (CST), a Canadian research organisation, commissioned the Sustainable Transport Indicators Project, the aim of which was to derive a robust set of indicators for sustainable transport (Gilbert and Tanguay 2000, Gilbert et al 2002). In developing the indicators, CST borrowed from TERM (EEA 2000) by specifying seven questions representing key policy areas for which indicators would be necessary. These policy questions are shown in Table 4-5 below.

<table>
<thead>
<tr>
<th>Key questions</th>
<th>Indicator groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Is the performance of the transport sector improving in respect of its adverse impacts on environment and health?</td>
<td>Environmental and health consequences of transport</td>
</tr>
<tr>
<td>2 Is transport activity changing in directions consistent with positive answers to the other questions?</td>
<td>Transport activity</td>
</tr>
<tr>
<td>3 Are land use, urban form, and transportation systems changing so as to reduce transportation effort?</td>
<td>Land use, urban form and accessibility</td>
</tr>
<tr>
<td>4 Are we increasing the efficiency of use of current infrastructure and changing the infrastructure supply in sustainable ways?</td>
<td>Supply of transport infrastructure and services</td>
</tr>
<tr>
<td>5 Are the patterns of expenditure by governments, businesses, and households, and the associated pricing systems, consistent with moving towards sustainability?</td>
<td>Transportation expenditures and pricing</td>
</tr>
<tr>
<td>6 Is technology being used more in ways that make vehicle transport systems and their utilization more sustainable?</td>
<td>Technology adoption</td>
</tr>
<tr>
<td>7 How effectively are environmental management and monitoring tools being used to support policy- and decision-making towards sustainability?</td>
<td>Implementation and monitoring</td>
</tr>
</tbody>
</table>

Table 4-5: Key policy questions for indicator classification suggested by CST
CST then proceeded to identify and define a suite of indicators to cover the seven policy areas. The following guiding principles were used to develop the indicators:

- An indicator should represent an issue of concern to sustainable transportation, as elaborated in CST’s definition, or provide a clear answer to one of the seven questions in Table 4-5 above;

- An indicator should be capable of being reflected as a time series, so that information can be provided on changes in performance;

- A qualifying variable should come from what the project team considers to be a reputable and reliable source.

Using the policy questions in Table 4-5 and the guiding principles above, CST was able to develop ten overarching indicators, which were the final output of the Sustainable Transport Indicators Project (Gilbert et al 2002).

4.4.2.4 Other theme-based sustainable transport indicator applications

In addition to the examples discussed above, various other theme based indicator approaches have been developed for sustainable transport assessment and evaluation. As part of the Quantifiable/Sustainable city project for example, Kupiszewska (1997) developed a conceptual model for transport sustainability within which 40 indicators were classified under four themes and proposed as being suitable for evaluating the success of transport policies in achieving sustainability aims. Similarly, the SPARTACUS (System for Planning and Research in Towns and Cities for Urban Sustainability) project (Lautso and Toivanen 1999), classified 20 indicators under six themes with a view to providing a sound and theoretically consistent basis for building and evaluating long term strategies for sustainable transport and land use. In yet another application, Ricci (1999) proposed a set of 19 indicators based around 12 thematic issues, to evaluate progress towards sustainability in urban transport planning and management. Similarly, Nicholas et al (2003) proposed and applied 24 indicators to the Lyons conurbation (France), classified around four themes.
The specific themes around which these four applications classified sustainable transport indicators are shown in Table 4-6 below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Environment and Resources</td>
<td>Air pollution</td>
<td>Accessibility</td>
<td>Operational</td>
</tr>
<tr>
<td>Quality of Life</td>
<td>Consumption of natural resources</td>
<td>Mobility</td>
<td>Economic</td>
</tr>
<tr>
<td>Economic Performance</td>
<td>Health</td>
<td>Equity</td>
<td>Environmental</td>
</tr>
<tr>
<td>Intermediate objectives</td>
<td>Equity</td>
<td>Economic Activity</td>
<td>Social equity</td>
</tr>
<tr>
<td></td>
<td>Opportunities</td>
<td>Traffic density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic Benefits</td>
<td>Air Quality</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acoustic quality</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spatial Development</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of resources</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Safety and security</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Visual impact</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cultural heritage</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4-6: Themes used in various sustainable transport indicator compilations**

Similar theme based approaches were also used by Borken (2003) and Imran and Low (2003) to compile sustainable transport indicators appropriate to the German and Pakistani contexts respectively.

### 4.5 Reflections on sustainable transport indicator frameworks

While early sustainable transport indicator frameworks classified component indicators around the single environmental dimension, theme-based and multidimensional frameworks are now the predominant platforms for modern sustainable transport indicator development. These multidimensional frameworks are inherently more suitable for sustainability assessment as they are able to consider the various social and economic factors that are key to the concept. The examination and review conducted above of applications of indicator-based sustainable transport assessment, have revealed a number of issues, gaps, challenges and opportunities for future research and development of indicator-based assessment frameworks. These issues, gaps and opportunities are discussed and summarised in the next section.
4.6 An overall assessment of past work – A SWOC analysis

A Strengths, Weaknesses, Opportunities, Challenges (SWOC) analysis provides a useful mechanism for drawing together the earlier discussion and review of the various approaches in practice and in the literature to indicator-based sustainability and sustainable transport assessment.

SWOC analysis is one the family of Strength, Weakness, Opportunity, Threat (SWOT) analyses techniques. These techniques provide a simple and easy to understand approach for organising and illuminating strengths and weaknesses in any investigative context. Once these are identified, the analysis can then aid in illuminating opportunities for future work and development, as well as highlight the challenges that will have to be overcome in order to realise such opportunities.

As a consequence of these inherent attributes, SWOT type analyses provide easily usable mechanisms for isolating and arranging the key issues identified in the scoping and review stages of research. They are also inherently useful in the preliminary stages of decision-making and as a precursor to planning, and have been applied in a wide variety of contexts (Bryson and Einsweiler 1988, Kotler 1988, Johnson et al 1989, Bartol and Martin 1991, Wheelen and Hunger, 1995, Kangas et al 2003).

Given the natural suitability, a SWOC analysis is utilised in this chapter to summarise the review of the literature and previous work, with a view to clearly illuminating the strengths and weaknesses of current approaches to sustainable transport indicator-based assessment and directing a path for the research presented in this thesis.

4.6.1 Strengths of previous research and approaches

Work on sustainable development indicators have been undertaken since the Brundtland Report (WCED 1987), and intensified after the Rio Declaration (United Nations 1992). Given such a long history and the current pervasiveness of the goal of sustainability, it is not surprising that past and existing indicator frameworks display various strengths that can serve as useful platforms for future indicator development. Some of the strengths of the approaches to indicator-based sustainability assessment reviewed during this research are examined in the various sub-sections below.
Linkages to key themes and principles of sustainability
A fundamental problem in operationalising the concept of sustainability is that it is an innately vague and therefore contested concept. Some of the various work reviewed in this chapter have provided a useful approach for overcoming this vagueness by linking indicators to key tenets, themes and objectives of sustainability. While some approaches link indicators to broad issues, others have endeavoured to achieve some precision by linking indicators to more precise themes and objectives. Together, these provide a plethora of tested ‘tenets’ of sustainability, some of which can provide a useful starting point for future linking and development of sustainability indicators.

Recognition of the need for stakeholder participation
More evident in assessment of the broader concept of sustainable development than in transport specific indicator frameworks, is the recognition that participation is necessary in sustainability assessment. Very often, such participation is obtained through consultations during the indicator selection process. Sustainable Seattle (1998), NTREE (2003), Yuan et al (2003) and Bell and Morse (2004) for example, utilised thematic workshops to garner the views of relevant experts and laymen.

Availability of a large pool of indicators
Perhaps the most notable contribution of the vast work that has been undertaken in developing indicator frameworks is the consequent large pool of indicators that now exists as a result. While there are some common indicators in all applications, it is often the case that new indicators are proposed and developed with each new application. This has led to an abundance of sustainability indicator sets, each comprising of a broad range of indicators. This plethora of indicators provides a large pool from which indicators can be selected for future work and assessment.

4.6.2 Weaknesses of previous research and approaches
As discussed in the previous chapter, indicator-based assessments can be more transparent, consistent and useful for decision-making than other approaches. Whether they fulfil their potential however, depends on how well such frameworks are designed and executed, and how well the indicators are selected. From the review conducted above, some shortcomings of exiting indicator frameworks are evident.
The selection of indicators is often ad-hoc and arbitrary

The benefits of basing indicators around key sustainability themes have been previously discussed. Unfortunately however, many indicator frameworks appear to be simply extensive compilations of indicators categorised under the headings or organised in a suggested format (e.g., PSR), without any indication of a systematic method or process for selecting the component indicators. Mitchell (1996) posits that sustainability indicator sets derived in this manner may be ineffective in promoting sustainable development and can even be detrimental to the process. Moreover, as a consequence of the absence of any obvious theoretical or methodological underpinnings to justify their selection, the credibility of such indicator sets is often questionable at best (Bossel 1999, Lenz et al 2000).

Indicators selected tend to provide a poor reflection of the attendant systems

The arbitrary selection of indicators is often exacerbated by a similar lack of systematic procedures for selecting the themes that determine classification and choice (Malkina-Pykh 2002). This problem combined with the inherent biases of analysts, often result in indicator sets that are overly dense in some areas, primarily in ‘environmental issues’ and sparse or even empty in other important areas. This has led Briassoulis (2001) to observe ‘that in their present form, indictors provide only a fragmented picture of an already ill defined concept: sustainable development’.

Few systematic and auditable approaches for incorporating stakeholder views

Many researchers try to justify selected indicators, as well as fulfil the need for some level of citizen participation in sustainability analyses, through broad consensus building and consultation processes that seek to gauge agreement among stakeholders on the set of selected indicators. The extent to which stakeholder views determine or are incorporated into indicator choice is often uncertain however, as there are few systems to ensure that such diverse views are entered into the selection process in a clear, transparent and auditable manner (Eckerberg and Mineur 2003).2 Focus groups such as those used by the Civilising Cities Initiative (Jones and Lucas 2000, Jones et al 2003) or thematic workshops such as those used by Sustainable Seattle (1998),

2 A notable exception to this include Miller (2001) who utilised delphi method for deriving indicators of tourism sustainability within the UK tourism sector by interviewing a sample of 74 individuals who had published on the subject of sustainability in any one of four major tourism journals.
NTREE (2003), Yuan et al (2003) and Bell and Morse (2004), while useful in bringing key stakeholders together, provide no auditable mechanisms to show how stakeholder preferences were elicited and entered into the indicator selection process.

**Inadequate recognition of the context-specific nature of sustainability analysis**

Recognition and customisation of chosen indicator sets to suit context is key to sustainability assessment. Mitchell (1996) has argued that no single universal set of sustainability indicators exist, but that rather several sets exist, corresponding to the specific purposes and to the local circumstances. Consequently, sustainability indicator-based assessment frameworks should not be prescriptive, but should instead be flexible enough to enable local context to be taken into consideration. Unfortunately however, most indicator-based assessment frameworks do not allow for customisation and adjustments to reflect local or other specific circumstances. The Pressure-State-Response framework (PSR), on which many current approaches are modelled, was primarily created for application on a national or global scale to evaluate discrepancies between the state of the environment and desired environmental quality. The problem is further exacerbated as the inherent lack of clear processes does not render these frameworks amenable to localised customisation.

**4.6.3 Opportunities for sustainable transport indicator research**

From the weaknesses and strengths of the approaches to sustainable transport indicator assessment described above, it is evident that there is a fundamental need for more systematic, transparent and auditable approaches to selection and compilation of sustainable transport indicators. Such improvements are required in three areas.

**Systematisation of the processes and criteria that determine indicator choice**

There is an obvious gap, and hence opportunities for future research, in clear, systematic and transparent processes to guide selection of a limited number of indicators, and in mechanisms that enable post-audit of the selection process (Spangenberg 2002). There is a need for systems that facilitate clear specification of the issues and criteria relevant to indicator selection, and provide transparent methods for factoring them into the selection process. A clear methodology would also enable other developers to learn from other applications and approaches (Mitchell 1996).
A systematic approach for eliciting and incorporating stakeholder values

As previously stated, existing frameworks do attempt to include stakeholder views in the selection of sustainability indicators. However, current approaches tend to lack the systemisation and transparency that would enable auditing and decomposition of the effects of stakeholder values on the indicator selection process. There is therefore a need for such clear, systematic and auditable mechanisms for eliciting and incorporating stakeholder values in the indicator selection process.

Building flexibility into frameworks so that context can be adequately reflected

Current indicator frameworks are generally not amenable to local customisation so that the applicability of indicator choice to local context is maximised. Therefore, building some level of flexibility into the indicator selection process is a gap in current sustainable transport indicator-based assessment that requires addressing.

4.6.4 Challenges to developing mechanisms for indicator selection

In attempting to realise the opportunities for research in the previous section, there will be a need to overcome certain challenges that could have implications on the development of methodological approaches that build on the existing strengths, address the weaknesses, and capitalise on the opportunities. Two of the most pertinent challenges to development of systematic frameworks are discussed below.

Sustainability is a complex and broad concept

Sustainability is a broad and complex concept. As a consequence, attempting to capture its essence within a coherent framework will be a considerable challenge due primarily to the large amount of information and issues that have to be considered in the analysis. Due consideration will therefore have to be given to this issue.

Enabling consideration of all possible contexts is difficult

As a result of the aforementioned breadth and complexity of sustainable transport, the stakeholders, contexts and scales at which sustainability assessment is undertaken will vary largely. Developing a framework that is flexible enough for application to these different contexts, capable of incorporating the values of different stakeholders and accommodating the differing scales, will undoubtedly be a very challenging task.
4.7 Summary

Since the Brundtland Commission’s Report (WCED 1987), numerous approaches and frameworks have been developed and applied for derivation of indicators within the broader context of sustainable development. In many instances, these applications have been the forerunners for current sector-specific application of sustainability indicators and therefore have had bearing on development and applications of sustainable transport indicators. While the volume of past work on development of indicators for the narrower concept of sustainable transport is substantially less, there have nonetheless been some useful lessons learned from both types of applications that can guide future development of suitable indicator-based assessment frameworks.

A Strengths, Weaknesses, Opportunities, Challenges (SWOC) analysis was deemed to be a useful framework for drawing together the various literature and past applications of indicator-based sustainability assessment in a way that would clearly reveal the improvements required as well as highlight features of current applications that can be built upon in future work. A quadrant matrix is useful for diagrammatically representing the four themes of the SWOC framework and the results of the SWOC analysis. In that regard, a SWOC quadrant matrix detailing the key Strengths, Weaknesses, Opportunities and Challenges identified during the review of current and past approaches for deriving sustainable transport indicators is shown in Figure 4-5 below.

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Linkages to key sustainability themes and objectives</td>
<td>- Development of systematic processes for indicator selection</td>
</tr>
<tr>
<td>- Recognition of the need for stakeholder participation</td>
<td>- Development of robust processes for eliciting stakeholder values</td>
</tr>
<tr>
<td>- Availability of a large pool of indicators</td>
<td>- Building flexibility into the selection process to suit context</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Indicator selection is often arbitrary and ad hoc</td>
<td>- Sustainability is a broad and complex concept</td>
</tr>
<tr>
<td>- The selection of themes often poorly reflect the system</td>
<td>- Achieving the level of flexibility for applicability to all context is difficult</td>
</tr>
<tr>
<td>- No systematic approaches for including stakeholder views.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4-5: The SWOC Matrix summarising the key findings of the review
The SWOC analysis and the attendant quadrant matrix shown above serve two important purposes in the context of this thesis. Firstly, it summarises the key points of the literature review and identifies where future work is required, and where such a need exists, provides a direction to guide such future work. Within this context and as clearly shown in the matrix above, there is a need to incorporate systematic processes into the indicator selection process. Such systematisation is necessary not only in the way that the factors, criteria and issues that influence indicator selection are synthesised, but also in the way that stakeholder values are incorporated into the analysis. Additionally, it is obvious from the review that flexibility, which is of paramount importance in considerations of sustainability, is largely lacking in current indicator frameworks. There is therefore also a need to address this gap.

A second role of the SWOC Matrix and its illumination of the strengths and weaknesses of current sustainable transport indicator-based assessment frameworks, is that it provides a set of key factors, i.e., strengths and weaknesses, which can be used to assess the suitability of any indicator-based assessment framework that may be developed in the future.

Having identified these research needs and gaps therefore, the subsequent chapters of this thesis will present and demonstrate an approach to indicator-based sustainable transport assessment, that builds on the strengths of current approaches and which takes due cognisance of the identified challenges. The SWOC matrix in Figure 4.5 will also be used to assess whether this developed framework has the relevant strengths and addresses the key gaps, capitalises on the opportunities and redress the weaknesses of current frameworks identified in the review presented in this chapter.
Chapter Five: A methodological framework for indicator-based sustainable transport assessment

CHAPTER FIVE: A methodological framework for indicator-based sustainable transport assessment

5.0 Overview

Having established the importance of systematic frameworks for sustainable transport indicator selection, and the current non-existence of such systematic processes, this chapter presents the main contribution of the research – a methodological approach to aid the systematic selection of sustainable transport indicators. Among other things, the principles and processes inherent in the framework are introduced and discussed.

5.1 Introduction

The previous chapters have shown that despite the increasing popularity of sustainable transport as an overarching paradigm and goal of modern transport planning, and the equivalent popularity of indicators as assessment tools, robust analytical approaches do not currently exist to enable systematic indicator-based sustainable transport assessment. Naturally, sustainable transport indicators will prove more credible and useful for decision making if they are selected within the context of a systematic, participatory, robust and logical framework. Past applications of indicators have suffered, inter alia, from inadequate capture of the key components of sustainable transport, an incapacity for participation and have been largely arbitrary and consequently lacked the systematisation and logic to guide transparent and credible assessment. A new approach is therefore needed that will enable systematic indicator-based assessment of sustainable transport in a way that captures the key components of transport sustainability while adhering to relevant principles of sustainability.

5.2 The ELASTIC framework

The Evaluative and Logical Approach to Sustainable Transport Indicator Compilation (ELASTIC) is a flexible methodological framework for selecting appropriate and key sustainable transport indicators. The output of ELASTIC is the Transport Sustainability Profile (TSP) - an un-aggregated suite of sustainable transport
Chapter Five: A methodological framework for indicator-based sustainable transport assessment

indicators which when presented simultaneously can provide a snap-shot of the progress of the transport system towards or away from sustainability. ELASTIC ensures the selection of a key subset of indicators by evaluating and illuminating the strengths and weakness of potential sustainable transport indicators through a structured and participatory framework.

In the most general sense, the ELASTIC processes can be divided into five broad stages as shown in the diagrammatic conceptual model of the ELASTIC methodology in Figure 5-1 below. The feedback loop reflects the cyclic nature of the ELASTIC approach since the selected indicators will illuminate priorities and gaps that will redefine the focus and vision of the sustainable transport assessment process. A more detailed narrative and graphical description of ELASTIC is given later in this chapter.

![Figure 5-1: A general conceptual model of the ELASTIC framework and processes](image-url)
5.3 Basis and key principles of the ELASTIC Framework

In order to effectively serve its purpose as a methodological approach for selecting indicators suitable for transport sustainability assessment, the ELASTIC framework and its attendant outputs are based on eight key principles as outlined below.

1. Sustainable Transport is a continuum rather than a static state
ELASTIC does not view sustainability as a definitive end-state. The position is taken instead that sustainable transport is a 'continuum' and not a destination *per se* (Shearman 1990, Shriberg 2002). Consequently, the ELASTIC framework does not seek to define reference values or targets for sustainable transport indicators, but seek only to illuminate a general direction towards or away from sustainability.

2. A minimal number of Indicators
The ELASTIC framework seeks to derive only a limited number of indicators for inclusion in the TSP. As discussed in previous chapters, such minimisation is necessary for practical reasons, as well to avoid a potential overload of information which may only confuse the assessment and decision-making processes. The aim therefore is to derive a minimal set of suitable indicators that are theoretically sound, applicable and which provide the most relevant and useful signals to decision makers.

3. The Indicators should be of highest quality
Indicators are inherently imperfect (Mitchell 1996), and since ELASTIC utilises only a small number of indicators, the ramifications of such imperfections can be significant. To minimise any possible distortions in the information provided by indicators, ELASTIC ensures that only indicators of the highest quality are selected for inclusion in the TSP. A key requirement is that indicators should as far as possible, meet all the desired characteristics of indicators previously stipulated in Box 3-2.

4. Indicator selection process is goal and objective-led
For an indicator-based assessment to be effective, the indicators have to illuminate key issues relevant to the concept of sustainable transport. In addition to indicator quality therefore, a key tenet of ELASTIC is that choice of indicators should be determined by, and linked to the vision and key objectives of sustainable transport.
5. **Transport sustainability assessment and indicators are context specific**

Due to the multiplicity of interpretations, perspectives and issues inherent in consideration of sustainable transport, and the differing capabilities and circumstances of localities and regions, sustainability assessment and therefore the required indicators, will necessarily differ with context (Maclaren 1996, Mitchell 1996, Schleicher-Tappeser and Strati 1999). Consequently, the ELASTIC framework does not seek to derive a suite of universally applicable indicators, but instead derives different sets of indicators for different applications, based on the geographical, cultural and spatial contexts in which they are to be applied.

6. **Stakeholder participation is key to sustainability assessment**

The need for participation in sustainability assessment has already been discussed in Chapter three of this thesis. It is necessary to ensure that indicators chosen are meaningful to the public and reflect an understanding of their values and objectives (Shields *et al* 2002). A key tenet of ELASTIC is therefore that the views and values of all stakeholders who may affect or be affected by the transport decisions and impacts, must be incorporated in the sustainable transport indicator selection process.

7. **Sustainability assessment is relevant to all spatial levels**

There is now increasing realisation that sustainability analysis is not solely an issue to be addressed on global scales and that indeed, analysis at the regional and local levels may have distinct advantages (Giaoutzi and Nijkamp 1994, Capello *et al* 1999, Nijkamp and Vreeker 2000, Benneworth *et al* 2002, Chan and Huang 2004, etc.). The ELASTIC framework therefore aims to be suitable for application at any spatial level, including the national, regional, local and even neighbourhood scales.

8. **The TSP may reveal new priorities and guide revision of the objectives**

As reflected by the feedback loop in Figure 5-1 above, the Transport Sustainability Profile derived from ELASTIC may itself illuminate new issues and priorities which can in turn influence the choice and subsequent weighting of ELASTIC's objectives. The indicators may for example reveal that an issue previously considered to be important is in fact progressing well. The derived indicators may also identify 'sleeper issues', that is, key problems that may have previously overlooked. It may be the case therefore, that current objectives are replaced or their weightings changed.
5.4 Multi-Criteria Decision Analysis: backbone of ELASTIC

As can be seen from the key principles listed above and the diagrammatic conceptual model introduced earlier, the ELASTIC framework seeks to select a suite of indicators by systematically evaluating them against a number of criteria in a way that takes stakeholder values into consideration. Achieving the above aim of ELASTIC is therefore essentially a Multi-Criteria Decision Analysis (MCDA) problem.

MCDA is an approach to simplifying complex decision problems that are characterised by multiple and often conflicting objectives and criteria. Among other things, MCDA provides a structured approach to guide decision making in such circumstances. Its purpose however, is to serve as an aid to decision making, not to make the decision (DETR 2000 a).

Given a set of alternatives, each characterised by a set of assessments for selected criteria and an interest group whose opinions regarding the selection of criteria and the assessments have to be considered, MCDA provides a systematic procedure to define the attractiveness of competing alternatives with a view to identifying the best one, the best subset or to rank them (Massam 1988, DETR 2000 a). To achieve this aim, MCDA breaks down the problem into more manageable pieces to allow data and judgements to be brought to bear on the pieces, and then re-assembles the pieces to present a coherent overall picture to decision makers. Logically, the options will differ in their performance on the various criteria and objectives. Additionally, conflicts and trade-offs will be evident amongst the criteria and objectives themselves. The final outcome of the MCDA process is therefore a preferred alternative or subset of alternatives chosen based on their performance across all criteria and the trade-offs among the criteria themselves. A particular benefit of MCDA is that the final outcome is based upon a rigorous definition of priorities and preferences decided upon by the interest group relevant to the decision.

Numerous MCDA techniques exist and their numbers are still rising. ELASTIC brings together appropriate MCDA tools and techniques in a single coherent framework, the ultimate aim of which is to systematically select an appropriate suite of sustainable transport indicators to guide sustainable transport assessment.
5.4.1 Strengths and weaknesses of Multi-Criteria Decision Analysis

MCDA techniques, as a family of approaches, possess several desirable characteristics that provide them with clear strengths over other decision-making approaches and over informal judgement unsupported by analysis (Hobbs and Horn 1997, DETR 2000 a, Mendoza and Prabhu 2003). Some of the strengths of MCDA include:

- The ability to accommodate numerous criteria in the analysis;
- The facility for involvement of experts, interest groups, and stakeholders;
- A clear documentation of assumptions which enhances auditability;
- Trade-offs among fundamental concerns are explicitly illuminated and their effects on the decision process clearly shown;
- The decision problem is broken into manageable components which are more amenable to human cognitive abilities;
- The analysis need not be data-intensive and MCDA techniques are generally capable of utilising both qualitative and quantitative data;
- The structured approach and the decomposition of the problem render MCDA approaches transparent and are therefore easily understood by participants.

Despite the many advantages highlighted above, MCDA techniques also suffer from some weaknesses. Some of the weaknesses are listed below (Hobbs and Horn 2000).

- While not requiring much data inputs, the application of MCDA can often generate excessive data concerning how options perform on numerous criteria;
- The cost and effort of assembling and educating stakeholders may be high;
- Due to the problem of costs, the views of a minority of representatives are normally taken to reflect the views of all stakeholders.

5.5 The ELASTIC Process

ELASTIC maximises the strengths of MCDA and minimises the weaknesses to select a suite of indicators guided by specification of clear objectives and criteria, incorporation of the values of key stakeholders, transparent evaluation and the application of sensitivity analysis to confirm the robustness of indicator choice.
A detailed diagram of the ELASTIC processes and components is shown in Figure 5-2 below.

**Figure 5-2: A detailed schematic of the ELASTIC Process**

The various stages of the ELASTIC process as displayed in the diagram above, are described in detail in the subsequent sections of this chapter.
5.6 Assembling the long list of indicators for analysis

As shown in Figure 5-2 above, application of ELASTIC commences with the identification and assembling of a long list of suggested or potential sustainable transport indicators. It is from this long initial list of alternative indicators that a smaller subset will eventually be derived. There is no limit to the number of indicators that can be used at this stage, although the larger the number the greater the demands on time and effort that will be required to evaluate the entire set of indicators. Similarly, there is no specified source from which the initial set of indicators should be chosen. It is envisaged however, that some of the possible ways through which the long list can be derived will include the following:

i) A pre-defined or recommended pool: In many instances, numerous indicators are suggested by government or regional authorities. These indicators can serve as the initial long list from which a suitable subset will eventually be selected.

ii) Developed or identified using other methods: Many indicator applications have utilised broad consultations with stakeholders to identify indicators. Similarly, methods such as PICABUE (Mitchell et al 1995) have proposed ways through which indicators can be developed. In both cases, the end result can be a long list of indicators to which ELASTIC can then be applied.

iii) Compiled from past work and applications: Sustainable transport indicators have been applied in many contexts, both in the academic literature and in practical applications. During the planning process for example, numerous indicators will be available to the planner from previous years. These indicators can therefore form the initial long list entered into the ELASTIC process.

The above is not an exhaustive list of possibilities. The initial long indicator set can be derived from a combination of these methods as well as from other sources and through other mechanisms.
5.7 Defining the vision and goals of ELASTIC

The vision of the ELASTIC framework is known *a priori*. It is to select a suite of key indicators which when presented together can provide an overall view of the movement of the transport system towards or away from sustainability. This overarching goal is too broad and too vague to aid the indicator selection process however. To bring greater clarity to the process therefore, ELASTIC decomposes this holistic goal into its component elements so that indicator evaluation and selection is guided by narrower, clearer and more precise and interpretable sub-goals and criteria.

5.7.1 Benefits of decomposing a decision problem

Decomposition of complex decisions can significantly simplify and therefore aid the decision making process and its outcomes. Among other things, decomposition results in a deeper and more accurate understanding of what one should care about in the decision context. According to Fischer (1977), decompositional approaches assist in defining the decision problem by allowing for consideration of a larger number of attendant criteria and objectives than the decision maker can make holistically. On the contrary, attempts to examine the problem holistically without decomposition often results in evaluation based on a limited number of attributes. By addressing the problem in a piece-meal fashion, systematic decomposition of complex problems relaxes the information processing and cognitive demands on the decision maker, and thus reduces the potential for error in judgment (Kleinmuntz 1990). Two methods of decomposing goals and objectives in multi-criteria decision problems have been suggested in the literature (Buede 1986, Keeney 1992). These are;

i. **The top-down approach**: This approach is vision-led. The broad goal of the decision problem is ascertained and a value structure is developed by dividing and subdividing this broad goal into sub-goals, criteria and so forth.

ii. **The bottom-up approach**: This approach is driven by the alternatives. In this case, a value structure is generated by probing the major differences between the identified alternatives. The identified differences among alternatives are then classified into categories taken to represent criteria.
5.7.2 Hierarchical top-down goal decomposition in ELASTIC

The bottom-up approach is clearly inappropriate in the context of ELASTIC as the initial long list of indicators will often be too large a set for all individual indicators to be scrutinised against each other for differences. ELASTIC therefore decomposes the vision for indicator selection using a hierarchical 'top-down' approach, with the broadest and primary goal of the process at the top, followed by cascading layers each specifying more precisely the meaning of the objective immediately above. This continues until the most precisely defined criteria are at the bottom of the hierarchy.

The hierarchical 'top-down' approach to decomposing and structuring a decision problem provides a number of advantages. Some of these are enumerated below (Brownlow and Watson 1987, Saaty 1990, Keeney 1992).

i) It defines an easy structure to follow: The hierarchical representation of goals and criteria clearly indicates the set of objectives over which attributes should be defined. The easy to follow structure of a hierarchy also helps to identify missing objectives, since the logical pattern facilitates the easy identification of gaps or redundancy in the hierarchy.

ii) Importance and position of elements are easily established: The higher-level goal and criteria relate to general concerns. They are easily identified and provide a clear basis for specification of lower-level objectives. The lower-level objectives collectively indicate the degree to which the associated higher-level objectives are achieved. Therefore, hierarchical representations can show how changes in priorities of high-level goals affect the priorities of elements at the lower levels. Similarly, the trade-offs amongst the objectives are illuminated more clearly when the problem is structured in a hierarchy.

iii) Facilitates the application of MCDA techniques: All the various MCDA methods require that the decision problem is structured in a hierarchy (see for example, Miller 1970, Keeney and Raiffa 1976, Saaty 1980, Von Winterfelt 1980, Brownlow and Watson 1987, etc.). The ELASTIC hierarchical design therefore enhances its amenability to all these various MCDA techniques.
5.7.3 Structure of the ELASTIC goal hierarchy

It has been made clear in the previous section that hierarchies provide a useful structure for arranging the goals and objectives of a complex decision problem such as selection of key sustainable transport indicators. However, a hierarchy has to be formulated with due care to ensure that it maximises understanding and is conducive to the human decision-making and cognitive processes (Pöyhönen et al 2001).

The ELASTIC hierarchical arrangement of goals and criteria is therefore structured around three logical theoretical constructs. These layers of the hierarchy are described in descending order in Box 5-1 below.

Overall Goal
The Overall goal characterises the reason for interest in the decision situation and defines the breadth of concern. It therefore defines the vision that is desired to be obtained through the process. This is pre-defined for ELASTIC and will typically be the selection of a key suite of sustainable transport indicators.

Sub-goals
The above high-level goal of ELASTIC, while setting the context of the decision problem, is too all-encompassing and vague to guide the indicator selection process. To provide clearer guidance for the selection process therefore, the overarching goal needs to be broken down in a way that provides narrower focus. Therefore this second layer of the hierarchy is comprised of sub-goals that provide a clearer definition of the overall goal.

Criteria
The sub-goals while useful, can still be relatively too broad to clearly guide the selection process. The third level of the hierarchy is therefore a set of specific and narrow criteria that decompose the sub-goals to provide an even more precise focus for the decision problem. Among other things, these criteria are expected to be mutually exclusive and must be capable of being assessed on a measurable scale. The specification of key criteria is a very important stage in applying ELASTIC as they represent the bases against which the suitability of sustainable transport indicators is measured and evaluated. These criteria therefore translate into tangible and measurable terms, the vision and goals of the ELASTIC framework.

Box 5-1: The components of the ELASTIC goal hierarchy
5.8 Populating the ELASTIC goal hierarchy

It is clear that appropriate structuring of the hierarchy of goals is key to the ELASTIC process. The theoretical construct of the ELASTIC hierarchy has been shown previously in Box 5-1. To operationalise the hierarchy however, there will be a need in each ELASTIC application to populate the component layers. The ELASTIC approach to populating the populating and specifying the various layers of the hierarchy are discussed in the sub-sections below.

5.8.1 The overall goal of the ELASTIC framework

As has been stated at various points in this chapter, the overall goal of ELASTIC is specific and is pre-defined. The goal is to select a manageable suite of sustainable transport indicators which when presented together can provide an indication of the movement of the transport system towards or away from sustainability. Stated more formally;

\[
\text{Given a set } A \text{ of suggested sustainable transport indicators, ELASTIC enables the selection of a subset } A' \text{ of } A, \text{ comprised of as small as possible a number of sustainable transport indicators, judged by stakeholders to be the most appropriate for assessing the sustainability of a given transport system.}
\]

As by-products of the ELASTIC process, the following outcomes may also be achievable:

- **A rank-ordering of the indicators from the best to the worst**
  During application of ELASTIC, the full set of indicators are evaluated and a measure of performance derived for each. Using their respective measures, a ranking of indicators in the set of alternatives \( A \) or \( A' \), can then be defined.

- **Classification of indicators into pre-defined homogeneous groups**
  ELASTIC illuminates the performance of indicators on select criteria using a systematic process. It is then a straight-forward exercise to categorise the indicators from the set of alternatives \( A \) based, for example, on their performance on criteria \( C_1 \) and \( C_2 \).
5.8.2 The sub-goals and criteria of the ELASTIC framework

To further define the overarching and holistic goal of the ELASTIC process, it is decomposed into two prescribed sub-goals. These sub-goals are:

1. To maximise the methodological quality of the indicators;

2. To maximise the relevance of indicators to the concept of sustainable transport.

5.8.2.1 Maximising the methodological quality of the indicators

To perform their roles adequately, indicators are required to have certain methodological strengths and attributes. These attributes often relate to the confidence and ease of the input of data, and in the integration and output of information relevant to the indicator. Among other things, methodological quality determines the feasibility and usefulness of an indicator. Methodological strengths are also key to acceptance and credibility of the indicators by decision makers and stakeholders alike. Therefore, the more methodologically sound the indicators are, the intuitively better they are taken to be. Based on this tenet, the first sub-goal of ELASTIC is to maximise the methodological quality and analytical soundness of selected sustainable transport indicators.

5.8.2.1.1 Criteria relating to methodological quality

There are numerous characteristics and attributes related to the input, integration and output of information that can determine the methodological quality and analytical soundness of an indicator. A full list of such methodological characteristics was shown previously in Box 3-2. ELASTIC has taken the most encompassing of these characteristics and embedded them in the framework as criteria to determine the methodological quality of indicators. Given that the desirable characteristics of indicators are well established in the literature and practice, the five ELASTIC methodological criteria shown in Box 5-2 below, are prescribed and are not expected to change with application. As will be discussed in the subsequent subsections however, the importance weight attributed to each criterion will differ with context.
Chapter Five: A methodological framework for indicator-based sustainable transport assessment

Box 5-2: The methodological criteria prescribed in the ELASTIC framework

In obtaining this reduced subset of five criteria, an effort has been made to capture the essence of the broader set of nine criteria previously shown in Box 3-2. As would have been observed, there was inevitably some overlap in the previous set. ‘Clarity in value’ for example, is captured to a great extent by ‘Interpretability’. Similarly, ‘Measurability’ and ‘Logical and scientific defensibility’ are synonymous. In deriving the reduced subset in Box 5-2, great care has been taken to specify their definitions in such a way that they adequately cover those criteria that they have subsumed and which have now been omitted. This was the case with both ‘Interpretability’ and ‘Measurability’, which were defined such that they incorporated ‘Clarity in value’ and ‘Logical and scientific defensibility’ respectively.

It will be noted that the criterion ‘Policy relevance’ previously shown in Box 3-2 is not covered in this revised Box 5-2 as it is adequately met by ELASTIC’s second sub-goal of relating indicators to ‘the concept of sustainable transport’. The way in which this sub-goal, and by extension ‘Policy relevance’ is addressed by ELASTIC is discussed below.
5.8.2.2 Relevance of indicators to the concept of sustainable transport

As the overall goal of ELASTIC is to select a set of key sustainable transport indicators, it is necessary to ensure that they capture as much as possible, issues that are key and pertinent to the concept of sustainable transport. May et al (2003) for example, suggest that the process of monitoring sustainable transport needs to be based on objectives and on indicators relevant to those objectives.

However, sustainable transport is a fuzzy concept and as a consequence, statements about sustainability and sustainable transport are often very general and broad. This has served to foster a variety of legitimate interpretations of sustainable transport (Gudmundsson 2003a). A key tenet of the ELASTIC framework is that such interpretation of sustainable transport must be dictated by context. It is this context-specific interpretation of sustainable transport that indicators would then be expected to reflect. Even a context-specific interpretation of sustainable transport however, would still be inherently too general to guide indicator selection and evaluation. Consequently, it will be necessary bring precision to any interpretation by decomposing it into key objectives.

The ELASTIC methodology therefore integrates context-specific interpretations of sustainable transport into the indicator selection process by enabling the specification of key and precise objectives of sustainable transport reflecting the given context and the accepted interpretation of sustainable transport in that locale. Indicators are then appraised based on the strength of their relevance to these objectives.

5.8.2.2.1 Criteria elaborating on relevance to sustainable transport

By linking the indicator selection process to key objectives of the given sustainable transport system, it is ensured that the resulting indicators will be well founded, and that the indicators’ relationship to the context-specific interpretation of sustainable transport will be well established and credible.

As a result of the broadness and varying interpretations of the concept of sustainable transport, numerous objectives can be suggested in any given context. Examples of objectives that have been suggested in the literature and practice were shown
previously in Table 2-1. That was not an exhaustive list however, and it is plausible that additional objectives may be proposed. Indeed, the application of the indicators may themselves illuminate gaps and priority areas which may identify or necessitate re-stating or redefinition of the sustainable transport objectives in a given context.

In view of the fact that different interpretations and therefore different objectives of sustainable transport will exist in different applications and context, a key feature of ELASTIC is that it is not prescriptive in its specification of sustainable transport objectives. Logically, they will have to reflect a reasonable interpretation of transport sustainability. However, ELASTIC allows the context to determine the choice of objectives. As such, and unlike the methodological criteria, no definitive sustainable transport objectives are prescribed by ELASTIC.

5.8.3 The value tree: Diagram of the ELASTIC hierarchy

Once the goal, sub-goals and criteria of the ELASTIC framework have been defined, the full complement can be shown diagrammatically. The ELASTIC value tree is a graphical and hierarchical representation of the goal, sub-goals and criteria in a given indicator selection problem. The competing indicators are not included in the value tree. Instead, the value tree forms the basis on which they are evaluated. A generic ELASTIC value tree is shown in Figure 5-3 below.

Figure 5-3: A generic ELASTIC value tree
The value tree presents a useful visualisation of the decision problem and can illuminate various factors about the full complement of goals and criteria (Keeney and Raiffa 1976, Buede 1986, Keeney 1992, Goodwin and Wright 1998). Pertinent issues about the sub-goals and criteria that can be illuminated by a value tree include;

- **Completeness**: If the tree is complete, all the criteria that are of concern to the decision-maker would have been included.

- **Operationality**: This criterion is met when all the lowest-level attributes in the tree are specific enough for the decision maker to evaluate and compare them for different options.

- **Decomposability**: This criterion requires that performance of an option on one criterion can be judged independently of its performance on another.

- **Redundancy**: If two attributes duplicate each other because they actually represent the same thing, then one of those attributes is clearly redundant.

- **Size of the tree**: The larger the tree, the more difficult it is to analyse it.

As will be demonstrated in subsequent chapters, ‘completeness’ can only be truly ascertained by thoroughly interrogating the tree with a view to confirming that the variety of issues influencing sustainability have been adequately reflected. However, the ELASTIC value tree provides a valuable preliminary indication of ‘completeness’ by enabling simultaneous viewing of the various issues and criteria in a single graphical representation.

### 5.9 Weighting the sub-goals and criteria

Specification and population of the goal hierarchy is fundamental to the ELASTIC framework and sets the stage for the ensuing analysis which ultimately culminates in identification and selection of the suite of indicators collectively known as the Transport Sustainability Profile (TSP).
While the populated goal hierarchy clearly displays the goals and criteria on which eventual indicator evaluation will be based, specification of these goals and criteria alone cannot unilaterally guide the indicator selection process. This is due to the need to take consideration of two important tenets of the ELASTIC framework, namely:

1. **The need for participation**

2. **The context-specificity of sustainable transport assessment**

### 5.9.1 The need for participation

Active participation and inclusion of relevant stakeholders in the decision-making process is a key principle of sustainability and sustainable transport planning (Innis and Booher 2000, Szyliowicz 2003). Therefore, in compiling an indicator set it is necessary to involve stakeholders in the development and selection process.

The various benefits of involving stakeholders in the assessment process have previously been discussed in Chapter three and include the fact that multiple groups are better suited to address the broad issue of sustainability, and the fact that involvement of stakeholders enhances their sense of ownership of the indicator set.

Once the goals and criteria have been specified therefore, a key element of ELASTIC’s subsequent processes is to ensure that the views of relevant stakeholders and interest groups are included in the analysis. This is ensured, as will be discussed later, by enabling them to prioritise and express preferences among the various goals and criteria in the ELASTIC value tree.

### 5.9.2 The context-specificity of sustainable transport

The fact that different localities and stakeholders will interpret sustainable transport differently which will then be reflected by varying objectives for sustainable transport, has been previously discussed. Additionally, after having chosen a given set of objectives, different localities and stakeholders will also have different priorities among the sub-goals and criteria according to their particular circumstances (Minken
Therefore, given the context-specific nature of sustainable transport, not only should the set of goals and criteria be chosen to reflect the specific nuances of the area to which they applied, but the different levels of emphasis given to sub-goals and criteria must also be illuminated (Cocklin 1995, Gustavson et al 1999).

In recognition of the need to adequately reflect context, the subsequent ELASTIC processes also seek, *inter alia*, to illuminate the relative importance of the various components of the value tree based on the priorities assigned to its different components by stakeholders in the context in which the indicators are to be applied.

5.9.3 **Participatory weighting of the value tree's components**

To ensure adequate participation of stakeholders and that the context-specific nature of sustainable transport is captured, a mechanism is needed which enables the different sub-goals and criteria in the value tree to be prioritised in a way that takes due consideration of the local context and which is based on stakeholders' values. The approach of the ELASTIC framework is to derive context-specific 'weights of importance' for the various sub-goals and criteria. A weight in this context is a numeric value assigned to a sub-goal or criterion that indicates its importance to achieving the overall goal, relative to other sub-goals and criteria in the value tree. Among other things therefore, the numeric weights allow the trade-off between the various ELASTIC sub-goals and criteria to be ascertained.

Logically, to meet ELASTIC's key tenets, any technique used to derive weights for the various sub-goals and criteria in the value tree, must be able to:

- *Reflect the context in which the assessment is being undertaken*;
- *Incorporate and reflect the values of key stakeholders*;
- *Ultimately enable the evaluation and selection of indicators*.
5.10 Weighting techniques in Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) provides numerous techniques for derivation of weights for competing elements in any context. In this regard, MCDA techniques can therefore be useful for derivation of numeric weights of importance for the various sub-goals and criteria in the ELASTIC value tree. Invariably however, some MCDA techniques will meet the ELASTIC requirement for flexibility and stakeholder participation better than others. Several potential MCDA weighting techniques and their suitability to ELASTIC are examined below. Eventually, a preferred ELASTIC approach is identified and the choice adequately justified.

5.10.1 The 'Fixed Point Scoring' weighting method

This weighting method proceeds by first assigning a fixed number of points, such as 100, 10 or any other number. A decision-maker is then required to distribute these points among the different criteria that are being weighted (Easton 1973). The rationale for allocation is simple; the more points a criterion receives the greater its relative importance. Assigning 0 points to a criterion is equivalent to ignoring it and conversely, assigning 100 points to one criterion is equivalent to ignoring all other criteria but that one. Individual criterion ratings can be normalised so that all weights sum to 1, by dividing the points allocated to a criterion by the maximum number in the scale. An example of normalisation for a scale with a maximum of 100 points is shown in Equation 5-1 below.

\[ w_j = \frac{r_j}{100} \]

**Equation 5-1**

Where:
- \( w_j \) is the normalised weight (ranging in value from 0 to 1) for criterion \( j \);
- \( r_j \) is the fixed score (a number between 0 – 100) assigned to criterion \( j \).

A key advantage of a fixed point scoring system is that it forces the decision makers to make trade-offs in a decision problem. As such, fixed point scoring is the most direct means of obtaining weighting information from the decision maker. Moreover, it requires minimal amount of operations and calculations to transform the fixed-point score supplied by decision maker into a vector of weights.
A major disadvantage of fixed-point scoring however, is that those required to assign the weights may find making the trade-offs difficult. Fixed point scoring requires one to directly ascribe higher importance to one criterion by lowering the importance of another. This requires careful and precise consideration of the relative importance of each criterion (Zeleny 1974). Another related disadvantage of the fixed-scoring method is that when used in group settings, convergence and agreement of individual weights and ranks may be impossible (Barron and Barret 1996). Moreover, this method lacks a sound theoretical foundation and its practicality is limited to a small number of criteria.

5.10.2 Graphical weighting method

With the graphical weighting technique, the decision maker is required to indicate preferences utilising visual scales. The preferences expressed on these scales ultimately forms the basis for derivation of quantitative weights. There are many variations of the graphical weighting technique. One of the most popular approaches is to require the decision maker to place a mark on horizontal lines reflecting the competing criteria as shown in Figure 5-4 below. The importance of a criterion increases as the mark is placed closer to the right end of the line. A quantitative score is calculated by measuring the distance from the mark to the left of the line. The scores are then normalised to derive a vector of criteria weights.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Less Important -------- More important</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-4: Graphical weighting example

The advantage of this method lies in its obvious simplicity. It enables decision makers and stakeholders to express preferences in an easily understandable graphical manner. However, this method also presents a difficult problem to the decision maker in demarcating useful trade-offs. Moreover, as with the fixed point scoring approach, the graphical weighting technique is unsupported by any formal theoretical underpinnings.
5.10.3 Ranking methods of weighting

As the name implies, ‘ranking methods’ require the decision maker to rank the criteria in order of importance reflecting his or her preferences. Once the criteria have been arranged in some order, the ranks are then converted to numeric weights. Stillwell et al (1981) have proposed several procedures for converting rank-order information into numeric weights. Three of these procedures are presented below.

The **Rank Sum** method derives weights by applying the following formula;

\[ w_i = \frac{n - R_i + 1}{\sum_{j=1}^{n} (n - R_j + 1)} \]  \hspace{1cm} \text{Equation 5-2}

Where: \( w_i \) is the normalised weight (ranging in value from 0 to 1) for the criterion \( i \);
\( n \) is the number of criteria under consideration;
\( R_i \) is the rank position of criterion \( i \).

The **Rank Reciprocal** procedure computes weights from the normalised reciprocals of a criterion’s rank using the formula in Equation 5-3 below:

\[ w_i = \frac{1/R_i}{\sum_{j=1}^{n} (1/R_j)} \]  \hspace{1cm} \text{Equation 5-3}

Where: \( w_i \) is the normalised weight of criterion \( i \);
\( R_i \) is the rank for the \( i \)th criterion.

The **Rank Exponent Method** requires the decision maker to specify the weight of the most important criterion on a 0-1 scale. This weight is entered into equation 5-4 below.

\[ w_i = \frac{(n - R_i + 1)^z}{\sum_{j=1}^{n} (n - R_j + 1)^z} \]  \hspace{1cm} \text{Equation 5-4}

The value of \( z \) can be derived through an iterative procedure. Once \( z \) is determined, weights for the remaining criteria can be calculated. When \( z = 0 \), all weights will be equal; and when \( z = 1 \), the method becomes the same as the ‘rank sum’ procedure.
Advantages and Disadvantages of Ranking
The ranking approach to deriving criterion weights is attractive due to its simplicity. In practice however, the number of criteria present in most MCDA applications limits the practicality of using ranks. The larger the number of criteria the more difficult it is to reliably order them (Voogd 1983). Ranking techniques have also been criticised for lack of adequate theoretical foundations (Kleindorfer et al 1993).

5.10.4 Swing-weighting approach
The swing weighting technique assigns numerical weights to criteria by assessing the desirability of a criterion relative to other criteria (Von Winterfeldt and Edwards 1986). The decision maker is first asked which of the criteria he would improve if all criteria were at an equal, poor performing point. The criterion with the biggest swing in preference from 0 to 100 is identified. This criterion is then assigned a score of 100, and becomes the standard against which all other criteria are judged.

Once this criterion is chosen, all other criteria are assessed one at a time, by comparing the swing to the swing in the 'standard' criterion. For example, if the second criterion is judged to represent 80 percent of the swing value of the standard criterion, it is assigned a score of 80. The process is continued for all other criteria.

\[
\begin{array}{c|c|c}
\text{Criterion 1} & \text{Criterion 2} & \text{Criterion 3} \\
\hline
100 & \text{Best} & \text{Best} \\
85 & \text{Best} & \text{Worse} \\
0 & \text{Worse} & \text{Worse}
\end{array}
\]

**Figure 5-5: Derivation of swing weights for a set of criteria**

In the example above for example, the swing from the worst to the best position for criterion 2 is considered to be 85% as important as the swing of criteria 1, so, it is given a score of 85. Similarly, a swing from the worst to best position for criterion 3 is considered to be 75% as important as a swing in criterion 1, so criterion 3 is given a score of 75. Numeric weights are derived by normalising these percentage scores.
5.10.5 The problems with the above approaches

The weighting mechanisms discussed above suffer from several common shortfalls. A primary concern is the fact that none of them are based on robust theoretical foundations (Kleindorfer et al. 1993). Similarly, they all require the decision maker to make direct comparison of the differing criteria either by applying swing preferences, graphical marks, ranking or scores. Zeleny (1974) has argued that attempting to extract information regarding preferences by directly questioning the decision maker is an innately defective process as humans are inherently incapable of processing the relevant information about all criteria into stable weights. This difficulty is exacerbated as the number of criteria increases. Moreover, as there is no structured process to guide any of the above techniques, it is not infeasible that application of the respective procedure may vary from one application to the next. Such absence of a defined process also limits the auditability of the results of these methods. Finally, as suggested by Barron and Barret (996), methods that directly elicit weights are unsuited for group decision making as forging some agreement and balancing the conflicts among the different weightings is often impossible.

5.11 Analytic Hierarchy Process: ELASTIC weighting approach

To be effective, ELASTIC will necessarily have to adopt a weighting technique that alleviates the problems with the above methods, particularly the pervasive absence of robust theoretical underpinnings. The Analytic Hierarchy Process was deemed to be appropriate for this purpose.

Originally devised by Saaty (1980), the Analytic Hierarchy Process (AHP) is a systematic and theoretically-grounded method for deriving relative weights of importance (or priorities) for a set of criteria, objectives or indeed, any set of alternatives. Weights are not assigned directly as in the methods described in section 5-10 above. Instead, AHP converts the subjective individual comparisons of criteria into ratio-scale weights that can then be aggregated across all relevant individuals to provide group-weights for the criteria (Forman and Gass 2001). Among other things, this non-direct weighting approach enables the incorporation of data, experience, insight and intuition in a logical and methodological manner. AHP is therefore well suited to the analysis of the complex concept of sustainability as it allows the
incorporation of both objective and subjective considerations into the decision making process (Forman and Selly 2002). Due to these positive attributes, AHP has been widely applied to solution of complex problems across a wide spectrum of areas and sectors. Some of the areas to which AHP has been applied are shown in Table 5-1.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Application</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Environmental Planning</td>
<td><strong>Energy and environmental management</strong></td>
<td>Bose and Anandalingam, 1999</td>
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<td></td>
<td><strong>Design of renewable power systems</strong></td>
<td>Chedid et al, 1998</td>
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<td></td>
<td><strong>Decision support for energy conservation</strong></td>
<td>Kablan, 2004</td>
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<tr>
<td></td>
<td><strong>Environmental Impact Assessment</strong></td>
<td>Solnes, 2003</td>
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<td></td>
<td><strong>Water Resource Planning</strong></td>
<td>Willet and Sharda, 1991</td>
</tr>
<tr>
<td>Transport</td>
<td><strong>Planning transport fuel use</strong></td>
<td>Poh and Ang, 1999</td>
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<td></td>
<td><strong>Predicting alternative transport fuel use</strong></td>
<td>Winebrake and Creswick, 2003</td>
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<tr>
<td></td>
<td><strong>Regulating on marine freight loads</strong></td>
<td>Yang and Perakis, 2004</td>
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<td></td>
<td><strong>Evaluating rail transit strategies</strong></td>
<td>Gerçek et al, 2004</td>
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<td><strong>Evaluating transport projects</strong></td>
<td>Ferrari, 2003</td>
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<td></td>
<td><strong>Traffic planning for earthquakes</strong></td>
<td>Modarres and Zarei, 2002</td>
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<tr>
<td>Economic modelling and</td>
<td><strong>Forecasting the economic resurgence</strong></td>
<td>Blair et al, 2002</td>
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<td>forecasting</td>
<td><strong>Budget planning in the Public Sector</strong></td>
<td>Greenberg and Thomas, 1994</td>
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<td><strong>Costing</strong></td>
<td>Partovi, 1991</td>
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<td></td>
<td><strong>Forecasting Foreign exchange rates</strong></td>
<td>Blair et al, 1987</td>
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<td></td>
<td><strong>Analysing international trade</strong></td>
<td>Saaty and Cho, 2001</td>
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<td>Product Selection</td>
<td><strong>Computer selection</strong></td>
<td>Moshe, 1993</td>
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<td><strong>Selection of alternative mission architecture for space exploration</strong></td>
<td>Tavana, 2004</td>
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<td><strong>Selection of catering services</strong></td>
<td>Kahraman et al, 2004</td>
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<td><strong>Selection of financial instruments</strong></td>
<td>Meziani and Rezvani, 1990</td>
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<tr>
<td>Facilities and systems</td>
<td><strong>Planning facility layout</strong></td>
<td>Partovi and Burton, 1992</td>
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<tr>
<td>Planning</td>
<td><strong>Planning nuclear facilities and plants</strong></td>
<td>Zio et al, 2003</td>
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<td></td>
<td><strong>Assessing designs Mechanical Engineering</strong></td>
<td>Pedrycz, 1992</td>
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<td><strong>Comparing livable cities</strong></td>
<td>Saaty, 1986a</td>
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<tr>
<td></td>
<td><strong>Promoting participatory health care</strong></td>
<td>Singpurwalla et al, 1999</td>
</tr>
</tbody>
</table>

Table 5-1: Examples of applications of the Analytical Hierarchy Process
5.11.1 The AHP procedure

Essentially, AHP provides a method for converting subjective assessments of relative importance into a set of overall scores or weights. Once the decision problem has been decomposed and the ELASTIC value tree developed therefore, the application of AHP proceeds in two broad stages as described below.

i. Elicitation of comparative judgments: This stage involves the construction of pairwise comparisons for all combinations of elements at the various levels of the ELASTIC value tree, with respect to their importance to achieving the goal or sub-goals in the levels above.

ii. Synthesis of priorities: In this stage, the subjective comparisons made above are used to derive numerical weights reflecting the relative importance of the various sub-goals and criteria in the ELASTIC value tree.

5.11.1.1 Eliciting of comparative judgments

Cognitive psychological studies have shown that human beings perform poorly at assimilating and processing large quantities of information. AHP therefore attempts to minimise the strain on human capabilities by only requiring the individual to compare two elements at a time. This is done through a systematic series of pairwise comparisons of the sub-goals and criteria. To enable the comparisons, AHP proceeds by taking two criteria, for example criteria $C_i$ and $C_j$, and asking two questions:

a) Which of the two criteria is more important to meeting the higher-level goal?

b) How much or how many more times is said criterion more important relative to the lesser important criterion?

There is obviously a wide spectrum of possible answers to the second question above. Using cognitive experiments and psychological analysis, Saaty (1980) has delineated the possible answers into a nine-point semantic scale reflecting a range of strength of preference from "about the same" to "extremely more important". Furthermore, Saaty also codified these qualitative descriptions of strength of preferences into numeric intensities of importance as shown below in Table 5-2 below.
Chapter Five: A methodological framework for indicator-based sustainable transport assessment

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>The two criteria contribute equally to achieving the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Importance</td>
<td>Experience and judgement slightly favours one criterion over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgement strongly favours one criterion over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>A criterion is strongly favoured over another and its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one criterion over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>For compromise between the above values</td>
<td>Intermediate values that can be used to represent shades of judgement between the five basic assessments above.</td>
</tr>
</tbody>
</table>

Table 5-2: Saaty's codified semantic intensity scale for pairwise comparisons

5.11.2 Principles and Axioms of the Analytic Hierarchy Process

The AHP process is guided by four well defined axioms (Saaty 1986 b). To put the subsequent description of AHP’s synthesis of numeric weights into perspective, it is useful to first examine these axioms of AHP.

i) Reciprocal Judgments Axiom

Where, $P_c(C_1, C_2)$ is a paired comparison of criteria $C_1$ and $C_2$ with respect to their parent, sub-goal $B$, and representing how many times more criterion $C_1$ possesses a property than does criterion $C_2$; and

$P_c(C_2, C_1)$ is a paired comparison of criteria $C_2$ and $C_1$ with respect to their parent, sub-goal $B$, and representing how many times more criterion $C_2$ possesses a property than does criterion $C_1$;

Then; $P_c(C_2, C_1) = \frac{1}{P_c(C_1, C_2)}$

Therefore, if criterion $C_1$ is assigned one of the non-zero numbers in Table 5-2 above when compared with criterion $C_2$, then $C_2$ has the reciprocal value when compared with $C_1$. For example, if $C_1$ is felt to be ‘very strongly more important’ than $C_2$, and therefore assigned the number 7; then $\frac{1}{7}$ would be assigned to $C_2$ relative to $C_1$. 

100
ii) **Homogeneity Axiom**

This axiom states that the elements being compared should not differ significantly in the property being compared, as there will tend to be larger errors in judgment. When constructing a hierarchy of criteria or sub-goals therefore, one should endeavour to arrange related elements in homogeneous clusters so that they do not differ greatly.

iii) **Hierarchical or feedback dependent structure**

The weightings and rankings of elements in a hierarchy do not depend on lower level elements. Thus, while the preference for criteria is almost always dependent on the higher level sub-goals, the importance of sub-goals will not be dependent on the various criteria.

iv) **Rank Order Expectations**

Individuals who have reasons for their beliefs should make sure that their preferences are adequately represented for the decision outcome to match their expectations. The generality of AHP makes it applicable in a variety of ways. Adherence to this axiom prevents inappropriate applications.

### 5.11.3 Synthesis of priorities

When the outcomes of the pairwise comparisons are reflected using Saaty's numeric scale of intensities, a matrix of ratios, A, can be obtained showing the general relativities between criteria as reflected in the pairwise comparative judgements. As per Saaty's scale and the axiom of reciprocal judgements, the value assigned to a cell \((a_{ij})\) in this matrix of ratios will always be in the interval \([1/9, 9]\).

For example, let \(C_1, C_2, ..., C_n\) be a set of criteria, and the quantified judgements on a pair of criteria \(C_i, C_j\) are represented by an \(n\)-by-\(n\) matrix A as described above. If criterion \(C_i\) (row element) and criterion \(C_j\) (column element) are judged to be of equal importance, then \(a_{ij}\) (the value in the matrix at the intersection of row \(i\) and column \(j\)) will be 1. However, if \(C_j\) is judged to be 'strongly more important' than \(C_i\), then \(a_{ij}\) is set to 5 as per Saaty's scale in Table 5-2. On the other hand, if \(C_i\) is 'strongly more important' than \(C_j\), then \(a_{ij}\) is set to the reciprocal of the importance score (i.e., 1/5).
As each criterion is logically of equal importance to itself, the values entered into the diagonal cells of the matrix will always be equal to 1. Therefore, for a set of \( n \) elements in a matrix, one needs \( \left( n^2 - 1 \right)/2 \) comparisons since there are \( n \) 1’s in the diagonal cells for comparing elements with themselves and of the remaining judgements, half are reciprocals. An example of a matrix of ratios \( A \) derived from pairwise comparisons of a set of criteria, \( C_1, C_2, C_3, \ldots, C_n \), is shown below.

\[
A = \begin{pmatrix}
1 & a_{12} & a_{13} & \cdots & a_{1n} \\
a_{12}/a & 1 & a_{23} & \cdots & a_{2n} \\
a_{13}/a & a_{23}/a & 1 & \cdots & a_{3n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
a_{1n}/a & a_{2n}/a & a_{3n}/a & \cdots & 1
\end{pmatrix}
\]

Having recorded the quantified judgements on pairs \( (C_i, C_j) \) as numerical entries \( a_{ij} \) in the matrix \( A \), the next step is to assign to the \( n \) criteria, \( C_1, C_2, C_3, \ldots, C_n \), a set of numerical weights \( w_1, w_2, w_3, \ldots, w_n \) that 'reflect the recorded judgements'.

Intuitively, the ratios in matrix \( A \) derived from the various comparative judgements will reflect the perceived relative weights, \( w \)'s, of the \( n \) criteria. Thus the relationship between the weights \( w_j \) and the judgements \( a_{ij} \) can be given as;

\[
\frac{w_i}{w_j} = a_{ij} \quad \text{(for all } i, j = 1, 2, 3, \ldots, n)\]

Equation 5-5

The matrix \( A \) can therefore be re-formulated as;

\[
A = \begin{pmatrix}
w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\
w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\
w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n
\end{pmatrix}
\]
If it is assumed, as above, that the ratios of comparative judgements are inherently based on relative criteria weights, Saaty (1980) proposes that the vector of true scale weights, \( w \), can be recovered by using the following equation:

\[
\begin{pmatrix}
\frac{w_1}{w_1} & \frac{w_2}{w_1} & \frac{w_3}{w_2} & \cdots & \frac{w_n}{w_n} \\
\frac{w_2}{w_1} & \frac{w_2}{w_2} & \frac{w_3}{w_3} & \cdots & \frac{w_n}{w_n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
\frac{w_n}{w_1} & \frac{w_n}{w_2} & \frac{w_n}{w_3} & \cdots & \frac{w_n}{w_n}
\end{pmatrix}
\begin{pmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{pmatrix}
\begin{pmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{pmatrix}
= n
\]

Where \( A \) has been multiplied on the right by a vector of weights \( w \). The result of the multiplication is \( nw \). The problem of solving for the non zero solution to this set of equations is very common in engineering and physics and is known as an eigenvalue problem. Thus to recover the scale \( w \) from the matrix of ratios \( A \), one must solve the following eigenvalue problem:

\[
Aw = nw \quad \text{or} \quad (A - nI)w = 0 \quad \text{Equation 5-6}
\]

This a system of homogeneous linear equations. It has a non-trivial solution if and only if the determinant of \( A - nI \) vanishes. That is, \( n \) is an eigenvalue of \( A \). The solution to this set of equations is, in general found by solving an \( n \)th order equation for \( n \). Thus, in general, there can be up to \( n \) unique values for \( n \), with an associated \( w \) vector for each of the \( n \) values.

In this case however, the matrix \( A \) has a special form in that \( A \) has unit rank, since each row is a constant multiple of the first row. The rank of the unit matrix is 1, and thus all the eigenvalues of \( A \) are zero, except one. Since the sum of the eigenvalues of a matrix is equal to its trace, i.e., the sum of its diagonal elements, and in this case the trace of \( A \) is equal to \( n \), the size of the matrix.

Thus \( n \) is the principal eigenvalue of \( A \), and has a nonzero solution \( w \). The solution consists of positive entries and is unique within a multiplicative constant. It is the principal right eigenvector of \( A \).
To make \( w \) unique, one can normalise the entries by dividing by their sum. Since dividing two readings from a ratio scale results in an absolute number, normalisation transforms a ratio scale into an absolute number. Thus, given the comparison matrix, one can recover the original scale in relative terms. In this case, the solution is any column of \( A \) normalised. The matrix \( A \) has two relevant properties:

- It is reciprocal. The condition \( a_{ij} = 1/a_{ji} \) holds true;
- It is consistent. The entries satisfy the condition, \( a_{jk} = a_{ik}/a_{ij} \).

Thus the matrix can be constructed from a set of \( n \) elements which form a spanning tree across the rows and columns. If values from a standard scale are used to make the comparisons, the principal eigenvectors recovers these values in normalised form.

5.11.4 The presence of inconsistent judgements

In the general case, the precise value of \( w_i/w_j \) cannot be given, but instead only an estimate is obtained as a numerical value. For example, consider an estimate of these values by an expert who is assumed to make small perturbations of the ratio \( w_i/w_j \). This implies small perturbations of the eigenvalues.

The problem now becomes \( A'w' = \lambda_{\text{max}}w' \), where \( \lambda_{\text{max}} \) is the largest eigenvalue of \( A' \), and \( w' \) is its corresponding eigenvector.

The problem is now ascertaining how good the estimate of \( w \) is. Note that if \( w \) is obtained by solving \( A'w' = \lambda_{\text{max}}w' \), the matrix \( A \), whose entries are \( w_i/w_j \), is a consistent matrix. It is a consistent estimate of the matrix \( A' \). \( A' \) itself need not be consistent. In fact, the entries of \( A' \) need not even be transitive; i.e., \( C_1 \) may be preferred to \( C_2 \) and \( C_2 \) to \( C_3 \), but \( C_3 \) may be preferred to \( C_1 \).

There are several reasons suggest several reason why the values in the pairwise comparisons may be inconsistent (Saaty 1999, Forman and Selly 2002). Some of these reasons are shown in Box 5-3 below.
Clerical Error
When entering one or more judgments prior to analysis, i.e., into a computer, the wrong value may be erroneously entered.

Lack of Information
If the person whose judgements are being elicited has little or no information about the factors being compared, then judgments will tend to be random and high inconsistencies will result.

Lack of Concentration
Lack of concentration during the judgment process caused by fatigue or a lack of interest in the decision can also cause inconsistencies.

Inherent Inconsistency in the real world
The real world is rarely perfectly consistent and is sometimes fairly inconsistent due to random fluctuations, underlying causes, or a combination. Regardless of the reasons, real world inconsistencies will reflect themselves in judgments.

Inadequate model structure
A final cause of inconsistency is "inadequate" model structure. Lack of homogeneity within clusters, unrelatedness and sparseness can contribute to inconsistency due to the extreme judgments necessary.

Box 5-3: Some reasons for inconsistent judgements

5.11.5 Treatment of Inconsistency
AHP allows inconsistency, but provides a measure of the inconsistency for each set of judgments. This measure is an important by-product of the process of deriving priorities based on pairwise comparisons.

It turns out that $A'$ is consistent if and only if $\lambda_{\text{max}} = n$ and that it is always the case that $\lambda_{\text{max}} \geq n$ (Saaty 1977, Saaty 1986 b, Saaty 2000). The existence of the vector $w'$ with positive components and its uniqueness to within a multiplicative constant in the inconsistent case, is rigorously proven by using perturbation theory applied to the consistent case. Thus, $w'$ belongs to a ratio-scale.
Since small changes in $a_{ij}$ imply a small change in $\lambda_{\text{max}}$, the derivation of the latter from $n$ is a deviation from consistency and can be represented by $(\lambda_{\text{max}} - n)/(n - 1)$. This is referred to as the Consistency Index (C.I).

When the consistency has been calculated, the result is compared with those of the same index of a reciprocal matrix whose entries are randomly selected from Table 5-2 above. This index is called the Random Index (RI), and is obtained from an ensemble of reciprocal matrices whose entries are randomly selected from the 1–9 scale and their reciprocals. Thus for a matrix of order $n$, a number of matrices of the same order are randomly constructed and the CI $(\lambda_{\text{max}} - n)/(n - 1)$ computed for each. Table 5-3 shows the typical order $n$ of the matrices and the corresponding average RIs.

<table>
<thead>
<tr>
<th>Order of matrix ($n$)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Random Consistency Index (RI)</td>
<td>0</td>
<td>0</td>
<td>0.52</td>
<td>0.89</td>
<td>1.11</td>
<td>1.25</td>
<td>1.35</td>
<td>1.40</td>
<td>1.45</td>
<td>1.49</td>
</tr>
</tbody>
</table>

Table 5-3: The average Random Index per orders of matrices.

The ratio of CI to the average RI for the same order of matrix is called the Inconsistency ratio (IR). Saaty (1990) surmises that an IR of 0.10 (10%) or less is acceptable and is positive evidence of informed judgement.

5.11.6 Stakeholder participation and aggregation of weights

One of the many reasons why AHP is appropriate for the participatory approach at the core of ELASTIC, is that it enables the aggregation of individual judgements into a single overall group weighting. The application of ELASTIC will typically require elicitation of pairwise comparative judgements from a wide spectrum of individual stakeholders on the various sub-goals and criteria in the ELASTIC value tree. The greater the number of stakeholders and the wider the cross-section, the more participatory and therefore intuitively better the analysis. Once the pairwise comparisons have been undertaken therefore, AHP is applied and a set of weights for the various sub-goals and criteria are derived reflecting the specific values and preferences of each individual. To obtain a single set of overall group weights, the
individual weights then have to be aggregated. There are two philosophical approaches to aggregation within the context of AHP (Forman and Peniwati 1998).

i) **Aggregation of individual judgements:** In this case, the individual pairwise comparisons and ratios are combined into ‘aggregate comparisons’. This method is applicable when the analysis is not interested in individual preferences and biases. Therefore, it assumes that individuals have relinquished their own personal preferences and values, and are acting together in such a way that the group can be viewed as a new individual.

ii) **Aggregation of individual priorities:** This approach is applicable when an individual is taken to be acting in his or her own right, each with his or her own value system. As such, it is the resultant alternative priorities of the various individuals that are aggregated.

The participatory principle of ELASTIC seeks to ensure that the differing perspectives and values of individual stakeholders are entered into the analysis. It is not the intent that all these individuals should behave as one. Instead, the aim is for all of the individual judgements to each contribute to the determination of the overall weights. Consequently ELASTIC adopts the latter aggregation approach, that is, the weights and priorities reflecting the values of each individual are first determined and then mathematically aggregated across all stakeholders to derive overall weights.

5.0.1.1 **Mathematical aggregation of weights**

Any mathematical method that is applied to aggregate individual priorities, must take due consideration of the Pareto principle which states that:

- **Given two alternatives, A and B; if each member of a group of individuals prefers A to B, then the combined group must also prefer A to B.**

The pareto principle therefore seeks to ensure unanimity and agreement between individual judgement and the overall group weightings. Forman and Peniwati (1998) have shown that aggregation of individual priorities using the basic arithmetic mean procedure in Equation 5-7 below will satisfy the pareto principle.
\[ \bar{x} = \frac{\sum_{i=1}^{n} w_i}{n} \quad \text{Equation 5-7} \]

*Where:* \( \bar{x} \) is the mean weighting for the criterion under consideration; 
\( w_i \) is the weight given to the criterion by individual \( i \); 
\( n \) is the number of individuals in the sample.

The pareto principle is satisfied by Equation 5-7 since the following will hold true;

\[ \text{If} \quad a_i \geq b_i, \quad i = 1, 2, \ldots, n \quad \text{then,} \quad \frac{\sum_{i=1}^{n} a_i}{n} \geq \frac{\sum_{i=1}^{n} b_i}{n} \]

Given the suitability of the arithmetic mean for aggregating individual priorities, it is the mathematical approach for aggregation of individual weights used in ELASTIC.

**5.11.6.1 Consistency in aggregated priorities**

Xu (2000) has shown that where the set of judgement matrices \( A_1; A_2; \ldots, A_n \), by individuals in a group are of sufficient consistency, then the combined group matrix \( A \) will also be of sufficient consistency. Similarly, an aggregated priority matrix is of acceptable consistency (i.e., IR \( \leq 0.10 \)) under the condition that each individual \( A_i (i = 1, 2, \ldots, n) \) is of acceptable consistency.

Therefore, overall group consistency is assured if each individual member's judgement is consistent.

**5.11.6.2 Computational support—The Expert Choice software package**

As with any analytical technique, AHP is simplified considerably by use of computer software. Expert Choice is a popular dedicated AHP software package (www.expertchoice.com). It is developed by Expert Choice Inc., a company founded by Dr. Thomas Saaty himself and Dr. Ernest Forman, a Professor at George Washington University. Expert Choice is user friendly and simple to use. It enables the entering of judgments in either numerical, graphical, or verbal modes and has a menu driven interface that enables easy handling of otherwise difficult analysis. Among other things, the involvement of Dr Thomas Saaty assures its theoretical soundness and ensures an adequate breadth of useful features.
5.11.7 Advantage of AHP as ELASTIC's weighting approach

The underlying principles and characteristics of AHP render it preferable to other weighting techniques for use in ELASTIC. Some of these are examined below.

i. **Theoretical soundness**: AHP is based on the well-defined mathematical structure of consistent matrices and their associated right-eigenvector's ability to generate true or approximate weights (Mirkin 1979, Saaty 1980, 1990). These theoretical underpinnings of AHP have been 'proven' through numerous applications and validation experiments (Forman and Glass 2001).

ii. **The weights and priorities are not arbitrarily 'assigned'**: Unlike other techniques, AHP weights are not derived by direct and arbitrary assignment of scores. The ratio scale priorities or weights are obtained indirectly from the decision maker's judgments. This enhances reliability as has been shown by Goyal and Deshpande (2001) in an empirical comparison of various weight assignment techniques in Environmental Impact Assessment.

iii. **Illuminates a clear understanding of the trade-offs involved**: The use of pairwise comparisons illuminates the decision problem and enables a clear understanding of the trade-offs in the elements being compared. In empirical applications, AHP processes and techniques have been found to better elucidate and clarify the decision problem and help participants understand the trade-offs between the different criteria (Hajkowicz et al 2000).

iv. **Inconsistency Ratio**: AHP has a consistency test that can illuminate inconsistent judgements. Unlike other weighting techniques therefore, the analyst is given an indication of the consistency of the weights derived.

v. **Enables easy and efficacious judgements**: AHP elicits the pairwise judgements verbally, numerically or graphically. The minimal cognitive requirements have emboldened Forman and Gass (2001) to suggest, with perhaps some hyperbole, that in the 20 years of applying AHP, they were yet to meet anybody who had difficulties understanding AHP's questions.
5.11.8 Criticisms of AHP as a weighting method

Despite the above advantages of AHP however, a number of criticisms have been levied against the technique (see for example, French 1988, Goodwin and Wright 1998, etc.). The key criticisms are examined below.

i. **Inability to accommodate a large number of criteria:** For a set of *n* elements, AHP requires *n*(*n* - 1)/2 pairwise comparisons to be undertaken. Derivation of weights for a large number of attributes would therefore require vast amounts of time, effort and human resources. As such AHP is inappropriate when weights are required for a large number of elements.

This problem is irrelevant in the context of ELASTIC however, as the main purpose of the sub-goals and criteria is to bring precision to the definition of sustainable transport. As such a small number is always advantageous since a large number would perpetuate the vagueness surrounding the concept.

ii. **Rank reversal:** Introducing new elements in applications of AHP can reverse the relative ranking of original options. This 'rank reversal' phenomenon was first reported by Belton and Gear (1983) who surmised, *inter alia*, that such inconsistency is due to the fact that the relative values for all criteria are required to sum to one.

Saaty and Vargas (1984) rebutted that rank reversal is not only a desirable characteristic of AHP, but also reflective of reality since human preferences will be affected by the presence or absence of alternatives, which may be due either to changed ranges of options available, or to a realisation that a previously unrecognised criterion should be taken into consideration.

ELASTIC is intended to be a flexible tool which adequately captures context. Therefore if rankings and weightings of ELASTIC’s criteria change due to variation of the context in which they are being considered, then this would only contribute to ELASTIC’s flexibility. As such, the issue of ‘rank reversal’ is not considered a problem within this context.
iii. **Criteria are weighted separately from evaluation of alternatives:** AHP has been criticised by Stewart (1991) because it derives importance weights separately from evaluation of alternatives and as such expresses weights 'in the absence of context'. Forman and Gass (2001) argue however, that such separation is inherent in all weighting techniques.

Again, this perceived problem is irrelevant in the context of ELASTIC. As has been alluded earlier, a vast number of alternative indicators may be evaluated in any given context, and as such it will often be necessary to undertake the evaluation of the alternatives separately from the criteria and objectives weighting process. Indeed, it may even be the case that evaluation and weighting will be undertaken by different groups of individuals. Given that weighting and evaluation are inherently separate in ELASTIC, the fact that AHP also separates the two therefore has no adverse effects at all.

### 5.12 Scoring the performance of indicators on the criteria

Once the weights for the various components of the value tree have been derived, the next stage in the ELASTIC process is to evaluate the performance of the long list of indicators against the various criteria. This is done through the derivation of a vector of outcome scores, $S^a$, for each indicator $a$. This vector is made up of a set of outcome scores such that $S^a = s^a_1, s^a_2, ..., s^a_n$, where $n$ is the number of criteria and $s^a_j$ is a score representing the performance outcome of indicator $a$ on criterion $j$.

Key to this stage of the ELASTIC framework therefore, is the derivation of these scores, $s^a_1, s^a_2, ..., s^a_n$ for each indicator, $a$, in the long list. In order to maximise objectivity and transparency, the ELASTIC process requires that these scores are obtained using a succinct, clear and easily decipherable scoring process.

Numerous techniques exist for deriving such scores of performance. Indeed, in addition to calculating weights for the criteria, all the methods described earlier in this chapter can theoretically be used for deriving scores for evaluating the performance of indicators on the various ELASTIC criteria.
As has been mentioned previously however, many of these weighting methods require inordinate resources and effort where the number of alternatives is large. Given that the ELASTIC methodology may be used to select a subset from initial indicator sets of large sizes, a sufficiently flexible, conducive and easily applicable performance scoring mechanism is required.

5.12.1 Direct Rating - The Elastic performance scoring approach

The ELASTIC approach is to utilise a ‘direct rating’ technique to obtain outcome scores reflecting the performance of indicators on the lowest-level criteria in the value tree. As the name implies, direct rating techniques derive outcome scores by the direct assignment of a number to each indicator from a defined scale (Von Winterfeldt and Edwards 1986, Nijkamp et al 1990). The numerical value assigned represents the level and degree of an indicator’s performance on the specified criterion.

To score indicator performance, ELASTIC utilises a 5-point likert scale, with indicator performance improving with ascending numbers as shown in Table 5-4.

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Performance (0 = extremely poor, 4 = Outstanding)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator 1</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>Indicator 2</td>
<td>0 1 2 3 4</td>
</tr>
<tr>
<td>Indicator 3</td>
<td>0 1 2 3 4</td>
</tr>
</tbody>
</table>

Table 5-4: Example of direct rating entries for evaluating indicators on a criterion

The assigned numeric values are then normalised to derive evaluative outcome scores depicting indicator performance, using the equation below.

\[
\text{Normalised outcome score} = \left( \frac{\text{Basic numeric value}}{\text{Sum of all likert scores in category}} \right) \times 100
\]

The ease and simplicity of direct rating makes it perfect for a situation such as is likely in ELASTIC, where there may be numerous alternatives to be evaluated.
5.0.1.2 The role of the Analyst in evaluating indicator performance

While the general approach to the ELASTIC framework is a participatory one, the scoring of indicators will have to be undertaken by an Analyst, or a team of Analysts. This is necessary for a number of reasons, some of which are discussed below:

1. The sheer number of indicators:
   As the aim of ELASTIC is to select a small suite of indicators from a potentially large set, the number of indicators that require scoring may be large. A full scoring process would require \( n \times m \) entries to be made; where \( n \) is the number of indicators and \( m \) is the number of criteria.

   This could be a very demanding analytical task and it would be unreasonable to require stakeholders to undertake such.

2. The technical demands of indicator scoring:
   The technical demands of indicator performance evaluation impose constraints on participation. Lay members of the public will not typically have the expertise to score individual indicators against criteria nor have access to data and information necessary to undertake the scoring. This problem is compounded further by the inherent complexity of the concept of sustainable transport.

To overcome the above problems as well as minimising subjectivity and any biases that may arise, indicators in the application of ELASTIC will typically be scored by an Analyst or a team of Analysts. As stated before, ELASTIC requires that the methods and approaches used in evaluation and assignment of scores are unambiguous, clear, transparent and auditable.

The 5-point likert scoring system must therefore be supplemented by mechanisms that aid auditability. Such mechanisms could, for example, take the form of narrative text to give meaning and to justify the numeric performance scores assigned.
5.13 Numerical aggregation and preliminary selection

Once weights have been derived for the various sub-goals and criteria in the value tree, and outcome scores assigned to each indicator based on its performance on the criteria, these measures can then be aggregated to derive an overall weighted measure of an indicator's performance. It is these overall weighted measures that will then guide the indicator selection process. There are various methods available for such numerical aggregation (Triantaphyllou 2000 provides an elaborate discussion of these techniques). The approach taken in the ELASTIC framework is to use the Simple Additive Weighting (SAW) model to aggregate the weights and outcome scores.

5.13.1 Simple Additive weighting (SAW) Model

Also known as the weighted sum model, weighted linear combination, or weighted scoring method, the basis of the simple additive weighting (SAW) is that if there are \(m\) alternatives and \(n\) criteria, then the best alternative is the one that has the highest total weighted sum score (Triantaphyllou 2000). Due to its simplicity, the SAW method is probably the best known and most widely used MCDA method and is deemed to be a reliable and useful technique (Triantaphyllou 2000). Despite its simplicity, Hwang and Yoon (1981) have observed that the 'theory, simulation computations, and experience all suggest that the SAW method yields extremely close approximations to very much more complicated non-linear forms, while remaining far easier to use and understand'.

The method is governed by the assumption of additive utility. That is, the overall performance score of each alternative is equal to the sum of the products of the relevant criteria weights and scores. Within the ELASTIC context therefore, SAW is used to derive an overall Weighted Indicator Performance Score (WIPS) for each indicator, \(a\), in the initial large set of assembled indicators, \(A\). The Weighted Indicator Performance Score (WIPS) is computed by multiplying the importance weight of the \(k\)th sub-goal, \(g_k\), by the importance weight of the \(j\)th criterion, \(w_j\), multiplying the product by the normalised outcome score of indicator \(a\) on criterion \(j\), \(s_j^a\), and then summing across all criteria, \(n\). This can be written formally as:
\[ WIPS_a = \sum_{j=1}^{n} s_j^a (g_{k} w_j) \quad \text{for all } j = 1, 2, 3, \ldots, n \text{ and } k = 1, 2 \]  \hspace{1cm} \text{Equation 5-8}

**Where:**
- \( WIPS_a \) is the overall weighted performance score of indicator \( a \);
- \( g_k \) is the importance weight of sub-goal \( k \);
- \( w_j \) is the importance weight of criterion \( j \);
- \( s_j^a \) is the normalised outcome score for indicator \( a \) on criterion \( j \).

### 5.13.2 Selection of a preliminary subset of indicators

When the normalised values of the indicator outcome performance scores are used in the analysis, all alternative indicators in the assembled large set will record a WIPS somewhere in the range of 0 to 100. Logically, the higher the WIPS, the better the performance of the indicator. The aim of the ELASTIC framework is therefore:

\[ WIPS_a = \max_{a} \sum_{j=1}^{n} s_j^a (g_{k} w_j), \quad \text{for all } a = 1, 2, 3, \ldots, m \]  \hspace{1cm} \text{Equation 5-9}

Using Equations 5-8 and 5-9, an initial subset of indicators can be obtained by selecting a defined number of indicators with the highest WIPS values. The intuitive ELASTIC approach is to select an initial subset of the top \( \approx 20 \) best performing indicators. However, the exact number initially selected will depend on the context and on the original number of indicators in the full assembled indicator set.

### 5.14 Sensitivity Analysis

ELASTIC, like all other models and frameworks, is only a representation of a process. It is not the exact replica of the system, as simplifications, such as in the formulation of the value tree, have been necessary in order to make the model operational. Simplifications are useful as they enable the operational description of an otherwise complex problem (Braat and van Lierop 1987). However, simplifications also introduce some risk that essential elements and mechanisms of the real world process may not be adequately captured. This difficulty becomes even more acute when the issue under consideration is as complex and broad as sustainable transport.
Another inherent problem of models, is the potential for unintentional errors. Despite the best efforts to ensure the highest level of robustness in the various ELASTIC procedures for example, it is not unfeasible that stakeholders' statements about preference between criteria, as well as the scoring of indicators by the Analysts, could both be subject to cognitive limitations and inherent biases.

While the magnitude of these effects may vary, for the sake of prudence, it is always required that some method is included in any methodological analysis to explore the effects of such inevitable uncertainties on the process and outcomes.

Sensitivity analysis is a useful technique for evaluating a model's performance and robustness. Essentially, sensitivity analysis examines the extent to which variation occurs in the model outcomes when input parameters are systematically varied over some range of interest, either individually or in combination. The purpose of sensitivity analysis is not necessarily to arrive at a different recommendation but rather to provide greater confidence and a more secure basis on which to make recommendations and decisions (Qureshi et al 1999, Jessop 2004).

In the context of ELASTIC therefore, sensitivity analysis is necessary to examine how robust the preliminary selected subset of indicators are to changes in ELASTIC's inputs. The ultimate aim is to choose from the preliminary subset, an even smaller suite of those indicators that consistently perform the best under a variety of differing circumstances and with varied model inputs.

### 5.14.1 Sensitivity analysis methods

Numerous methods exist for conducting sensitivity analysis. Saltelli et al (2000) classify the various methods into two broad categories:

- **i. Local sensitivity analysis methods**
  
  Methods for local sensitivity analysis seek to evaluate the changes in the model outputs caused by variation of a single input parameter $x_i$ when all other $x_j, j \neq i$, are kept constant. Local methods are therefore not applicable when the aim of the analysis is to compare the effect of various input factors on the outputs.
ii. Global sensitivity analysis methods

Global sensitivity analysis methods vary all the input parameters simultaneously and as such, sensitivity is measured over the entire range of input variables. Stated more formally, global sensitivity analysis evaluates the effect on the output caused by variation of $x_i$ when all other $x_j, j \neq i$, are varied as well.

Within the context of ELASTIC, two categories of input variables will require varying during sensitivity analysis. These are (i) the weights attached to the various sub-goals and criteria, and (ii) the performance outcome scores assigned to indicators. Given the fact that each category will itself be made up of several variables, the unsuitability of local sensitivity methods that only consider changes in one model input is obvious. The ELASTIC framework therefore utilises global sensitivity analysis methods.

5.14.2 Monte Carlo Simulation

Monte Carlo simulation provides a useful tool for global sensitivity analysis and is the approach used in ELASTIC. Monte Carlo simulation uses probabilistic numerical methods to gain insight into the behaviour of complex random process (Render and Stair 1991). Essentially, the method utilises probabilistic simulation to undertake multiple random evaluations of a given model. The idea is to imitate various real world situations mathematically, study the resultant properties and characteristics, and then draw conclusions (Render and Stair 1991). One of the major advantages of monte carlo simulation therefore, is that numerous 'possible' scenarios can be generated without actually conducting physical experiments (Ossenbruggen 1994). As a consequence of the fact that it allows simultaneous varying of multiple weights and outcome scores, monte carlo simulation techniques have seen increasing application for sensitivity analysis in MCDA problems (see for example, Butler et al 1997, Levary and Wan 1998, Suslick and Furtado 2001).

5.14.3 Monte Carlo Simulation procedure in ELASTIC

The Monte Carlo simulation process applied in the Sensitivity Analysis module of ELASTIC is summarised graphically in Figure 5-6 below. The stages are described in greater detail in the subsequent sub-sections.
As can be seen in Figure 5-6 above, the sensitivity analysis module in ELASTIC involves four broad stages, namely:

i) Selection of ranges and distributions for each input variable, \( x_i \);

ii) Generation of a sample from the ranges and distributions specified in (i);

iii) Evaluation of the model for each indicator in the preliminary selection;

iv) Re-ranking and selection of the best performing indicators.

Figure 5-6: ELASTIC Monte Carlo Simulation – based Sensitivity Analysis algorithm
### 5.14.3.1 Selection of ranges and distribution for each input variable

Numerous types of probability distributions exist. Some of the most common, as well as a brief description of each, are shown in Table 5-5 below. Evans *et al* (2000) provides a more detailed description of a wider selection of distributions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta Distribution</td>
<td>The Beta distribution is used to determine the probability of the occurrence of an event, given a number of trials ( n ) have been made with a number of recorded successes.</td>
</tr>
<tr>
<td>Binomial Distribution</td>
<td>Shows the number of success from ( n ) trials where there is a probability ( p ) of successes in each trial.</td>
</tr>
<tr>
<td>Discrete Distribution</td>
<td>This is a general type of function often used to describe a variable that can take one of several explicit discrete values.</td>
</tr>
<tr>
<td>Exponential distribution</td>
<td>Describes the time between occurrences of an event that is purely random with constant probability per unit time of occurrence.</td>
</tr>
<tr>
<td>Gamma Distribution</td>
<td>Models the time required for ( \alpha ) events to occur, where the events occur randomly in a Poisson process with a mean time between events of ( \beta ).</td>
</tr>
<tr>
<td>Normal Distribution</td>
<td>The normal distribution occurs in a wide variety of applications due, in part, to the central limit theorem. It is frequently observed that variations of a naturally occurring variable will be normally distributed.</td>
</tr>
<tr>
<td>Pareto Distribution</td>
<td>Used to model a variable that has a minimum, but also most likely, value and for which the probability density decreases geometrically towards zero.</td>
</tr>
<tr>
<td>Poisson Distribution</td>
<td>Models the number of occurrences of an event in time ( T ) when the time between events follow a Poisson process. If ( \beta ) is the mean time between events, as used by the exponential distribution, then ( \lambda = T/\beta ).</td>
</tr>
<tr>
<td>Triang Distribution</td>
<td>The Triang distribution is used as a rough modelling tool where the range (( a ) to ( c )) and the most likely value within the range (( b )) can be estimated. The Triang distribution offers considerable flexibility in its shape and the parameters are easy to define and conceptualise.</td>
</tr>
<tr>
<td>Uniform Distribution</td>
<td>The uniform distribution is used as a very approximate model when no (or little) data is available.</td>
</tr>
<tr>
<td>Weibull Distribution</td>
<td>Is used to model the time until occurrence of an event where the probability of occurrence changes with time.</td>
</tr>
</tbody>
</table>

*Table 5-5: Selection of probability distributions and their most common applications*

Saltelli *et al* (2000) has shown that sensitivity analysis generally depends more on the selected ranges than on the assigned distributions. Therefore, in the absence of previous information about the statistical distributions of the input variables, a crude characterisation may be adequate, especially if the analysis is primarily explanatory.

In this regard, two types of distributions are assumed for the two categories of numeric inputs into the ELASTIC framework, namely:
1. Normal Distribution for the sub-goals and criteria weights

The normal distribution is the most applied statistical distribution. This is a direct result of the Central Limit Theorem which at its simplest, states that the mean $\mu$ of a population of independent observations under certain general conditions, will tend to approximate a normal distribution. Since the weights allocated to the sub-goals and criteria are based on the aggregation of many independent and random individual weights, a normal distribution is assumed.

The normal distribution is characterised by two parameters; the mean $\mu$, which is the average, and the standard deviation $\sigma$, which is a measure of spread. In ELASTIC, the sample mean $\bar{x}$ is the weight of the criterion, derived from aggregating individual stakeholder weights. The sample standard deviation, $SD$, is easily obtained as a by-product of the weight averaging process.

2. Triang distribution for the indicator performance outcome scores:

As shown in Table 5-5, the triang distribution follows a triangular arrangement, where the distribution is bounded by a range ($a$ to $c$) representing the absolute 'minimum' and 'maximum' values for the simulation, and a defined ($b$), representing the 'most likely' value within that range.

In the context of ELASTIC therefore, a triang distribution can be defined by setting the outcome score assigned to the indicator by the Analyst during the previous evaluation stage, as the most likely value ($b$), and then specifying the scores one-point below and above on the likert scale, as the minimum ($a$) and maximum value ($c$) values respectively.

Logically, for the triang distribution, the following rules must apply:

- The minimum value must be less than or equal to the most likely value.
- The most likely value must be less than or equal to the maximum value.
- The minimum value must be less than the maximum value.
5.14.3.2 Generation of a sample of numbers

The second step in monte carlo analysis involves the generation of a sample of numbers from the distributions developed in the previous stage. Various sampling methods exist, of which the most popular are Random sampling, Stratified sampling and Latin Hypercube sampling techniques (Vose 1996, Saltelli 2000).

Random Sampling

In random sampling, a sample \((X_1, X_2, X_3, \ldots, X_n)\) is generated from the joint distribution of the input variables or, when these are independent, from their marginal distributions. From a statistical point of view, random sampling has a clear advantage in that it produces unbiased estimates of the mean and variance.

Stratified Sampling

The purpose of stratified sampling is to achieve a better coverage of the sample space of the input factors. For example, let the sample space \(S\) of the input vector \(X\) be partitioned into \(I\) disjoint strata, \(S_1, \ldots, S_I\). The size of \(S_i, I = 1, \ldots, I\), is represented as the probability that \(X\) is an element of \(S_i\), that is, \(p_i = P(X \in S_i)\). A random sample \(X_h, h = 1, \ldots, n_i\), is then obtained from \(S_i\) where \(\sum_{i=1}^{I} n_i = N\). In particular, when \(I = 1\), the result is a random sample over the entire sample space.

Latin hypercube Sampling

Latin hypercube sampling may be considered to be a particular type of stratified sampling. For each input factor \(X_j, j = 1, \ldots, k\), is divided into \(N\) intervals of equal marginal probability \(1/N\), and one observation of each input factor is made in each interval. One of the realisations on \(X_I\) is randomly selected (each observation is equally likely to be selected), matched with a randomly selected realisation on \(X_2\), and so on, to get \(X_I\). These collectively constitute the first sample, \(x_I\). One of the remaining realisations on \(X_I\) is then matched at random with one of the remaining observations on \(X_2\), and so on, to get \(X_2\). A similar procedure is followed for \(X_3, \ldots, X_N\), which exhausts the observation and results in a Latin hypercube sample. The method has the advantage over the other two techniques of ensuring that the input factor has all portions of its distributions represented by input values (Vose 1996).
5.14.3.3 Evaluation of the model

The third step in the Sensitivity Analysis is the simulated evaluation of the ELASTIC simple additive weighting (SAW) model for each of the indicators in the preliminary suite. The inputs into the SAW model are the mean simulated sub-goal and criteria weights and outcome scores derived after \( m \) monte carlo simulation runs as shown in the diagrammatic representation of the ELASTIC sensitivity analysis algorithm in Figure 5-6. ELASTIC does not prescribe the number, \( m \), of simulation runs that will have to undertaken. This will depend on the software and resources available. However, the number of simulations will have to be sufficiently large to enable the drawing of reasonable assumptions from the simulated weights and outcome scores.

5.15 Derivation of the Transport Sustainability Profile

Entering the mean weights and outcome scores from the simulation runs into the SAW model will, in some cases, result in new Weighted Indicator performance Scores (WIPS) for the preliminarily selected indicators. By ranking these indicators based on the newly derived WIPS, it will then be possible to select a smaller suite of the most stable and best performing indicators from the previously selected preliminary subset of indicators. The number of indicators to be carried forward is not specified by ELASTIC. It is recommended however, that no more than the 15 best performing and most stable indicators should be carried forward. The exact number will again depend on the context, the target audience and the available resources.

It is this final subset of \( \approx 15 \) indicators selected after sensitivity analysis that is taken to make up the Transport Sustainability Profile (TSP), an un-aggregated and small suite of sustainable transport indicators which when presented simultaneously can provide a picture of the sustainability of a transport system.

5.16 Summary

This chapter described ELASTIC, a robust methodological framework for selection of a small suite of key sustainable transport indicators. ELASTIC is based on the application of Multi-Criteria Decision Analysis (MCDA) and is therefore systematic, hierarchical, communicable and clearly shows the logic and processes underlying the
Chapter Five: A methodological framework for indicator-based sustainable transport assessment

selection of indicators and the weights, scores and factors that determine their selection. Among other things, MCDA is designed to take explicitly into account multiple and usually conflicting objectives in supporting the decision process. ELASTIC is also participatory and enables the direct involvement of stakeholders in the weighting of the various sub-goals and criteria which set the overarching framework for selection of the indicators. As such, the process, the categories of data and information that are included, and the choice of specific indicators, all reflect the values, biases, interests, and insights of the stakeholders in the area where the assessment is being applied.

The sub-goal and criteria weights derived from the judgements of stakeholders and the scores allocated by the Analysts to each indicator are aggregated using a Simple Additive Weighting (SAW) model, to derive a Weighted Indicator Performance Score (WIPS) for each indicator. These WIPS are then used to select a preliminary suite of indicators. To ensure that only the most consistently best performing indicators are carried forward however, sensitivity analysis is undertaken to test the robustness of the performance of indicators in the preliminary suite, and to identify from amongst them, an even smaller subset of those indicators that perform the best after $m$ number of monte carlo simulation runs. It is these indicators, found to be robust and which perform consistently well even after sensitivity analysis, that are taken to form the Transport Sustainability profile (TSP), an unaggregated suite of key indicators, the main output of the ELASTIC framework.
6.0 Overview

This chapter seeks to demonstrate the ELASTIC framework by describing an application to the England, UK. A brief descriptive background is first provided about the UK sustainability planning and policy-making context, after which the suitability of the ELASTIC framework within that context is ascertained. The application of ELASTIC and the attendant inputs into the process are then described in detail.

6.1 Introduction

UK policymaking and planning generally follows a three-tiered structure. National policy typically sets the overarching framework for regional policy, which in turn influences local planning and decision making. Figure 6-1 below shows how these different tiers relate to each other in the context of sustainable development and sustainable transport policy making and planning in the UK.

<table>
<thead>
<tr>
<th>Sustainable Development Policy Making</th>
<th>Sustainable Transport Policy Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>National Transport Planning and Monitoring</td>
</tr>
<tr>
<td></td>
<td>Regional Transport Planning and Monitoring</td>
</tr>
<tr>
<td>Regional development Planning and Monitoring</td>
<td>Local Transport Policy and Monitoring</td>
</tr>
<tr>
<td>Local development Policy and Monitoring</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-1: Planning and policy-making structure for sustainability in the UK
As has been stated in the previous chapters, and as is evident from Figure 6-1 above, analysis of sustainable transport cannot be undertaken in isolation from the broader concept of sustainable development. To provide an adequate background and context for the application of ELASTIC to England therefore, a review is first conducted of the UK policy and assessment processes for the broader concept of sustainable development. This is then followed by a similar and more specific review of relevant sustainable transport planning and assessment mechanisms at each tier of the UK’s policy-making framework.

Once this background and policy review is concluded, the application of the ELASTIC framework to England UK, and the attendant inputs, are then described.

6.2 The UK national sustainable development policy context

The current context for sustainable development policy and decision making in the UK is set by ‘A better quality of life’, the UK’s sustainable development strategy (DETR 1999 a). Among other things, the strategy sets four key aims for UK sustainable development policy. These four aims are shown in Box 6-1 below.

<table>
<thead>
<tr>
<th>Social Progress that recognises the needs of everyone</th>
</tr>
</thead>
<tbody>
<tr>
<td>The key premise of this objective is that everyone should share the benefits of increased prosperity and be able to enjoy a safe and clean environment.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effective protection of the environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>This aim seeks to limit global environmental threats, and to enhance safety and good human health by minimising hazards such as poor air quality.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prudent use of natural resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>This aim advocates efficient use of natural resources and the development of alternatives where such natural resources are consumed by human use.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maintenance of high levels of economic growth and employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>The key concern of this objective is that economic growth should be achieved in a way that enables everyone to share in high living standards and greater job opportunities.</td>
</tr>
</tbody>
</table>

Box 6-1: Aims of the UK sustainable development strategy
6.2.1 Indicators as preferred assessment and monitoring tools

Key to the UK sustainable development strategy was the recognition that planning for sustainability requires identification of priorities and aims, and measures of whether such aims are being achieved. The strategy therefore emphasised the need for sustainability monitoring and assessment mechanisms that are flexible enough to cope with the fact that over time, 'sustainable development priorities are likely to change', and which enable 'involvement of all stakeholders in a transparent reporting system' (Para. 10.12). Indicators were explicitly identified as the preferred sustainability measurement and monitoring tools. Suggestions of an 'overall index' were dismissed due to the inherent problems of determining the 'choice of components and weightings' and 'the difficulty of interpreting a combined index' (Para. 3.9).

6.2.2 Assessing sustainable development on a national level

To assess sustainable development on a national level, two categories of indicators were proposed in the strategy, namely *Headline Indicators* and *Core Indicators*.

**Headline Indicators**

Intended to provide a high level overview of the UK’s achievement of a 'better quality of life for everyone', headline indicators are top-tier indicators that reflect the achievement of the key objectives of the strategy. The headline indicators as proposed in the strategy are shown in Table 6-1 below.

<table>
<thead>
<tr>
<th>Sub-objectives</th>
<th>Headline indicator</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintaining high and stable levels of economic growth and employment</td>
<td>Total output of the economy (GDP) and GDP per head</td>
<td>H1</td>
</tr>
<tr>
<td></td>
<td>Total investment as a percentage of GDP</td>
<td>H2</td>
</tr>
<tr>
<td></td>
<td>Percentage of people of working age who are in work</td>
<td>H3</td>
</tr>
<tr>
<td>Social progress which recognises the needs of everyone</td>
<td>Success in tackling poverty and social exclusion</td>
<td>H4</td>
</tr>
<tr>
<td></td>
<td>Educational qualifications at age 19</td>
<td>H5</td>
</tr>
<tr>
<td></td>
<td>Expected years of healthy life</td>
<td>H6</td>
</tr>
<tr>
<td></td>
<td>Homes judged unfit to live in</td>
<td>H7</td>
</tr>
<tr>
<td></td>
<td>Levels of crime</td>
<td>H8</td>
</tr>
<tr>
<td>Effective Protection of the Environment</td>
<td>Emissions of greenhouse gases</td>
<td>H9</td>
</tr>
<tr>
<td></td>
<td>Number of days air pollution is moderate or higher</td>
<td>H10</td>
</tr>
<tr>
<td></td>
<td>Road traffic</td>
<td>H11</td>
</tr>
<tr>
<td></td>
<td>Rivers of good or fair quality</td>
<td>H12</td>
</tr>
<tr>
<td></td>
<td>Populations of wild birds</td>
<td>H13</td>
</tr>
<tr>
<td></td>
<td>New homes built on previously developed land</td>
<td>H14</td>
</tr>
<tr>
<td></td>
<td>Waste arising and waste management</td>
<td>H15</td>
</tr>
</tbody>
</table>

Table 6-1: Headline indicators proposed in the UK sustainable development strategy
The 15 key headline indicators specified above are intended 'to move in the right direction over time, or where a satisfactory level has been reached, to prevent a reversal' (Para. 3.7). Since 2000, the UK Government has published yearly reports on progress against each of the headline indicators, where data is available, for the English Regions in the annual publication, ‘Regional quality of life counts’.

**Core Indicators**

The headline indicators are overarching in scope and therefore relatively broad. To provide more precise measures of performance therefore, the headline indicators are supplemented by a substantially larger set of narrower focused 'core' indicators. The core indicators reflect specific issues and are therefore intended to provide a more comprehensive assessment of national progress towards sustainable development than that provided by the headline indicators.

Unlike the Headline indicators, the set of 150 core indicators are compiled at five-year intervals and have been published twice since the national strategy in the form of ‘Quality of Life Counts: Indicators for a strategy for sustainable development for the United Kingdom’ (DETR 1999 b) and its 2004 update (DEFRA and ONS 2004).

### 6.3 The regional sustainable development policy context

The headline and core indicators specified above are intended for application at the national level and are typically led by central government. The English regions, while guided by the overarching national framework, are faced with circumstances different to national ones, and as such require sustainability policy and monitoring frameworks appropriate to their needs.

#### 6.3.1 Regional Sustainable Development Frameworks

'Regional Sustainable Development Frameworks' represent the key mechanism in the 1999 UK Sustainable Development Strategy for implementation of its policies at the regional level (Para. 7.81). The main role of these high level non-statutory strategic documents is to identify regional needs and priorities and generally to set a vision for sustainable development in the regional context.
Monitoring Regional Sustainable Development Frameworks

The 'Guidance on Preparing Regional Sustainable Development Frameworks' (DETR 2000 b) emphasises the need for regular monitoring and review. Particularly, in developing the RSDF, the guidance mandates the adoption of a wide range of indicators relevant to the region and specific regional issues, but set within the context of national themes. While the guidance encourages inclusion where data is available, of the headline indicators, there is greater emphasis on the need to adopt indicators that are most appropriate to the region’s specific circumstances and priorities.

6.3.2 Regional Spatial Strategies

The UK Planning and Compulsory Purchase Act 2004 received Royal Assent on 13 May 2004, and came into force across the UK on 28 September 2004 (HMSO 2004). Part 1 of the Act places a statutory requirement on regional planning bodies to produce a Regional Spatial Strategy (RSS) which replaces the previous Regional Planning Guidance (DETR 2000 c). The purpose of the RSS is to articulate a strategic spatial framework for a region and to set priorities for the environment, transport, infrastructure, economic development and other spatial issues. Of relevance to this study is the fact that section 39 (2) of the Act mandates that the RSS should be developed with the objective of contributing to sustainable development.

Monitoring Regional Spatial Strategies

Among the stipulations of the Act is a requirement for the Regional Planning Body (RPB) to submit an annual monitoring report to the Secretary of State, the aim of which is to show whether the strategy is achieving its aims. In developing an RSS therefore, the RPB is required to show that it has established a monitoring and review mechanism. Draft Planning Policy Statement 11: Regional Planning (ODPM 2003 a) emphasises the need for appropriate indicators to enable such monitoring.

6.4 Sustainable Development planning at the local level

The local level, while falling under the general auspices of both national and regional policy making, is faced with its own circumstances. Consequently, provision is made within the UK planning structure for local sustainability planning and assessment.
6.4.1 Community Strategies

Part I of the Local Government Act 2000 placed on principal Local Authorities a duty to prepare 'Community Strategies', the overall aim of which is to enhance the sustainability and quality of life of local communities by providing a vision of goals, arrangements and actions to improve its inhabitants' quality of life (DETR 2000 d).

Monitoring community strategies

The Government's guidance on preparation of Community Strategies (DETR 2000 d) made clear the need for 'monitoring the implementation of the action plan, for periodically reviewing the community strategy, and for reporting progress to local communities'. Given the participatory nature of Community Strategies, the guidance also emphasised that such monitoring should involve local partners and the wider community. In particular, Local Authorities are encouraged to identify indicators relevant to their local circumstances and needs from a menu of 29 indicators of sustainable development published in 'Local Quality of Life Counts'(DETR 2000 e).

6.4.2 Local Development Frameworks

Part 2 of the Planning and Compulsory Purchase Act 2004 provides for the preparation of a portfolio of local development documents which together set the platform for the expression and delivery of spatial planning at the local level. This portfolio is collectively referred to as the 'Local Development Framework' and replaces the previous Local Plans, Unitary Development plans and Structure plans (DETR 2000 f). Among other things, the Act specifies that the Local Development Framework must be in general conformity with the RSS, and should also act as the spatial complement to the community strategy.

Monitoring the Local Development Framework

Part 2 (35) of the Planning and Compulsory purchase Act 2004 places a statutory requirement on Local Planning Authorities to prepare an Annual Monitoring Report to show how the authority is performing against all relevant targets. Draft Planning Policy Statement 12 - Local Development Frameworks (ODPM 2003 b) stipulates that such monitoring should be guided by indicators in an objective-led framework that establishes transparent links between objectives and related indicators.
6.5 The UK national transport policy context

For the most part, current UK transport policy emanates from the 1998 Government White Paper A New Deal for Transport: Better for Everyone (DETR 1998). The White Paper had the expressed aim of formulating a long term strategy to deliver sustainable transport and in so doing set five objectives for transport in the UK as shown in the Box 6-2 below.

- Environmental Impact: To protect the built and natural environment.
- Safety: To improve safety.
- Economy: To support sustainable economic activity and get good value for money.
- Accessibility: To improve access to facilities for those without a car and to reduce severance.
- Integration: To ensure that all decisions are taken in the context of the Government's integrated transport policy.

Box 6-2: Overarching objectives for UK transport policy set by the 1998 White Paper

To achieve the objectives above, the White Paper set out a wide range of measures and policies with a view that they could contribute to the sustainability of the UK transport system.

Since 1998, various other strategy documents have been developed and published by the UK Government to deliver the priorities identified in the Integrated Transport white paper. Key among these are the 'The 10 Year Plan for Transport' published in July 2000 which sets out the UK Government's strategy for modernising the transport network to provide an integrated system (DETR 2000 g), and the 'The Future of Transport' White Paper which extended and built upon the 10 year plan to cover the next 30 years (DfT 2004 a). Some of the general principles of the White Paper have also been integrated into the development planning process through Planning Policy Guidance 13: Transport which has the stated objective of integrating planning and transport at the national, regional, strategic and local level with a view to promoting more sustainable transport choices for people and freight (DETR 2001).
6.5.1 Regional Transport Strategies

Although described in this section for obvious convenience, Regional Transport Strategies (RTS) are actually components of the previously discussed Regional Spatial Strategies (RSS). The RTS sets out the delivery of national transport policies and programmes in the regions, outlines the transport and related land-use policies and measures required to support the RSS, and provides a long term vision for transport in the region (ODPM 2003 a). The preparation of the RTS is an integral part of the RSS process as it (the RTS) plays a key role in providing better integration between transport and spatial planning which is fundamental to delivering more sustainable travel patterns (DfT and ODPM 2003).

Monitoring Regional Transport Strategies

Given that Regional Transport Strategies were also required as part of the now defunct Regional Planning Guidance (DETR 2000 c), detailed guidance on how to monitor the regional Transport Strategy have previously been set out in Monitoring Regional Planning Guidance: Good Practice Guidance on Targets and Indicators (ODPM 2002). The guidance is explicit in its requirement that the RTS is monitored within a robust analytical framework comprised, inter alia, of targets and indicators that are clearly linked to its key objectives and policies.

6.5.2 Local Transport Plans

Local Transport Plans are the key mechanism through which the wide-ranging measures and action proposed in the 1998 White Paper are implemented on a local level. All local authorities in England, with the exception of the London Boroughs, are mandated by the Transport Act (2000) to produce and implement an LTP, which is a comprehensive integrated transport strategy that covers all forms of surface transport at the local level (DETR 2000 h).

In producing an LTP, local authorities are encouraged to set their own objectives and targets, according to local priorities and circumstances, providing they reflect national themes. Specifically, LTPs are required to be built on objectives consistent with the 1998 White Paper's overarching objectives for transport shown in Box 6-2 above.
Monitoring and assessing local transport plans
Under the provisions in the Transport Act (2000), local authorities are required to monitor LTPs and keep them under review. In this regard, the Government’s ‘Guidance on Full Transport Plans’ (DETR 2000) specifies that LTPs must include a comprehensive but focused set of indicators for measuring performance and to assess whether the LTP is delivering its stated objectives. To assist Local Authorities in identifying indicators for inclusion in the Annual Progress Reports, the government annually publishes guidance in the form of ‘How to monitor indicators in local transport plans and annual progress reports’. Two categories of indicators have been suggested in the 2004 version of the guidance, namely a small set of ‘Core Indicators’ and a larger menu of ‘Performance Indicators’ (DfT 2004).

Core Indicators
Eight ‘core’ indicators are proposed in the 2004 edition of the guidance on monitoring LTPs. These indicators were taken to reflect national priorities and as such, all Local Authorities are required to report against them where applicable. These core indicators are shown in Table 6-2 below.

<table>
<thead>
<tr>
<th>Area</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road Maintenance</td>
<td>Road Condition</td>
</tr>
<tr>
<td>Public transport – bus</td>
<td>Number of bus passenger journeys</td>
</tr>
<tr>
<td></td>
<td>Bus passenger satisfaction</td>
</tr>
<tr>
<td>Cycling</td>
<td>Number of cycling trips</td>
</tr>
<tr>
<td>Road safety</td>
<td>Number of killed or seriously injured (all ages)</td>
</tr>
<tr>
<td></td>
<td>Number of children killed or seriously injured</td>
</tr>
<tr>
<td>Light Rail</td>
<td>Light rail passenger journeys</td>
</tr>
<tr>
<td>Accessibility</td>
<td>% of households within 13 minutes walk of an hourly or better bus service</td>
</tr>
</tbody>
</table>

Table 6-2: Core indicators proposed in the 2004 guidance on indicators for LTPs

Menu of Non Core Performance Indicators
In addition to the core indicators above, the guidance also suggests a larger menu of ‘performance’ indicators which are intended to reflect those indicators most commonly used across local authorities. Authorities are not expected to report against all of these indicators, but are encouraged to use those that are most appropriate to their circumstances and which are most relevant to their priorities.
6.6 Application of ELASTIC to the UK context

From the foregoing sections of this chapter, it will be clear by now that indicators are integral to the UK's sustainable development and sustainable transport assessment processes. It is also clear that there is an overwhelming requirement, in some cases statutory, for derivation of sustainable transport indicators not only within the specific sustainable transport planning context, but also in broader sustainability assessment. A mechanism that enables selection of key sustainable transport indicators would therefore be useful in the UK context.

The ELASTIC framework described in Chapter five of this thesis, provides a robust methodological approach for derivation of an appropriate suite of sustainable transport indicators, in a way that incorporates stakeholder values and reflects the specific context to which they are applied. Given these attributes, ELASTIC can be a useful tool for derivation of sustainable transport indicators in the UK context. The roles that ELASTIC might be able to play within the UK policy and planning contexts are summarised in Table 6-3 below.

<table>
<thead>
<tr>
<th>Policy</th>
<th>Indicator based assessment</th>
<th>Role for ELASTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable Development Strategy</td>
<td>✔</td>
<td>Selection of a set of key sustainable transport indicators to inform the 'Road Transport' headline indicator.</td>
</tr>
<tr>
<td>Regional Sustainable Development Frameworks</td>
<td>✔</td>
<td>Selection of sustainable transport indicators to assess sustainability of the regional transport system.</td>
</tr>
<tr>
<td>Regional Spatial Strategies</td>
<td>✔</td>
<td>Selection of a set of key sustainable transport indicators to inform the success of the RTS.</td>
</tr>
<tr>
<td>Local Development Frameworks</td>
<td>✔</td>
<td>Selection of sustainable transport indicators to assess contribution of transport to local sustainability.</td>
</tr>
<tr>
<td>Community Strategies</td>
<td>✔</td>
<td>Selection of key sustainable transport indicators to assess transport's contribution to quality of life.</td>
</tr>
<tr>
<td>White Paper on Transport/PPG 13</td>
<td>✔</td>
<td>Selection of a set of key sustainable transport to assess the sustainability of the national transport system.</td>
</tr>
<tr>
<td>Regional transport Strategies</td>
<td>✔</td>
<td>Selection of a set of key sustainable transport indicators to assess whether the RTS is achieving its aims.</td>
</tr>
<tr>
<td>Local transport Plans</td>
<td>✔</td>
<td>Selection of sustainable transport indicators for inclusion in the Annual Performance Reports.</td>
</tr>
</tbody>
</table>

Table 6-3: Roles for ELASTIC in the UK Planning and policy-making context
6.7 England as a national platform for application

England is the largest and the most populous of the four countries which together make up the United Kingdom. As a result of its size and population, legislation passed by the UK Government tends to have most direct applicability to England. The legislative and administrative separation has become even more evident since three key pieces of legislation, The Scotland Act 1998, The Government of Wales Act 1998 and The Northern Ireland Act 1998, which each gave differing degrees of home-rule to the other three countries that make up the UK, namely Scotland, Wales and Northern Ireland respectively. As a result of these and other legislation, these three countries now have a form of devolved government consisting of legislative and executive branches (Burrows 2000).

Due to this administrative devolution, Scotland, Wales and Northern Ireland are empowered to deliver policies and legislation which reflect the individual country’s circumstances. This includes legislation and policy for sustainable development. Consequently, most of the legislation and assessment frameworks reviewed in the previous sections of this chapter have most direct applicability to England.

Given the previously shown relevance of ELASTIC to the various UK legislation and policies (see Table 6-3), and the fact that these laws and strategies have most direct relevance to the English context, the ELASTIC framework is demonstrated in this thesis by applying it to England, UK.

6.8 Applying ELASTIC to England

It will be recalled from Chapter five that there are generally three inputs required for application of the ELASTIC framework, namely;

1. A long list of potential sustainable transport indicators.
2. A hierarchy of sub-goals and criteria for evaluation of the indicators.
3. An interest group whose values are entered into ELASTIC’s processes.

The choices and use of the inputs and the way they are entered into the application of ELASTIC to England, are described in the sub-sections below.
6.8.1 The initial long list of indicators

Inherent to ELASTIC's processes is the requirement for an initial long list of potential sustainable transport indicators from which a suitable subset would then be subsequently derived. For the purposes of this study, two sources were deemed useful for assembling the initial long indicator list, namely:

i. The literature on sustainable transport indicators initiatives and applications.

ii. The various indicators suggested for selective use within the UK sustainable development and sustainable transport planning contexts.

In the latter case, where the sources are broad sustainable development indicator sets, only those indicators relevant to transport are extracted and included in the long list.

Using the guiding principles above, a total of 200 suggested sustainable transport indicators were derived from the nine sources shown in Table 6-4 below.

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modelling for sustainable cities: The transport sector (Kupiszewska 1997)</td>
<td>32</td>
</tr>
<tr>
<td>Indicators for the integration of environmental concerns into transport policies (OECD 1999)</td>
<td>27</td>
</tr>
<tr>
<td>Indicators of transport and environment integration TERM 2002 (European Environmental Agency 2002)</td>
<td>38</td>
</tr>
<tr>
<td>Sustainable Transport Indicator Project, CST (Gilbert et al 2002)</td>
<td>14</td>
</tr>
<tr>
<td>The 'Civilising Cities' initiative (Jones et al 2003)</td>
<td>15</td>
</tr>
<tr>
<td>PROSPECTS Project's Methodological Guidebook (Minken et al 2003)</td>
<td>19</td>
</tr>
<tr>
<td>Quality of life counts (DETR 1999e)</td>
<td>35</td>
</tr>
<tr>
<td>Local Quality of Life Counts (DETR 2000)</td>
<td>12</td>
</tr>
<tr>
<td>How to monitor indicators in Local Transport Plans and Annual Progress Reports – 2004 Update (DfT 2004b)</td>
<td>8</td>
</tr>
</tbody>
</table>

Total number of Indicators 200

Table 6-4: Sources and number of indicators entered into the initial long list
6.8.2 Sub-goals and criteria for evaluation of Indicators

As discussed in Chapter five, ELASTIC systematically selects a small suite of sustainable transport indicators by evaluating alternatives in the long list against prescribed broad sub-goals. Two broad sub-goals are specified within the ELASTIC context, which together set a higher-level context for evaluation of indicators, namely;

i. Maximising the methodological quality of the indicators;

ii. Maximising the relevance of indicators to the concept of sustainable transport.

Because of their broadness, the ELASTIC process requires that these sub-goals are elaborated through more precise and measurable lower-level criteria.

6.8.2.1 Criteria to reflect the methodological quality of indicators

The literature is very clear about the methodological and analytical characteristics that are desirable of indicators (see for example, Anderson 1991, Meadows 1998, Jackson et al 2000, Pastille Project 2002). As already shown in Chapter five, in developing the ELASTIC Methodology, an effort has been made to summarise these desirable characteristics into the five key criteria shown in Box 6-3 below.

<table>
<thead>
<tr>
<th></th>
<th>Measurability: A sustainable transport indicator should be capable of being measured in a theoretically sound, dependable and easily understood manner.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ii)</td>
<td><strong>Ease of availability</strong>: It should be possible to easily and at a reasonable cost, collect reliable data on the indicator or calculate/predict the value of the indicator using accepted models.</td>
</tr>
<tr>
<td>iii)</td>
<td><strong>Speed of Availability</strong>: Data from which the indicator is derived or calculated should be regularly updated with a view to ensuring the shortest time lag possible between the state of affairs being measured and the indicator becoming available.</td>
</tr>
<tr>
<td>iv)</td>
<td><strong>Interpretability</strong>: An indicator and its calculation should yield clear, unambiguous information that is easily understandable to the target audience.</td>
</tr>
<tr>
<td>v)</td>
<td><strong>Transport’s Impact Isolatable</strong>: It should be possible to isolate transport’s share of the impact that the indicator is purporting to measure.</td>
</tr>
</tbody>
</table>

Box 6-3: Methodological criteria for evaluating indicators in the ELASTIC framework
These criteria are prescribed by ELASTIC and are not intended to be changed between applications, although as will be shown later, the level of importance assigned to each criterion will vary with context.

6.8.2.2 Criteria to reflect relevance to the concept of sustainable transport

As part of the study, a comprehensive review was undertaken of the various objectives of sustainable transport proposed in the literature and practice. As previously shown in Chapter two, it was found that the various suggested objectives of sustainable transport can be classified under five overarching objectives. These five overarching objectives, which are slight variations of the key objectives specified in the PROSPECTS project (May et al 2001), are shown again in Box 6-4 below, and are used in this application of ELASTIC as criteria to bring greater precision to the sub-goal ‘Maximising the relevance to the concept of sustainable transport’.

| i) Livable Streets and Neighbourhoods: A sustainable transport system should be designed and operated in a way that enhances the physical, aesthetic and other special characteristics of the area, such that it supports community identity and comfort and encourages social, cultural and recreational activity within the community. |
| ii) Protection of the Environment: A sustainable transport system should minimise natural resource consumption, ensure the preservation of vital habitats and reduce transport-related emissions and wastes that affect the global climate, biological diversity and the integrity of essential ecological processes. |
| iii) Equity and Social Inclusion: A sustainable transport system should contribute to both social and spatial equity by meeting the basic mobility needs of all social, economic and geographical groups, and providing them with access to a full range of facilities, services and activities. |
| iv) Health and Safety: A sustainable transport system should be designed and operated in a way that minimises hazards to health, the incidence and fear of transport-related crime, and the numbers, severity and risks of traffic accidents to all transport users. |
| v) Support of a Vibrant and Efficient Economy: A sustainable transport system should support a vibrant economy and contribute to economic growth while simultaneously supporting market mechanisms that promote fuller cost accounting which reflect the true social, economic and environmental costs of activities. |

Box 6-4: Objectives used to show relevance to sustainable transport
6.8.2.3 Appropriateness of the objectives to the UK context

The position is taken in this thesis that the overarching objectives shown in Box 6-4 above are well suited for use in the UK context as collectively, they fit well with the stated objectives of the UK 1999 Sustainable Development Strategy and the 1998 White Paper on Transport.

The fit of the key objectives of the two UK strategies above with the objectives used in this application of ELASTIC to England, is shown below in Table 6-5. As can be seen, there is clear compatibility between the five objectives utilised in the application and the objectives of the UK White Paper on Transport (DETR 1998) and the UK Sustainable Development Strategy (DETR 1999a).

<table>
<thead>
<tr>
<th>Relevant UK Strategy</th>
<th>Objectives used in the application of ELASTIC to the UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable Development Strategy</td>
<td>Livable Streets &amp; Neighbourhoods</td>
</tr>
<tr>
<td></td>
<td>- Protection of the Environment</td>
</tr>
<tr>
<td>White Paper on Transport</td>
<td>- Protect the Built and Natural Environment</td>
</tr>
</tbody>
</table>

Table 6-5: Compatibility of relevant UK policy objectives with the objectives used

6.9 Value Tree for the application of ELASTIC to England

Once the ELASTIC sub-goals have been decomposed into precise and measurable criteria, a value tree showing the full hierarchical complement of sub-goals and attendant criteria can then be derived to graphically show the inputs into the application of the framework.

Using the lower level criteria previously shown in Boxes 6-3 and 6-4, the value tree derived for this specific application of ELASTIC to England, UK is shown in Figure 6-2 below.
Figure 6-2: Value tree for the application of ELASTIC for selection of sustainable transport indicators for England, UK
6.10 Surveys of Interest Groups and Stakeholders

Once the ELASTIC value tree has been defined, the next stage in the ELASTIC process is the derivation of importance weights for the different components of the tree. As stated in Chapter five, the participatory tenet of ELASTIC demands that the sub-goals and criteria weightings are determined by the distributional judgements of relevant interest groups and stakeholders. The complement and number of stakeholders and stakeholder groups is not prescribed by ELASTIC, although intuitively, the greater the inclusiveness, the better the requirement for participation will be met. Logically however, the stakeholders whose judgements are elicited and reflected in the weights must have an interest in sustainable transport or be affected by the outcome of the assessment process.

In order to obtain the necessary sub-goal and criteria weights for this application, surveys were conducted to elicit distributional judgements from two groups of relevant transport specialists, namely (i) Transport Planners at English Municipal Councils and Authorities and (ii) Transport-related Academics at English universities.

6.10.1 Transport Planners at English Municipal Councils

UK municipal transport planners are required, among other things, to produce Local Transport Plans, which seek to design and implement transport strategies that best meet the needs of their localities. As previously shown in this chapter, a key theme of current transport planning in the UK is the integration of sustainability objectives. As such, the view is taken that that the judgements of these experts could provide a reliable and informed basis for weighting the ELASTIC sub-goals and criteria.

6.10.1.1 Identification of a sample

_The Municipal Yearbook_, published annually by Hemming Information Services, lists the key employees of all municipal authorities in England. The 2002 edition of the yearbook (Hemming Information Services 2002) was used as the source for identifying the Transport Planners whose judgements on the components of the value tree were then elicited through questionnaire surveys.
6.10.2 Transport-related Academics at English Universities

Sustainable transport, as a paradigm of transport planning, has made remarkable inroads into academia. This is evident for example, by the fact that various articles and special issues have been published by academic journals on the subject of sustainable transport (see for example, \textit{Transport Policy}, July 2000, Volume 7 Number 3; \textit{Municipal Engineer}, March 2002, Volume 151, Issue 1; \textit{International Social Science Journal}, June 2003, Volume 55, Issue 2). Moreover, the enhancement of transport sustainability is often cited as a motivation for transport research in the UK (see for example, Coleman 2000, Root 2001, Lyons and Harmon 2002, Dickinson \textit{et al} 2004, etc.). Given the current pervasiveness of sustainable transport in academia, the judgements of transport-related English Academics were viewed as being a useful platform for determination of importance weights for this application of ELASTIC.

6.10.2.1 Identification of a sample

The University Transport Studies Group (UTSG) conference is held annually and brings together Transport Academics from throughout the UK. In January 2003, the UTSG conference was hosted by the Transport Studies Group at Loughborough University. All attendees at this conference from English Universities were identified and subsequently surveyed to elicit their distributive judgements with regard to the various sub-goals and criteria in the ELASTIC value tree.

6.10.3 Survey 1: Methodological quality of indicators

The first round of surveys were conducted in two stages; that is (i) a survey of Transport Planners and (ii) a survey of Academics. The survey took the form of mail questionnaires specially designed to elicit information in the format required for applying the Analytic Hierarchy Process (AHP) - the ELASTIC weighting approach.

6.10.3.1 Pre-notification

Prior to the questionnaires being sent out, pre-notification emails and letters were sent out to inform identified prospective participants of the impending survey and requesting their cooperation. For Transport Planners, where the holder of the position of ‘Transport Planner’ was clearly shown in \textit{The Municipal Yearbook}, the pre-
notification letter was sent directly to that individual. In instances where the year book had not categorically specified the holder of the position, the pre-notification letter was sent to the Director of the department with responsibility for transport planning, asking for the department’s participation and requesting the Director to designate a subordinate to whom the questionnaire could be sent.

Where the Academics were concerned, the pre-notification emails and invitations to participate were sent directly to the individuals, as a list of the names and email addresses of conference attendees was included in the 2003 UTSG conference pack.

A generic version of the pre-notification letter sent to intended participants in the first set of surveys is shown at Appendix A1.

6.10.3.2 The Survey Process

Following the pre-notification, the questionnaires were sent by first class post to individuals who had not indicated an aversion to participating in the survey, or who were nominated by the Director of their departments (in the case of some Transport Planners). Each questionnaire was accompanied by a Cover Letter, a ‘Guide to completing the questionnaire’ and a stamped addressed envelope for return of the completed questionnaire. A generic version of the Cover Letter sent along with the first set of questionnaires is shown at Appendix A2.

6.10.3.3 The Guide to completing the questionnaire

Given the unorthodox design of the questionnaire and the fact that participants were being requested to express judgements about criteria that are open to various interpretations, it was necessary to include some mechanism to provide the participant with unambiguous definitions of the criteria under consideration, and also to provide guidance on how to complete the questionnaire. In this regard, a ‘Guide to completing the questionnaire’ was sent with every questionnaire. It clearly defined the methodological characteristics that participants were being asked to compare and also gave detailed guidance on how the questionnaire was to be completed. The ‘Guide to completing the questionnaire’ for the first round of surveys is shown at Appendix A3.
6.10.3.4 The Questionnaire

The questionnaire used in the first round of surveys was made up of two main sections. The first section elicited general information with regard to the background of the participant and his/her views on sustainable transport.

The second section of the questionnaire is where the distributional judgements of the participants were sought. In order to acquire data in a way amenable to analysis using the AHP method specified in the ELASTIC process, the participants were asked to make subjective pairwise comparisons between the five suggested methodological criteria that indicators should meet. An example of a pairwise comparison that the participants were asked to make is shown in Figure 6-3 below.

In deciding on an indicator of 'Sustainable Transport', which of the following criteria would you deem more important for indicator choice and how strongly? Please circle the appropriate number.

<table>
<thead>
<tr>
<th>Measurability</th>
<th>Speed of Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>9  8  7  6  5  4  3  2  1  2  3  4  5  6  7  8  9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-3: Example of a pairwise comparison that participants are required to make

Participants were requested to base their responses on the rating scale shown in Table 6-6 below, which is a modified version of Saaty’s (1980) scale. (This scale was given and described to participants in the accompanying ‘Guide to complete questionnaire’).

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Importance</td>
<td>The two criteria being compared are of equal importance to choosing a sustainable transport indicator</td>
</tr>
<tr>
<td>3</td>
<td>Moderate Importance</td>
<td>Experience and judgement slightly favours one criterion over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong Importance</td>
<td>Experience and judgement strongly favours one criterion over the other</td>
</tr>
<tr>
<td>7</td>
<td>Very Strong Importance</td>
<td>A criteria is favoured very strongly over the other</td>
</tr>
<tr>
<td>9</td>
<td>Overwhelmingly More Important</td>
<td>The evidence favouring one criteria over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values to represent shades of judgement between the five basic assessments above</td>
<td>There may be times when experience and judgement may not render one criteria comparable to another in accordance with the five scales above. Instead, a middle value between two scales may be more appropriate.</td>
</tr>
</tbody>
</table>

Table 6-6: The scale on which respondents were requested to base their judgements
A total of 57 questionnaires were sent to Transport Planners at select County Councils and Metropolitan Borough Councils throughout England. Similarly, 65 questionnaires were sent to transport-related Academics at various English Universities.

The questionnaire sent to Transport Planners in the first round of surveys is shown at Appendix A4. The slightly different version sent to Academics is at Appendix A5. Only the first sections of the two questionnaires, i.e., where background information were requested from the respondents, were different. Essentially, in this section Academics were asked about their research and attendant activities, while Transport Planners were asked questions that related more to their practical experiences.

6.10.4 Survey 2: Relevance to objectives of sustainable transport

As required by ELASTIC, it was also necessary to elicit stakeholder’ judgements to derive weights for the various objectives of sustainable transport used in this application. A second mail questionnaire survey process was used for this purpose.

6.10.4.1 Pre-notification

Pre-notification letters and emails were again sent out to all Transport Planners and Academics to whom pre-notification correspondence had been sent in the first survey, irrespective of whether they had agreed to participate in the survey or not. As in the first stage, the pre-notification email informed potential participants of the impending survey and asked for their cooperation. Those who did not want to participate were asked to indicate such by email or by telephone, while those who did not object to being sent the questionnaire were simply asked not to respond to the pre-notification. A generic version of the second pre-notification letter is shown at Appendix B1.

6.10.4.2 The Survey Process

Following the pre-notification process, the questionnaires were again sent by first class post to individuals who had not indicated an aversion to participating in the survey. As in the first survey, enclosed with each questionnaire was a Cover Letter, a stamped addressed envelope and a ‘Guide to completing the questionnaire’. A generic version of the second Cover Letter is shown at Appendix B2.
6.10.4.3 The Guide to completing the questionnaire

The ‘Guide to completing the questionnaire’ sent with the second questionnaire sought to minimise confusion in interpretations of the specified objectives of sustainable transport. As such, it clearly defined the five objectives that participants were being asked to compare and again gave detailed guidance to participants, using examples, on how to go about completing the questionnaire. This ‘Guide to completing the questionnaire’ used in the second survey is shown at Appendix B3.

6.10.4.4 The Questionnaire

This second questionnaire was divided into three sections. The first section elicited general information from the participants about their views on the sustainable transport decision-making process.

As before, the second section is where the pairwise comparisons of the various objectives of sustainable transport were presented. An example of a pairwise comparison that the participants were asked to make is shown in Figure 6-4 below.

<table>
<thead>
<tr>
<th>Health and Safety</th>
<th>1 2 3 4 5 6 7 8 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livable Streets &amp; Neighbourhoods</td>
<td>9 8 7 6 5 4 3 2 1</td>
</tr>
</tbody>
</table>

If you were seeking to assess the overall sustainability of a transport system based on its performance on given sustainability objectives, which of the following sustainable transport objectives would you deem more important to your decision, and how strongly so?

Please circle the appropriate number.

Figure 6-4: Example of a pairwise comparison given in the second survey stage

The key to the number rating is the same modification of Saaty’s (1980) scale that was previously shown in the Table 6-6 above, which was again given in the accompanying ‘Guide to completing the questionnaire’.

6.10.4.5 Appropriateness of respondents prioritising objectives

A key question in developing and applying the ELASTIC Methodology was whether it was indeed ethical to request that stakeholders prioritise amongst the various sustainable transport objectives.
Prioritising among sustainability objectives is fundamental to the flexibility of ELASTIC, and its expressed tenet of context-specificity. It will be recalled that this tenet was specified for ELASTIC due to the overwhelming support in the literature for the need to capture the differences in interpretation of sustainability by enabling stakeholders to prioritise amongst sustainability objectives based on their context. Shields et al (2002) for example, looked extensively at the role of 'values and objectives' in indicator-based sustainability assessment. Among other things, they recognised that 'different segments of the population will often hold differing, though legitimate, viewpoints about the relative importance of alternative sustainability goals'. Similarly, Schleicher-Tappeser and Strati (1999) and Gudmundsson (2003 a) in discussing the broadness and ambiguity of the concept of sustainability, argued that it should be shaped by sustainability goals, which should in turn reflect specific interpretations of sustainability.

It is these different, and indeed context-specific, interpretations of sustainability that ELASTIC is seeking to capture by requiring stakeholders to rank the issues in a way that reflects their given contexts.

On the more practical question of whether respondents are capable of making such comparisons, it will be recalled that the semantic scale shown in Table 6-6 and Figure 6-4 above, allows respondents to specify a wide range of preferences, including giving equal weighting to the various objectives. By choosing a value of (1) for all pairwise comparisons, the respondent would effectively be giving equal weighting to them. As such, respondents who felt that the objectives were of equal importance or should not be compared, would be able to indicate such by selecting (1) for every comparison.

6.10.5 Comparison of the sub-goals

In the third section of the second questionnaire, participants were asked to make a single pairwise comparison of the two ELASTIC sub-goals. Essentially, respondents were required to compare the importance of 'Methodological quality' and 'Relevance to sustainable transport', for selecting a sustainable transport indicator.
Chapter Six: Application of ELASTIC to England – Context and inputs

The single pairwise comparison that made up this section is shown below.

If you were asked to choose a sustainable transport indicator based on either its Methodological Quality or its Relevance to sustainable transport which of the two criteria would you deem more important to your selection and how strongly so?

Please circle the appropriate number.

<table>
<thead>
<tr>
<th>Methodological Quality (i.e., measurability, interpretability, data availability, isolatability of impacts, etc.)</th>
<th>Relevance to Sustainable Transport (i.e., the indicator’s provision of information relating to transport’s contribution to livable streets, protection of the environment, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6-5: The single pairwise comparison of sub-goals presented to participants

A total of 74 questionnaires were sent to Transport Planners throughout England in this second stage of the survey process, while 65 were sent to transport-related Academics at English Universities.

The questionnaire sent to Transport Planners in the second round of the survey process is shown at Appendix B4. The slightly different version sent to Academics is shown at Appendix B5. It should be noted however, that the only difference in the questionnaires was a single question in the first section. Essentially, Transport Planners were required to indicate the level of influence that various stakeholder groups actually have on the sustainable transport planning process in their areas, while Academics were asked to indicate the level of importance they would hypothetically attribute to the same stakeholder groups based on the contribution that the stakeholders could make to achievement of sustainable transport. The information obtained from this question was used to derive an Influence/Importance matrix for stakeholders which is described in greater detail in the next chapter.

6.11 Evaluation of indicators and derivation of TSPs

Once the surveys were completed, the next stage in the ELASTIC process was to analyse the responses and the judgements provided in the pairwise comparisons to derive weights for the various ELASTIC sub-goals and the criteria and then to obtain Weighted Indicator Performance Scores (WIPS) for each indicator in the initial long list. As per the ELASTIC process, these WIPS will then form the basis for selection of
the indicators that together will make up the Transport Sustainability Profile (TSP) for England. The analysis of the survey responses and the subsequent weighting and indicator selection process are described in Chapter seven, where the results and outcomes of the application of ELASTIC to England are given.

6.12 Summary

In order to demonstrate the utility and inherent attributes of ELASTIC, the methodological framework for selecting sustainable transport indicators presented in this thesis, it is necessary to apply it in a way that illuminates its practicalities. In that regard, ELASTIC is applied in this thesis is to England, UK.

To provide some background to the application, the current UK sustainable development and sustainable transport planning context was first described in detail. From the description of current UK sustainability policy and assessment requirements, it was clear that ELASTIC could play a useful role in the UK planning and decision-making context. Once the suitability of ELASTIC to the UK context had been established, the application to England were then discussed in detail. This commenced with a description of the various inputs into ELASTIC as well as the process of their derivation. This included a description of the long list of indicators, the various sub-goals criteria used to decompose the decision problem, the stakeholders whose judgements were elicited and the various surveys conducted to obtain stakeholders' judgements.

Having described the background to the application, the suitability of ELASTIC to the UK policy context and the major inputs into the process, this chapter has set the platform for weighting of the various components of the ELASTIC value tree, evaluation of the long list of indicators and derivation of TSPs for England and attendant regions. These next steps are given in Chapter seven where the results of the application of ELASTIC to England are discussed.
CHAPTER SEVEN: Application of ELASTIC to England, United Kingdom - Results and discussions

7.0 Overview

This chapter details and discusses the results of the application of the ELASTIC framework to England, UK. It proceeds by first analysing the survey responses. Aspects of the survey responses are then used to derive weights for the various sub-goals and criteria inherent in ELASTIC. The long list of indicators are subsequently evaluated and Weighted Indicator Performance Scores derived for each. A suite of the best performing indicators, is then taken to form the Transport Sustainability Profile.

7.1 Introduction

The previous chapter has provided the necessary background information and descriptions of the various inputs and survey processes relating to the application of ELASTIC to England, UK. This chapter complements Chapter six by analysing and describing the results of the surveys, and discussing the derivation of weights and the evaluation of indicators inherent in ELASTIC's processes. The ultimate outputs of the analyses are TSPs, each comprising of a small and context-specific suite of key sustainable transport indicators derived from the systematic application of ELASTIC. It must be emphasised however, that the TSPs derived are intended only to provide proof of the ELASTIC concept. That is, to demonstrate a systematic and logical approach to selecting a suite of sustainable transport indicators. Due, among other things, to issues related to the composition and breadth of the stakeholders interviewed however, the derived set of indicators should not be viewed as definitive.

7.2 Survey response rates

As described previously, two separate mail questionnaire surveys were conducted among English Transport Planners and Academics. The questionnaires sought to obtain background information about the participants, but more importantly they elicited their judgements on the various sub-goals and criteria specified in this application of ELASTIC. The response rates for the two surveys are discussed below.
Survey 1: Elicitation of judgements on criteria reflecting methodological quality
In the first round of surveys, a total of 57 questionnaires were sent to transport planners at select County Councils and Metropolitan Borough Councils throughout England. Of these, 38 were completed, representing a 67% response rate. Similarly, 64 questionnaires were sent to transport-related Academics at various English Universities, of which 34 were returned. This represented a 53% response rate.

Survey 2: Elicitation of judgements on objectives and the sub-goals
In the second round of surveys, 74 questionnaires were sent to transport planners throughout England. 39 questionnaires were returned and used in this analysis, representing a 53% response rate. As in the first phase, 64 questionnaires were again circulated to transport-related Academics at English institutions. 30 of these questionnaires were completed and returned, representing a response rate of 47%.

7.3 Background and personal information

The first section of each questionnaire in both survey stages, elicited general information from the participants about their backgrounds and their personal views on sustainable transport. As discussed in the Chapter six, the intent was for such background information to put the weightings of sub-goals and criteria, and the subsequent application of ELASTIC, into clearer context. These expressed views of respondents on sustainability and sustainability assessments can also be used to evaluate the appropriateness of the subsequent ELASTIC weightings and outputs. The responses to these various general background questions put to the stakeholders surveyed, are described and analysed in the sub-sections below.

7.3.1 Clarity of the concept of sustainable transport

Despite its increasing importance and popularity as a policy goal, the concept of sustainable transport is still often poorly understood by relevant stakeholders (Gudmundson 2003 a). Therefore, to ascertain the clarity of the concept to the stakeholders surveyed, the first question of the first questionnaire requested each respondent to indicate how clear the concept of sustainable transport is to him/her. The pie charts in Figure 7-1 below, show separately the responses obtained from the samples of Transport Planners and Academics respectively.
Chapter Seven: Application of ELASTIC to England – Results and discussions

The responses as reflected in the diagrams above, suggest that more Transport Planners viewed themselves as having a clear understanding of the concept of sustainable transport than do Academics. This is evidenced by the fact that 89% of Transport Planners stated that they had either a ‘Clear enough’ or ‘Very clear’ understanding of the concept of sustainable transport, while only 50% of Academics declared the same. When the two groups are combined however, a total of 71% of all respondents indicated that they either had a ‘Clear enough’ or ‘Very clear’ understanding of the concept of sustainable transport. On the other hand, 26% of the total sample indicated that the concept was not clear enough to them.

7.3.2 Sustainable transport as a goal in the respective professions

In the first survey, respondents were also asked whether achieving or contributing to sustainable transport is stated as an overarching goal in their respective professions. In the case of the Transport Planners, of interest was whether contributing to, or enhancing, sustainable transport is stated as one of the goals of their respective council’s transport division or department. For Academics, the question was whether enhanced sustainability has been stated as a goal or intended outcome of any current or past transport related research. The responses received from the two groups surveyed are shown graphically in Figure 7-2 below.
Chapter Seven: Application of ELASTIC to England – Results and discussions

Transport Planners

- Explicitly stated: 92%
- Alluded to, but not explicitly stated: 8%
- Not stated: 0%

Academics

- Explicitly stated: 41%
- Alluded to, but not explicitly stated: 35%
- Not stated: 24%

Figure 7-2: Sustainable transport as a goal of Transport Planning or Research

It is clear from Figure 7-2 above that sustainable transport is an often stated goal of both practical transport planning and of academic transport research. This is reflected by the overwhelming 92% of the sample of Transport Planners who indicated that Sustainable Transport is 'Explicitly stated' as a goal of their transport planning divisions, while an additional 8% stated that while not explicitly written, it is alluded to in their work, policies etc. Similarly, 41% of Academics stated that enhanced sustainability has been 'Explicitly stated' as a goal of past or current transport research, while another 35% indicated that while not explicitly stated as a goal, it is often alluded to in research projects and publications. These results confirm a fundamental motivation for this research, specifically that sustainable transport is now a pervasive goal of transport planning practice and research.

7.3.3 Existence of frameworks for assessing transport sustainability

Since the majority of respondents indicated that sustainable transport is often stated as a goal in their respective professions, a logical question was whether any mechanisms existed for them to evaluate their progress in achieving the stated or alluded goal. In the first questionnaire therefore, respondents were asked to indicate whether mechanisms existed in their organisations to assess their progress towards or away from sustainable transport. The responses are shown in Figure 7-3 below.
Chapter Seven: Application of ELASTIC to England – Results and discussions

The pie charts above show that despite the fact that the majority of respondents had indicated that sustainable transport is a goal of their respective professions, there clearly exist few mechanisms in their organisations to assess progress towards this stated goal. This is evidenced by the fact that 55% of Transport Planners indicated that either no assessment framework exists, or that personal judgement is their sole guide. Similarly, 82% of Academics indicated that no mechanism exist to assess the contribution of their research to achieving the goal of sustainable transport.

These results are especially relevant to the research presented in this thesis as they validate the need for development of a methodological framework that could aid in sustainable transport assessment. While indeed the literature had previously revealed this research gap, these survey results show that there is a real gap in practice as well.

7.3.4 Views on the feasibility of a single index of sustainable transport

Chapter three of this thesis previously highlighted the desire among some policy makers and members of the research community, for the derivation of a single sustainability index. Whether this is possible, or even ethical, is an issue that remains the subject of considerable debate in sustainability research.
Given the clear value that a single index would have in sustainability analysis due to the ease of interpretability among other things, it was thought useful to garner the views of stakeholders on this issue. As such, in the second round of surveys, respondents were asked to indicate, based on their personal experiences, whether they believed that the concept of sustainable transport could be captured in a single index or whether multiple indicators were more adequate. The responses are shown below.

**Transport Planners**

- It can be captured in a single index: 8%
- Indicators are more practical: 79%
- Neither single index nor indicators are useful: 13%

**Academics**

- It can be captured in a single index: 3%
- Neither index nor indicators are useful: 9%
- Indicators are more practical: 94%

**Figure 7-4: The feasibility of a single index for assessing sustainable transport**

It is clear from the above results that the vast majority of respondents view indicators as the most practical way of capturing the concept of sustainable transport. This position was taken by 79% of Transport planners and 94% of Academics. Contrastingly, only 8% and 3% of Transport Planners and Academics respectively, opined that the concept of sustainable transport could be captured by a single index.

These results again have positive implications for this research project as they validate the approach of the ELASTIC framework which seeks to guide sustainable transport assessment through a suite of key indicators. While there is vast support for this approach in the literature as previously discussed in chapters three and four, it is encouraging that this view is also shared by key stakeholders.
7.3.5 **Appropriate spatial scale for sustainable transport assessment**

Decision making for sustainable transport can be undertaken at a number of spatial scales. This has obvious implications for transport sustainability assessment as the most effective assessment tool will be that which is capable of performing at the most appropriate spatial scale. It was therefore deemed useful to get an indication from stakeholders of the spatial scale at which they believe sustainable transport tools should be applicable if they are to be effective. This was done in the second questionnaire which asked survey participants to indicate the spatial level they believed to be most appropriate for taking actions and decisions for sustainable transport. The responses to this question are shown in Figure 7-5 below.

**Figure 7-5: The appropriate spatial scale for sustainable transport decision making**

As reflected in the view shared by 51% of Transport Planners and 64% of Academics, it is clear that the majority of respondents believed that decisions and actions for sustainable transport should be taken at all spatial scales. These results suggest that appropriate sustainable transport assessment tools should be capable of being applied at a variety of spatial levels. This augurs well for ELASTIC, which, with its inherent flexibility and transferability, is applicable at a variety of spatial scales.
7.3.6 Analysis of stakeholder powers in transport decision-making

Stakeholder analysis is a tool developed by the British Overseas Development Administration (1995) to identify and prioritise stakeholders in areas where aid projects are funded. Stakeholder analysis, *inter alia*, illuminates the powers (or lack of them) of respective stakeholders. As such, it was thought useful to apply this technique in this context to illuminate the power balance in sustainable transport decision making in England. Stakeholder analysis assesses stakeholder powers by comparing the influence of different stakeholders on the formulation of policies and strategies, to their importance to achieving the policy goal. Among other things therefore, it can reveal those stakeholders with high importance for the success of sustainable transport strategies, but little power to affect the decision making process.

To conduct the stakeholder analysis in this instance, two different tasks were assigned in the second questionnaire to the two stakeholder groups surveyed.

i. **Transport Planners** were required to indicate the level of influence that six categories of stakeholders had on the sustainable transport planning process in their areas. A 5-point likert scoring scale was used to assess the level influence, with ‘0’ being ‘No influence’ and 4 being ‘Ultimate veto power’. The overall values given to influence of stakeholder groups was derived by taking the arithmetic mean of the scores given to each stakeholder group by all Transport Planners.

ii. **Academics** were asked to indicate on a similar 5-point likert scale, the level of importance they would attribute to the contribution that each of the same six categories of stakeholders could make to achievement of sustainable transport. These scores were used to obtain an overall importance value for each of the six stakeholder groups by using a basic arithmetic mean aggregation procedure.

The overall mean scores given to the ‘Influence’ and ‘Importance’ of the various stakeholder groups as derived from the scores attributed by the samples of Transport Planners and Academics respectively are shown in the Table 7-1 below.
### Table 7-1: Mean Score for Influence and Importance of various stakeholders

Once the overall mean ‘Influence’ and ‘Importance’ scores have been calculated for each stakeholder group, the values can be used to derive an ‘Importance/Influence’ Matrix as shown in Figure 7-5 below. This matrix is essentially a scatter plot of the mean scores above, with ‘Influence’ on the vertical axis and ‘Importance’ on the horizontal axis. The plot is divided into four quadrants which each ‘generally’ reflect the relative influence and importance of respective groups.

![Figure 7-6: Influence/Importance matrix for stakeholders as viewed by respondents](image-url)
Chapter Seven: Application of ELASTIC to England – Results and discussions

The numbers on the axis have no definitive meaning. 3 does not absolutely mean 'high', but on this given matrix, it is in the higher end, so it has been designated as such. Given another scale, '3' may have easily been in the 'lower' quadrants.

The stakeholders in the lower left quadrant of the matrix are those currently viewed to have Low Influence on the sustainable transport decision making process, but who are also viewed as being of Low Importance to the success of sustainable transport strategies. Given that the values for Influence and Importance are both low, there is no anomaly and therefore no perceived imbalance in the power of stakeholders in this quadrant. Based on the scores given by English Transport Planners and Academics, this quadrant comprises of Local businesses and Pressure groups.

Stakeholders in the upper left quadrant are those perceived to have a High Influence on sustainable transport decision making, but viewed as having Low Importance to the success of sustainable transport strategies. There is an obvious power anomaly in this quadrant, since the level of influence of these stakeholders is not commensurate with their importance to achieving sustainable transport. Based on the survey results, the stakeholder groups in this quadrant are Transport Operators and Politicians.

Proceeding clockwise, the upper right quadrant shows those stakeholders that are viewed as having High Importance and High Influence. In this application, the only category of stakeholders in this quadrant are Transport Planners. Again, there is no anomaly here as the level of influence of these stakeholders is generally commensurate with their perceived importance to achieving sustainable transport.

On the other hand, the lower right quadrant shows those stakeholders who are perceived to be Highly Important to the realisation of sustainable transport, but who currently have Low Influence on sustainable transport decision making. Using the mean scores attributed by the Transport Planners and Academics in this application, this quadrant currently comprises of Local People. Logically, there is an anomaly in the power of stakeholders in this quadrant as they are not currently afforded a level of influence commensurate to their perceived importance.
These results have implications for sustainable transport assessment methods as they highlight a need to enhance the involvement of important but under-represented stakeholders in the decision making process. As such, these results validate the ELASTIC indicator-based assessment approach, which is participatory and able to incorporate a wide spectrum of stakeholder values and views.

7.4 Derivation of weights for sub-goals and criteria

Once the background information and personal views of the respondents had been obtained as described above, the subsequent sections of the questionnaires elicited the judgements of survey participants on the various components of the ELASTIC value tree. It is these judgements that are then used in the derivation of weights for the various ELASTIC sub-goals and criteria. The sub-sections below describe the survey results and the consequent weight derivation process.

7.4.1 Weights for the criteria reflecting methodological quality

In the first survey, respondents were required to perform pairwise comparisons of the various methodological criteria inherent in ELASTIC. As has been described in the previous chapter, respondents indicated their preferences between criteria by assigning a number based on a 9-point semantic scale, which demonstrated whether a criterion was preferred over another, as well as the strength of such preference.

For example, a respondent may have taken the view that the criterion Measurability is 'Moderately more important' than Ease of Availability. On the semantic scale shown in Chapter six (based on Saaty 1980) and distributed in the ‘Guide to Completing the Questionnaire’, a judgement of ‘Moderately more important’ is reflected by the number (3). As such, when faced with the above pairwise comparison in the questionnaire, the respondent would be required to circle the number (3) nearer to the preferred criterion, in this case Measurability, as shown in Figure 7-7 below.

<table>
<thead>
<tr>
<th>Measurability</th>
<th>9 8 7 6 5 4</th>
<th>Ease of Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>2 1 2 3 4 5 6 7 8 9</td>
</tr>
</tbody>
</table>

**Figure 7-7:** How a pairwise comparison is made in the completed questionnaire
7.4.1.1 Use of Expert Choice software to apply AHP

To derive weightings for the criteria based on the judgements of each respondent, ELASTIC requires the application of the Analytic Hierarchy Process (AHP). As described in Chapter five, the Expert Choice software package (www.expertchoice.com) provides a user-friendly platform for applying AHP. Among other things, Expert Choice enables the entering of judgments in either numerical, graphical, or verbal modes and has a menu driven interface that enables easy handling of the otherwise demanding AHP calculations. In the pairwise comparison shown in Figure 7-7 above for example, the number (3) circled to show that Measurability is 'Moderately more important' than Ease of availability could be easily entered by sliding a bar to the number (3) nearer to Measurability in Expert Choice’ numerical mode as shown in the screenshot in Figure 7-8 below.

![Figure 7-8: Screenshot of the Expert Choice interface for entering judgements](Image)

As shown above, sliding the bar to the number (3) automatically enters the corresponding number in the grid below. The full complement of entries in the grid above shows that judgements had already been entered for all the other criteria. As can be seen in the bottom-most row in the grid, Expert Choice also automatically provides the Inconsistency Ratio (I.R) of the set of judgements. In this case, the judgments are exactly at the accepted I.R limit of 0.10. Once the judgements have been entered into Expert Choice, AHP can be applied to convert them into numeric weights by selecting the following commands from the Expert Choice menu.
Chapter Seven: Application of ELASTIC to England – Results and discussions

 ⇒ [Assessment]

 ⇒ [Calculate]

For the full set of judgements shown in Figure 7-8 above, activating the above menu commands in Expert Choice returned the following weights for the five criteria.

Figure 7-9: Example of weights returned by Expert Choice for a set of judgements

7.4.2 Aggregation of individual weights for the Methodological Criteria

The output of Expert Choice is a set of weights for an individual. To obtain group weights, these weights have to be aggregated. ELASTIC uses a basic arithmetic mean procedure to weights. This procedure was used to aggregate individual criteria weightings into (i) group weights for Transport Planners and Academics respectively; and (ii) overall weights for the entire sample. These are shown in Table 7-2.

<table>
<thead>
<tr>
<th>Methodological Criteria</th>
<th>Transport Planners N=38</th>
<th>Academics N=34</th>
<th>Overall Weights N=72</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std Deviation</td>
<td>Mean</td>
</tr>
<tr>
<td>Measurability</td>
<td>0.2185</td>
<td>0.1108</td>
<td>0.2249</td>
</tr>
<tr>
<td>Ease of Availability</td>
<td>0.1447</td>
<td>0.1033</td>
<td>0.1390</td>
</tr>
<tr>
<td>Speed of Availability</td>
<td>0.0733</td>
<td>0.0776</td>
<td>0.0664</td>
</tr>
<tr>
<td>Interpretability</td>
<td>0.3548</td>
<td>0.1428</td>
<td>0.3144</td>
</tr>
<tr>
<td>Isolatability</td>
<td>0.2087</td>
<td>0.1274</td>
<td>0.2553</td>
</tr>
</tbody>
</table>

Table 7-2: Group weights and overall weights derived for the methodological criteria
7.4.3 Discussion of the weightings for methodological criteria

The rankings of the methodological criteria, based on the weights attributed, are generally the same for both groups sampled in the survey. Interpretability was ranked highest in both instances. The only discrepancy between the groups is in ranking of the second most important criterion. For the Transport Planners, Measurability is attributed the second highest weighting, while for the Academics, Isolatability is ranked second. Not surprisingly, Isolatability and Measurability are ranked third by each of the above groups respectively. Ease of Availability and Speed of Availability are given the penultimate and lowest rankings respectively by both groups.

When both sample groups are combined to derive overall weights, the rankings of the criteria in descending order are as follows; Interpretability, Isolatability, Measurability, Ease of Availability and finally, Speed of Availability.

Comparison of weights by groups

The Student's $t$-test is a parametric statistical test that can be used to test for differences between means. It can therefore ascertain whether significant differences exist between the mean weights given by Transport Planners and Academics to individual criteria. The null hypothesis tested by the $t$-test is that the two weights are equal (i.e., $H_0: \mu_{TP} = \mu_{Ac}$). The alternative hypothesis is that the weights are not equal ($H_A: \mu_{TP} \neq \mu_{Ac}$). The $t$-test statistic is derived using the following equation;

$$ t = \frac{w_{jTP} - w_{jAc}}{\sqrt{\frac{s_{TP}^2}{n_{TP}} + \frac{s_{Ac}^2}{n_{Ac}}}} \quad \text{Equation 7-1} $$

Where:

- $w_{jTP}$ is the mean weight attributed to criterion $j$ by Transport Planners;
- $w_{jAc}$ is the mean weight attributed to criterion $j$ by Academics;
- $s_{TP}^2$ is the standard deviation of the mean Transport Planners weighting;
- $s_{Ac}^2$ is the standard deviation of the mean Academics' weighting;
- $n_{TP}$ is the number of Transport Planners in the sample;
- $n_{Ac}$ is the number of Academics in the sample.
The value of \( t \) is then assessed against a prescribed critical value, \( t^* \), which is the value of \( t \) expected to be obtained by chance with the appropriate degrees of freedom (\( df \)); Where \( df \) is calculated by Equation 7-2 below.

\[
df = n_{TP} + n_{Ac} - 2 \quad \text{Equation 7-2}
\]

Where: \( n_{TP} \) and \( n_{Ac} \) are the sample sizes as previously defined in equation 7-1.

The critical values of \( t^* \) are found in a ‘Statistical Table of Values of the \( t \) Distribution’ found in texts such as Murdoch and Barnes (1998), and are given for different degrees of freedoms and various levels of significance (for example, 0.05). If the absolute value of the observed \( t \) is greater than the critical value \( t^* \), the null hypothesis (\( H_0 \)) is rejected, and the mean weights attributed to the criterion by the two samples are determined to be statistically different at that significance level.

The Statistical Package for Social Sciences (SPSS) was used to derive observed values of \( t \) to compare the weights given to each criterion by Transport Planners and Academics. The results are shown in Table 7-3 below.

<table>
<thead>
<tr>
<th>Methodological Criteria</th>
<th>( t )</th>
<th>( df )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurability</td>
<td>0.210</td>
<td>70</td>
</tr>
<tr>
<td>Ease of Availability</td>
<td>-0.230</td>
<td>70</td>
</tr>
<tr>
<td>Speed of Availability</td>
<td>-0.484</td>
<td>70</td>
</tr>
<tr>
<td>Interpretability</td>
<td>-1.073</td>
<td>70</td>
</tr>
<tr>
<td>Isolatability of transport's impact</td>
<td>1.397</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 7-3: \( t \) values for comparison of methodological criteria weightings

At 70 \( df \)s and with a significance level of 0.10, the value of \( t^* \) shown in the ‘Table of Values of the \( t \) Distribution’ is 1.658. This value is clearly larger than all of the derived values of \( t \) for the various criteria as shown in the second column of Table 7-3 above. Therefore the null hypothesis (\( H_0 \)) is not rejected for any of the weightings. That is, there are no statistically significant differences between the weightings by Transport Planners and those by Academics for any of the methodological criteria.
Spread and distribution of weights

Box plots are useful tools for graphically summarising the distribution of an aggregated set of data. As shown for the entire sample in Figure 7-10 below, Box Plots display the weight distributions adjacent to each other, thus allowing visual comparison of the central tendency and other features of the various criteria weights.

![Box plots of criteria weights](image)

**Criteria reflecting methodological quality**

**Figure 7-10**: Distribution of overall weights for the various methodological criteria

The shaded boxes represent the interquartile ranges containing the middle 50% of all weights for the respective criteria. It is clear from the graph that the weights assigned for the criterion **Interpretability** are generally higher than those for other criteria, while weights for the criterion **Speed of Availability** are typically lower than those for other criteria. The whiskers extend from the boxes to the highest and lowest values and provide a crude depiction of the spread of values. Such variation in weights is more accurately described by the standard deviation (SD) previously shown in Table 7-2. As suggested by the whiskers, the weights for **Speed of Availability** are the least scattered with an SD of 0.602. Conversely, the weights attributed to the criterion **Interpretability** are the least homogeneous as reflected by the highest SD of 0.159.
7.4.4 Weights for the key objectives of sustainable transport

In the second phase of the survey process, the respondents were asked to conduct pairwise comparison of various key objectives of sustainable transport that indicators would be expected to reflect. The Expert Choice software was again used to apply AHP to derive individual weights for the objectives. The individual weights were then aggregated using an arithmetic mean procedure. This was done first within the sample groups, which was then followed by derivation of overall weights by aggregating the weights assigned by all respondents. The group weights and the overall aggregated weights calculated for the sustainable transport objectives are shown in Table 7-4.

<table>
<thead>
<tr>
<th>Objectives of Sustainable Transport</th>
<th>Transport Planners N=39</th>
<th>Academics N=30</th>
<th>Overall Weights) N=69</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std Deviation</td>
<td>Mean</td>
</tr>
<tr>
<td>Livable Streets and Neighbourhoods</td>
<td>0.1549</td>
<td>0.0779</td>
<td>0.1581</td>
</tr>
<tr>
<td>Protection of the Environment</td>
<td>0.1673</td>
<td>0.1454</td>
<td>0.2427</td>
</tr>
<tr>
<td>Equity and social inclusion</td>
<td>0.1612</td>
<td>0.0853</td>
<td>0.1748</td>
</tr>
<tr>
<td>Health and Safety</td>
<td>0.3267</td>
<td>0.1657</td>
<td>0.2819</td>
</tr>
<tr>
<td>Support of a vibrant and efficient economy</td>
<td>0.1899</td>
<td>0.1309</td>
<td>0.1425</td>
</tr>
</tbody>
</table>

Table 7-4: Group weights and overall weights for the sustainable transport objectives

7.4.4.1 Discussion of the weightings for the objectives of sustainable transport

The only agreement in the rank ordering of sustainable transport objectives between the two stakeholder groups was on the most important, which both groups determined to be Health and Safety. For Transport Planners, the remaining objectives were ranked in the following descending order; Vibrant Economy, Protection of the Environment, Equity and Social Inclusion and then Livable Streets. For Academics, the descending order was; Protection of the Environment, Equity and Social Inclusion, Livable Streets and finally, Vibrant Economy.

When the weightings of both groups were combined the ranking of the objectives in descending order was as follows; Health and Safety, Protection of the Environment, Support of a vibrant Economy, Equity and Social Inclusion and then Livable Streets.
A student $t$-test was again conducted to compare the two sets of weights in order to ascertain whether the weights given to the objectives by the two samples were significantly different to each other. The output from SPSS, which shows the observed $t$ values in the second column, is given below in Table 7-5.

<table>
<thead>
<tr>
<th>Objectives of Sustainable Transport</th>
<th>$t$</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livable Streets and Neighbourhoods</td>
<td>-0.144</td>
<td>67</td>
</tr>
<tr>
<td>Protection of the Environment</td>
<td>-1.992</td>
<td>67</td>
</tr>
<tr>
<td>Equity and social inclusion</td>
<td>-0.576</td>
<td>67</td>
</tr>
<tr>
<td>Health and Safety</td>
<td>1.073</td>
<td>67</td>
</tr>
<tr>
<td>Support of a vibrant and efficient economy</td>
<td>1.565</td>
<td>67</td>
</tr>
</tbody>
</table>

Table 7-5: $t$ values for comparing weights of sustainable transport objectives

At 67 degrees of freedom and a significance level of 0.10, the value of the random $t^*$ shown in the ‘Table of Values of the $t$ Distribution’ (Murdoch and Barnes 1998), is again 1.658. By comparing this to the observed values of $t$ in the second column of Table 7-5 above, it can be seen that $t^*$ is only less than the observed values of $t$ for the objective Protection of the Environment. Therefore, in this one instance, the null hypothesis ($H_0$) is rejected and the alternative hypothesis ($H_A$) accepted, that the weights given to this objective by the two sample groups are significantly different.

Essentially therefore, the weight of 0.2427 given to Protection of the Environment by Academics is significantly higher then the weight of 0.1673 assigned to the same objective by Transport planners. While examination of the underlying causes for such difference is outside the scope of this study, a reasonable assumption is that Transport Planners generally work under political pressures which require them to deliver outputs that are visible and which are typically linked to increased employment and economic growth. Academics on the other hand, perhaps due to working in a more ‘theoretical’ environment, are more considerate of the less profitable, but more ethical issue of ‘Protection of the Environment’.

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Distribution and Spread of the weights

To illuminate the nuances and the distribution of all the weights of both samples, a box plot, as shown below in Figure 7-11 below, was again derived for the overall weightings of the sustainable transport objectives.

![Box plot of weightings for sustainable transport objectives](image)

**Figure 7-11: Distribution of overall weights for the objectives of sustainable transport**

From the shaded boxes, which represent the middle 50% of weights for each criterion, it can be seen rather unsurprisingly that the objective **Health and Safety** generally had higher assigned weights. Typically, there was no clear difference in the interquartile ranges of the distribution of weights for the remaining objectives. The whiskers extending from the boxes also follow the previously highlighted trends and are typically of similar length amongst the various objectives, except for **Health and Safety** for which the span of the whiskers are significantly wider than the others. This crude depiction of spread by the whiskers is validated by the measures of standard deviation (SD) previously shown in Table 7-4, with **Health and Safety** having the highest SD of 0.1722 and **Livable Streets** having the lowest SD of 0.0895.
7.4.5 Weights for the sub-goals

Once judgements for the various criteria had been derived, the last stage of the survey process elicited the judgements of stakeholders with regard to the two broad ELASTIC sub-goals. As described in the previous chapter, these judgements were elicited through a single pairwise comparison in the third section of the second questionnaire, where the respondents were asked to express their preferences between the sub-goals Methodological Quality and Relevance to the concept of Sustainable Transport.

Table 7-6 below shows the mean groups weightings of the sub-goals given by Transport Planners and Academics respectively. The third column of the table shows the overall weights derived when the samples are combined.

<table>
<thead>
<tr>
<th>ELASTIC sub-goals</th>
<th>Transport Planners N=39</th>
<th>Academics N=30</th>
<th>Overall weights N=69</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std Deviation</td>
<td>Mean</td>
</tr>
<tr>
<td>Methodological quality</td>
<td>0.4877</td>
<td>0.2247</td>
<td>0.4700</td>
</tr>
<tr>
<td>Relevance to sustainable Transport</td>
<td>0.5123</td>
<td>0.2247</td>
<td>0.5300</td>
</tr>
</tbody>
</table>

Table 7-6: Weights derived for the two overarching ELASTIC sub-goals

7.4.5.1 Discussion of the weightings for the sub-goals

As can be seen above, the ranking order of the two sub-goals was the same for both samples, with Relevance to Sustainable Transport being weighted more importantly than Methodological Quality in both instances.

To ascertain if there was any significant statistical difference between the groups' weightings for the sub-goals, a student's t test comparison of means was again conducted. The observed values of t for both sub-goals are shown in Table 7-7 below.

<table>
<thead>
<tr>
<th>ELASTIC sub-goals</th>
<th>t</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methodological strengths</td>
<td>-0.306</td>
<td>67</td>
</tr>
<tr>
<td>Relevance to Sustainable</td>
<td>0.306</td>
<td>67</td>
</tr>
<tr>
<td>Transport</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7-7: Observed t values for comparison of group weightings of sub-goals
As has been previously shown, at 67 Degrees of Freedom (df) and with a significance level of 0.10, the value of random $t^*$ shown in the ‘Table of Values of the $t$ Distribution’, is 1.658. This value is clearly larger than both observed values of $t$ in the second column of the table above. Therefore the null hypothesis, $H_0$, is not rejected, and it is concluded that there is no significant statistical difference between the two sets of sub-goal weights.

Distribution and Spread of the weights

To show the distribution of the weights aggregated to form the overall weightings for the two sub-goals, a box plot for the two sets of weights was derived as shown in Figure 7-12 below.

![Box plot of distributions of all weights assigned to sub-goals](image-url)

**ELASTIC Sub-Goals**

**Figure 7-12**: Box plot of the distributions of all weights assigned to the sub-goals

As expected, the interquartile range for Relevance to Sustainable Transport is slightly higher than that for Methodological Quality which corresponds to the slightly higher overall mean weighting for the former sub-goal.
Chapter Seven: Application of ELASTIC to England – Results and discussions

The spread of the weights as crudely reflected by the length of the whiskers are almost identical. This is confirmed by the measures of Standard Deviation which, as previously shown in Table 7-6, have the exact value of 0.2368 for both sub-goals.

While Relevance to Sustainable Transport is slightly preferred, the similarity in the weights assigned to the two ELASTIC sub-goals in this section, the absence of any significant statistical difference as ascertained by the t-test comparison of means, and the similarity in the ranges and standard deviations of weights, suggest that the stakeholders in this survey viewed the two sub-goals Methodological Quality and Relevance to Sustainable Transport as having relatively similar high-level importance for determining the suitability of indicators for sustainable transport assessment.

These results generally validate the underlying assumptions of ELASTIC that these two sub-goals are both of fundamental high-level importance for selecting a sustainable transport indicator. The high weightings for both suggest that the stakeholders surveyed also considered the two sub-goals to be highly important.

7.5 The weighted value tree

Having ascertained the weights for all the sub-goals and criteria inherent in application of ELASTIC, a weighted value tree can then be obtained by inserting the weights of the various sub-goals and criteria at the relevant nodes of the ELASTIC value tree previously shown in Figure 6-2.

The weighted value tree for the ELASTIC application to England, utilising the overall weights derived from the entire sample, is shown in Figure 7-13 below. It should be noted however, that group specific value trees could have been derived for Transport Planners and Academics respectively, by using the specific group weights of the various criteria and sub-goals. Indeed, later in this chapter, the sample will be disaggregated by region to derive region-specific weights for which region-specific ELASTIC trees can be derived as well. The weighted value tree shown in Figure 7-13 below however, is for the country of England, based on the judgements and priorities of English Transport Planners and transport-related Academics.
Figure 7-13: Weighted ELASTIC value tree for England, UK based on judgements of English Transport Planners and Transport Academics
7.6 Scoring Indicator performance on criteria

Once a weighted value tree has been derived, the next stage in the ELASTIC process is the scoring of indicators based on how well they perform on the various sub-goals and criteria in the value tree. As described in Chapter five, ELASTIC uses a direct rating technique where the Analyst assigns an outcome score to each indicator reflecting the level and degree of that indicator’s performance on the respective criteria.

Logically, two scoring schemes are required for the two clusters of criteria representing the dual sub-goals inherent in the ELASTIC process, namely Methodological Quality and Relevance to Sustainable Transport. As it is the Analyst who conducts the scoring exercise, it is important that these scoring systems are devised in a way that minimises subjectivity and maximises transparency in the assigning of outcome scores.

7.6.1 Normalisation of scores

The scoring systems each utilised a 5-point likert scale from which the Analyst assigns appropriate outcome score to indicators. The higher the score assigned, the better the performance of the indicator on that criterion. The absolute numeric outcome scores assigned were normalised using equation 7-3 below.

\[
\text{Normalised score} = \frac{\text{Basic Numeric Score}}{\text{Sum of numeric scores in category}} \times 100 \quad \text{Equation 7-3}
\]

Application of the above normalisation procedure ensured that each outcome score was shown as a percentage and that all possible normalised scores for each criterion summed to 100.

The two scoring schemes used in this application of ELASTIC and the interpretations of the numbers in the likert scale are shown in the sub-sections below.
### Scoring system for evaluating methodological criteria

The indicators were evaluated against the criteria reflecting methodological quality using the scoring system in Table 7-8 below.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score</th>
<th>N. Score</th>
<th>Verbal score</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurability</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>Cannot be conceptualised nor measured</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>Can be conceptualised, but difficult to measure in clear units</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>Measurable either quantitatively, qualitatively or monetarily</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>Measurable with two of the above methods</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Outstanding</td>
<td>Measurable with all three methods</td>
</tr>
<tr>
<td><strong>Ease of Availability</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>Impossible to derive data for the indicator</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The data is obtainable but at exorbitant costs or effort</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>Data for the indicator has to be estimated or modelled</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>Data is readily available from 'quality' publications at national levels</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Outstanding</td>
<td>Data is readily available from 'quality' publications at sub-national levels</td>
</tr>
<tr>
<td><strong>Speed of Availability</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>Data is not published or data is only available after 15 years</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>Data is available within 10 years</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>Data is available within 5 years</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>Data is available yearly</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Outstanding</td>
<td>Data is available within less than a year</td>
</tr>
<tr>
<td><strong>Interpretability</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator cannot be interpreted in a way relevant to sustainable transport</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The desired direction of movement for the indicator is unclear</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>Gives overall picture but inherent components are concealed</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>Can be clearly interpreted and preferred direction clear</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Outstanding</td>
<td>Combines two or more indicators in a way that is clear and understandable</td>
</tr>
<tr>
<td><strong>Transport's impact isolable</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>Transport has no impact on the issue the indicator is concerned with</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>Transport has an impact but its share of impact cannot be isolated</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>Methods of isolating transport's impact are uncertain</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>Impact isolable with high levels of certainty using models or software</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Outstanding</td>
<td>Transport's isolated impacts are directly observed</td>
</tr>
</tbody>
</table>

Table 7-8: Scoring system for evaluating indicators' methodological quality
### Scoring system for evaluating relevance to Sustainable Transport

The scoring system used to score the relevance of indicators to sustainable transport as reflected by their relevance to the various objectives of sustainable transport in the ELASTIC value tree, is shown in Table 7-9 below.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Score</th>
<th>N.Score</th>
<th>Verbal score</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Livable Streets and neighbourhoods</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator has no clear irrelevance to the principle</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The indicator has some loose/vague relevance on the principle</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>The indicator has some clear but indirect relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>The indicator has direct, but only moderate relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Very favourable</td>
<td>The indicator has direct and strong relevance to the principle</td>
</tr>
<tr>
<td><strong>Protection of the environment</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator has no clear irrelevance to the principle</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The indicator has some loose/vague relevance on the principle</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>The indicator has some clear but indirect relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>The indicator has direct, but only moderate relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Very favourable</td>
<td>The indicator has direct and strong relevance to the principle</td>
</tr>
<tr>
<td><strong>Equity and social inclusion</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator has no clear irrelevance to the principle</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The indicator has some loose/vague relevance on the principle</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>The indicator has some clear but indirect relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>The indicator has direct, but only moderate relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Very favourable</td>
<td>The indicator has direct and strong relevance to the principle</td>
</tr>
<tr>
<td><strong>Health and Safety</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator has no clear irrelevance to the principle</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The indicator has some loose/vague relevance on the principle</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>The indicator has some clear but indirect relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>The indicator has direct, but only moderate relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Very favourable</td>
<td>The indicator has direct and strong relevance to the principle</td>
</tr>
<tr>
<td><strong>Support of a vibrant and efficient economy</strong></td>
<td>0</td>
<td>0</td>
<td>Extremely poor</td>
<td>The indicator has no clear irrelevance to the principle</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>10</td>
<td>Poor</td>
<td>The indicator has some loose/vague relevance on the principle</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>20</td>
<td>Acceptable</td>
<td>The indicator has some clear but indirect relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>30</td>
<td>Favourable</td>
<td>The indicator has direct, but only moderate relevance to the principle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>40</td>
<td>Very favourable</td>
<td>The indicator has direct and strong relevance to the principle</td>
</tr>
</tbody>
</table>

Table 7-9: Scoring system for evaluating indicators' relevance to sustainable transport
7.6.2 Information Sources used to guide indicator evaluation

To ensure the highest levels of objectivity, various sources were used during the indicator evaluation stages to guide the assignment of outcome scores.

For the methodological criteria, the sources tended to be UK statistical publications which illuminated information about the availability of data for the suggested indicators, the frequency at which they are published, the extent to which transport’s share of the impact is shown and how the indicators are measured. The key UK statistical publications used in this application of ELASTIC were namely;

- Social Trends No. 34. (ONS 2004)

For evaluation of the relevance of indicators to sustainable transport objectives, the sources used for guidance tended to be official publications highlighting the impacts of transport on the specific objectives. The publications used included the following;

- Transport and the Environment (Royal Commission on Environmental Pollution 1994)
- Transport and the Economy (Standing Advisory Committee on Trunk Road Assessment 1999)
- Transport, Environment and Health (Dora and Phillips 2000)
- Making the connections: Final report on Transport and Social Exclusion. (Social Exclusion Unit 2003)

The various academic journal articles referred to in Chapters two and four were also used as sources for evaluating relevance of indicators in the initial long list to sustainable transport objectives.
7.7 The indicator evaluation process and results

The evaluation of indicators was undertaken using three spreadsheets in a single Microsoft Excel Book. In the first spreadsheet, Worksheet 1, the indicators were evaluated using descriptive narrative text which provided a detailed verbal description of indicators' performance on each criterion. The intention was that this worksheet would set the platform for the subsequent numerical scoring as well as provide a clear and auditable justification for the subsequent scores of performance. Worksheet 2 converted the narrative descriptions in Worksheet 1 into normalised numeric outcome scores of the indicators' performance on the given criteria, using the scoring systems shown previously in Tables 7-8 and 7-9. (The full set of normalised outcome scores assigned to indicators in this application of ELASTIC as given in Worksheet 2 are shown at Appendix C1). The final Worksheet 3 is where the Simple Additive Weighting (SAW) model described in Chapter five is applied to derive an overall Weighted Indicator Performance Score (WIPS) for each indicator. In this final worksheet, each normalised score given in Worksheet 2 is multiplied by the quantified importance weights of the relevant sub-goals and criteria, to derive weighted scores of indicator performance on each criterion. In the final column of Worksheet 3, these weighted scores of indicator performance on each criterion are combined using the simple additive model to derive a single overall WIPS per indicator.

7.7.1 Summary characteristics of the full set of WIPS derived

Table 7-10 below shows summary statistics describing key features of the full set of WIPS derived when all the indicators in the long list had been evaluated.

<table>
<thead>
<tr>
<th>Descriptive Statistics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>17.431</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>05.739</td>
</tr>
<tr>
<td>Range</td>
<td>26.250</td>
</tr>
<tr>
<td>Minimum</td>
<td>04.340</td>
</tr>
<tr>
<td>Maximum</td>
<td>30.590</td>
</tr>
<tr>
<td>Percentiles</td>
<td></td>
</tr>
<tr>
<td>25th Percentile</td>
<td>14.049</td>
</tr>
<tr>
<td>50th Percentile</td>
<td>17.875</td>
</tr>
<tr>
<td>75th Percentile</td>
<td>21.347</td>
</tr>
</tbody>
</table>

Table 7-10: Summary descriptive statistics for the full set of WIPS
As can be seen in Table 7-10 above, the average WIPS for the full set of indicators was 17.431. The best performing indicator had a WIPS of 30.590, while the worst performing indicator scored only 4.34. This gives a 'range' of 26.250, which suggest a wide spread in the values of the WIPS derived, as can be seen from the wide span of the whiskers in Figure 7-14 below.

![Box plot showing the distribution of the WIPS](image)

**Figure 7-14:** Box plot showing the distribution of the WIPS

Some particularly useful statistics for the set of WIPS are shown in the row of Table 7-10 labelled ‘Percentiles’. The 25th Percentile shows the value below which 25 percent of the WIPS fall, which in this case is 14.0488. Similarly, the 50th percentile shows the value below which 50% of the WIPS fall, which in this case is 17.8752. As can be seen in the above table, the 75th percentile is 21.3474. The WIPS between the 75th percentile and the 25th percentile gives the inter-quartile range - also reflected by the shaded box in the Box Plot above, representing the values between which middle 50% of the WIPS distributions fall.
7.7.2 Selection of a Preliminary suite of indicators

Having derived WIPS for all indicators, it was then a simple process to select the 20 best performing indicators to form a preliminary suite of key indicators as required by the ELASTIC methodology. Shown in Table 7-11 below, the WIPS for this preliminary set of 20 indicators ranged from 23.169 to 30.590. Examination of a Frequency table derived in SPSS showed that 23.169 represented the 85th percentile WIP. This means that the top 15% best performing indicators were taken forward.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Indicator</th>
<th>WIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorised Traffic Volume (veh.-kms)</td>
<td>30.591</td>
</tr>
<tr>
<td>2</td>
<td>Number of Cycling Trips</td>
<td>28.869</td>
</tr>
<tr>
<td>3</td>
<td>Vulnerable Road User Accidents</td>
<td>28.680</td>
</tr>
<tr>
<td>4</td>
<td>Local Air Pollutants( NO₂, VOC, SO₂, CO and PM₁₀)</td>
<td>27.289</td>
</tr>
<tr>
<td>5</td>
<td>Modal Share of Public Transport</td>
<td>26.287</td>
</tr>
<tr>
<td>6</td>
<td>Social/External cost of transport</td>
<td>26.160</td>
</tr>
<tr>
<td>7</td>
<td>Quality of Public Transport</td>
<td>26.038</td>
</tr>
<tr>
<td>8</td>
<td>Availability of key services locally</td>
<td>25.751</td>
</tr>
<tr>
<td>9</td>
<td>Total number of killed or seriously injured (in road accidents)</td>
<td>25.902</td>
</tr>
<tr>
<td>10</td>
<td>CO₂ emissions from Transport</td>
<td>25.677</td>
</tr>
<tr>
<td>11</td>
<td>Public awareness of transport sustainability issues</td>
<td>25.457</td>
</tr>
<tr>
<td>12</td>
<td>Percentage of freight moved by road</td>
<td>25.450</td>
</tr>
<tr>
<td>13</td>
<td>Length of traffic-free routes for cyclists and walkers</td>
<td>25.022</td>
</tr>
<tr>
<td>14</td>
<td>Access to public transport</td>
<td>24.405</td>
</tr>
<tr>
<td>15</td>
<td>Percent of population affected by high traffic noise levels</td>
<td>24.248</td>
</tr>
<tr>
<td>16</td>
<td>Energy consumption by the road transport sector</td>
<td>24.052</td>
</tr>
<tr>
<td>17</td>
<td>Crime committed on or while waiting for public transport</td>
<td>23.925</td>
</tr>
<tr>
<td>18</td>
<td>Total number of road motor vehicles</td>
<td>23.914</td>
</tr>
<tr>
<td>19</td>
<td>Transport Related Wastes</td>
<td>23.599</td>
</tr>
<tr>
<td>20</td>
<td>Public Participation in transport planning</td>
<td>23.169</td>
</tr>
</tbody>
</table>

Table 7-11: Ranking and WIPS for the preliminary twenty best performing indicators
7.8 Sensitivity Analysis

To determine the robustness of the choices above, and to select an even smaller subset of consistently best-performing indicators, sensitivity analysis was conducted to test the performance of the preliminary selection of indicators in Table 7-11 above. The aim was to reduce this number to a subset of 15 key indicators.

The analysis was undertaken using Crystal Ball software which is an easy-to-use spreadsheet-based Monte Carlo simulation package (information about Crystal Ball is available at http://www.decisionengineering.com). The advantage of Monte Carlo simulation is that it enables simultaneous changes in sub-goals and criteria weights as well as in outcome scores and therefore provides multiple simulated outcomes based on these variations in inputs. To adequately reflect the decision context however, the simulations have to be bounded around realistic parameters and distributions.

As described in Chapter five, the Normal Distribution is assumed for the sub-goal and criteria weights in ELASTIC. To ensure that the simulations were as realistic as possible, the distributions were defined in Crystal Ball by the ‘Mean’ weights and the Standard Deviations shown in Tables 7-2, 7-4 and 7-6 above. The possible values of all simulated sub-goal and criteria weights, that is $g_i$ and $w_j$, were also constrained to between 0 and 1, that is, $0 \leq g_i, w_j \leq 1$.

The Triangular distribution was assumed for the outcome scores. This distribution is based on the definition of three parameters, representing (a) the minimum possible value, (b) the most likely value, and (c) the maximum possible value. The (normalised) outcome score assigned to the indicator by the Analyst, is defined as the ‘most likely’ value. The minimum and maximum values are defined as one point down from the ‘most likely value’ on the likert scale and one point up respectively.

1000 simulations were ran in Crystal Ball, where the ELASTIC model inputs for each indicator were varied around the appropriate parameters and within the distributions described above. The distribution of WIPS for the 20 preliminary indicators are shown in the box plots in Figure 7-15 below. (For clarity, the outliers and extreme values have been excluded from the plots).
Figure 7-15: Distribution of WIPS for the preliminary subset of indicators after 1000 simulation runs in Crystal Ball
As expected, after 1000 simulations, there were significant variations in the distribution of WIPS for the various indicators. This is clearly visible from the uneven shaded boxes as well as the differences in the lengths of the whiskers.

Generally, the lengths of the whiskers and heights of the shaded boxes corresponded to the previous ranking of indicators in the preliminary selection shown in Table 7-11 above. However, as can be seen in Table 7-12 below, there were some changes in the ranking of indicators after the mean WIPS for the 1000 runs were calculated.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Indicators</th>
<th>WIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>1</td>
<td>Motorised Traffic Volume</td>
<td>3.17</td>
</tr>
<tr>
<td>2</td>
<td>Number of Cycling Trips</td>
<td>3.05</td>
</tr>
<tr>
<td>3</td>
<td>Vulnerable Road User Accidents</td>
<td>3.56</td>
</tr>
<tr>
<td>4</td>
<td>Local Air Pollutants</td>
<td>3.19</td>
</tr>
<tr>
<td>5</td>
<td>Modal share of Public Transport</td>
<td>3.34</td>
</tr>
<tr>
<td>6</td>
<td>Percentage of freight moved by road</td>
<td>3.27</td>
</tr>
<tr>
<td>7</td>
<td>CO₂ emissions from Transport</td>
<td>3.21</td>
</tr>
<tr>
<td>8</td>
<td>Social/External cost of transport</td>
<td>2.75</td>
</tr>
<tr>
<td>9</td>
<td>Public Awareness of Transport sustainability issues</td>
<td>2.44</td>
</tr>
<tr>
<td>10</td>
<td>Availability of key services locally</td>
<td>2.63</td>
</tr>
<tr>
<td>11</td>
<td>Quality of Public Transport</td>
<td>2.98</td>
</tr>
<tr>
<td>12</td>
<td>Total number of killed or seriously injured (in road accidents)</td>
<td>2.95</td>
</tr>
<tr>
<td>13</td>
<td>Energy consumption by the road transport sector</td>
<td>3.20</td>
</tr>
<tr>
<td>14</td>
<td>Length of cycling and walking Paths</td>
<td>2.94</td>
</tr>
<tr>
<td>15</td>
<td>Access to Public Transport services</td>
<td>2.61</td>
</tr>
<tr>
<td>16</td>
<td>Percent of population affected by high traffic noise levels</td>
<td>3.27</td>
</tr>
<tr>
<td>17</td>
<td>Total number of road motor vehicles</td>
<td>3.01</td>
</tr>
<tr>
<td>18</td>
<td>Transport related Wastes</td>
<td>3.10</td>
</tr>
<tr>
<td>19</td>
<td>Public participation in Transport planning</td>
<td>2.53</td>
</tr>
<tr>
<td>20</td>
<td>Crime committed on or while waiting for public transport</td>
<td>2.56</td>
</tr>
</tbody>
</table>

Table 7-12: Revised ranking and WIPS after 1000 monte carlo simulation runs
7.9 Selection of a final suite of indicators

As already stated, after the simulation runs there were changes in the ranking of indicators relative to the ranking previously shown in Table 7-11. The biggest improvement in rank is by the indicator *Percentage of freight moved by road* which was elevated from No. 12 in the preliminary suite of indicators to No. 6 after Sensitivity Analysis. Similarly, the indicator *CO₂ emissions from Transport* jumped 3 notches from No. 10 to No. 7. *Public Awareness of transport sustainability issues* also improved its rank from No. 11 to No. 9, while *Energy consumption by the transport sector* jumped up three notches from No. 13 to No. 16.

Logically, there were also some reductions in indicator rankings. Specifically, the indicator *Social/External cost of transport* fell from No. 6 to No. 8; *Quality of Public Transport* fell from No. 7 to No. 11; *Availability of local services* fell from No. 8 to No.10; *Total number of killed or seriously injured (in road accidents)* fell from No. 9 to No. 12; *Length of traffic-free routes for cyclists and walkers* fell from No. 13 to No.14; *Access to public transport* fell from No.14 to No.15; and finally, *Road traffic noise levels* fell one notch from No. 15 to No. 16.

Of particular interest to this application are the top 15 best performing indicators. It can be seen from Tables 7-11 and 7-12, that despite the various changes in rankings, only one indicator that was previously in the top 15, fell out, namely *Road traffic noise levels* which fell one notch from No. 15 to No. 16. This indicator is replaced in the top 15 by *Energy consumption by the transport sector*, which, as previously stated, jumped three notches from No. 16 to No. 13.

Having completed 1000 monte carlo simulation runs in which the various ELASTIC inputs were varied for each indicator in the preliminary subset, the 15 consistently best performing indicators, i.e., those with the highest mean WIPS after sensitivity analysis, are now clearly illuminated.

This final suite of the 15 best performing and most appropriate sustainable transport indicators for England, based on the values of English Transport Planners and transport-related Academics are shown in Table 7-14 below.
Chapter Seven: Application of ELASTIC to England – Results and discussions

<table>
<thead>
<tr>
<th>Rank</th>
<th>Indicators</th>
<th>WIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorised Traffic Volume</td>
<td>31.568</td>
</tr>
<tr>
<td>2</td>
<td>Number of Cycling Trips</td>
<td>30.602</td>
</tr>
<tr>
<td>3</td>
<td>Vulnerable Road User Accidents</td>
<td>29.495</td>
</tr>
<tr>
<td>4</td>
<td>Local Air Pollutants</td>
<td>28.527</td>
</tr>
<tr>
<td>5</td>
<td>Modal share of Public Transport</td>
<td>27.740</td>
</tr>
<tr>
<td>6</td>
<td>Percentage Freight transported by Road</td>
<td>27.627</td>
</tr>
<tr>
<td>7</td>
<td>CO₂ emissions from Transport</td>
<td>27.626</td>
</tr>
<tr>
<td>8</td>
<td>Social/External costs of Transport</td>
<td>27.403</td>
</tr>
<tr>
<td>9</td>
<td>Public Awareness of Transport sustainability issues</td>
<td>27.184</td>
</tr>
<tr>
<td>10</td>
<td>Availability of key services locally</td>
<td>27.072</td>
</tr>
<tr>
<td>11</td>
<td>Quality of Public Transport</td>
<td>26.980</td>
</tr>
<tr>
<td>12</td>
<td>Total number of killed or seriously injured (in road accidents)</td>
<td>26.868</td>
</tr>
<tr>
<td>13</td>
<td>Energy consumption by the road transport sector</td>
<td>26.142</td>
</tr>
<tr>
<td>14</td>
<td>Length of cycling and walking Paths</td>
<td>25.978</td>
</tr>
<tr>
<td>15</td>
<td>Access to Public Transport Services</td>
<td>25.796</td>
</tr>
</tbody>
</table>

Table 7-13: Final suite of sustainable transport indicators for England

It is this set of 15 indicators that make up the Transport Sustainability Profile for England and is the ultimate output of ELASTIC. The indicators in this group of 15 represent a subset from the initial long list of indicators that have been selected systematically and in a way that reflects the values and judgements of the stakeholders surveyed, which in this case were Transport Planners and Academics.

7.9.1 Deriving context-specific TSPs for regions of England

A key attribute of ELASTIC is that it is capable of deriving TSPs that reflect the values and judgements of stakeholders in the specific areas to which the indicators are to be applied. To demonstrate this capability of ELASTIC, it was thought useful to apply the framework to derive sub-national indicators, reflecting the values of stakeholders in specified regions of England. To facilitate the demonstration, the country of England was divided into three broad regional groupings, reflecting the northern, central and southern regions as shown in Table 7-14 below.
Group 1 | Group 2 | Group 3
---|---|---
Northern Regions | Central Regions | Southern Regions
North East England | East Midlands | South East England
North West | West Midlands | South West England
Yorkshire and the Humber | East of England | London

Table 7-14: Regional groupings for derivation of TSPs for regions of England

Context-specific TSPs can be derived for each of the three groups simply by disaggregating the entire sample of stakeholders by the regional groupings and deriving weights for the various components of the ELASTIC value tree that would then reflect the specific values of the disaggregated groups.

When the full sample of stakeholders were split by the regional groupings shown in Table 7-14 above, the following region-specific weights were obtained for the criteria reflecting Methodological Quality.

<table>
<thead>
<tr>
<th>Regional Stakeholders</th>
<th>Measurability</th>
<th>Ease of Availability</th>
<th>Speed of Availability</th>
<th>Interpretability</th>
<th>Isolatability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>Northern England</td>
<td>0.197</td>
<td>0.135</td>
<td>0.169</td>
<td>0.110</td>
</tr>
<tr>
<td>Academics</td>
<td></td>
<td>0.250</td>
<td>0.188</td>
<td>0.144</td>
<td>0.136</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>0.222</td>
<td>0.160</td>
<td>0.157</td>
<td>0.120</td>
</tr>
</tbody>
</table>

| Transport Planners | Central England | 0.198 | 0.071 | 0.097 | 0.042 | 0.061 | 0.029 | 0.402 | 0.114 | 0.243 | 0.132 |
| Academics | | 0.228 | 0.148 | 0.144 | 0.051 | 0.072 | 0.047 | 0.308 | 0.200 | 0.249 | 0.135 |
| Total | | 0.208 | 0.103 | 0.114 | 0.050 | 0.064 | 0.036 | 0.368 | 0.154 | 0.245 | 0.131 |

| Transport Planners | Southern England | 0.286 | 0.128 | 0.211 | 0.140 | 0.060 | 0.028 | 0.264 | 0.115 | 0.179 | 0.135 |
| Region Academics | | 0.205 | 0.120 | 0.132 | 0.122 | 0.068 | 0.028 | 0.322 | 0.178 | 0.274 | 0.168 |
| Total | | 0.237 | 0.127 | 0.163 | 0.132 | 0.065 | 0.027 | 0.299 | 0.156 | 0.237 | 0.160 |

Table 7-15: Weights for the methodological criteria disaggregated by region

Similarly, when the stakeholders were disaggregated, the region-specific weights shown in Table 7-16 below were derived for the objectives of sustainable transport used in this application of ELASTIC.
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Regional Livable Streets & Protection of Equity & social Health and Economic Stakeholders

<table>
<thead>
<tr>
<th>Regional Stakeholders</th>
<th>Livable Streets &amp; Neighbourhoods</th>
<th>Protection of Environment</th>
<th>Equity &amp; social Inclusion</th>
<th>Health and Safety</th>
<th>Economic Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.143</td>
<td>0.061</td>
<td>0.175</td>
<td>0.169</td>
<td>0.180</td>
</tr>
<tr>
<td>Academics</td>
<td>0.190</td>
<td>0.166</td>
<td>0.219</td>
<td>0.195</td>
<td>0.176</td>
</tr>
<tr>
<td>Total</td>
<td>0.160</td>
<td>0.110</td>
<td>0.191</td>
<td>0.176</td>
<td>0.179</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.180</td>
<td>0.087</td>
<td>0.182</td>
<td>0.158</td>
<td>0.140</td>
</tr>
<tr>
<td>Academics</td>
<td>0.144</td>
<td>0.087</td>
<td>0.363</td>
<td>0.183</td>
<td>0.128</td>
</tr>
<tr>
<td>Total</td>
<td>0.169</td>
<td>0.087</td>
<td>0.239</td>
<td>0.184</td>
<td>0.136</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.133</td>
<td>0.081</td>
<td>0.136</td>
<td>0.086</td>
<td>0.166</td>
</tr>
<tr>
<td>Academics</td>
<td>0.147</td>
<td>0.067</td>
<td>0.199</td>
<td>0.126</td>
<td>0.196</td>
</tr>
<tr>
<td>Total</td>
<td>0.142</td>
<td>0.072</td>
<td>0.174</td>
<td>0.114</td>
<td>0.183</td>
</tr>
</tbody>
</table>

Table 7-16: Weights for objectives of sustainable transport disaggregated by region

The weightings for the ELASTIC sub-goals derived when the various stakeholders were disaggregated by region, are shown in Table 7-17 below.

<table>
<thead>
<tr>
<th>Regional Stakeholders</th>
<th>Methodological Quality</th>
<th>Relevance to sustainable Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.543</td>
<td>0.226</td>
</tr>
<tr>
<td>Academics</td>
<td>0.596</td>
<td>0.310</td>
</tr>
<tr>
<td>Total</td>
<td>0.562</td>
<td>0.254</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.440</td>
<td>0.237</td>
</tr>
<tr>
<td>Academics</td>
<td>0.382</td>
<td>0.231</td>
</tr>
<tr>
<td>Total</td>
<td>0.422</td>
<td>0.231</td>
</tr>
<tr>
<td>Transport Planners</td>
<td>0.444</td>
<td>0.224</td>
</tr>
<tr>
<td>Academics</td>
<td>0.444</td>
<td>0.224</td>
</tr>
<tr>
<td>Total</td>
<td>0.459</td>
<td>0.214</td>
</tr>
</tbody>
</table>

Table 7-17: Weights for the sub-goals disaggregated by region

Having derived the regional weights for the various ELASTIC sub-goals and criteria, the SAW model was applied and sensitivity analysis conducted to obtain a region-specific TSPs for each of the regional groups. These are shown in Table 7-18 below.
<table>
<thead>
<tr>
<th>Rank</th>
<th>Northern England</th>
<th>Mean WIPS</th>
<th>Central England</th>
<th>Mean WIPS</th>
<th>Southern England</th>
<th>Mean WIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorised Traffic Volume</td>
<td>33.041</td>
<td>Motorised Traffic Volume</td>
<td>31.478</td>
<td>Motorised Traffic Volume</td>
<td>31.300</td>
</tr>
<tr>
<td>2</td>
<td>Number of Cycling Trips</td>
<td>31.986</td>
<td>Number of Cycling Trips</td>
<td>30.375</td>
<td>Number of Cycling Trips</td>
<td>30.395</td>
</tr>
<tr>
<td>3</td>
<td>Vulnerable Road User Accidents</td>
<td>31.112</td>
<td>Local Air Pollutants</td>
<td>28.710</td>
<td>Vulnerable Road User Accidents</td>
<td>29.741</td>
</tr>
<tr>
<td>4</td>
<td>Local Air Pollutants</td>
<td>29.842</td>
<td>Vulnerable Road User Accidents</td>
<td>28.375</td>
<td>Local Air Pollutants</td>
<td>27.978</td>
</tr>
<tr>
<td>5</td>
<td>Modal share of Public Transport</td>
<td>29.300</td>
<td>Social Costs of Transport</td>
<td>28.290</td>
<td>Modal Share of Public Transport</td>
<td>27.775</td>
</tr>
<tr>
<td>6</td>
<td>Percent freight moved by road</td>
<td>29.180</td>
<td>Public Awareness of sustainability issues</td>
<td>27.840</td>
<td>Social Costs of Transport</td>
<td>27.305</td>
</tr>
<tr>
<td>7</td>
<td>CO₂ emissions from Transport</td>
<td>29.133</td>
<td>CO₂ emissions from Transport</td>
<td>27.634</td>
<td>Public awareness of sustainability issues</td>
<td>27.212</td>
</tr>
<tr>
<td>8</td>
<td>Quality of Public Transport</td>
<td>29.014</td>
<td>Percent freight moved by road</td>
<td>27.542</td>
<td>Availability of key services locally</td>
<td>27.162</td>
</tr>
<tr>
<td>9</td>
<td>No. killed or seriously injured</td>
<td>28.617</td>
<td>Availability of key services locally</td>
<td>27.122</td>
<td>Percent freight moved by road</td>
<td>27.119</td>
</tr>
<tr>
<td>10</td>
<td>Energy consumption by road transport</td>
<td>27.734</td>
<td>Modal share of Public Transport</td>
<td>27.015</td>
<td>CO₂ emissions from Transport</td>
<td>26.980</td>
</tr>
<tr>
<td>11</td>
<td>% of Pop’n affected by high noise levels</td>
<td>27.577</td>
<td>Access to Public Transport</td>
<td>25.976</td>
<td>No. killed or seriously injured</td>
<td>26.942</td>
</tr>
<tr>
<td>12</td>
<td>Availability of key services locally</td>
<td>27.471</td>
<td>Length of cycling and walking paths</td>
<td>25.974</td>
<td>Quality of Public Transport</td>
<td>26.837</td>
</tr>
<tr>
<td>13</td>
<td>Public awareness of sustainability issues</td>
<td>27.314</td>
<td>Energy consumption by road transport</td>
<td>25.972</td>
<td>Length of cycling and walking paths</td>
<td>26.042</td>
</tr>
<tr>
<td>15</td>
<td>Total number of road vehicles</td>
<td>26.657</td>
<td>% of Pop’n affected by high noise levels</td>
<td>25.723</td>
<td>Total number of road vehicles</td>
<td>25.703</td>
</tr>
<tr>
<td>16</td>
<td>Length of cycling and walking routes</td>
<td>26.495</td>
<td>Transport wastes</td>
<td>25.645</td>
<td>Energy consumption by road transport</td>
<td>25.668</td>
</tr>
<tr>
<td>17</td>
<td>Energy Efficiency of Transport</td>
<td>26.188</td>
<td>Transport wastes recycled</td>
<td>25.265</td>
<td>Total number of road vehicles</td>
<td>25.312</td>
</tr>
<tr>
<td>18</td>
<td>Access to Public Transport</td>
<td>26.147</td>
<td>% of Pop’n affected by high noise levels</td>
<td>24.728</td>
<td>Transport related wastes</td>
<td>24.445</td>
</tr>
<tr>
<td>19</td>
<td>Transport related Wastes</td>
<td>25.498</td>
<td>Total number of road vehicles</td>
<td>24.152</td>
<td>Participation in transport planning</td>
<td>24.278</td>
</tr>
<tr>
<td>20</td>
<td>Crimes committed on or waiting for Transport</td>
<td>24.103</td>
<td>Crimes committed on or waiting for Transport</td>
<td>23.439</td>
<td>Crimes committed on or waiting for Transport</td>
<td>23.697</td>
</tr>
</tbody>
</table>

Table 7-18: Choice and ranking of indicators (after 1000 simulations) based on the values of the disaggregated sample of stakeholders
7.10 Critical assessment of ELASTIC's processes and outputs

As stated in section 7-1, the demonstration of ELASTIC presented in this chapter is intended only to serve as 'proof of concept' and to show how the framework can be applied to obtain a suite of sustainable transport indicators. Consequently, the indicators derived from this demonstrative process are not intended to be definitive.

In any case however, when applying a methodological framework such as ELASTIC, there will logically be a need to obtain some indication of the veracity and usefulness of its outputs, and as such, checks and tests of whether the method has indeed derived key sustainable transport indicators in line with its stated tenets, will be necessary.

It will be recalled for example, that in Chapters three and five, various desirable characteristics and roles of indicators and indicator frameworks were specified. Similarly, the aims of ELASTIC and the expectations of UK stakeholders as elucidated through their expressed views on sustainability and their weightings of sustainable transport objectives, have been presented in earlier chapters. Given that these issues collectively provide a 'wish list' of sorts for sustainable transport indicators in this application, it would be useful to examine how well they are met by ELASTIC’s processes and outputs as have been presented in this chapter.

In that regard, the suite of indicators shown in Table 7-13, which was obtained from the application of ELASTIC to England, will be critically examined in the subsections below with a view to assessing how well they meet key desirable characteristics as have been discussed during the course of this thesis.
7.10.1 The TSP and desirable characteristics of indicators

By virtue of the fact that the ELASTIC process is guided by the evaluation of indicators against, *inter alia*, five key criteria related to the desirable characteristics of the indicators, it would be expected that the indicator set would collectively meet most of the desirable attributes specified in Box 3-2.

Indeed, the majority of the 15 final indicators met the criterion 'Measurability' quite well. The exceptions were the indicators *Quality of public transport* and *Access to Public Transport Services* which are both less amenable to measurement than the others in the indicator suite.

Similarly, all the indicators met the criterion of 'Significance' in some way or the other. This was expected as the ELASTIC indicator selection process proceeds, in part, by evaluating indicators based on how well they reflect key objectives of sustainable transport. As such, every indicator will reflect in some way, at least one key objective of sustainable transport. By extension, this process also meant that the criterion 'Policy Relevance' was also met by every indicator, in some way or another.

The indicators also do well where the criterion 'Logically or scientifically defensible' is concerned. Again, this is due to the fact that in selecting the suite of indicators, a key requirement was that the indicator must be 'interpretable'. The consideration of this criterion in the selection process was further strengthened by the fact that 'interpretability' was given a very high weighting by the stakeholders surveyed.

'Speed of availability' and 'Ease of Availability', the two methodological criteria weighted lowest by stakeholders, were not always met by the selected set of suite of indicators shown in Table 7-13. The indicators *Social costs of transport* and *Public participation in transport planning* are not even published and their calculation is contentious at best. However, because these criteria were weighted lowest, shortcomings in indicator performance were neutralised by better performance on more heavily weighted criteria. An obvious problem here is that there is a possibility that a suite of indicators could be...
derived which, though theoretically measurable, may not have the data readily available to enable such measurement. Whether this potential problem can be alleviated, for example, by specifying constraints in the ELASTIC evaluation process to ensure that indicators that perform below a specified threshold on a given criteria are excluded from inclusion in the TSP, will be discussed in the concluding chapter of this thesis.

7.10.2 The TSP and the SWOC matrix

Figure 4-5 previously summarised, in the form of a Strengths – Weaknesses – Opportunities – Challenges (SWOC) matrix, the key findings of the critical review of the sustainability assessment literature that informed the subsequent development of the ELASTIC framework. Logically therefore, in evaluating the application of ELASTIC presented in this chapter, it would be useful to assess how the demonstrated ELASTIC process and the consequent outputs have addressed the issues identified in the matrix.

Strengths of current frameworks identified in the literature

Four key strengths of existing sustainability indicator frameworks were shown in the matrix (Figure 4-5). ELASTIC has incorporated and built on these strengths.

In determining the key criteria against which indicators were evaluated, ELASTIC drew heavily from 'key sustainability themes and objectives' that had been proposed in the sustainability assessment literature. Recognition of the 'need for stakeholder participation' was another strength in current sustainability literature that ELASTIC built upon by providing a robust method for eliciting and synthesising stakeholder views within the sustainability assessment context.

Lastly, ELASTIC capitalised fully on the 'availability of a large pool of sustainability indicators' that have resulted from the numerous indicator-based sustainability assessments undertaken. Indeed, in applying ELASTIC to England, no new indicators were developed. Instead, a subset was selected from the large pool that already exists.
Weaknesses of current frameworks and consequent opportunities

It will be recalled that in Chapter four, various weaknesses were identified in previous sustainability assessment exercises, which in turn presented opportunities (i.e., gaps) for ELASTIC to address. Two key weaknesses identified were that indicator selection in previous applications often tended to be 'arbitrary and ad hoc' and that 'no systematic approaches existed for including stakeholder views' in the assessment process. ELASTIC has endeavoured to overcome these weaknesses by providing a robust and systematic approach for indicator-based sustainability assessment, which incorporates among other things, pairwise comparison surveys together with the application of AHP, to elicit and synthesise stakeholder views.

Another key weakness identified in the critical review of past indicator-based sustainability assessment was that 'the selection of themes often poorly reflected the system'. Again ELASTIC has endeavoured to alleviate this problem by providing a framework where the selection of indicators is lead by key objectives of sustainable transport. As such, it is intended that the selected indicators will adequately reflect transport sustainability within the context in which they is applied. (Section 7.10.3 below discusses how well this 'intention' was met in the application of ELASTIC to England).

Challenges identified from the literature

In developing and applying ELASTIC, it was necessary to overcome two key challenges identified in the literature. A first challenge was the sheer broadness and complexity of the concept of sustainability. ELASTIC has endeavoured to address this challenge by developing a framework that links indicators to key themes which in turn are taken as having decomposed the 'broad' concept of sustainability. Another related challenge was the difficulty in achieving an assessment tool flexible enough for applicability in a range of contexts. It would appear that ELASTIC has demonstrated itself to be very strong in this respect. As shown by the three suites of indicators for three different regions of England in Section 7.9.1, the method derives a different suites of indicators depending on the stakeholders surveyed. In doing so, ELASTIC demonstrates a high level of context-specificity and flexibility.
7.10.3 'Completeness' of the objectives and the subsequent indicators

It will be recalled from Chapter five, that in organising hierarchical frameworks such as ELASTIC, a very important requirement is that it meets the criterion of 'Completeness'. Keeney (1992) states that if a 'tree is complete, all the criteria that are of concern would have been included'. In the context of ELASTIC, the issue of concern is obviously sustainable transport, and therefore, if ELASTIC is to have addressed the issue of sustainable transport adequately, then the range of objectives of sustainable transport that it incorporates must be broad enough to cover the issue of sustainable transport 'completely'.

Indeed, the concept of 'completeness' can also be extended to the indicators themselves. In this case, if the suite of indicators selected is 'complete' then they should adequately cover the range of 'sustainable transport objectives' against which they are evaluated and by extension, the concept of sustainable transport that those objectives represent.

7.10.3.1 Completeness of the set of objectives of sustainable transport

Determining the range and number of objectives for entry into any ELASTIC application will ultimately be a difficult task, as the practical requirement to minimise the number of objectives for consideration by stakeholders will inevitably conflict with the need to adequately encompass the broad concept of sustainable transport. In the application demonstrated in this chapter, five key objectives for sustainable transport were specified based on review of the sustainability assessment literature and specific UK policy documents. It was previously shown in tables 2-1 and 6-5 that there was a reasonably good fit between the ELASTIC objectives and those of the UK sustainable development strategy and the various academic sources.

Due to the broadness of the application however, i.e., to an entire country, it is possible that in some areas or to some stakeholders, the key issues may have been different than the five specified in this application. ELASTIC aims to be flexible and has endeavoured to capture the difference in importance weightings that will be given to different
objectives in different contexts. In this application however, no consideration was given to the fact that a 'complete' set of objectives in one context may not be 'complete' in another. Theoretically, ELASTIC is indeed capable of capturing such 'completeness', as the framework allows different objectives to be utilised in different application. To truly capture 'completeness' in this application for example, a preliminary survey would have been necessary in every context in which ELASTIC is to be applied, to ascertain Stakeholders' views on the sustainability objectives relevant to their context. This would then have been followed by another survey to attach weights to these identified objectives.

7.10.3.2 Completeness of the indicator set

Of equal importance in ascertaining the 'soundness' of the derived TSP is to assess the 'completeness' of its complement of indicators. In this case, if the indicator set is complete, it will reflect the values of the stakeholders as implied by the given sustainability goals in the ELASTIC value tree and their weightings. Indeed, it should be noted that because varying priorities are assigned to objectives, it is possible that they will not be reflected equally. One would expect at least however, that the indicators would capture the stakeholders' interpretation of sustainability by reporting on the key objectives in line with their priorities.

A cursory glance at the final suite of 15 indicators shown in Table 7-13 shows that it covers all the objectives of sustainable transport in some way or the other. Because the ELASTIC method gives an aggregate score to indicators based on their performance, *inter alia*, across all objectives, most of the indicators in the set are those that impacted multiple objectives. There are however some indicators which, whilst impacting multiple objectives, had a high relevance to one or two. This is the case for example with *Vulnerable Road User Accidents* which clearly has a high relevance to the objective 'Health and Safety'. Similarly, *Local Air Pollutants* has a high level of relevance to 'Livable Streets and Neighbourhoods' as well as 'Protection of the Environment'.
Two objectives particularly did not seem as singularly well represented by the indicator set as others. These were ‘Equity and social inclusion’ and ‘Support of a vibrant and efficient economy’. As previously stated, due to the ELASTIC approach, these objectives would have been captured aggregatively by a number of indicators. However, ‘Equity and Social Inclusion’ was only singularly represented once, i.e., by the indicator Access to Public Transport Services. Similarly, ‘Support of a vibrant and efficient economy’ was also only the key focus of a single indicator, Social/External costs of transport. Again, the question of whether this potential issue can be addressed by including constraints in the ELASTIC process to ensure, for example, that each objective is singularly reflected by a ‘specified’ number (or proportion) of indicators, will be discussed in the concluding chapter of this thesis.

7.10.4 The potential of the indicator set to aid decision making

A key test of any indicator set is to assess how well they could intuitively guide sustainable transport decision making. Box 3-3 had previously specified a set of ‘roles’ that a sound set of indicators could be expected to perform in the decision-making and communication process. An assessment of how well suited the suite of ELASTIC indicators shown in Table 7-13 to performing these roles would be very useful in determining their soundness. In that regard, each of these roles and the suitability of the ELASTIC indicators to performing them are looked at below.

- Capturing the multidimensionality of sustainable transport
In the context of ELASTIC, the multidimensionality of sustainability is taken to be represented by the sustainable transport objectives. Within the indicator set shown in Table 7-13, each objective has been represented, although as previously alluded some are reflected less clearly than others.

- Highlights problems and set priorities for action
The ELASTIC indicators are based on broad priorities (i.e., key objectives) for sustainable transport. However, the indicators are intended to subsequently identify,
within the context of these broad themes, specific priorities that can be looked at. The 15 indicators in Table 7-13 each specify a key issue that should be reported on. In so doing, they are setting these specific issues as priorities for action.

- **Breaks down complex problems**
  As far as ELASTIC is concerned, the indicators represent the ultimate decomposition of the concept of sustainability. As stated earlier however, some sustainability issues are represented within the indicator set more clearly than others. Therefore, it is questionable that the indicator set has indeed broken down the complex concept of sustainability. This would have been truly ascertainable if the indicators were actually applied.

- **Well suited for feeding into policy analysis**
  Section 7.10.1 previously raised the identified problem that there were indicators in the final ELASTIC suite for which data is difficult to collect or for which the required data is produced infrequently. This certainly raises a question about the suitability of the current indicator suite for policy analysis. If the data cannot be derived or is highly infrequent, the indicators' usefulness for policy analysis will undoubtedly be minimised.

- **Amenable to comparison and benchmarking**
  All the indicators in the suite are capable (theoretically) of being measured. If they were all to be measured therefore, they would be useful for comparison and benchmarking. However, as highlighted above, there are problems with some of the indicators in the suite with regards to the availability and frequency of data to enable such measurement.

- **Educating the Public**
  The indicator in the TSP with which the public would be least familiar is *Social/External costs of transport*. However, the logic behind the subject of 'externalities' is conceptually easily understandable, and as such, is likely to be clear to the public if well explained. Apart from *Social/External costs of transport*, the other indicators are concerned with issues that are widely known. It would therefore be expected that if data was available for robust measurement, the indicator set could serve useful for educating the public.
7.11 Summary

This chapter has presented the results of the application of ELASTIC to England, UK. The inputs into this specific application, including the attendant surveys had been previously described in Chapter six. The first sections of the questionnaires sent out in the ELASTIC surveys elicited various information from the respondents geared at gaining some general background information about them as well as obtaining their views on the philosophical approaches of the ELASTIC framework.

The responses and views expressed in these preliminary sections of the completed questionnaires generally validated ELASTIC’s approach. For example, almost all respondents indicated that sustainable transport is a goal within their respective professions, but the majority also stated that no framework existed within their work environments to aid them in assessing progress towards this goal. This suggests, inter alia, that there is a need for a framework like ELASTIC that can aid and guide such assessment. Similarly, an overwhelming majority of the stakeholders surveyed expressed the view that multiple indicators, such as those at the core of the ELASTIC approach, provide the most feasible tools for sustainable transport assessment. The views of the two samples of transport specialists were also garnered with regard to the involvement of stakeholders in the sustainable transport decision making process. Analysis of their responses showed that there is currently a great discrepancy between the influence that some stakeholder groups have on the transport planning process, and their importance to achieving the goal of sustainable transport. ELASTIC which is inherently capable of incorporating the views of multiple stakeholders can assist in ameliorating such anomalies by providing a mechanism through which the views of those who are seldom heard can be captured and incorporated into the transport decision making process.

Once the sections of the questionnaires that elicited background information from the stakeholders had been analysed, the weights of the various components of the ELASTIC value tree were then derived from the judgements expressed in the pairwise comparisons undertaken by the respondents. The results and subsequent statistical comparisons showed that there were no significant differences in the weights attributed to the various
methodological criteria by the two stakeholder groups whose judgements were elicited. On the other hand however, subsequent statistical tests showed that there were statistically significant differences in the weights attributed by Transport Planners and Academics to one sustainable transport objective, namely Protection of the Environment. As with the methodological criteria, there were no significant differences in the weights attributed to the two sub-goals.

The long list of indicators were then scored against the various criteria. The outcome scores from this evaluation of performance were aggregated with the sub-goal and criteria weights using the Simple Additive Weighting (SAW) model to obtain Weighted Indicator Performance Scores (WIPS) for each indicator. Initially, the top 20 best performing indicators were selected. After a high-dimensional sensitivity analysis using monte carlo simulation however, this preliminary subset was reduced to a final suite of 15 indicators which made up the Transport Sustainability Profile (TSP) for England.

To further demonstrate the ability of ELASTIC to derive context-specific indicators and rankings, the stakeholders were dividing into three regional groupings broadly reflecting the northern, central and southern regions of England. Region-specific weights for the various sub-goals and criteria were obtained and entered into the ELASTIC process to derive TSPs reflecting the specific judgements of stakeholders in the specified regions.

This chapter has fully demonstrated the capabilities, applicability and practicality of ELASTIC. A critical analysis at the end of the chapter indicated however, that there are some areas where ELASTIC's process could be improved and where its resultant indicators, as applied to England, may prove inadequate in some respects. The platform has therefore been set for drawing conclusions for the research process and application, and for suggesting directions through which ELASTIC can be improved and further tested in the future. These are addressed in the next chapter.
CHAPTER EIGHT: Conclusions of the research

8.0 Overview

This chapter concludes the thesis by reflecting on the outcomes of the research in relation to the stated aims and objectives. After assessing the extent to which the aims and objectives have been met, the contributions of the thesis to sustainable transport planning research and practice are then discussed. As is traditional, the chapter concludes with recommendations for further work.

8.1 A novel methodological approach to indicator selection

It will be recalled that the main aim of this thesis was to develop and apply a generic and transferable methodological framework that will facilitate the selection of key indicators which can then guide the assessment and monitoring of the sustainability of a given transport system.

This overall aim and the attendant objectives of the research have been met.

The main output of this thesis has been the Evaluative and Logical Approach to Sustainable Transport Indicator Compilation (ELASTIC), a methodological framework which provides a flexible, participatory and systematic approach for selecting sustainable transport indicators. The ultimate output of ELASTIC is the Transport Sustainability Profile (TSP), a suite of indicators which when presented together can provide an insight into the sustainability of a transport system.

At its most basic, ELASTIC applies a rigorous process to ensure the selection of a minimal number of high quality and highly relevant indicators for inclusion in the TSP. At the heart of the ELASTIC methodology is the application of Multi-Criteria Decision Analysis (MCDA), a proven family of techniques for simplifying complex decision
problems that are characterised by multiple and often conflicting objectives and criteria. MCDA techniques have numerous advantages that make them suitable for application in the sustainability assessment context. Among other things, MCDA techniques are capable of accommodating numerous criteria in the analysis, enable direct involvement of multiple stakeholders, explicitly illuminate trade-offs among fundamental concerns and allow for the decomposition of complex decision problems into manageable components.

To achieve a small suite of key indicators, i.e., the TSP, ELASTIC sets two overarching sub-goals that guide the indicator selection process:

1. To maximise the methodological quality of the indicators;

2. To maximise the relevance of indicators to the concept of sustainable transport.

These sub-goals are subsequently decomposed into several lower-level criteria. To meet the participatory tenet of ELASTIC, numeric weights of importance weights are assigned to the sub-goals and criteria based on the expressed judgements of those stakeholders who may affect or be affected by the outcome of the sustainable transport assessment process. A review of available MCDA techniques showed that the Analytic Hierarchy Process (AHP), a weighting technique developed by Saaty (1980), is best suited for the weighting of the various sub-goals and criteria inherent in ELASTIC. The suitability of AHP was due, inter alia, to its theoretical soundness, its structured approach and the clear illumination of trade-offs both in the weights derived and in the presentation of the decision problem to stakeholders.

To undertake the evaluation of potential indicators against these criteria, the ELASTIC approach is for the Analyst to apply a ‘direct rating’ scoring system to assign outcome scores to the indicators in the initial long list based on their performance on each criterion. The importance weights attributed to the sub-goals and criteria based on the judgements of stakeholders and the outcome scores attributed to indicators by the Analyst
are then combined using the ‘Simple Additive Weighted’ (SAW) model to derive an overall Weighted Indicator Performance Score (WIPS) for each indicator. It is then a basic process to select a preliminary subset of those indicators with the highest WIPS.

To ensure however, that the selection is robust and stable, a high-dimensional sensitivity analysis is undertaken using monte carlo simulation in which all ELASTIC inputs are varied in numerous simulated model runs so that resultant changes in the WIPS can be observed. The ELASTIC approach is then for a smaller suite of the consistently best performing indicators after multiple simulations to be taken forward.

ELASTIC was demonstrated in this thesis through application to England, UK. The values of two categories of stakeholders, namely English Municipal Transport Planners and transport-related Academics at English Universities, were used in the analysis to select a suite of 15 sustainable transport indicators for England, from an initial set of 200. It is this suite of 15 indicators that is taken to make up the Transport Sustainability Profile (TSP). By disaggregating the samples of stakeholders into broad regional groupings, it was also possible to derive context-specific TSPs for these specified English regions.

8.2 Contributions of the thesis to knowledge

Naturally, the main contributions of the research have stemmed from, or are related to ELASTIC, the novel methodological framework developed and presented in this thesis that enables the assessment of sustainable transport based on the systematic and rigorous derivation of a Transport Sustainability Profile (TSP) - a suite of indicators which when shown together can provide an insight into the sustainability of a transport system. As a consequence of the tenets on which it is based, as well as the process that it employs, the ELASTIC framework, and its application to England described in this thesis, provides various benefits for sustainable transport planning practice and research.

It will also be noted however, that the ultimate development of ELASTIC was only possible after extensive scoping and review of past applications and discussions of
indicator-based sustainable transport assessment. These scoping stages of the research facilitated the identification of strengths, needs and gaps in current sustainable transport assessment, which in addition to guiding the development of ELASTIC, can also inform future work and research on sustainable transport assessment.

The key contributions to knowledge that have been facilitated by the development of ELASTIC as a framework, the attendant scoping processes that preceded and guided its development, and its application to England, are discussed below.

Illumination of current strengths and gaps in sustainable transport assessment
As alluded to above, an extensive review of the literature and past work on sustainable transport assessment was conducted as part of this research. Using a Strengths Weaknesses Opportunities Challenges (SWOC) analysis, valuable features of current approaches and needs for future research were subsequently identified from the review. Key strengths of current and past approaches to indicator-based sustainable transport assessment include the specification and linkages of indicators to themes, the recognition of the need for stakeholder participation and the availability of a large pool of indicators. On the other hand, weaknesses of current approaches include arbitrariness of indicator selection, poor reflection of the system provided by resultant assessments, the absence of systematic approaches for incorporating stakeholder values and inadequate recognition of context. As a consequence of the above gaps, several opportunities for future work on sustainable transport assessment were identified, such as the need for systematisation of the processes and criteria that determine indicator choice, development of a systematic approach for eliciting and incorporating stakeholder values in assessment and building flexibility into assessment frameworks so that they can adequately reflect context. Recognising the challenges posed by the complexity and broadness of the concept of sustainability, the subsequent research effort was geared at developing an approach that built on the strengths identified while addressing the gaps and weaknesses. The resultant outcome of that aspect of the research is discussed below. However, it must be pointed out that the strengths, weaknesses, gaps and opportunities illuminated by the review can also aid wider understanding of the pertinent aspects of sustainable transport assessment.
A novel and systematic approach for sustainable transport indicator selection
To address the gaps identified in the review of current and past applications of indicator-based sustainable transport assessment, the main output of this thesis has been the Evaluative and Logical Approach to Sustainable Transport Indicator Compilation (ELASTIC), a methodological framework that provides a rigorous approach for selecting key indicators of sustainable transport. Given its inherent systematic processes, ELASTIC enables indicators to emerge more naturally and can be adjusted to suit the needs of a given locale or a set of stakeholders. As with any decision analysis tool however, ELASTIC will not solve the indicator selection problem, nor is it intended to do so. Its purpose is to provide insight and promote structure and due process to help decision makers make better decisions in the context of sustainable transport assessment.

Among the many benefits of this systemisation, is that the various stages of the process can be clearly shown to those interested in order to justify and explain if necessary, why a particular indicator was selected, or not selected. Similarly, if questions are raised later and there is a need to audit the indicator selection process, ELASTIC provides a clear structure that can be revisited to enable such auditing. Consequently therefore, indicator-based assessment facilitated by ELASTIC can enhance the credibility of the selected indicators and the consequent assessment process.

An approach for operationalising the concept of sustainable transport
Given that the ELASTIC framework is driven, *inter alia*, by sustainable transport objectives, as ranked by relevant stakeholders, the process can provide a conceptual description of the various components and phenomena of the transport system that are relevant to sustainability within that specific context, and the trade-offs among them as determined by the stakeholders. Given the fuzzy nature of sustainable transport, the highlighted objectives and the trade-offs, as well as the consequently chosen indicators, can play a valuable role in translating the nebulous concept of sustainable transport into clearer practical terms since together they would reflect those themes, issues and concerns that are taken by relevant stakeholders to be of most importance to the transport sustainability.
Chapter Eight: Conclusions of the research

A mechanism for capturing and entering stakeholder values into assessment

Participation of those who can affect or may be affected by the decision is key to sustainability analysis. Examination of previous work had shown an absence of any robust and auditable mechanisms for capturing stakeholder values and entering them into the sustainable transport assessment process. ELASTIC remedies this situation by providing a robust method for capturing and entering stakeholder values and judgements into sustainability analysis. Stakeholder values are elicited via pairwise comparisons of desirable characteristics of indicators and key objectives of sustainable transport. The judgements expressed in these pairwise comparisons are then analysed using the Analytic Hierarchy process (AHP) to derive quantified weights of importance for each criterion and sub-goal. These quantified weights of importance are therefore based on the preferences and judgements of stakeholders, and since they form the basis for indicator selection and ultimately for the sustainable transport assessment process, ensure that stakeholder values are incorporated in the analysis.

The process of eliciting, analysing and entering stakeholder values into the sustainable transport assessment process have been described fully in this thesis and has been demonstrated through the application of ELASTIC to England, UK.

'Proof of concept' of a new approach to sustainability assessment

The thesis was concerned with developing a novel methodological framework for indicator-based sustainable transport assessment. A key element of the research however, was the actual application of the framework to England which was described in Chapters six and seven. This application has served as a valuable 'proof of concept' in that it has demonstrated the way in which the various steps of ELASTIC are undertaken in practice and indeed, ELASTIC's ability to derive a subset of key indicators. This application also showed that while representing a useful contribution to existing knowledge, there is still a need for further refining and adjustment of ELASTIC. Suggestions on the direction that such refinements may take are discussed in section 8.4.
8.3 Limitations of the research

There were several time and other constraints placed on this research by the fact that it was undertaken within the context of a Ph.D. As such, there were aspects of the work, that in an ideal setting could have been undertaken differently. This was especially the case with the application of the ELASTIC framework to England. Two particular aspects that could have enhanced this application would have been (i) inclusion of a broader range of stakeholders groups and (ii) assignment of outcome scores to indicators by a team of Analysts. These are each explained below in turn.

Inclusion of a broader range of stakeholder groups
In the application of the ELASTIC framework to England, the views and judgements of two key groups of stakeholders were elicited, namely Municipal Transport Planners and transport-related Academics. While these groups were useful for the purpose of demonstrating the framework and were especially well-placed to provide insightful judgements due to their professional interests, the reality is that they represent only two of the many stakeholder groups relevant to the sustainable transport planning context. The research sought to overcome this shortcoming by surveying larger samples than is generally required in MCDA applications. A suite of indicators based on the judgements of a broader range of stakeholders however, would have been more representative.

Assignment of outcome scores to indicators by a team of analysts
The assignment of outcome scores to indicators during the application of ELASTIC to England, was undertaken by a single analyst. To ensure the highest levels of objectivity in the outcome scores attributed to indicators however, evaluation of indicators by a team of analysts would have been more appropriate. Given the time and financial constraints under which the Ph.D was undertaken, as well as the number of entries that were required, i.e., 2000, it was not possible to assemble a team of experts to undertake the assignment of outcome scores. The research has endeavoured to minimise any possible biases in assignment of outcome scores by using respected publications for guidance, stating narratively in a separate spreadsheet database the reasons why a particular score was assigned and by conducting a robust high-dimensional sensitivity analysis.
8.4 Recommendations for further work

The underlying methodology of ELASTIC is sufficiently robust. As alluded in the previous section of this chapter however, it may be possible to better illuminate the practicality of the framework through application to a wider array of stakeholders. Moreover, while the ELASTIC framework provides a robust mechanism for selecting sustainable transport indicators, there may be need for further research to maximise the usefulness of these key indicators for the planning process once they have been selected. Some of the key research opportunities and recommendations for further work are discussed below.

**Application of ELASTIC to differing contexts and a wider range of stakeholders**

As previously discussed, the application of ELASTIC in this thesis has been within a specific geographic context and was based on the values of select groups of stakeholders. It would therefore be useful to test and demonstrate the applicability of ELASTIC to various other geographical and spatial contexts and with a wider range of stakeholder groups. There is the possibility, among other things, that the weight elicitation technique and attendant survey processes may have to be modified to suit other stakeholders. A questionnaire based on pairwise comparisons as applied in the application described in this thesis for example, may not be appropriate for 'the ordinary man on the street'.

**Investigating the potential for reference values and targets for indicators**

There has long been a desire among sustainability analysts for the specification of targets and reference values for indicators that would illuminate arrival at threshold levels. Similarly, many of the UK Government's indicator programmes discussed in Chapter six mandate regional and local authorities to set targets to show goal achievement. A key benefit of setting reference values for indicators is that they can then facilitate benchmarking which translates general assessment into clear categories of 'good', 'average' or 'bad' performance. Setting such reference values is not a trivial task however, due to the scientific uncertainty, spatially variable environmental and economic conditions and the qualitative character of some indicators. Identifying ways through which such reference values could be set would greatly enhance the utility of the indicators selected through the ELASTIC process.
Presentation of the indicators

Once the indicators have been selected using the ELASTIC framework, they then need to be presented to stakeholders and interested parties in a way that adequately communicates overall system performance. The small suite of key indicators go a long way towards providing such information in an interpretable way, and are preferable to long ad hoc lists. However, indicators, while presented holistically are still fundamentally individual units and when presented side by side, can only be viewed individually (Morse et al 2001). Development of a mechanism that can take the information inherent in these individual indicators selected by ELASTIC, to provide an overall or partial indication of the sustainability of a transport system would have many benefits.

Enhancing the quality of ELASTIC’s outputs

As discussed in the critical evaluation of the ELASTIC process and outputs presented in section 7-10, there is room for improvement in terms of how well the framework reflects the components of the broad issue of sustainability and how it ensures that its outputs are both usable and useful for sustainable transport decision making. A possible way through which the outputs of ELASTIC can be influenced to better mirror sustainable transport objectives and have greater compatibility with sustainable transport decision making, is by including constraints in the framework. Constraints may, for example, ensure that each objective is reflected at least by a pre-specified number of indicators, or that indicators must score a minimal value on one or more criteria to qualify for selection. Whether or not this, or any other modifications, will improve the quality of ELASTIC’s outputs is a question that should be addressed in future research.
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Appendices

Appendix A1: The pre-notification letter sent out to prospective survey participants informing them of the impending (first) questionnaire survey.

Appendix A2: The ‘Guide to Completing the Questionnaire’ sent out with questionnaires in the first stage of the survey process.

Appendix A3: Generic version of the Cover Letter sent with questionnaires in the first stage of the survey process.

Appendix A4: The actual questionnaire sent out to Transport Planners in the first survey.

Appendix A5: The actual questionnaire sent out to Academics in the first survey stage.

Appendix B1: The pre-notification letter sent out to prospective survey participants informing them of the impending (second) questionnaire survey.

Appendix B2: The ‘Guide to Completing the Questionnaire’ sent out with questionnaires in the second survey stage.

Appendix B3: Generic version of the Cover Letter sent with questionnaires in the second survey stage.

Appendix B4: The questionnaire sent out to Transport Planners in the second survey.

Appendix B5: The questionnaire sent out to Academics in the second survey stage.

Appendix C1: Normalised outcome scores assigned to indicators in the initial long list.
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Source</th>
<th>Description</th>
<th>Desired Direction</th>
<th>Methodological Quality</th>
<th>Relevance to Sustainable Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
<td>Emissions of NOx, VOC, SO2, CO and PMx</td>
<td>down</td>
<td>20.00</td>
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</tr>
<tr>
<td>2.</td>
<td></td>
<td>Noise Levels (% of pop affected by high noise levels)</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td>Fuel Consumption</td>
<td>down</td>
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</tr>
<tr>
<td>4.</td>
<td></td>
<td>Use of space by transport infrastructure</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td>Use of raw materials</td>
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<td>20.00</td>
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</tr>
<tr>
<td>6.</td>
<td></td>
<td>CO2 emissions</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>7.</td>
<td></td>
<td>Impact on flora and fauna</td>
<td>down</td>
<td>20.00</td>
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</tr>
<tr>
<td>8.</td>
<td></td>
<td>No. of scrapped cars per year</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td>Accessibility to services</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td>Road Transport Accidents</td>
<td>down</td>
<td>20.00</td>
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</tr>
<tr>
<td>11.</td>
<td></td>
<td>Quality of Public Transport</td>
<td>down</td>
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<tr>
<td>12.</td>
<td></td>
<td>Severance</td>
<td>down</td>
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</tr>
<tr>
<td>13.</td>
<td></td>
<td>Aesthetic impairment and negative impact on built heritage</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
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<tr>
<td>14.</td>
<td></td>
<td>Intra-generational equity</td>
<td>down</td>
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<tr>
<td>15.</td>
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<td>Public Participation</td>
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<tr>
<td>16.</td>
<td></td>
<td>Total road traffic in veh-km</td>
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<tr>
<td>17.</td>
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<td>Tolls paid by purpose</td>
<td>down</td>
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<tr>
<td>18.</td>
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<td>Car Occupancy</td>
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<tr>
<td>19.</td>
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<td>Average trip length by purpose</td>
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<tr>
<td>20.</td>
<td></td>
<td>Percentage of consumed goods produced locally</td>
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<tr>
<td>21.</td>
<td></td>
<td>Availability of local services (leisure, education, sport &amp; recreation)</td>
<td>down</td>
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<tr>
<td>22.</td>
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<td>Ratio of peak hour and off peak speeds</td>
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<td>0.00</td>
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<tr>
<td>23.</td>
<td></td>
<td>Total number of cars</td>
<td>down</td>
<td>20.00</td>
<td>0.00</td>
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<tr>
<td>24.</td>
<td></td>
<td>Number of passenger cars per 1000 people</td>
<td>down</td>
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<td>0.00</td>
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<tr>
<td>25.</td>
<td></td>
<td>Geographical distribution of traffic volume</td>
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<tr>
<td>Indicator</td>
<td>Source</td>
<td>Description</td>
<td>Desired Direction</td>
<td>Measurability</td>
<td>Availability</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>26</td>
<td>Modal Share of Public Transport</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>Modal share of Public transport modes.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>27</td>
<td>Length of traffic-free routes for cyclists and walkers</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>Length of segregated cycling and walking paths/routes.</td>
<td>![ ]</td>
<td>20.00</td>
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<tr>
<td>28</td>
<td>Percentage of road lengths in pedestrian areas with traffic calming</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>Roads with traffic calming as percentage of all roads.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>29</td>
<td>Car Ownership</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>% of households with access to a car.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>30</td>
<td>Net Present value of all transport costs and revenues</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>A summation of all internal, external and environmental costs, and revenues.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>31</td>
<td>Environmental Taxes as % of fuel costs</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>Environmental taxes as a percentage of fuel costs.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>32</td>
<td>Present value of money for promoting sustainability</td>
<td>Modelling For Sustainable Cities: The Transportation Sector (Kusnierzewski, 2007)</td>
<td>Total funds provided for promoting sustainable transport actions.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>33</td>
<td>Passenger trends by mode</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Passenger transport by mode expressed in passenger-km.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>34</td>
<td>Percentage height moved by road</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Road height transport by mode expressed as a percentage.</td>
<td>![ ]</td>
<td>20.00</td>
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<tr>
<td>35</td>
<td>Capital expenditure (total and by mode)</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>The total capital expenditure.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>36</td>
<td>Road network length</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Road network length in km and per unit area of national territory.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>37</td>
<td>Road vehicle stocks</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>The total number of vehicles.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>38</td>
<td>Break down of vehicle fleet by fuel type, age, class</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Structure of vehicle stocks by type of vehicle (passenger cars, goods vehicles) and type of fuel (diesel, petrol, 'clean vehicles').</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>39</td>
<td>Final energy consumption by the transport sector by mode and passenger</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>The relative contribution of transport to total final energy consumption.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>40</td>
<td>Population exposed to air pollution from transport</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Population exposed to air pollution from transport.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>41</td>
<td>Population exposed to transport noise greater than 65 dBA</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Population exposed to transport noise greater than 65 dBA.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>42</td>
<td>Transport-related waste</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total Transport-related waste.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>43</td>
<td>Transport waste recycled</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total Transport waste recycled.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>44</td>
<td>Social/External cost of transport</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>The total costs of transport's externalities on the environment and society.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>45</td>
<td>R&amp;D expenditure on eco-vehicles</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total R&amp;D expenditure on vehicles.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>46</td>
<td>R&amp;D expenditure on clean transport fuels</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total R&amp;D expenditure on clean transport fuels.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>47</td>
<td>Direct subsidies to transport</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total amount of funds directly allocated to subsidy of transport.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>48</td>
<td>Total economic subsidies (direct, implicit)</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Total amount of subsidies, direct and indirectly given to transport.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>49</td>
<td>Relative taxation of vehicle and vehicle use</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>The amount of taxes levied on vehicle use.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>50</td>
<td>Trends in public transport prices in real terms</td>
<td>Integrating concerns transport (OECD, 1999)</td>
<td>Rate of public transport prices.</td>
<td>![ ]</td>
<td>20.00</td>
</tr>
<tr>
<td>Indicator</td>
<td>Source</td>
<td>Description</td>
<td>Desired Direction</td>
<td>Meathodological Quality</td>
<td>Relevance to Sustainable Transport</td>
</tr>
<tr>
<td>----------</td>
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</tr>
<tr>
<td>Transport emission of greenhouse gases (CO2 and NOx) by road</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Transport emission of Carbon Dioxide and Nitrogen Dioxide by mode</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Population exposed to NOx exceeding EU air quality standards for Paris, NOx</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Populations exposed to air concentrations of selected pollutants, above current EU standards</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Fragmentation of ecosystems and habitats caused by transport</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Separation and Fragmentation of ecosystems and habitats caused by transport and transport infrastructure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity of transport infrastructure to designated areas</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Proximity of transport infrastructure to designated natural ecosystem sites</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access to transport services</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Availability of transport services (walking distance)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity of transport infrastructure networks, by mode and type of infrastructure (Motorway, national roads)</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>The number of vehicles that can be accommodated by transport infrastructure networks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of internalisation instruments, i.e., with a direct link to marginal external cost of different transport modes</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Levels of internalisation of external costs that exist</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Expenditure on personal mobility per person by income group</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Expenditure per person on personal mobility</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Overall energy efficiency of road transport</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Total transport activity undertaken per total energy consumed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Load factors for freight transport</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>The proportion of freight vehicle capacity that is utilised</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ispat of cleaner fuels and numbers of alternative-fuelled vehicles</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Number of alternative-fuelled vehicles</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average age of the vehicle fleet</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Average age of the vehicle fleet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of vehicle fleet meeting air and noise emission standards</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Proportion of vehicle fleet meeting air and noise emission standards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementation of a integrated transport strategy</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>The success of local authorities in implementing an integrated transport strategy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ispat of strategic environmental assessment in the transport sector</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Ispat of strategic environmental assessment in the transport sector</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Public awareness and behaviour</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Public awareness of sustainable transport initiatives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ispat of environmental management systems by transport companies</td>
<td>Transport &amp; Environment Reporting Mechanism (TEEM) (EUA 2002)</td>
<td>Ispat of environmental management systems by transport companies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of emissions of air pollutants from road transport</td>
<td>Sustainable Transportation Indicators Project (STIP) (Gilbert et al 2002)</td>
<td>Weighted index reflecting changes in each of four pollutants, i.e., CO, SO2, NOx and VOCs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index of incidence of road injuries and fatalities</td>
<td>Sustainable Transportation Indicators Project (STIP) (Gilbert et al 2002)</td>
<td>An index to show the change in the occurrence of injuries and fatalities over time.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Share of passenger travel not by land-based public transport</td>
<td>Sustainable Transportation Indicators Project (STIP) (Gilbert et al 2002)</td>
<td>Percentage of air travel by car/personal transport</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban land use per capita</td>
<td>Sustainable Transportation Indicators Project (STIP) (Gilbert et al 2002)</td>
<td>The amount of land used for urban purposes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indicator</td>
<td>Source</td>
<td>Description</td>
<td>Desired Direction</td>
<td>Measurability</td>
<td>Availability</td>
</tr>
<tr>
<td>-----------</td>
<td>--------</td>
<td>-------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>-------------</td>
</tr>
<tr>
<td>108</td>
<td>Relative household transport costs</td>
<td>Sustainable Transportation Indicators Project CIST (Gilbert et al. 2002)</td>
<td>Percentage of households spending on transport relative to total household expenditure</td>
<td>?</td>
<td>20.00</td>
</tr>
<tr>
<td>109</td>
<td>Index of the relative cost of urban travel</td>
<td>Sustainable Transportation Indicators Project CIST (Gilbert et al. 2002)</td>
<td>The ratio of the average public transport fare to the average cost of a litre of petrol, with the 1990 value of the ratio being set to 100</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>110</td>
<td>Energy intensity of cars and trucks</td>
<td>Sustainable Transportation Indicators Project CIST (Gilbert et al. 2002)</td>
<td>A weighted average of the energy intensities (in g CO\textsubscript{2} per unit distance of travel) for light, medium, and heavy vehicles at 1990 levels.</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>111</td>
<td>Emissions intensity of the road vehicle fleet</td>
<td>Sustainable Transportation Indicators Project CIST (Gilbert et al. 2002)</td>
<td>A weighted index of total vehicle CO\textsubscript{2} emissions from all road vehicles</td>
<td>20.00</td>
<td>20.00</td>
</tr>
<tr>
<td>115</td>
<td>Satisfaction with street cleanliness</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General satisfaction with cleanliness of streets</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>117</td>
<td>Reliability by mode</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>Reliability of transport services by mode</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>120</td>
<td>Satisfaction with quality of each mode</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General satisfaction with quality of service for each transport mode</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>121</td>
<td>Satisfaction with quality of public transport information</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General satisfaction with quality of transport information</td>
<td>20.00</td>
<td>40.00</td>
</tr>
<tr>
<td>122</td>
<td>Perception of quality/practicality of each mode</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General perception of the quality and practicality of each mode</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>124</td>
<td>Come on or when waiting for public transport</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General perception of the quality of public transport</td>
<td>20.00</td>
<td>10.00</td>
</tr>
<tr>
<td>125</td>
<td>Fear of crime when walking</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General perception of fear when walking</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>126</td>
<td>Satisfaction with consultation in transport planning and design</td>
<td>Civilising Cities Initiative (Jones et al. 2003)</td>
<td>General satisfaction with levels of consultation in transport planning and design</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>128</td>
<td>CO\textsubscript{2} cost</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>The actual CO\textsubscript{2} cost of transport, discounted by a value thought to represent marginal social cost of a small reduction of the sort that a national target has been reached</td>
<td>30.00</td>
<td>20.00</td>
</tr>
<tr>
<td>129</td>
<td>Air pollution cost</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>A weighted sum of local and regional air pollutants emitted by transport.</td>
<td>20.00</td>
<td>0.00</td>
</tr>
<tr>
<td>130</td>
<td>Noise cost</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>Unit cost of transport noise per veh km, by different class of vehicle, multiplied by the different classes of vehicle.</td>
<td>20.00</td>
<td>0.00</td>
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<td>131</td>
<td>Green area share</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>The area taken up by green area as a percentage of the total built area</td>
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<td>132</td>
<td>Main land uses (Transport)</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>The area of land for transport as a proportion of the total area of land</td>
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<td>133</td>
<td>Vulnerable user accidents</td>
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<td>Number of accidents involving pedestrians and a car, multiplied by average cost</td>
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<td>Local activity index</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>The measure of the attractiveness of an area as entered into a transport mode map (Top Generation of a residential choice model)</td>
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<td>135</td>
<td>Accident costs</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>Number of accidents multiplied by the unit costs of accidents of average severity</td>
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<td>137</td>
<td>Accessibility for those without a car</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>Consumer surplus per capita for those without a car as a proportion of overall surplus per capita</td>
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<td>Public transport performance</td>
<td>Methodological Guide Book - PROSPECTS (Minkin et al. 2003)</td>
<td>Frequency and geographical coverage of the public transport supply</td>
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<tr>
<td>Indicator</td>
<td>Source</td>
<td>Description</td>
<td>Desired Direction</td>
<td>Measurability</td>
<td>Availability</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-------------</td>
<td>------------------</td>
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<td>39</td>
<td>Quality of public transport for the mobility impaired</td>
<td>Methodological Guide Book - PROSPECTS (Mckeen et al. 2003)</td>
<td>Initial description of accessibility distances.</td>
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<td>Equity impact studies</td>
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<td>Consumer benefits plus compensation explained by group.</td>
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<td>43</td>
<td>Benefits accessibility by zone</td>
<td>Methodological Guide Book - PROSPECTS (Mckeen et al. 2003)</td>
<td>A map representation of the spatial distribution of benefits.</td>
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<td>Taxpayers money</td>
<td>Methodological Guide Book - PROSPECTS (Mckeen et al. 2003)</td>
<td>Net percentage of tax as a percentage of total net benefits.</td>
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<td>45</td>
<td>Growth Potential</td>
<td>Methodological Guide Book - PROSPECTS (Mckeen et al. 2003)</td>
<td>Sum of user benefits, producer surpluses and value of time.</td>
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<td>46</td>
<td>Social investment in Transport as % of GDP</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Investment by authorities in transport facilitation and technology.</td>
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<td>47</td>
<td>Consumer expenditure on sustainable transport</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Expenditure on consumer initiatives etc.</td>
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<td>Energy efficiency of road passenger travel</td>
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<td>Transport activity achieved per energy used.</td>
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<td>Harmful waste from transport</td>
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<td>Amount of hazardous waste produced from transport.</td>
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<td>Average km per mode of transport</td>
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<td>Total number of leisure trips by mode of transport.</td>
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<td>Modal share breakdown of students travel to school.</td>
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<td>58</td>
<td>Traffic congestion</td>
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<td>The amount of traffic congestion.</td>
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<td>Distance travelled relative to income</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Distance travelled relative to income.</td>
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<td>People finding access difficult</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Number of people who find it difficult to meet their transportation needs.</td>
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<td>Accessibility to jobs, shopping and leisure venues for disabled people.</td>
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<td>Fear of transport crime</td>
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<td>Perceived of crime and the likelihood of crime.</td>
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<td>10.00</td>
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<td>Rise in global temperature caused by transport</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Rise in global temperature caused by transport.</td>
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<td>10.00</td>
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<td>71</td>
<td>Deposition of fossil fuels caused by transport</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>The deposition of fossil fuels that can be attributed to transport.</td>
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<td>Ozone depletion caused by transport</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Ozone depletion in the ozone layer that can be attributed to transport.</td>
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<tr>
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<td>Acidification of UK caused by transport</td>
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<td>Acidification of the UK which can be attributed to transport.</td>
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<td>Prices of key resource fuel</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>The price of fuel.</td>
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<td>79</td>
<td>Awareness in schools</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Understanding and awareness in schools of sustainable transport.</td>
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<td>10.00</td>
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<td>80</td>
<td>Individual action for sustainable transport</td>
<td>Quality of life indexes (DETR 1999)</td>
<td>Actions taken by individuals to achieve sustainable transport.</td>
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</table>
## APPENDIX C1: Outcome scores assigned to Indicators in the initial long list

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Source</th>
<th>Description</th>
<th>Desired Direction</th>
<th>Measurability</th>
<th>Availability</th>
<th>Speed</th>
<th>Interpretability</th>
<th>Isotatle</th>
<th>Livable streets</th>
<th>Environment</th>
<th>Equity &amp; social</th>
<th>Health &amp; Safety</th>
<th>Efficient Economy</th>
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</thead>
<tbody>
<tr>
<td>185</td>
<td></td>
<td>Modal and distance of Travel to Work: Quality of Life Counts (DfTR 2000)</td>
<td></td>
<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>191</td>
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<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>20.00</td>
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<tr>
<td>194</td>
<td></td>
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<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>196</td>
<td></td>
<td>Number of killed or seriously injured (all ages): Monitoring indicators in LTPs (DfTR 2003)</td>
<td></td>
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<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>20.00</td>
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<td></td>
<td>Number of children killed or seriously injured: Monitoring indicators in LTPs (DfTR 2003)</td>
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<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>20.00</td>
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<td>20.00</td>
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<tr>
<td>199</td>
<td></td>
<td>Access to public transport: % of households within 13 minutes walk to an hourly or better bus service.</td>
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<td>☆☆☆☆☆</td>
<td>☆☆☆☆☆</td>
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<td>200</td>
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<td>Average time lost per vehicle km due to congestion: Monitoring indicators in LTPs (DfTR 2003)</td>
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