Sustainability indicators for sustainable transport infrastructure development

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Abstract

To preserve resources for future generation, there is rising agreement that transportation system sustainability should capture attributes of system effectiveness and system impacts on economic development, environmental integrity, and social quality of life. To make the region sustainable, sustainability assessment can be incorporated at the planning level in order to influence decision making, and support policies. This paper presents a review on methodologies that can be applied in sustainability assessment in transportation planning which can be used to incorporate sustainability more effectively in the planning process. This review on research study is potentially useful to road and transport infrastructural development agencies who are interested in understanding the range of tools and indicators being used for sustainability assessment, so that they can expand or refine their performance measures to capture sustainability in transportation planning, and using them in evaluating tradeoffs among challenging alternative as well as in identifying major alternative.

Key word: Sustainability indicator, road transport, assessment, planning

1.0 Introduction

Transport infrastructure like road, vehicle and people play a vital role in development of economy and employment for people. However their negative impact has adverse impact on society and future generation. Therefore rapid development of such infrastructure doesn’t sustainable picture of sustainable development. The word sustainable or sustainability has become a very controversial topic in road and transportation planning. Therefore many agencies are taking care of incorporating the definition even at regional and national scale planning level. World Commission on Environment and Development (WCED), 1987) provided definition of sustainability which is generally universally adopted worldwide “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This definition is widely adopted by different researcher across globe.

From review of different research work carried out it can be observed that all the transportation sustainability indicators review was classified into the following four major categories: transportation system effectiveness-related, economic, environmental, and socio-cultural equity-related indicators. However, the present status of addressing sustainability in transportation planning 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.

While there is no standard definition of sustainable transportation Jeon et al, 2013 defined sustainable transportation system, as shown in Fig. 1 which depicts essential four elements that should be included in the attributes of a sustainable transportation system.
Fig. 1 Four essential factors of transportation system sustainability
(Source: C.M. Jeon et al. 2013)

Considering a broader definition of transportation sustainability as improving the overall quality of life not just enhancing transportation systems, mission statements of about 40 percent of the State Departments of Transportation (DOTs) in the United States now include elements of sustainability (Jeon et al., 2010).

2. Current practices in sustainability assessment

Boyko et al., (2012) developed a toolkit for UK to facilitate the use of scenarios in any urban context and at any scale relevant to that context. The toolkit comprises two key components, namely, (i) a series of indicators comprising both generic and topic area-specific indicators (e.g., air quality, biodiversity, density, water) that measure sustainability performance and (ii) a list of characteristics (i.e., 1–2- sentence statements about a feature, issue or small set of issues) that describe four future scenarios. In combination, these two components enable to measure the performance of any given sustainability indicator, and establish the relative sensitivity or vulnerability of that indicator to the different future scenarios. An important aspect of the methodology underpinning the toolkit is that it is flexible enough to incorporate new scenarios, characteristics and indicators, thereby allowing the long-term performance of our urban environments to be considered in the broadest possible sense.

Lockwood (2013) assessed the forces working for and against the political sustainability of the UK 2008 Climate Change Act. The adoption of the Act is seen as a landmark commitment to action on climate change, but its implementation has not been studied in any depth. Recent events, including disagreements over the fourth carbon budget and the decarbonisation of the electricity sector, shows that while the Act might appear to lock in a commitment to reducing emissions through legal means; this does not guarantee political lock-in. An analysis of alternative sources of political durability was presented, drawing on a framework for understanding the sustainability of reform. It is argued that the Act has helped
create major institutional transformations, although the degree to which new institutions have displaced the power of existing ones is limited. The Act has produced some policy feedback effects, especially in the business community, and some limited investment effects, but both have been insufficient to withstand destabilisation by recent party political conflicts. The Climate Change Act of United Kingdom remains at risk.

Jeon et al., (2010) used Multiple Criteria Decision Making (MCDM) approach for evaluating selected transportation and land use plans in the Atlanta US region using multiple sustainability parameters. A composite sustainability index was introduced as a decision support tool for transportation policymaking, where the sustainability index considers multidimensional conflicting criteria in the transportation planning process. They conducted a comprehensive literature review on sustainability indicators from sixteen different initiatives around the world, including North America, Europe, Australia, and New Zealand (Jeon and Amekudzi, 2005). The review indicated that while a standard framework for evaluating progress toward sustainability did not exist, similar to the existing definitions of transportation sustainability, there are still common themes and dimensions. Most of sustainability indicators in the literature have been defined using frameworks that may be categorized as: (1) linkages-based frameworks, (2) impacts-based frameworks, and (3) influence oriented frameworks. The existing and emerging evaluation frameworks in Atlanta attempted to capture at least one of the following: (1) the causal relationships that lead to progress toward or deviation away from sustainability, (2) the impacts of decisions on the three important areas that define sustainability, i.e., the economy, environment, and social well-being or quality of life, and (3) the level of influence or control that the responsible agencies have over the causal factors of sustainability. The review also provided an extensive list of indicators sorted by the relative frequencies with which they appeared in the sixteen initiatives.

Jeon and Amekudzi, (2005) addressed sustainability in transportation planning and provision 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.

Hart (1998) also identified four frameworks for organizing sustainability indicators: (1) category or issue lists, (2) a goal–indicator matrix, (3) driving force–state-response tables, and (4) endowment–liability–current result–process tables. Category or issue lists usually refer to organizing indicators based on the main focus of each indicator: the environmental, economic, and social aspects of the community. The goal–indicator matrix relates indicators to a range of sustainability issues or a set of community goals. Diving force–state-response tables balance measures of causes or driving forces; measures of the results, or state; and measures of programs and other human activities designed to alter driving forces with the goal of improving the state. This framework shares same essentials with the linkages-based framework identified in the prior review. The last framework uses endowments, liabilities, current results, processes as headings in a table that checks for balance among measures of what we are leaving for future generations, what we have now, and what is happening to create both situations (Hart, 1998). What is common to each framework is the creation of indicators around specific themes.

Zegras (2006) presented the sustainability indicator prism that innovatively represents the hierarchy of goals, indexes, indicators, and raw data as well as the structure of multidimensional performance measures. As shown in Fig. 2, the top of the pyramid
represents the community goals and vision, the second layer represents a number of composite indexes around the selected themes, third layer represents indicators or performance measures building from raw data at the bottom of the pyramid. This concept can also be considered as the combination of Hart’s category or issue lists (environmental, economic, and social aspects) with the goal-indicator matrix, which organizes indicators/indexes around a set of community goals or various sustainability issues. This framework is especially helpful when decision makers first set the community goals for sustainability around the essential dimensions of sustainability (environmental, economic, and social dimensions, etc.) and indicators and composite indexes are constructed based on the categorized goals and objectives.

The critical points that emerge from these constructs are that performance measures must be developed to capture a community’s broader vision.

3.0 What is available for users or decision maker or planner?

Various tools and techniques such scenario planning; graphical models; system dynamics approaches; economic-based models; integrated transportation and land use models; simulation and decision analysis models; environmental impact analysis; and life cycle assessment (LCA) for qualitative analysis can be done to find sustainability of project. Apart from that there are many Quantitative sustainability models which have been applied in several European studies, including such 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. The SPARTACUS study uses an integrated transportation and land use model, MEPLAN, to evaluate the sustainability of selected transportation and land use scenarios.

Zietsman et al., (2003) used simulation and decision model which provides important insights for the integration of a sustainability evaluation process with a decision making process. They developed a single index for sustainable transportation from selected performance measures based on the multi-attribute utility theory (MAUT) technique. While these researchers mainly focus on quantifying the sustainability of selected corridor-level scenarios using a microscopic simulation model, CORSIM, the application of a multiple criteria decision making (MCDM) approach in the sustainability evaluation reveals the benefits of using indexes and is broadly applicable (Zietsman et al., 2003). Ideally, sustainability evaluation should incorporate broader impacts of transportation systems and model the necessary inter-
actions among these multi-dimensions. These critical elements were important guiding principles in framing the methodology developed for the evaluation, and can be considered as important guiding principles in general in the development of analysis tools for sustainability assessment.

In another study by Jeon et al., (2013) considered sustainability in regional transportation planning using the following steps: (1) identifying pertinent sustainability issues and regional sustainability goals for the metropolitan region of interest, (2) defining relevant performance measures for transportation system sustainability based on the predetermined issues and goals, (3) analyzing and quantifying the comprehensive sustainability impacts of alternative transportation and land use scenarios developed for the region, (4) constructing a Composite Sustainability Index (CSI) using the multiple criteria decision making (MCDM) theory, and (5) visualizing the sustainability indexes using a decision support tool in order to identify the most suitable plan for the predetermined sustainability-oriented objectives (Jeon et al., 2010).

Indicators developed by Jeon et al., (2013) is shown in Table 1 for existing metropolitan goals categorized into each dimension of sustainable transportation and the appropriate performance measures that can be used to assess each different goal for Atlanta Metropolitan Region in US. Each goal and objective is represented by one or more performance measures. It is worth mentioning that transportation system effectiveness is added to the three basic dimensions of sustainability because transportation mobility and system performance are indispensable components of transportation system sustainability.

In other study related to urban transport, Santos and Riberio (2013) used of sustainability indicators during the decision-making process for the case of Rio de Janeiro. They used set of 20 indicators which was selected and used as an example to evaluate their applicability to monitoring the lines of action regarding transportation in the Rio de Janeiro State Climate Plan. They found that that certain objectives cannot be monitored from the perspective of the sustainability criteria, and signal the importance of establishing monitoring criteria previously of public policy elaboration process. The use of the proposed indicators can help the public managers to monitor progress toward the goals presented in climate change policy for reducing greenhouse gas emissions and identify whether Rio de Janeiro is progressing toward sustainable development. Each indicator shows one aspect of sustainable transportation, as presented in Table 2. As it can be seen in Table 2, a set of 20 indicators was used to assess the sustainability of each transportation line of action, where applicable, as well as monitoring progress towards the goal of reducing GHG emissions. It is worth noting that the design of the actions presented in the Plan was not based on sustainability criteria, because the focus was on mitigating greenhouse gas emissions and the concept of sustainability was used as much broader perspective. Limitation of this Table 2 is that it makes the assessment on a qualitative basis.

Over a period of one hundred years the motor car has come to occupy a central role in all developed economies. It has trans formed our ability to travel easily and cheaply for work or leisure purposes, and it has changed the design of our urban spaces. Smith et al (2013) investigated the suitability of the Process Analysis Method (PAM) for measuring the sustainability of a transport system—a national car fleet delivering mobility in United Kingdom.
The PAM identifies sustainability impacts resulting from system processes, characterising the issues (consequences) arising from these impacts with indicators. It is transparent and systematic, and helps the user to create an indicator set which is comprehensive, whilst
avoiding double-counting. Particular issues can be further described with sub-indicators as mention in Table 3 which shows indicators as environment only.

Table 3: Environmental indicators of car transport system sustainability

<table>
<thead>
<tr>
<th>Input/output</th>
<th>Impact</th>
<th>Issue</th>
<th>EIR</th>
<th>Indicator</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Acidification</td>
<td>Increasing acidity in soil, lakes and rivers</td>
<td>Communities</td>
<td>Emissions of pollutants characterized</td>
<td>0.78 SO₂ equivalent</td>
</tr>
<tr>
<td></td>
<td>Eutrophication</td>
<td>Eutrophication</td>
<td>Communities</td>
<td>See above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Global Warming</td>
<td>Global warming increases</td>
<td>Communities</td>
<td>See above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phrenological Disruption</td>
<td>Damage to the brain</td>
<td>Communities</td>
<td>See above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Climate change</td>
<td>Climate change</td>
<td>Communities</td>
<td>See above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Secondary effects</td>
<td>Air pollution</td>
<td>Communities</td>
<td>See above</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Primary energy resource depletion</td>
<td>Energy resources</td>
<td>Communities</td>
<td>PM10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Material use</td>
<td>Waste-to-energy</td>
<td>Communities</td>
<td>Total waste</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Material processing and extraction</td>
<td>Release of pollutants</td>
<td>Communities</td>
<td>Heavy metals, toxic chemicals, ammonia reduced</td>
<td></td>
</tr>
</tbody>
</table>

* Includes renewable resources used at an unsustainable rate.

(Source: Smith et al., 2013)

Table 4 shows indicators as economic only if they describe issues affecting the economic sustainability of the system itself. These indicators are presented in Table 4. The human/social indicator set (Table 5) comprises a crucial part of the sustainability analysis, because it includes indicators for the major benefit of car transportation to society – the provision of mobility as a service.

Table 4: Economic indicators of car transport system sustainability

<table>
<thead>
<tr>
<th>Input/output</th>
<th>Impact</th>
<th>Issue</th>
<th>EIR</th>
<th>Indicator</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workforce</td>
<td>Value is added through the use of workforce</td>
<td>Generates profit</td>
<td>Capital Providers</td>
<td>Value added by automotive industry</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Accidents/casualties</td>
<td>Financial cost of accidents to society</td>
<td>Communities</td>
<td>Cost of physical damage, medical costs, emergency services</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Mobility is used to support economic activity</td>
<td>Speed of mobility is time saved relative to other modes of transport</td>
<td>Users</td>
<td>Value of time saved per km</td>
<td></td>
</tr>
<tr>
<td>Mobility</td>
<td>Additional revenue collected by the government as a result of car fleet operation</td>
<td>Government collects tax revenue to pay for public services</td>
<td>Communities</td>
<td>Fuel duty and Vehicle Excise Duty Collected</td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>Air pollution</td>
<td>Hazardous to human health</td>
<td>Communities</td>
<td>Cost to health services of treatment</td>
<td></td>
</tr>
<tr>
<td>Material use</td>
<td>Release of hazardous materials</td>
<td>Hazardous to human health</td>
<td>Communities</td>
<td>Cost to health services of treatment</td>
<td></td>
</tr>
</tbody>
</table>

(Source: Smith et al., 2013)

Table 6 shows the average employment during each year, as well as the costs (to businesses) per employee, which cover gross wages and salaries (including redundancy and severance payments) and social security costs.

Table 5: Human/social indicators of car transport system sustainability

<table>
<thead>
<tr>
<th>Input/output</th>
<th>Impact</th>
<th>Issue</th>
<th>EIR</th>
<th>Indicator</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workforce</td>
<td>Employment</td>
<td>People can support themselves</td>
<td>Employees</td>
<td>Jobs provided</td>
<td>Number of people employed</td>
</tr>
<tr>
<td>Energy</td>
<td>Air pollution</td>
<td>Hazardous to health</td>
<td>Communities</td>
<td>Morbidity induced by air pollution</td>
<td>Number of hospital admissions per year</td>
</tr>
<tr>
<td>Mobility</td>
<td>Mobility is provided</td>
<td>People are able to travel</td>
<td>Users</td>
<td>Mobility provided by car fleet</td>
<td>Number of people in transport per year</td>
</tr>
<tr>
<td>Service quality</td>
<td>People are able to perform trips under certain conditions</td>
<td>The mobility needs of the community are met</td>
<td>Communities</td>
<td>Equality of modal opportunity indicators</td>
<td>Various</td>
</tr>
<tr>
<td>Noise</td>
<td>Hazardous to health</td>
<td>Hazardous to health</td>
<td>Communities</td>
<td>Morbidity related to noise</td>
<td></td>
</tr>
<tr>
<td>Accidents/</td>
<td>Resulting injury</td>
<td>Casualties resulting from road traffic collisions</td>
<td>Communities</td>
<td>Number of killed or seriously injured per year</td>
<td></td>
</tr>
</tbody>
</table>
Whitmarsh (2012) introduced Multi-Level Perspective (MLP) as an analytical tool for identifying and engaging with diverse stakeholder groups, including mainstream (‘regime’) and alternative (‘niche’) organisations. The MLP can be improved by integrating natural, behavioural and political science insights, and particularly by elucidating how behavioural—institutional change might occur. This is critical for transport research given the expressed and observed public resistance to changing travel behaviour. There is considerable scope to integrate natural, behavioural and political science insights to expand and improve the MLP to elucidate how behavioural—institutional change might occur. This is particularly critical for transport research given the expressed and observed public resistance to changing travel behaviour.

Cascetta et al., (2013) suggested Public Engagement (PE) PE in planning and designing transportation systems, describing its interactions with other more formal phases of decision-making and some of the tools that can be used for the various levels. On the other hand, PE does not make full use of the potential of quantitative methods developed over the decades for the design and evaluation of transportation projects.

Sustainability indicators have been used in road transport, urban transport, cities and vehicle growth and planning by different researchers. Different approaches, indicators, purpose and reason for using such indicators are discussed as above. It is expected that decision makers can consider such approaches to preserve the future generation requirement and need while developing current infrastructures.

**Conclusion**

As interest in sustainability grows, more agencies will begin to incorporate the concept in planning. While there are several initiatives in this area in developed countries, where few regional agencies have developed planning tools that successfully incorporate the comprehensive concept of sustainability (transportation system effectiveness, economic, environmental, and social aspects of sustainability) in the development of long-range plans, transportation improvement programs, and project selection. The main intent is to present this paper to show emerging guidance on the critical elements of sustainability evaluation—both from the viewpoint of indicator frameworks and analytical models, and to demonstrate how a broad range of performance measures can be used effectively in sustainability evaluation within a multi-criteria framework—to assess tradeoffs and identify dominant alternatives when considering competing alternative plans for transport, vehicle in sustainable scenarios. The indicator set is thus likely to be widely applicable and is also manageable in size, both are important criteria for adoption by transport and sustainability practitioners for other developing countries also.
Reference:


