

SUSTAINABLE TRANSPORTATION INDICATORS: A REVIEW

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Abstract - One of the key aspects of sustainability whether economic, environmental, social is transportation. Therefore, sustainability in transportation system is an alarming topic among researchers, policymakers and transport scientists nowadays. In order to attain sustainability in transportation system, some indicators were needed to be identified for studies related to transport sustainability. To develop sustainable transport indicators, STI some efforts have been made. The aim of this study is to review the indicators used for measuring sustainability or performances of transport available to us in terms of different kind of sustainability by various researches.

Key Words: Transportation, Sustainability, Sustainable Development, Sustainable Transportation System, STIs

1. INTRODUCTION

As Industrialization began, humans started to depend on machines heavily to do their work efficiently and on time and in their effort, humans converted old modes of transport like bullock carts, horses etc, into machines such as cars, lowries, freight car etc., without knowing the ill effects of these modern machines known as transport. With increase in population, technology advanced, no. of transport and their means increased, speeds of transport increased and thus their fuel consumption as it was available in abundance and humans were still unaware of problems that were about to come but some researchers or environmentalist, or environmental scientists saw this development with a perspective that no one has ever seen before and they concluded that development of human race is highly unsustainable, i.e., it will lead to downfall of environment and human civilization and hence they gave a concept of sustainability system with a belief that it is the key to modernization of human race along with minimum harm to environment which was later introduced in transportation system available to us to counter many economical, environmental and social problems resulting from unsustainability of transportation.

1.1 Sustainable Development

“The development that fulfills the needs of present generation without compromising the ability of future generation to fulfill their own needs is termed as Sustainability”^[1]. The whole idea of sustainability is to use any resources in such a manner that it can be sustained or continued in future for upcoming generations. A major topic of concern for policymakers and planners both in developed and developing countries has always been Sustainability or Sustainable development. The rapid urbanization in developing countries leads to various transportation problems like

- Pollution
- Chronic Diseases
- Traffic congestion
- Rising cost, etc.

The most important among all are pollution and congestion, which are the basic transportation problem of most of the metropolitan cities all around the world. So, sustainability in transportation system is necessary to cope up with these leading problems of urbanization

1.2 Sustainable Transportation System

Any means of transportation that is ‘green’ and has low impact on the environment is referred as Sustainable Transportation. “A sustainable transportation 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, minimizes consumption of non-renewable resources, limits consumption of renewable resources to the sustainable yield level, reuses and recycles its components, and minimizes the use of land and the production of noise."^[2]

So, to cope up with problems of urbanization a method is needed to be established to measure or to evaluate the sustainability of transportation system available to us and if not stands up to the mark replace it with a new and efficient transportation system available which meets the needs of sustainable transportation system. So many countries and many researchers use sustainable transportation indicators, STI as an effective tool for monitoring the transport sustainability. Many efforts have been made to develop STIs. In this paper, we have reviewed indicators used in various studies used by different researchers all around the globe to identify STIs. For our study, we have taken) data from various researches to study and analyze types of indicators available and criteria on which they are based.

2. LITERATURE REVIEW

For sake of our study following researches have been reviewed and no. of indicators reported by those researches with a short review has been given in Table 1.

Table -1: Aim and review of various researches and no. of indicators reported by them.

STUDY	AIM/Review of the study	NO. of Indicators
<i>Frokenbrock et al. (2001)</i>	A practical guidebook which helps policymakers to access economical and social impacts of various transportation project.	8 social and economical impacts
<i>Dobranskyte et al. (2009)</i>	They have assessed & measured transport activities with a sole aim to measure sustainability of transport activities quantitatively for EU member States.	55 indicators under 5 sustainability dimensions. Note: - For our sake of study we have reviewed indicators for 3 key dimensions viz. economic, social and environmental.
<i>Zheng et al. (2011)</i>	This study has given practical metric in terms of sustainability to assess US transportation system, for those theoretical concepts of sustainability are transformed to practical use so that important information is to be provided to planners & policy makers.	11 STIs under 12 elements and 3 domains
<i>Hippu Salk Kristle Nathan and B. Sudhakara Reddy (2011)</i>	They have developed Sustainable Development Indicators (SDIs) using MVBB framework for transportation sector of Mumbai.	54 SDIs
<i>Reisi and Rajabifard (2013)</i>	They have reviewed through their studies the challenge of measuring transport sustainability using various indicators under key aspects of sustainability. To overcome the issue of using too many indicators for evaluation, in their study they develop a method for obtaining a composite transport sustainability index for Melbourne statistical local areas (SLAs).	12 indicators under 3 sustainability aspects
<i>Santos and Ribeiro (2013)</i>	They have evaluated sustainable transportation system using various indicators under some key categories and used as an example	20 indicators under 3 categories

	to evaluate their applicability to monitoring the lines of action regarding transportation in the Rio de Janeiro State Climate Plan.	
<i>PROPOLIS (2014)</i>	The goal of this research project of EU was to estimate such urban policies & to estimate their long-lasting effect in Dortmund, Germany. In this effort they gave their Indicator System. It has advantage over other indicator systems as other indicator are directly observed or measured while PROPOLIS is modelled or forecast.	35 indicators under 9 themes and 3 elements of sustainability
<i>Mahdinia et al. (2018)</i>	They have used Principal Component Analysis/Factor Analysis (PCA/FA) to derive an algorithm for measure of sustainability of transport and also determined sustainability transport indices for about 50 US states	89 STIs subdivided into 3 dimensions of sustainability
<i>Todd Litman, VTPI (2019)</i>	In their report they have defined sustainability, Liveability and gave process for sustainability planning and they have reported some STIs in past studies. They have also reported factors to be considered while selecting STIs.	41 indicators under 3 key sustainable dimensions from past study.

3. RESULTS & DISCUSSIONS

As most researches have given STIs considering 3 kinds of sustainability in transportation system viz., Economic, Environmental, Social Sustainability hence indicators based on these sustainabilities from above reviewed literature are listed in below Table 1

Table -2: STIs Used in Various Studies

ECONOMIC INDICATORS	ENVIRONMENTAL INDICATORS	SOCIAL INDICATORS
Investment Costs ^[10]	GHG's or GHGs Emissions per capita/area/total annual VKT/Total energy used(annual) ^{[6][8][10][11]}	PM Exposure ^[10]
User Benefits ^[10]	Acidifying Gases or SO _x , NO _x emissions ^{[5][7][10]}	NO ₂ Exposure ^[10]
Operator Benefits ^[10]	VOC _s (Volatile organic compounds) Emissions ^{[5][7][10]}	Traffic Noise Exposure ^{[5][10]}
Government Benefits ^[10]	Mineral Oils And their Products ^[10]	Traffic Deaths &Injuries (Per Capita or Person/Km) ^{[5][8][10][12]}
Accident Costs ^{[10][8]}	Land Coverage or Land Use or Land Consumption ^{[5][6][8][9][10]}	Justice of Economic Benefit Distribution ^[10]
GHGs or Emissions Costs ^[10]	Requirement of any new construction ^[10]	Segregation ^[10]

Noise Costs ^[10]	Open space Fragmentation ^[10]	Housing Standard ^[10]
Transport Intensity (GDP Relative) ^[5]	Open Space Quality ^[10]	City Centre Vitality ^[10]
Road, Railway, Maritime, Inland Waterway, Air Transport & Inland Waterway (For goods, Passenger & Freight) ^[5]	N ₂ O EMISSIONS ^[5]	Surrounding Region Vitality ^[10]
Transport Expenditure percapita/GDP per capita/per transportation Funds ^{[5][11][9]}	Particulate matter Emission (PM ₁₀ Or PM _{2.5}) ^{[5][7][8]}	Time Spent in Traffic or Passenger Journey Time ^{[10][5]}
Fuel Prices & taxes on motor vehicle per capita/per total annual VKT ^{[5][11]}	Ozone (O ₃) Concentration ^[5]	Service Level (Public Transport & Slow Modes) ^[10]
Direct User Costs or Vehicle Ownership Costs ^{[5][8]}	Carbon Mono oxide (CO) or Carbon Dioxide(CO ₂)Emissions ^{[5][7][8][9][12]}	City Centre Accessibility ^[10]
External Costs ^[5]	Methane (CH ₄) Emissions ^[5]	Services Accessibility ^{[3][4][6][8][9][10][11]}
GDP contribution ^[5]	Energy Consumption ^{[5][6][9]}	Open Space Accessibility ^[10]
Transport Infrastructure Investments per capita & Density of Infrastructure ^[5]	Fuel Consumption, Climate Change Emissions ^{[5][12]}	Passenger Journey Length (Per Mode) ^[5]
Quality of Roads ^[5]	Disruption of Habitat and Ecosystem ^[5]	Transport Quality for Disabled ^{[5][9][12]}
Length of Roads (per capita) ^[5]	Renewable Energy Use ^[5]	Mobility ^[5]
Affordability ^{[6][12]}	Consumption of Infrastructure Materials or Infrastructure ^{[6][9]}	Passenger Volume ^[5]
Equity of Finance ^[6]	Consumption of Vehicle Materials ^[6]	Chronic Diseases & Deaths due to Transportation activities or Pollution ^{[5][7][8]}
Mobility ^[6]	Pollution (Air, Water, Noise) ^{[6][12]}	Private Vehicles Ownership ^[5]
Resilience ^[6]	Waste Production ^[6]	Affordability ^{[5][12]}
Fluctuations in Travel costs ^[3]	Health Impacts of Regional and Local Pollutants And their Levels ^[4]	Transport Sector Contribution in Employment growth ^[5]
Travel Time ^{[3][11][12]}	Vibration and Noise ^[4]	Health ^{[6][9]}
Safety ^[3]	Visual Intrusion ^[4]	Traffic Safety (includes Pedestrian) ^{[3][4][6][9][11][12]}
Operating Costs of Vehicles ^[3]	Separation of Settlement and Biodiversity ^[4]	Interoperability of Government ^[6]
Economic Efficiency and Regeneration ^[4]	Urban Sprawl ^[4]	Involvement of Community ^[6]
% Household Budget for Transport ^[9]	Loss of Cultural Heritage ^[4]	Social Interaction ^[6]
Costs and Investments Transparency ^[9]	Non-Renewable Resources Depletion or Resource Efficiency ^{[8][12]}	Social Equity ^{[4][6]}
Harmful Aids and Green Budgetary Strategies ^[9]	Habitat Fragmentation and Protection ^[12]	Construction Disruption ^[3]
Annual Transportation Revenues per Transportation Expenditures/transportation funds ^[11]	Vehicle Travel ^[9]	Community Cohesion ^{[3][12]}
Transportation Funds per capita / per GDP/per GDP per capita ^[11]	Density of Land use ^[9]	Traffic Security ^[4]
Transportation Employees Per Capita ^[11]	Air Pollution Emissions per capita/area/total VKT/total energy used (annually) ^[11]	Economic Efficiency ^[4]
Freight Efficiency ^[11] or Freight	Lead Emissions ^[7]	User Satisfaction or Rating ^{[8][12]}

Shipment by rail per capita ^[12]		
User Satisfaction ^[12]	Hydrocarbon Emissions ^[7]	Diversity & Quality of Transport ^{[8][9][11]}
Employment Accessibility ^[12]	Toxic Substances Emissions ^[7]	Gender Equality/Equity among Communities, societies or groups ^[9]
Land Use Mix ^[12]	Share of Road with Both Side Plantation ^[7]	Fitness of Population ^[12]
Electronic Communication ^[12]	Vehicle Scrap Formed Per Year ^[7]	Cultural Preservation ^[12]
Variety of Transport ^[12]	Vehicle Scrap Recycled Per Year ^[7]	Drunk driving cases registered per year ^[7]
Modes Shared ^[12]	Amount of Disputed or Pending Cases In road and rail courts ^[7]	Unsafe driving cases registered per year ^[7]
Congestion Delay ^[12]		Hearing Diseases ^[7]
Cost Efficient ^[12]		% Population using Private transport (employees, School Children) ^[7]
Commercial Transport ^[12]		% Population using public transport ^[7]
Energy Efficiency (Monetary & Utility) ^[7]		Total Public Transport ^[7]
Energy Consumption per capita ^[7]		
Average Speed ^[7]		
Potholes Per Km Length of Road ^[7]		
Vehicles Per Road Length/ per 1K Population ^[7]		

Below table 2 lists those economic, environmental, social indicators which have occurred in most of the research studies.

Table -3: Mostly Used Indicators

ECONOMIC INDICATORS	ENVIRONMENTAL INDICATORS	SOCIAL INDICATORS
Accident Costs	GHG's or GHGs Emissions per capita/area/total annual VKT/Total energy used(annual)	Traffic Noise Exposure
Transport Expenditure per capita/GDP per capita/per transportation Funds	Acidifying Gases or SO _x , NO _x emissions	Traffic Deaths &Injuries (Per Capita or Person/Km)
Fuel Prices &taxes on motor vehicle per capita/per total annual VKT	VOC _s (Volatile organic compounds) Emissions	Time Spent in Traffic or Passenger Journey Time
Direct User Costs or Vehicle Ownership Costs	Land Coverage or Land Use or Land Consumption	Services Accessibility
Affordability	Particulate matter Emission (PM ₁₀ Or PM _{2.5})	Transport Quality for Disabled
Travel Time	Carbon Mono oxide (CO) or Carbon Dioxide (CO ₂) Emissions	Chronic Diseases & Deaths due to Transportation activities or Pollution
	Energy Consumption	Affordability
	Fuel Consumption, Climate Change Emissions	Health
	Consumption of Infrastructure Materials or Infrastructure	Traffic Safety (includes Pedestrian)
		Social Equity
		Community Cohesion

Above listed indicators in tables 2 & 3 can be used in Future studies such as Identification of STIs or Assessment of transportation measure or preparation of transport indices, etc.

4. CONCLUSIONS

This paper reviews the indicators mentioned in past studies and gives an idea of how these indicators can act as a tool for future transport sustainability studies and also how it helped in transport studies all around the globe. Also, it would be interesting to see how policy makers will see these indicators and if required derive new indicators either using research methods available to them or by using new research methods.

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