Chapter 3

Literature Review of Transport Sustainability

3.1 Definition

Sustainable development has become a major concern in both developed and developing countries since the publication of "Our Common Future on World Commission on Environment and Development" (Brundtland, 1987). The World Commission defined sustainable development in general as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

While the word "sustainability" becomes more and more widespread in various scientific disciplines, the definition of a sustainable transportation system is still considered undecided. Urban transport has complex characters. In all metropolitan regions in the world, the problem of the automobile is the major issue. Many long-term transportation improvement projects can temporary solve some problems, but may create another, or benefits may be offset; i.e. the reappearance of severe problems by the rebound phenomenon (Todd Litman, 2008). For example, adding roadway capacity can in the short-term help reduce traffic congestion but it may tend to increase total traffic volumes which may affect negatively traffic conditions in many locations, and it may also conflict economic, social and environmental objectives.

Thus, sustainable solutions of transportation problems consist of planning actions. These solutions are technically feasible, cost effective, and simultaneously have over the long run only neutral impacts or economic, social and environmental benefits to support the community-based objectives.

As there is no single definition of what constitutes a "sustainable" transportation system, numerous definitions of sustainable transport have been recognized adopting the above WCED definition of the year 1987. In these definitions, the common fundamental philosophy is that a sustainable transport system does not leave problems or costs for future generations and the users of the system should pay such costs today. These costs are not limited to environmental issues, but also include social and economic impacts caused by transportation (Szyliowicz, 2003), (Khisty & Arslan, 2005), (Timms, 2008), (Hatzopoulou & Miller, 2009), and (Samberg, Bassok, & Holman, 2011).

The planning of a sustainable transportation starts with the organization of urban space (land use planning). The main objective is to reduce the demand for transportation by reducing the number of trips and the length of travel distance. The organization of urban space helps in reducing the distances between places and people and as a result people travel less. Reducing the transportation demand reduces the use of limited resources and produces less adverse impact on the environment and economy.

A sustainable transportation planning also requires the necessity of an integrated and balanced public transportation services. Public transport has the capability to meet the different travel demands and also provides good connections with the service areas. By promoting attractive public transportation and non-motorized transportation (pedestrians and cyclists) the transportation system is made more efficient. As less people uses personal vehicles, the lower is the level of traffic congestion and demand for new roadways. Consequently, a sustainable transportation planning is essential for the abatement of harmful emissions and reducing accidents which have negative socio-economic impacts.

Thus, having a sustainable transportation system is very important as it will provide transport accessibility for all citizens to all places of their choices. This is the key to improved health, education and social standard.

A sustainable transportation planning may also work as a compound in the urban and regional development process. A city with a sustainable transport system can easily attract new businesses and other activities. Thus, the benefits of having a sustainable transportation planning is not limited to reducing traffic congestion and improving air quality only but it also brings economic prosperity and social benefits to the city.

From the discussion presented in the above paragraphs, it can be stated that, the main objectives of a sustainable transportation planning are:

i. Reducing travel demand, particularly by personal vehicles, and decrease the number of trips and trip lengths.
ii. Greater use of truly sustainable systems (i.e. public transport, walking and other non-motorized transport).
iii. Improving traffic safety.
iv. Efficient use of all available resources (natural, physical and financial).
v. Supporting community-based strategies.

Otherwise, a growing number of specific international transportation organizations have begun to characterize the "sustainability" of a transportation system. A comprehensive literature review conducts the following characteristics of a sustainable transport system (T Litman, 2008), (Eißel & Chu, 2013), and (Liu, Lund, & Mathiesen, 2013):

- It allows the basic and safe transport and access requirements of individuals and societies, and with social equity within and between generations;
- It is inexpensive, operates efficiently, offers choice of transport modes, and supports the economy; and
- It reduces pollution and emissions, and minimizes consumption of non-renewable resources and the use of land.

These characteristics are extensively used at present as the main features of a sustainable transport system for the following reasons:

- Increase mobility and provide more transport choices for each household income, people of all ages, and all trip purposes
- Encourage urban expansion
- Raise land value along the transport route

- Reduce the combined cost of housing and transportation
- Improve economic effectiveness through reliable and timely access to employment centers, educational opportunities, services and other basic needs by workers.

3.2 Sustainable Transport Criteria

The literature review indicates that the most widely used definition of a sustainable transportation solution that this solution is technically feasible, cost effective, and support community-based strategies (Mihyeon Jeon & Amekudzi, 2005). It should at least capture four elements of sustainability; i.e. transport effectiveness, economic development, environmental integrity, and the social quality of life. Figure 2 illustrates these essential four criteria that should be included in the characteristic of a sustainable transportation system. On the same way, the evaluation of the sustainable options should yield to sustainable criteria and indicators.

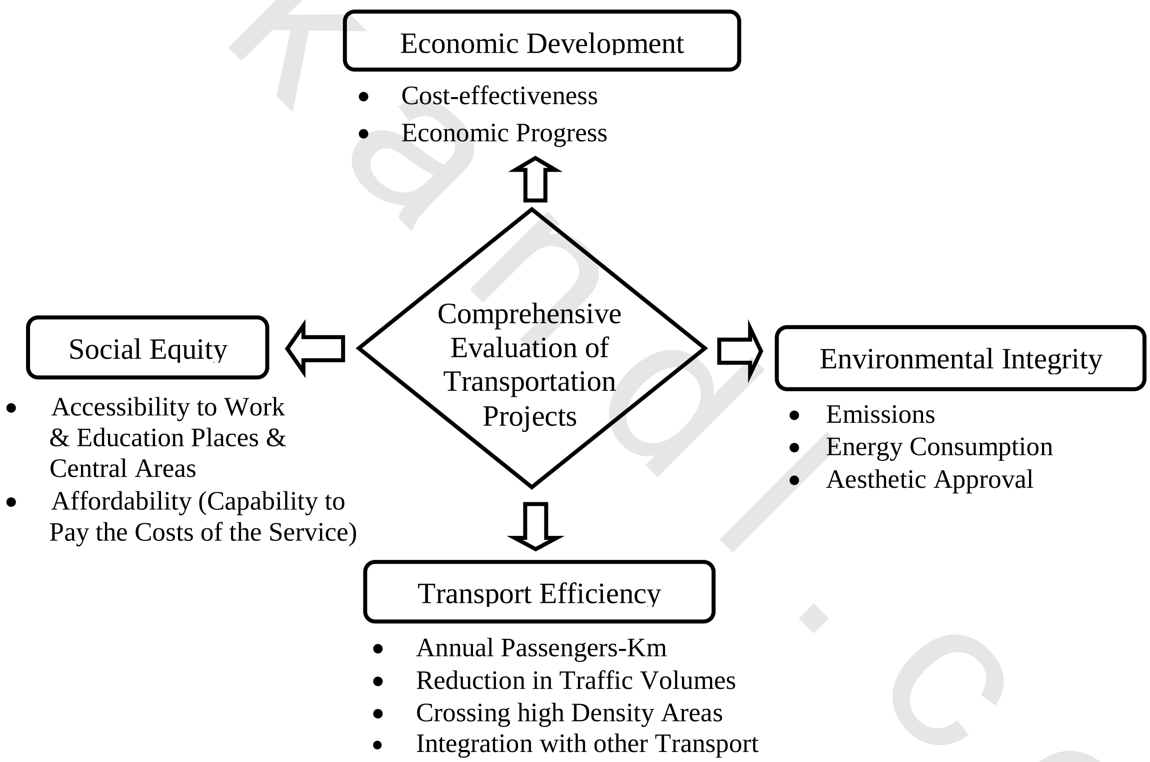

Figure 2: The Four essential Criteria of Transportation System Sustainability

These criteria must be added intensively to the conventional indicators which are currently used in the economic feasibility studies to compare solutions among others. The traditional feasibility studies are frequently applied as an effective and efficient method for evaluating transportation projects (with limited details and easy-to-measure impacts) to select the best cost effective solution.

The economic development refers to progress toward a community's economic goals, such as increased productivity, jobs, and business activities, and tax revenue. Many communities have also objectives to create new residential, commercial or industrial districts, and increase land use value. In addition, one of the most important targets is to reduce the land consumption for transportation facilities.

Transportation systems impose various environmental difficulties, including noise, air and water pollution; energy and land consumption, as well as aesthetic degradation. Thus, transport project evaluation should include comprehensive environmental impact analysis.

Social equity (called also fairness) refers to the distribution of impacts (benefits and costs) in the study area, and whether that distribution is considered fair and appropriate. Transport planning decisions often have significant equity impacts; such as:

- The quality of the transportation available affects people's economically and socially.
- Impacts on non-driver accessibility.
- Impacts on people with disabilities.
- Impacts on low-income households and communities.

The transport efficiency includes investigating the directs impacts of the project options, (for instance, average traffic speed, average daily traffic, density, delay, travel time, and level-of-service), and the indirect impacts (e.g. congestion impacts, impacts on transport project non-users, non-motorized trips, parking costs, integration with other transport services, and accessibility to adjusted land uses).

Thus, a comprehensive evaluation procedure can provide great advantages by integrating the benefits of the cost-effectiveness with indicators reflecting the community needs and goals; i.e. identify indicators that also support the development in the metropolitan area. In this case, a transportation project option may lead to economic progress, regional expansion, and land use development, as well as creating new jobs and activities within friendly and harmless environment.

For a comprehensive evaluation of transportation project options, particularly large-scale projects, cost-effectiveness from a feasibility study is not only sufficient to decide the best solution that can achieve the community needs. Decision-making should incorporate sustainability indicators that reflect the long-term economic, social and environmental impacts of each option in the study area. This means, sustainability evaluation should have indicators for land use development, and economic progress (economic), equity and livability, public security, traffic safety and health (social), as well as energy conservation, pollution reduction (environmental) and the transport efficiency. Such indicators help determine how a project option affects the community strategic goals.

The best practices for the comprehensive evaluation are the decisions to be made to identify the preferred large-scale project of a wide range of possible options; e.g. a transportation project, a multi-modal transportation system, or the selection of the top-priority project in a master plan for implementation.

3.3 Sustainable Transport Indicators

An indicator is a variable defined and selected to measure progress towards an objective. Single indicator is not adequate to present sustainability but a set of indicators can reflect various goals and objectives (Todd Litman, 2013). The indicators provide solid bases for decision-making. Thus, Indicators should be internally reliable and clear with respect to assumptions. Transparency is also an important aspect for indicator selection. Inappropriate or incomplete indicators can misdirect decision-makers.

(Nellthorp, Laird, & Mackie, 2005)defined sustainable transportation indicators (STI) as performance measures that give an indication of the sustainability. Indicators are increasingly being used to assess the sustainability of transport and facilitate decision making.

The following principles should be applied when selecting transportation performance indicators (Joumard & Nicolas, 2010) (Kolak, Akın, Birbil, Feyzioğlu, & Noyan, 2011) (Castillo & Pitfield, 2010):

1. Comprehensive: The indicators should consider the different objectives, costs, benefits, and impacts of the project options, and reflect various economic, social, technical, and environmental goals of the study area.
2. Measurable: An indicator should be capable of being measured in a theoretically sound, and it is possible to quantify or qualify. Some indicators may also needed to measure the users' satisfaction concerning specified issues, in this case responses are given on a rating scale (e.g. 1=Very satisfied, 2=Satisfied, 3=Not satisfied, 4=Very dissatisfied).
3. Independent: An indicator and its calculation should yield clear information that can be accessible and easily to be obtained.
4. Comparable: The indicators should be clearly defined and suitable for comparison trade-off between the different options.
5. Easy to Understand: The indicators must useful and understandable to decision-makers and all stakeholders.

Most of transport sustainable indicators in the above mentioned literature have been defined and organized using frameworks for policy makers. (Jeon, Amekudzi, & Guensler, 2013) conducted a comprehensive literature review on sustainable indicators from 16 different large-scale transportation projects around the world, including North America, Europe, Australia, and New Zealand. Many indicators are collected and applied at urban level concerning a give country or a specific region.

The review indicates that there are common criteria for their sustainability evaluation, while a standard framework for evaluating progress toward sustainability did not exist. The existing evaluation frameworks attempt to capture the impacts of decisions on the four important areas that define sustainability; i.e. the economy, environment, and social interests, as well as the transportation efficiency. The present status of addressing sustainability evaluation of urban transportation projects seems to indicate a higher focus on the effectiveness of transportation systems as well as the resulting environmental impacts (mainly air quality impacts), and less of a focus on economic and social impacts.

Indicator frameworks are different structures that can be established to organize sets of indicators. It make the interactions between different issues explicit (Miller, Witlox, & Tribby, 2013). These frameworks can organize the indicators in three ways:

1. Best-Practice Indicators
2. Goal-based Indicators
3. System Efficiency Indicators

3.3.1 Best-Practice Indicators

Sustainable indicators can be collected through a review of the international literature and governmental websites. The result is a long list of best-practice indicators which are organized based on the main focus of each indicator: the environmental, economic, social, and area-wide transportation aspects of the community. Based on the specific situations and goals of the study area and the targets of the project under investigation, a short list and a framework of sustainable indicators can be compiled.

The selection of the right indicators to guide sustainable transport assessment presents two fundamental challenges. Firstly, a large number of potential indicators exist (long list), and selecting a subset (short list) can be difficult. Secondly, indicators are only developing concepts. Selecting a group of indicators that provides a complete picture of performances of the transport project in the study area is therefore another challenge.

As with any goal, decision-makers are increasingly being required to monitor the sustainability performance of transport systems. Sustainable transport is a broad and complex goal however; any assessment tool must be able to adequately provide decision makers with informative signals on the multiplicity of issues involved. Indicators have been regularly proposed and applied for this purpose (Berger, Feindt, Holden, & Rubik, 2014).

The attractiveness of indicators in this context is derived from their ability to capture the multidimensionality of sustainable transport and break down the complex concept into small and manageable units of information. These attributes in turn facilitate comparison.

(Castillo & Pitfield, 2010), present a methodological framework for identifying and selecting sustainable transport indicators; i.e. evaluative and logical approach to sustainable transport indicator compilation (ELASTIC). In this methodology the selecting a subset of indicators based on stakeholder judgments.

Stakeholder participation is a key principle of sustainability to obtain the sub-goal and criteria weights. It is important that those affected by, and those who can affect sustainable transport decisions, are involved in the indicator selection process. The output is a small suite of specific sustainable transport indicators (indicator set) that can provide decision makers with informative signals on the multiplicity of issues involved.

Based on the literature review, Table 2 presents a catalog of indicators those commonly used to evaluate the sustainability of urban transportation projects, categorized according to the sustainable criteria. It shows also the direction of efficiency for each indicator (Mihyeon Jeon & Amekudzi, 2005).

Table 2: Examples of Possible best-Practice Indicators

Social Sustainability		
Indicators	**Description**	**Direction**
Non-User Rating	Overall satisfaction of transport system by non-users	More is better
Community Livability	Degree to which transport activities support community livability (Walkability and quality of street environment)	More is better
Cultural Preservation	Degree to which cultural and historic values are reflected and preserved	More is better
Affordability	Portion of budgets spent on transport by lower income households	More is better
Disabilities	Quality of transport facilities and services for disabled people	More is better
Traffic Safety	Per capita expected traffic casualty (injury and death) rates	Less is better

Economic Sustainability		
Indicators	**Description**	**Direction**
Travel Time	Average door-to-door commute travel time	Less is better
Land Consumption	Total land devoted to transportation facilities	Less is better
Economic Progress	No. of new jobs created by the transport system	More is better
Land Value	Establishment of new residential, commercial or industrial districts (areas)	More is better
Employment Accessibility	Number of job opportunities within 45-minute travel time of residents	More is better
Travel Costs	Portion of household expenditures devoted to transport	Less is better.
Facility Costs	Per capita expenditures on roads, parking and traffic services	Less is better
Crash Costs	Per capita expected crash costs	Less is better

Environmental Sustainability		
Indicators	**Description**	**Direction**
Energy Consumption	Per capita fossil fuel consumption	Less is better
Climate Change Emissions	Per capita emissions of CO_2 and other climate change emissions	Less is better
Other Air Pollution	Per capita emissions of "conventional" air pollutants (CO, VOC, NO_x, etc.)	Less is better
Noise Pollution	Portion of population exposed to high levels of traffic noise	Less is better
Water Pollution	Per capita vehicle fluid losses.	Less is better
Aesthetic Approval	Overall satisfaction of transport system	More is better

Transport System Efficiency		
Indicators	**Description**	**Direction**
Vehicle Travel	Per capita motor vehicle-kilometers, particularly in urban-peak conditions	Less is better
Mode Split For Non-Automobile Modes	Portion of travel made by non-automobile modes: walking, cycling, public transport, rideshare (taxi and collective taxi)	More is better
Transport System Integration	Integration with other transport services	More is better
Public Transport Capacity	Total passengers, total passenger-kilometers	More is better
Public Transport Accessibility To Adjusted Land Uses	Percentage of population living or working within public transport station service area	More is better
Congestion Delays	Per capita total traffic congestion delays	Less is better
Mobility	No. of person per day	More is better
Parking Demand	Total area needed	Less is better
Parking Convenience	Availability and accessibility	More is better
Efficient Priorities	Quality of traffic priorities for public transport and emergency vehicles	More is better

3.3.2 Goal-based Indicators

A framework relates indicators to a range of pre-defined sustainability issues and a set of community goals. Categorizing indicators according to the goals is then very helpful in showing linkages between the impacts of project options and sustainability. This framework makes it easier to see the progress toward multiple goals.

(Zegras, 2006) presents the sustainability indicator concept that represents the hierarchy of goals, objectives, indicators, and raw data as well as the structure of multi-dimensional performance measures. As shown in Figure 3, the top of the pyramid is the community goals and vision, the second layer includes sustainability criteria around the selected themes (environmental, economic, and social dimensions, etc.), third layer contains indicators or performance measures building from raw data at the bottom of the pyramid. This framework is especially helpful when decision makers first set the community goals for sustainability around the essential dimensions of sustainability and indicators are constructed based on the categorized goals and objectives.

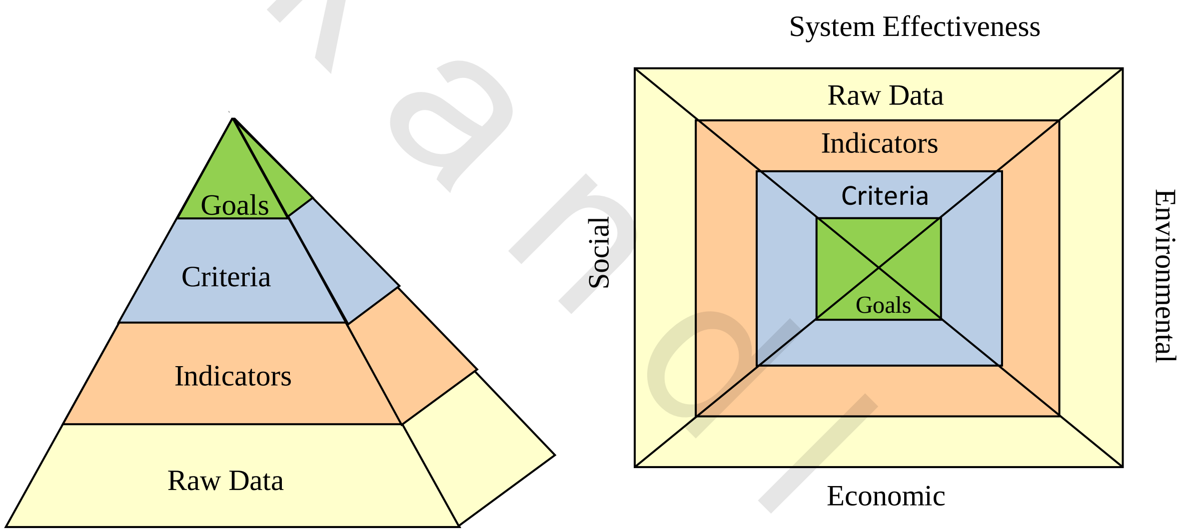

Figure 3: Sustainability Indicator Pyramid (Zegras, 2006)

Table 3 illustrates an example of a goal-based framework that categorizes indicators according to multiple community goals showing the linkages.

3.3.3 System Efficiency Indicators

The current used indicators for the evaluation of transportation projects based on traditional feasibility studies highly focus on transport system efficiency of the project options (cost-effectiveness and the direct measurable impacts). These indicators are frequently applied as an effective and efficient method for comparing alternatives; however they do not reflect the community needs and goals. Table 4 shows examples of indicators presenting cost-effectiveness and direct impacts of the project options.

Thus, comprehensive evaluation of transportation project options can then provide great advantages by integrating (1) the benefits of the traditional feasibility studies with (2) the sustainability issues that reflect and support the development in the metropolitan area.

Table 3: Example of a Goal-based Framework

Goals	Objectives	Indicators
Improve Sustainable Mobility	A) Decrease motor vehicle transport, and increase use of public transport modes	1) Total number of Vehicle-km (less is better) 2) Passenger-km (more is better)
	B) Improve public transport productivity	3) Public transport share 4) Rapid Transit System length 5) Service frequencies 6) Operating hours 7) Cost per passenger-km 8) Average trip time
	C) Increase accessibility of public transport	9) Percentage of population who live within 500 m of public transport stations 10) Portion of population within 800 m of Rapid Transit System in suburbs 11) Accessibility to central areas (commercial, industrial, and recreation) 12) Higher education access
Employment Accessibility	D) Increase accessibility of employments	13) Percentage of population who work within 500 m of public transport stations 14) Portion of population who work within 800 m of Rapid Transit System in suburbs
Improving Road traffic Conditions	E) Reduce congestion	15) Average travel speed 16) Average trip time
	F) Transport services for commercial users	17) Quality of transport services for commercial users
Enhance Environment	G) Decrease energy consumption	18) Per capita energy consumption devoted to transportation
	H) Decrease greenhouse gas (GHG) emissions	19) Per capita Transport-related GHG emissions
	I) Decrease emissions of air pollutants	20) Per capita total transport emissions of air pollutants
	J) Decrease space taken by transport facilities	21) Total land area consumed by transport facilities
	K) Increase safety	22) Annual number of expected traffic accidents, crashes, and fatalities per lane kilometer
	L) Expand economic opportunities	23) No. of new jobs created by the transport system 24) Household transport expenditures
	M) Improving Road facility costs	25) Per capita expenditures on roads, parking and traffic services
Social Equity	N) Environmental equity in the different urban areas	26) Equity of exposure to emissions 27) Equity of exposure to noise
	O) Non-drivers	28) Quality of transport services and access for non-drivers
	P) Disabilities	29) Quality of transport facilities and services for disabled people
	Q) Affordability	30) Portion of budgets spent on transport by lower income households

The best practices for the comprehensive evaluation are the decisions to be made to identify the preferred large-scale project of a wide range of possible options; e.g. an area-wide transportation project, a multi-modal transportation system, or the selection of the top-priority project in a master plan for implementation.

Table 4: Examples of Indicators presenting the Transport Efficiency of project options

Transport System Efficiency		
Indicators	**Description**	**Direction**
Cost-effectiveness	Benefit–Cost Ratio (BCR), Net Benefits	More is better
	Cost/effectiveness ratio	Less is better
	Net Present Value (NPV)	More is better
	Payback Period (PP)	Less is better
	Rate of Return (IRR)	More is better
	Equivalent Uniform Annual Costs (EUAC)	Less is better
Direct Impacts	Roadway level-of-service (LOS), which is an indicator of vehicle traffic speeds and congestion delay at a particular stretch of roadway or intersection	More is better
	Average traffic speeds	More is better
	Average congestion delay (average peak-period speed relative to a target speed)	More is better
	Travel time saving	More is better

3.4 Sustainability Evaluation Techniques

A growing number of qualitative and quantitative studies on the techniques applied for evaluating transportation system sustainability have been conducted around the world. The literature proposes various tools and methodologies such as scenario planning, integrated transportation and land use models, and multi-criteria decision analysis.

3.4.1 Scenario Planning

A scenario can be defined as a hypothetical sequence of logical and possible (but not necessarily probable) set of actions that may lead to a future vision. A future vision may include introducing new facilities or policies. Scenarios may involve a combination of actions. The objective of scenario formulation is to focus attention on causal processes and decision points.

Identifying scenarios that will result in a sustainable transportation system is a major challenge for policy makers, as scenario planning involves often a high level of doubt regarding the future effect on the mobility, safety, and urban environment (Shiftan, Kaplan, & Hakkert, 2003).

Otherwise, scenario planning approaches essentially incorporate uncertainties associated with the future planning elements, such as socio-economic data, population, employment, and travel demand, in planning.

Large-scale transportation projects are highly sensitive to economic changes because of the huge financial investment involved, the primary capital needed, the long time span of the project and the slow rate of returns.

Thus, the traditional methodology of scenario assessment, based on the benefit–cost framework is not always an appropriate approach for evaluating transportation project options and for investigating the cause-and-effect relationships between actions and impacts (Gunnarsson-Östling & Höjer, 2011).

3.4.2 Integrated Transportation and Land Use Models

Quantitative sustainability models have been applied in several European studies, including models as SPARTACUS (Systems for Planning and Research in Towns and Cities for Urban Sustainability), and ESCOT (Economic Assessment of Sustainability Policies of Transport) initiatives (SPARTACUS, 1998) and (Mihyeon Jeon & Amekudzi, 2005).

The SPARTACUS study uses an integrated transportation and land use model to evaluate the sustainability of selected transportation and land use scenarios. The transportation and land use interaction model captures how the degree of access (accessibility) provided by the transportation system can influence land use distribution, and, in turn, how the spacing of development can greatly influence regional travel patterns.

The ESCOT study, on the other hand, focuses more on evaluating the "economic" feasibility of sustainable scenarios using a system dynamics model. Emerging methods for evaluating sustainability are based on the broad concept of sustainability, defined earlier as including economic, environmental, and social parameters of sustainability, incorporating various types of integrated transportation – land use – environment models.

The input data of integrated transportation and land use models include policy packages, GIS databases and model databases. Policy packages to be tested are transformed to 'model language' by changing some of the model parameters or model data. GIS databases contain geo-referenced data of zone boundaries, transport networks, land use categories etc. in a geographic information system (GIS). All land-use transport models used are fully GIS-integrated, i.e. each model zone or model network link is represented in the GIS database.

The land-use transport models simulate the effects of policies on zonal activities, such as population or employment, and on mobility patterns, such as modal shares and link flows. The indicator modules receive the outputs of the land-use transport models and calculate the sustainability indicators.

The output part consists of sustainability indicator values which are further processed in the sustainability evaluation module. Other important information that helps to understand the behaviour of the system but is not used in the evaluation is stored as background variables. Examples for background variables are zonal population and employment, modal shares, car-km travelled etc. A web-based presentation tool shows the results of each policy in a standard form for comparisons between policies and between cities.

When there is lack of sufficient data base for applying scenario planning, as well as integrated transportation and land use models, the use of multi-criteria techniques for project selection has recently increased.