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STRATEGIES FOR AN URBAN ACCESSIBILITY SYSTEM TOWARDS IMPROVING SUSTAINABILITY OF AN URBAN FORM

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Abstract:
Accessibility in the urban areas has emerged as a key ingredient in determining sustainable development of cities due to the rapid urbanization and growth in transport demand. The increasing reliance on cars has contributed to congestion, environmental degradation, which underscores the necessity of integrated accessibility-based planning. This paper tries to understand the linkage between urban accessibility systems and the sustainability of urban form by suggesting strategic interventions to integrate transport planning and land-use design.

It relies on a comprehensive literature review including global and Indian research, and statistical evaluation techniques, including Analytical Hierarchy Process (AHP), Principal Component Analysis (PCA), traffic optimization and GIS-based analysis. The existing literature underlines the importance of compact urban shapes, mixed spatial use, and transit-oriented development in improving accessibility and alleviating environmental impacts. However, limited studies integrate these factors into a unified framework.

The findings suggest that multimodal transport systems, high-density development, and availability of services are all significant factors contributing to sustainable urban form. Non-motorized transport promotion, enhancement of public transport, and land-use planning are some of the strategies that can contribute immensely to the sustainability results. The researchers conclude that a quality urban accessibility system, which is backed by policy and planning interventions, is the key to attaining the long-term urban sustainability.

Keywords: Sustainability, Sustainable Transport system, Urban Form, Urban Accessibility.

1. INTRODUCTION

Accessibility in urban areas has become a prominent theme in the development of sustainable cities, especially considering the high rate of urbanization and population growth. The concept goes beyond physical mobility to include fair access to services, opportunities, and urban infrastructure. The increasing issues of congestion, environmental degradation and socio-spatial inequality in the past few decades have made planners and researchers reconsider the classic urban forms. Urban accessibility system strategies seek to combine land use, transportation, and environmental planning to develop not only efficient but also inclusive and resilient cities (Mobaraki & Oktay, 2022). Through emphasizing accessibility and not only mobility, urban systems will be in a better position to promote sustainable development agendas, by ensuring that individuals can travel to places of vital importance with a minimum environmental and social impact.

The sustainable urban form is defined by dense development, land mix, and effective transport networks (Živković, 2019). One major factor in the realization of these traits is

accessibility which determines how easily people can access various aspects of the urban environment. High accessibility will decrease dependence on personal cars, leading to decreased greenhouse gases and energy use (Pérez-delHoyo et al., 2021). It also increases the social inclusion by making sure that vulnerable and marginalized groups in the society will have equal access to employment, education, health facilities and recreational facilities, among others (Næss et al., 2014). In this regard, accessibility is not just a technical act but a multidimensional construct that is indicative of economic, social and environmental sustainability.

FIG 1: Understanding sustainable accessibility in urban planning(Sola et al., 2018).

The improvement of urban accessibility is commonly associated with the incorporation of land-use planning with the introduction of a public transport system (Ali et al., 2019). One such approach is transit-oriented development (TOD), which encourages high-density development around transit facilities and the adoption of public transportation and non-motorized transportation methods, including walking and biking. These approaches can decrease the travel distances and time and enhance the livability of cities (Al-Thani et al., 2019). Moreover, multimodal transport systems are being developed, which offer smooth connectivity between various transport systems and the overall accessibility is improved. These strategies are further facilitated by digital technologies and smart city initiatives, which offer real-time information, offer better traffic management, and enhance service delivery.

FIG 2: Features of the TOD model(Yahia et al., 2025).

The other important element of urban accessibility is the planning of common spaces and infrastructure. Universal design principles mean that urban spaces are friendly to everyone, both the elderly and those with disabilities (Hemani et al., 2017). Accessible public transport systems, safe cycling facilities, and pedestrian-friendly streets bring about more inclusive city shape (Maimaiti et al., 2025). Furthermore, green spaces like parks also increase the sustainability of the environment and the availability of natural facilities. All these factors will lead to a more balanced urban eco-system.

The economic aspect of accessibility and sustainability is also evident in terms of relationships. The accessibility can also enhance the local economies by enhancing the connectivity between residential and commercial centers (Vitale et al., 2020). It saves time and money in traveling and increases productivity and quality of life. Moreover, available urban systems will be an attraction to investment and innovation, which adds to long-term urban resilience. Nevertheless, the realisation of such systems involves planning, policy support, and collaboration with stakeholders (Arundel & Ronald, 2017). Urban sprawl, inappropriate infrastructure, and socio-economic differences are some of the challenges that need to be tackled using integrated and contextual approaches.

Conclusively, urban accessibility strategies will be paramount in enhancing the sustainability of urban design. Urban design must be oriented towards the attainment of greater efficiency and equity by focusing on accessibility over mobility. These elements of land use, transportation, technology, and accessibility must therefore be taken into consideration in any efforts to enhance the sustainability of urban design. With continued growth and development, the role of accessibility will become increasingly important.

1.2INITIATIVE TOWARDS SUSTAINABLE TRANSPORT ACROSS GLOBE

1.2.1 United Nation's Context

United Nations General Assembly published an agenda for Sustainable Development in an International Conference in 2012 at Rio de Jana Rio and is intended to be achieved by the year 2030.Out of 17th SDG's 2030, 11th SDG deals with "Sustainable Cities and Communities" which has 10 targets of which 2nd target deals with Affordable and Sustainable Transport Systems(Rasche

et al., 2013). Here, affordable means inclusive or available for all and sustainable means transport modes are consistent with wider concerns of sustainability.

In this situation there is a need to research and implement better sustainable transport system as sought from examples of measures like car restricting vehicles in city court, introduction of automated vehicles, motivating NMTs and walkability as introduces in some north European countries. The cities like Copenhagen, Vilnius, London, Lisbon, Amsterdam have already implemented the measures like restricting car entries, promoting NMTs and EVs(Marek Ogryzek et al,2020).However Indian context still continuing to develop car and private vehicle-oriented transport pattern.

1.2.2Indian Context

The lack of effective planning and land-use controls has led to widespread urban sprawl in India, increasing both the number and length of trips for most people, including public transport users (Bertaud, 2018; Census of India, 2021). With 23% of Indian urban pollution living in poverty, its public transport fairs are extremely low making it difficult to operate, maintain or replace. There are other challenges like inefficiency, road congestion, accidents, overcrowding, noise and lackof coordination. The most of metropolitan transport systems find it difficult to draw operating costs from the revenues generated by them.

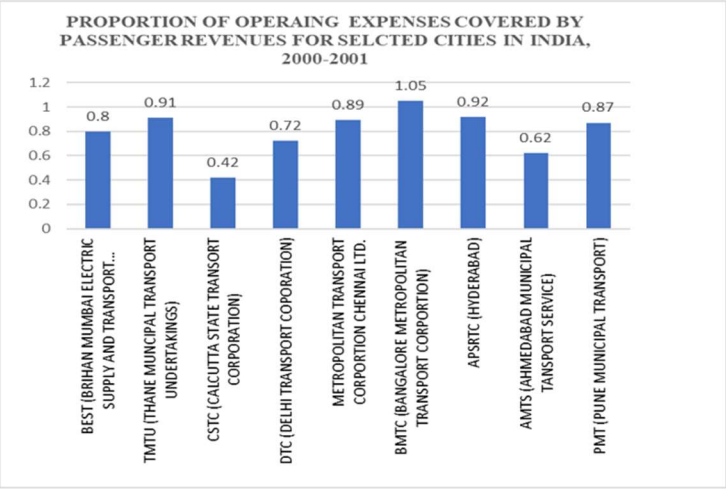


FIG 3: Operating Expenses cities in India, 2000-2001.
(Source: Association Of State Road Transportation Undertakings 2003)

In Delhi, motor vehicles are estimated to contribute around 67% of air pollution. Gasoline-powered vehicles are the primary source of carbon monoxide (CO), hydrocarbons (HC), and lead (Pb), while diesel vehicles are the main contributors to suspended particulate matter (SPM) and sulfur dioxide (SO_2) (CPCB, 2020).The problem is being multiplied as can be seen from the exponential growth of number of registered vehicles since 1950 from few thousands to 40 million and more for Cars or jeeps and two wheelers till 2001(Source: Ministry of Road Transport and Highways 2003).

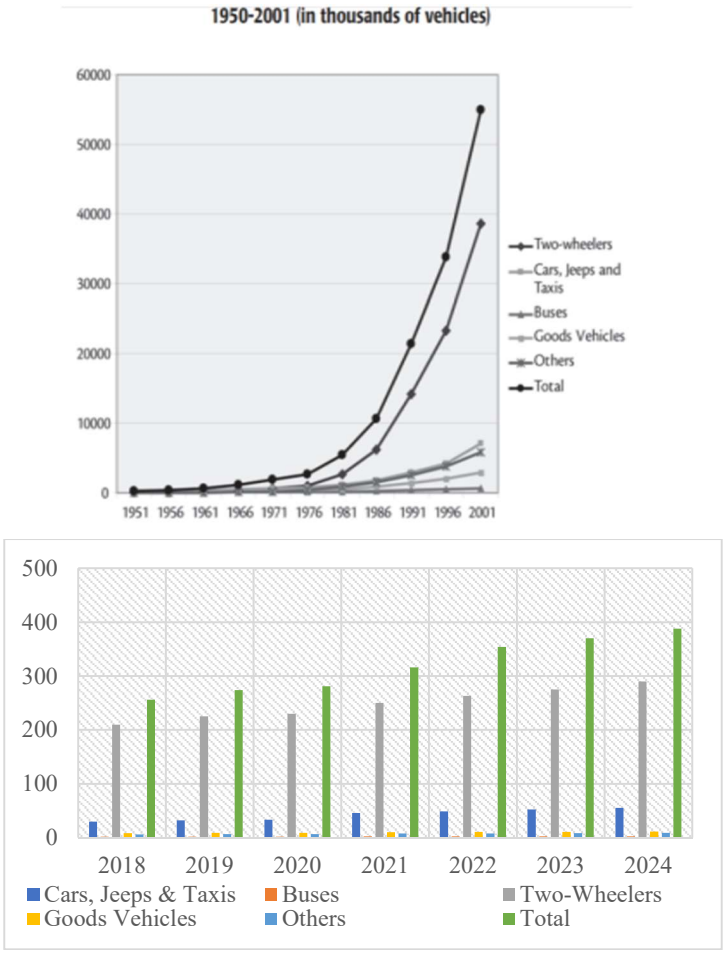


FIG 4:No. of Vehicles Registered from 1950-2001(in thousand)

1.2.3 Development of sustainable urban tansport system

Though most of the times urban forms are the result of natural growth and geographical situations,the work on transport system design and development for future offers the scope to induce sustainability to the urban form(Persia et al., 2016). Most cities have evolved their forms as a result of a sustainable network over the period of time.

As shown in Fig:4 Mumbai is linearly grown along railway networks: the western, central and harbor lines.Whereas Delhi, Bengaluru and Nagpur have grown along the radial and peripheral network of Ring roads and Highways in all directions radiating outwards (Gudmundsson et al., 2017).

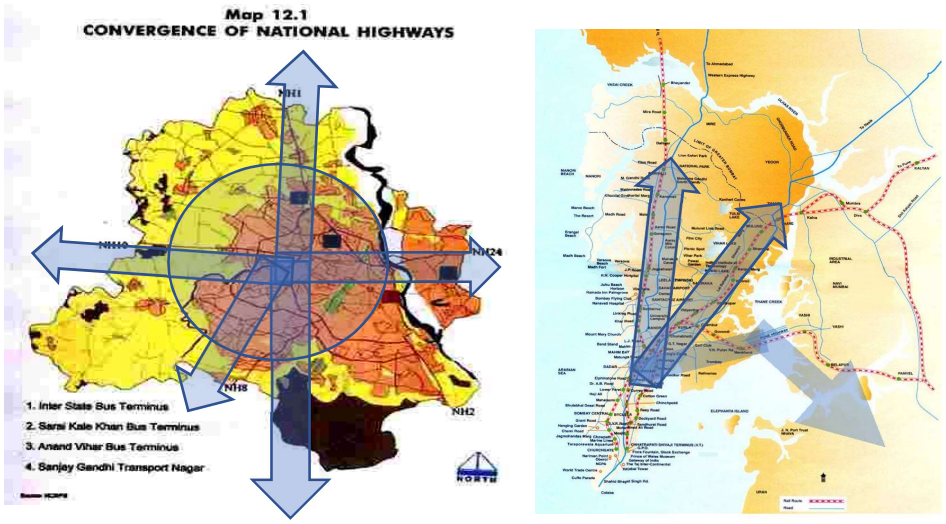


FIG 5: Relationship between Transport Network & Form

Urban The radial roads emanating from old city act as corridors of development and the lateral ring road acts as spreading network of small nodal centers of the development leading to the urban sprawl in wild proportions if not controlled or supplemented by suitable measures towards sustainability(Pojani& Stead2015). Sustainability, urban form, and transport systems are closely interrelated, with urban design directly influencing travel behavior, resource use, and environmental impacts (Ewing & Cervero, 2010).Public transport performance is influenced by factors that shape sustainable urban form, including development density, land-use diversity, urban design, and proximity to urban centers (Ewing & Cervero, 2010).

From environmental, economic and social concerns the sustainable transport system is essential to tackle the climate change at planet level and pollution levels at local level. The transport sector accounts for approximately 20–25% of total global energy consumption, making it a major contributor to environmental degradation (World Bank, 2018). Sustainable transport systems support environmental, social, and economic sustainability of urban communities (OECD, 2018).Studies are being undertaken to evolve the most compatible urban form to suit sustainable urban transport system that reduces trip length, minimize individual or car use, maximizes public transport and encourage walkability and cycling.

There is a need to understand the way and system to derive the factors on which sustainability of an urban form is dependent. Further, the indicators and set that will affect each factor from the past studies (Spirin et al., 2016). There have been many studies on individual factors affecting sustainability of an urban form such as land use, density, transport system, etc.

Whereas there is a gap in the study of the relationship between an accessibility system and sustainability of an urban form. Also, there is a gap to identify the set of indicators integrally from the studies to define it. So, the need is felt to conduct a study to research such indicators and formulate a set to measure their contribution towards sustainability by application on a practical area.

1.3 AIM AND OBJECTIVES

The present study aims to derive strategies for an urban accessibility system towards improving sustainability of an urban form.objectives to achieve the aim are as below:

1. To understand the urban form and urban accessibility system with its nuances and relationship from the literature review.
2. To study and derive indicators to express sustainability of an urban form and accessibility from literature cases.
3. To find out the methodology and system to assess the sustainability of an accessibility system and ways to interpret it statistically.
4. To derive the strategies for an accessibility system so as to improve sustainability of the parent urban form from the literature and case studies of statistical interpretations.

1.4 METHODOLOGY AND SCOPE

The methodology decided is to reach study objectives sequentially from the literature papers published and their findings. Further the indicators for sustainability interpretation are to be derived from the paper case studies. From the results of these studies the strategies for sustainable accessibility are to be derived.

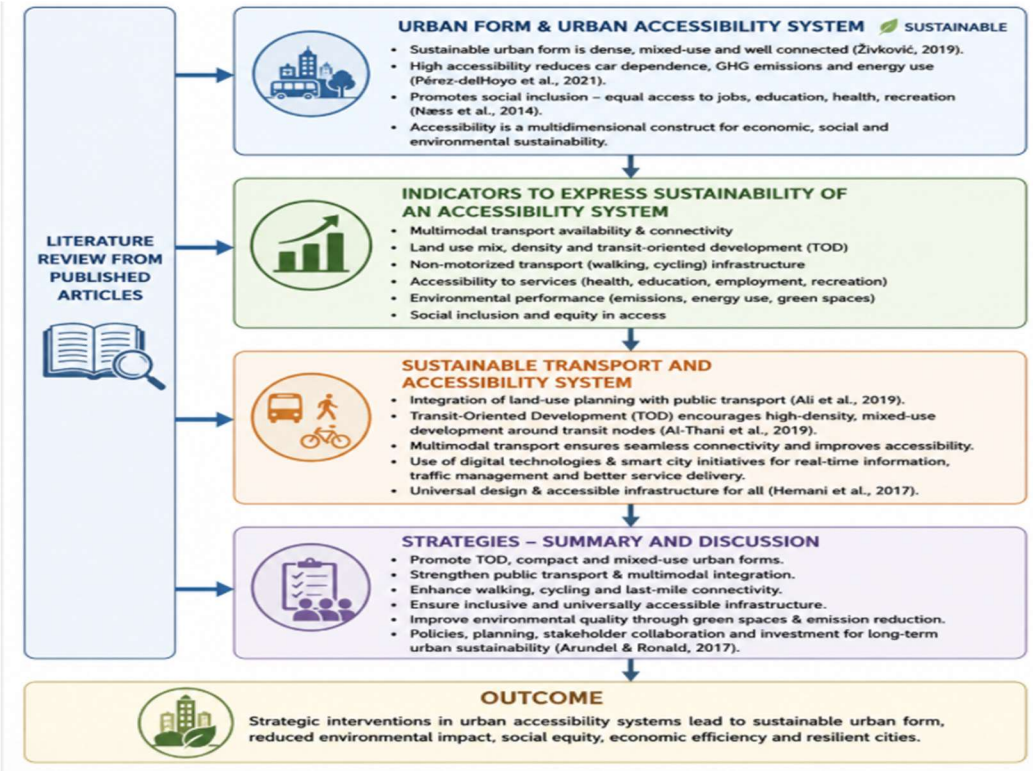


FIG 6: Urban Accessibility Methodology Framework

The scope of this study is limited to the studies from published paper articles and books only. It will not account for personal non data driven inferences. It will be limited till the summarizing and commenting on available information. It will not indulge in to technical experimentation or any kind of laboratory analysis for the same.

2. LITERATURE REVIEW

Understanding Urban Sustainability in the context of Urban Form and Urban Accessibility

The literary meanings from dictionary drew the meanings and definitions as below:

A.Sustainability: It is the ability to maintain environmental, social, and economic well-being for present and future generations.

B. Urban Form: It refers to spatial pattern, population distribution, land uses and the accessibility networks to connect economic activities, social groups and institutions within an urban area. (UN-Habitat,2013)

C. Transport Network Typologies: It refers to the different patterns and structures of transportation networks that influence urban movement and development.

D. Sustainable Transportation: It is a transport system that provides efficient mobility while minimizing environmental, economic, and social impacts.

E. Urban Accessibility and Urban Accessibility System: It is the ease with which people can reach desired services, facilities, activities, and destinations within an urban area. Whereas the system is an integrated framework of land use and transportation that enables convenient and equitable access to urban opportunities and services.

The concept of accessibility refers to reach or benefit or access to use some service or facility or amenity.Better accessibility can extend benefits to everyone. It can be towards people, goods, services and information. Better access to all is seen as the notion of development.

Most important issue of it is What is to be accessed?, For whom to be accessed? and How to be accessed?.

2.1 SUSTAINABILITY

The sustainability is a universally accepted core value of life. Brundtland (1984) definition of sustainability-as "abilityto make development sustainable to ensure that it meets the need of present without compromising the ability of future generation to meet their own needs". Sustainability is assessed through environmental (Planet), economic (Profit), and social (People) dimensions, ensuring balanced development. It also includes cultural sustainability to preserve and promote sustainable practices and heritage across generations.Urban form and transport systems are closely linked, and their interaction plays a critical role in achieving environmental, social, and economic sustainability in cities.

2.2 URBAN FORM:

The urban form is majorly derived from cities transport route pattern. This pattern derives urban propagation and thus forms as well. Urban forms can be broadly categorized into Qualitative Urban Forms and Spatial Urban Forms. Qualitative urban forms describe the density and development characteristics of a city, including compact and dispersed cities. Spatial urban forms describe the physical arrangement and growth pattern of urban areas, including linear/radial, polycentric, satellite, fringe, and edge cities.

Every pattern mentioned above has its relationship with transport system and its network. There can be a specific accessibility System to enhance sustainability of an urban form. Urban form elements such as density, land-use mix, and public transport availability influence travel behavior and environmental impacts.

If the urban form is compact, it is characterized by high population density and mixed land use, which reduces car dependency and supports a rich and efficient public transport system. In contrast, dispersed urban forms are associated with low densities, segregated land uses, and higher dependence on private vehicles. Linear and polycentric urban forms exhibit intermediate characteristics, with mixed densities and land-use patterns and a moderate level of car dependency (Ewing & Cervero, 2010).

Compact urban forms with high density and mixed land use reduce car dependency and support efficient public transport, whereas dispersed forms show low densities and high reliance on private vehicles. Linear and polycentric forms exhibit mixed densities and moderate car dependency. Table 2 shows Urban form and its elements with example.

Table2: Urban Form &its Elements

Type of Form	City Type	Density/Space	Land Use	Car Dependency	Public Transport	Example
Qualitative	Compact	High / Contained	Mixed	Low	Rich / Efficient	Vienna, Austria
	Dispersed	Low / Uncontained	Segregated	High	Poor	Los Angeles, USA
Spatial	Linear	Mixed / Contained	Limited Mix	Medium	Medium	Pomona Freeway 60, USA
	Polycentric	Mixed / Medium	Mixed	Medium	Medium	European Cities
	Satellite	Mixed / Medium	Mixed	Medium	Medium	Luton & Reading, England
	Fringe	Low / Uncontained	Segregated	High	Poor	Almere, Netherlands
	Edge	Mixed / Medium	Mixed	Medium	Medium	Burlington, Massachusetts, USA

2.3 TRANSPORT NETWORK TYPOLOGIES

As stated by Rodriguez J.P.,2021, shows typologies with respect to their network The transport and urban spatial structures which derive the urban form through propagation of settlement around it assume the four typologies as given in Table3.

Table 3: Transport Network Typologies& Sample Case

Type	Network Characteristics	Key Features	Examples
Type I – Completely Motorized Network	Low-density urban development with secondary roads converging onto highways	Strong automobile dependence; limited public transport; dispersed land use	Denver, Dallas, Los Angeles
Type II – Weak Center	Average densities with spatially dispersed urban form	CBD primarily accessed by private vehicles; public transport not cost-effective	Melbourne, San Francisco
Type III – Strong Centre	High-density urban core with strong transit orientation	High public transport accessibility; secondary roads converge on ring roads; emergence of efficient transit systems	Paris, New York, Toronto

Type IV – Traffic Limitation	Transit-oriented central area	Automobile use restricted in CBD to preserve heritage and urban character; cars mainly used in peripheral areas	London, Singapore, Vienna

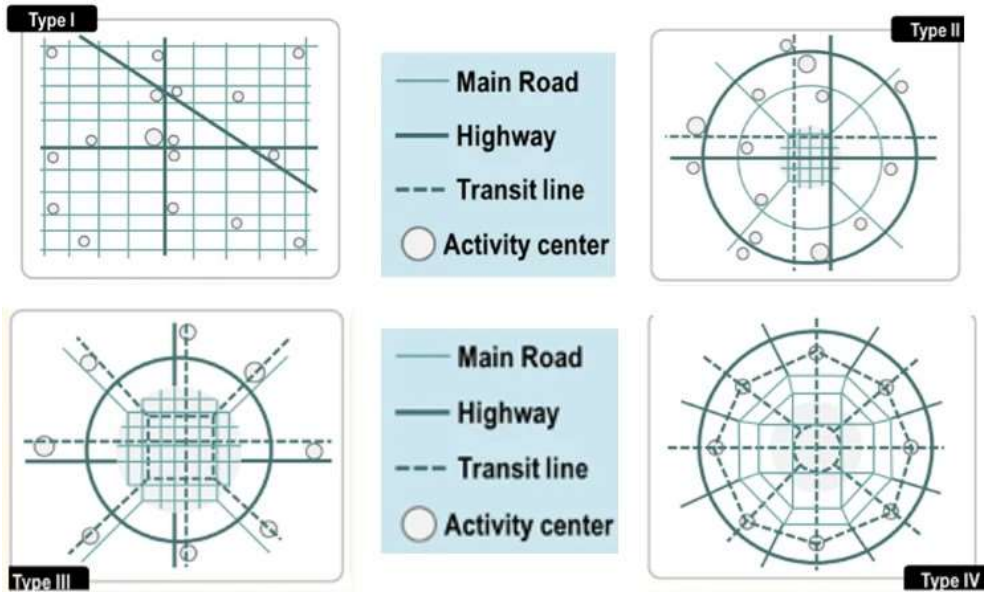


FIG 7: Urban transport network typology(Rodrigue, 2021).

Also, the figure 7 illustrates organized and disorganized movement patterns in monocentric and polycentric urban structures, highlighting primary and secondary traffic flows between central and sub-centers.

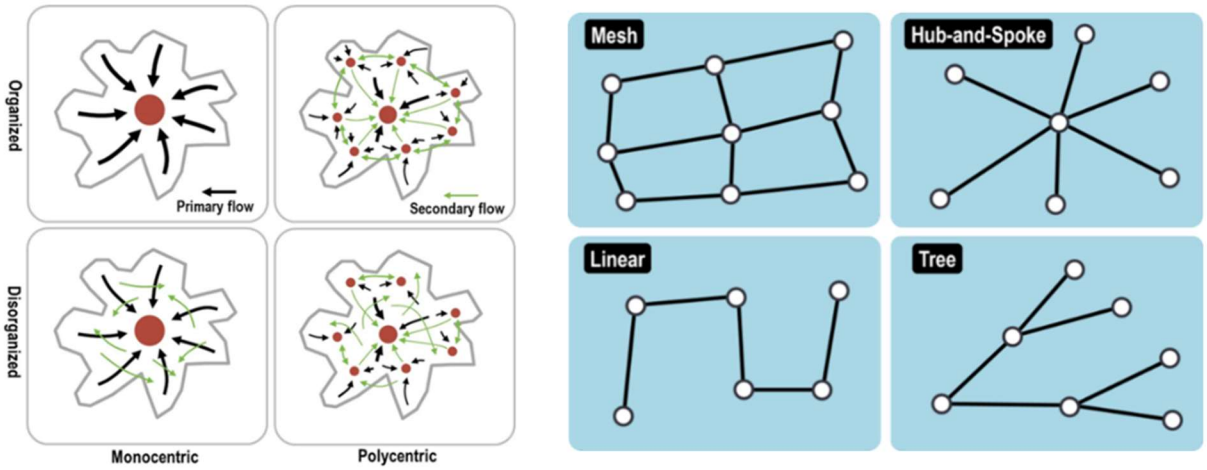


FIG 8: Network topologies Possible Urban Mobility Patterns (Rodrigue, 2021).

The Network pattern and topologies define the form and possible mobility patterns.Dispersed forms do spend more energy on transport services due to low density and increased trip lengths.This is relevant from per capita energy consumption(Source: Rodrigue J.P.,2021) in figure 9.

Urban forms are based on certain preconceived ideas and planning concepts that guide sustainable urban development. These include Neo-traditional Development, Urban Containment, Compact City, and Eco-city. Each of these urban forms may incorporate one or more design concepts related to urban form, such as compactness, sustainable transport, density, mixed land uses, diversity, passive solar design, and greening, which together contribute to environmentally responsible, socially inclusive, and economically efficient urban development.

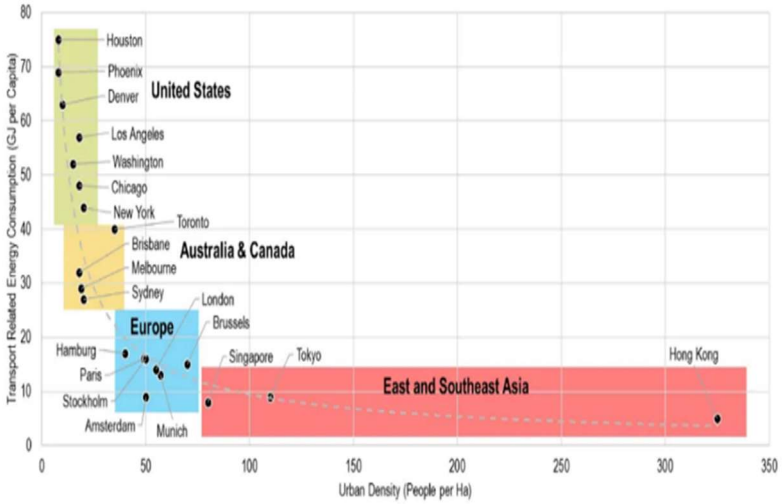


FIG 9: Energy consumption vs Urban density(Rodrigue, 2021).

For the above design criteria/ concepts the scaler assessment of four kinds of urban form is done with 1-3 points scale is allocated for each criterion to assess sustainability of each form. The resulting matrix is as below in table 4.

Table 4: Matrix Assessing the sustainability of urban form

Design Concept (criteria)	**Neo-traditional Development**	**Compact City**	**Urban Containment**	**Eco-city**
Density	1.Low 2. **Moderate** 3. High	1.Low 2. Moderate 3. **High**	1.Low 2. **Moderate** 3. High	1.Low 2. **Moderate** 3. High
Diversity	1.Low 2. Moderate 3. **High**	1.Low 2. Moderate 3. **High**	1.Low 2. **Moderate** 3. High	1.Low 2. **Moderate** 3. High
Mixed Land Use	1.Low 2. Moderate 3. **High**	1.Low 2. Moderate 3. **High**	1.Low 2. **Moderate** 3. High	1.Low 2. **Moderate** 3. High
Compactness	1.Low 2. **Moderate** 3. High	1.Low 2. Moderate 3. **High**	1.Low 2. **Moderate** 3. High	1.**Low** 2. Moderate 3. High
Sustainable transportation	1.Low 2. **Moderate** 3. High	1.Low 2. Moderate 3. **High**	1.Low 2. **Moderate** 3. High	1.Low 2. Moderate 3. **High**
Passive solar design	1.**Low** 2. Moderate	1.**Low** 2. Moderate	1.**Low** 2. Moderate	1.Low 2. Moderate

	3. High	3. High	3. High	3. **High**
Greening Ecological design	1.Low 2. **Moderate** 3. High	1.**Low** 2. Moderate 3. High	1.**Low** 2. Moderate 3. High	1.Low 2. Moderate 3. **High**
Total Score	15 points	17 points	12 points	16 points

Above matrix suggest that compact urban form is more sustainable followed by ecological urban form. This Matrix shall help planners in assessing the contribution of different urban forms to sustainability. However, different planners can develop their own combination of design concepts to attain better sustainable form which has probably "high density and diversity, compact and mixed land use, and has ecological elements" with sustainable transport.

2.4 URBAN ACCESSIBILTY

The concepts of traffic, mobility, and accessibility are interrelated and hierarchical in nature. Traffic represents the quantitative movement of vehicles or flows, mobility refers to the ability to move or travel, while accessibility denotes the ability to reach desired activities, services, or destinations. Among these, accessibility is the broadest concept, as it integrates land-use patterns, transport systems, and travel opportunities (Litman, 2013).

Urban accessibility can be viewed as a product of the interplay between urban form, transportation systems, (Mulley C. et al 2020).

2.5 SUSTAINABLE TRANSPORTATION

A sustainable transportation system is one that respects human health, ecological preservation, and social fairness both within and between generations while safely meeting the fundamental access needs of people and society. Such a system is affordable, operates efficiently, provides a choice of transport modes, and supports a vibrant economy. At the same time, it limits emissions and waste to levels that the planet can absorb, minimizes the consumption of non-renewable resources, ensures that renewable resources are used within sustainable yield limits, promotes reuse and recycling of components, and reduces land consumption and noise generation.

A transport system can become more sustainable with respect to society if it meets the basic human needs of health, comfort, and convenience without placing stress on the social fabric. It should support development at a human scale and provide a reasonable choice of transport modes, housing types, communities, and lifestyles. In addition, the system should generate noise only within levels acceptable to communities and ensure safety for people as well as their property (Black, 2010).

Compact cities can reduce overall travel distances; however, individuals may still prefer to use private cars. Mixed-use development can help shorten travel distances, but residents may not necessarily live adjacent to their workplaces or daily activity locations. Although locating homes near facilities, and facilities near residential areas, can minimize overall travel demand, people may still choose not to use the closest services. Walk- and cycle-friendly development can encourage non-motorized modes, yet some individuals may continue to favor car use. Similarly, locating homes and businesses near public transport nodes can improve accessibility to transit, but this does not always guarantee a shift away from private vehicles. Car-free developments, car-free areas, and clear zones can restrict car use and encourage alternative modes, although such measures may merely displace traffic problems to other locations. Even where settlements are large enough to provide the critical mass needed to support sustainable transport systems, the private car may

still remain the preferred mode of travel. According to Ihsan Abbas Jasim et al, 2021 following factors of an urban form and transit system do contribute sustainability of urban form.

2.5.1 Spatial Urban Structure

It is a combination of form and function within a specific system, where the *form* or shape refers to the interconnected elements such as the road network, homes, stores, parks, and other physical components (Talen, 2011).

2.5.2 Public Transportation

There is a strong interrelationship between land-use planning and transportation in numerous ways, and these two elements are so closely interconnected that it is difficult to separate them. Land-use planning plays a crucial role in shaping travel behavior and transport demand. (Farhan S and Abdelmoneim M G, 2018).

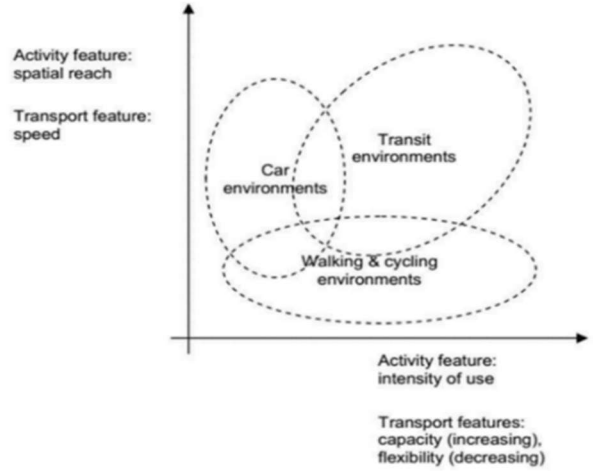


FIG10: Correlation between Public Transport & Land use form (Source: Jasim, I., et.al. 2021)

Fig.10 shows the benefits and limitations of different modes of transport such as:

- Car a fast and highly flexible mode transport however is a bit costly and has little capacity.
- Public transport like buses, local trainshave a large capacity, cheap and fast though it is not that flexible
- Pedestrian as known by all of us is free, flexible but the speed is restraint.

2.5.3 Density of Urban Development

Urban development density is often quantified in terms of employment or population density. Increased urban accessibility and sustainability are greatly aided by high population density. By providing a greater range of services and facilities, higher densities reduce the need for long-distance travel and increase the opportunities available to inhabitants.

2.5.4 Diversity in Activities

Diversity in activities through mixed land use in urban areas promotes the functional integration of land uses and leads to economic savings by providing convenient access to a wide range of services and opportunities. (Sorensen A and Okata J.,2010).

2.5.5 Urban Design

It can offera convenient ecosystem for transportation at street level.

i) Street grid pattern

Uses of intersecting streets (gridpattern) make walking trips easier. (Farhan S L, et.al, 2019).

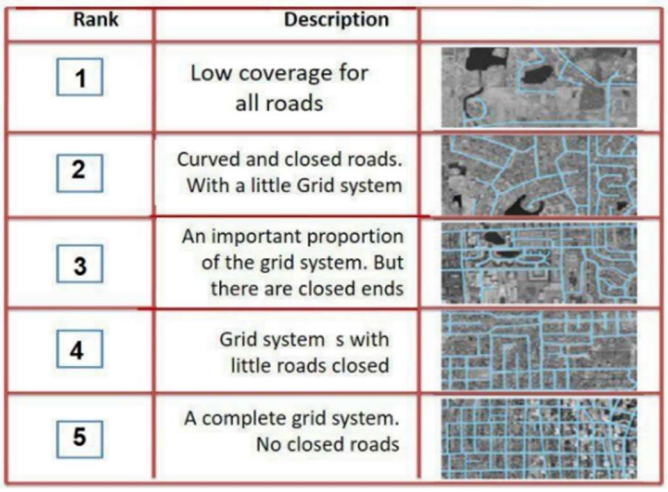


FIG 11: Street relational Classification system

ii) *Development of site*

To take advantage of the wide-ranging impact of public transport, urban development is often concentrated along public transport corridors and around transit nodes.

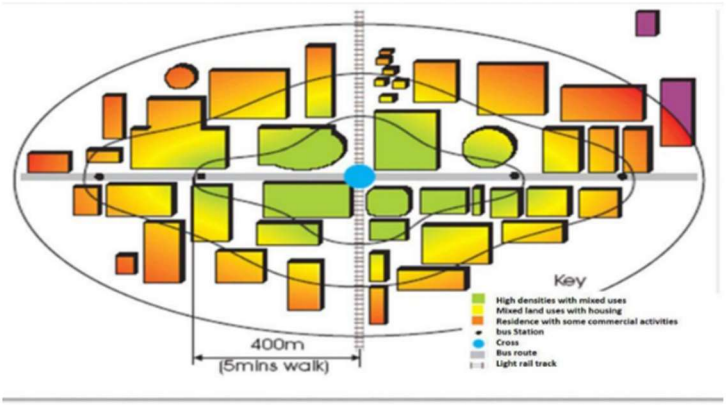


FIG 12: Locating high density in activity nodes within a walkable catchment

Advanced, high-intensity activity nodes are typically located at the central points of public transport networks in small urban areas and are often concentrated within the Central Business District (CBD). (Banister D et. al, 2011).

iii) *Design of neighbourhood and public places*:

By enhancing pedestrian connections to public transit stops and lowering reliance on private vehicles, good urban planning can promote the use of public transportation. (Nam K. et.al, 2012).

iv) *Designing public transport lane*:

Transport lanes can greatly promote walking and cycling if they are planned as busy public streets with shops, restaurants, and service establishments. Streets are made more appealing and vibrant by dynamic street frontages, which generate constant human activity.(Gehl, 2010).Role of NMTs towards development of sustainable transport system major ones to listare as below:

Sustainable transport infrastructure & economic returns: A bibliometric analysis Bygisa Badasa et al, Analyses Journals on sustainability, transport and infrastructure between 2000 to 2019.

Table 5: Results of Bibliometric and Keyword Analysis

Indicator	Description	Value
Sustainability-related papers (2000)	Number of publications in 2000	42
Sustainability-related papers (2019)	Annual publications in 2019	322
Sustainable transport–related papers	Total number identified	77
Papers analyzed for keyword occurrence	Total papers included	2,997
Keywords identified (≥10 occurrences)	Total keywords meeting threshold	5,842
Sustainable mobility	Keyword occurrences	139
Sustainable transport	Keyword occurrences	132
Sustainable	Keyword occurrences	83
Infrastructure	Keyword occurrences	78
Transportation	Keyword occurrences	75

3.STATISTICAL METHODS FOR ASSESSMENT OF SUSTAINABILITY IN TRANSPORTATION

The sustainability assessment depends on various parameters and criteria. For simultaneous consideration of all the criteria decided for assessment of sustainability the use of statistical methods is apt. There can be various statistical methods such as-

i) Analytical hierarchyProcess (AHP)
ii) Principal Component Analysis (PCA)
iii) Traffic optimization
iv) GIS based spatial analysis

Yedla et al. (2002) applied the Analytical Hierarchy Process (AHP) as a multi-criteria decision-making tool to evaluate options for achieving an environmentally sustainable transportation system in Delhi. Given that Delhi's Road traffic is predominantly composed of two-wheelers and private cars, selected policy options focused on reducing vehicular emissions and improving fuel efficiency. The AHP framework evaluated the following alternatives:

- Option I, replacing two-stroke two-wheelers with four-stroke two-wheelers (AI);
- Option II, converting conventional fuel cars to compressed natural gas (CNG) cars (AII)
- Option III, converting conventional fuel buses to CNG buses (AIII).

In order to enhance sustainable transportation decision-making, this organized framework made it possible to compare the operational, economic, and environmental effects. The ranking procedure must be completed collaboratively by a group of actors since various stakeholders may give the offered options varying priorities. All types of stakeholders who have a direct or indirect impact on the transportation system should be included in this group. Environmental specialists, energy specialists, users, government agencies or legislators, vehicle associations, and automotive

research institutes are important stakeholder groups. Involving a wide range of stakeholders guarantees a fair, open, and inclusive decision-making process that better represents a variety of viewpoints and facilitates the choice of ecologically sound and socially acceptable transportation methods(Yedla et al., 2002).

List of criteria based on which the comparative judgements are made.

1. Energy efficiency (energy)
2. Emission reduction potential (ERP) (environment)
3. Economic feasibility (cost)
4. Technological preparedness/availability (technology)
5. Implement ability/adaptability
6. Barriers to the implementation of these options (barriers)

3.1Analytical hierarchy Process (AHP)

- **QUANTITATIVE CRITERIA**

Energy

$$ESP = 1 - \frac{Ejt_{alt}}{Ejt_{old}}$$

ESP = Energy saving potential,

E_{jt}-alt = energy required for travel mode j in alternative technology in the year t,

E_{jt}-old = energy requirement of the travel mode j in existing technology in the year.

Environment

$$ERP = 1 - \frac{Pit_{alt}}{Pit_{old}}$$

ERP ¼ emission reduction potential,

Pit-alt = emission of pollutant type i in the alternative technology in the year t,

Pit-old = emission of pollutant type i in the existing technology in the year t.

Cost

$$LSC = \frac{levelised\ cost}{PKM_{jt}}$$

LSC = levelized service cost,

LC = annualised cost of the option (includes capital cost, operation costs, O & M costs, taxes),

PKM_{jt} = total passenger kilometres covered by travel mode.

- **QUALITATIVE CRITERIA**

Weighted Arithmetic Mean Method(WAMM)

Group members' subjective assessments are gathered through pairwise comparisons. Priority matrices for the criterion, stakeholders (actors), and alternatives are obtained through a questionnaire survey, especially under qualitative criteria. In order to ensure that the collective preferences of all stakeholdersare methodically represented in the AHP analysis, the group consensus matrix utilizing WAMM is determined using the following equation.

$$P_g A_j = \sum_{1}^{n} W_i\, P_i(A_j)$$

Where, $P_g A_j$ = group priority of alternative A_j,

$P_i(A_j)$ =priority of A_j given by member E_i,

W_i = weight to be given to the preference of E_i,

n = number of group member.

CNG car as an alternative option showed much higher potential in energy saving compared to the other two alternative options.

Table 5: Priority of all under the "energy" criteria

Priority of all under the "energy" criteria		
Alternative option	***ESP***	***Priority***
4-Stroke 2-wheelrs	0.314	0.0489
CNG Cars	0.422[a]	0.5494[a]
CNG Buses	0.032	0.0416
[a] = car and taxi have been added together		

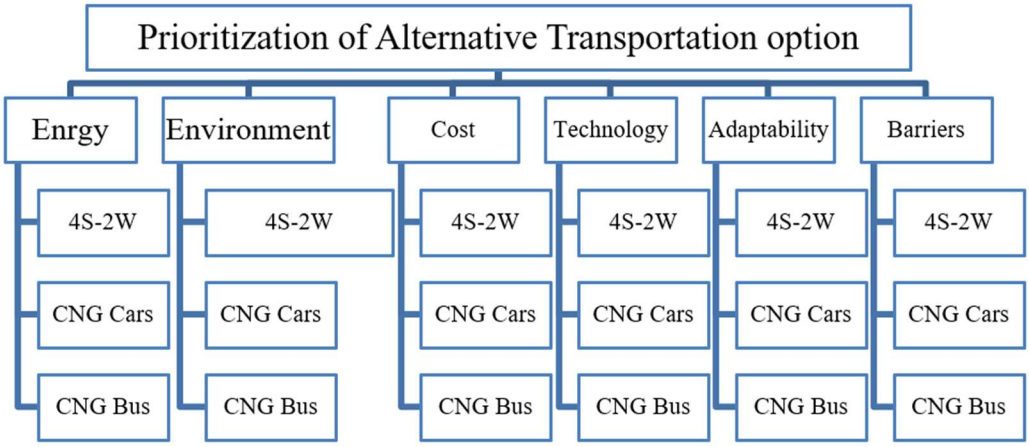


FIG 13: Prioritization of alternative transportation option

AHP Model for Sustainability Assessment

The main aim of sustainable transportation is to integrate economic, social and environmental at all phases of a transportation system design.

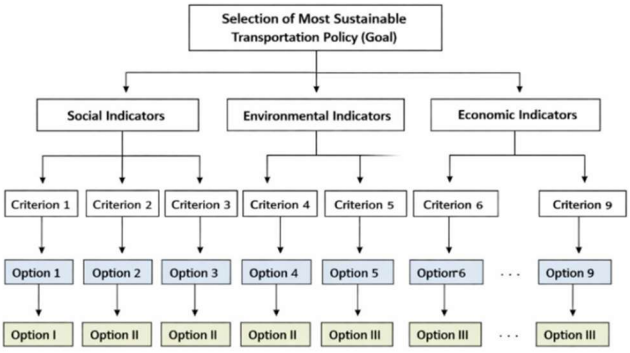


Fig 14: AHP Model for Sustainable Transport Policy

3.2 Principal Component Analysis (PCA)

Public transportation networks have grown quickly in densely populated urban areas to meet growing mobility constraints (UN-Habitat, 2013). By reducing correlated variables, like time-based traffic flows, into a smaller set of uncorrelated components while maintaining maximum variance, PCA minimizes dimensionality (Jolliffe & Cadima, 2016). In transportation

research, this method is especially helpful for streamlining complicated datasets and bolstering sound decision-making procedures.

PCA is applied to handle Volumetric Traffic Data – Washington D.C. Metro, The Washington Metropolitan Area Transit Authority (WMATA) provided the fare card record data. Four attributes are present in every record in the dataset: entry station, entry time, exit station, and exit time. The system manages about 600,000 journeys per weekday, about 200,000 travels on weekends, and an average of over 14 million trips per month, according to an analysis of these records. There is an uneven distribution of passenger demand among stations, with some seeing much larger traffic levels than others.

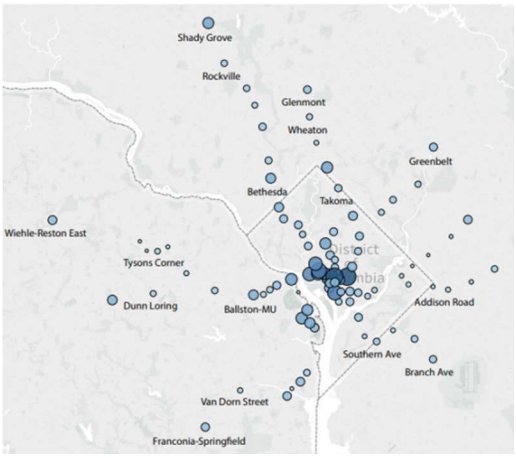
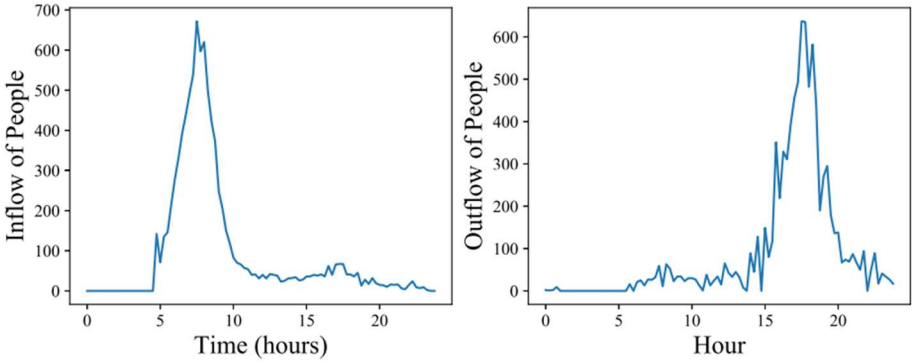


FIG15: Spatial distribution of metro stations in the Washington, DC(WAMATA,2017)

Stations with increased passenger activity are shown by larger, darker circles in the spatial representation. For example, Union Station recorded almost 650,000 passenger arrivals and departures in January 2017, making it the busiest station. (WAMATA,2017)

Time series reflecting traffic volume per station were created by aggregating passenger inflows and outflows at 15-minute intervals. The number of passengers fluctuates with time as well as between stations. Three exemplary stations were chosen for this study: Vienna Station, which serves as a typical commuter station and is situated in a primarily residential neighbourhood; Federal Triangle Station, which is located in the city centre; and Arlington Cemetery Station. Following standard procedures for transit demand and time-series analysis, a typical daily passenger volume profile was then looked at for each of these stations in order to analyse temporal demand patterns(Jolliffe & Cadima, 2016).



(a) Vienna station on February 8, 2017.

FIG 16: Variation of in and outflow of passengers w.r.t time at Vienna station

5.SUSTAINABLE TRANSPORT: Better Practices—Case Studies

Many European cities support for public transport and cycling in daily mobility to reduce air pollution, traffic jams & Co2 emissions (Jäppinen, S et.al.2013). Walking and cycling asan affordable transport option can counteract the negative effects of car use for all (Bachand-Marleau, J et.al. 2012).

4.1 IN COPENHAGEN, Denmark

This article gives the volley of better practices for sustainability enhancing transport systems. Some of them are listed as below: -

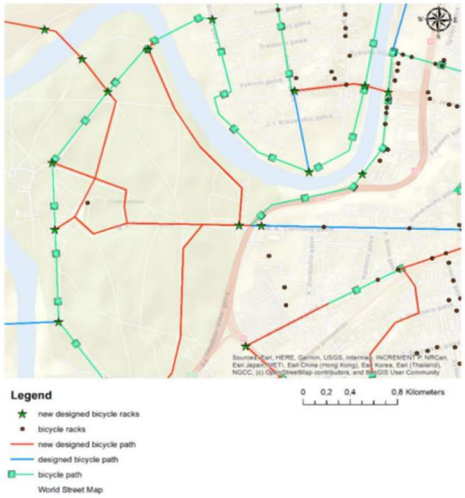


FIG 17: Designed and existing bicycle network and bicycle rack locations(Source: Esri. 2020).

According to the City of Copenhagen (2010), there were an additional 350 km of bike tracks added to the existing network. In addition, there are a plethora of cycling amenities in the city, such as green "waves" that separate cyclists from infrastructure and allow them to navigate the town during peak hours without stopping. The reconfiguration of several crossroads prioritised bicyclists, relocating the automobile stop lines five meters behind the bike lanes.

4.2 IN LONDON, UK

Many social movements succeeded in reducing the usage of private automobiles and increasing the use of public transit and a citywide bike network. Paying to enter the city center: Restricted admission to the city center deterred automobile usage, which led to a decrease in greenhouse gas emissions in London. On the flip side, affordable public transport inspires.

Prime Minister Boris Johnson's campaign, called Charge Point, encourages citizens to use electric cars for free charging points in London which increased number of sales and registered electric cars (Transport for London UK, 2013.)

4.3 In VILNIUS , Lithuania

Here the existing infrastructure and actions have been analysed along with the problematic areas. The Urban sprawl is suggested to be concern and hurdle to sustainable transport system. The GIS tools have been used by dividing city in to 51 (traffic analysis zone) TAZ for its analysis. Further model of accessibility created on the basis of accessibility of city Centre, population density and number of jobs on zone, density of public network and number of daily trips in each zone.

5. RESULTS AND DISCUSSIONS

The parallel study provides the methodology and literature statistical methods provide for the base of analysis. Following summary and observations from the literature can also be drawn:

5.1 MODES OF SUSTAINABLE AND GREEN TRANSPORTATION

The amount of energy needed to operate the vehicles in the current modes of transportation is tremendous. They release toxic gasses that pollute the environment and cause health issues. It is helpful to employ eco-friendly forms of transportation to get rid of these negative effects. Here are a few eco-friendly transportation options accessible today.

Sustainable transportation includes environmentally friendly mobility options that reduce emissions, energy consumption, and traffic congestion. Modes such as bicycles and walking produce no greenhouse gas emissions and promote healthy lifestyles. Electric vehicles, electric bikes, and electric motorcycles operate on battery power and significantly reduce air pollution. Green trains and monorails provide efficient mass transit with low environmental impact due to their use of electricity and high passenger capacity. Additionally, carpooling minimizes the number of vehicles on roads, while hybrid and clean-fuel-based vehicles improve energy efficiency and reduce carbon emissions, contributing to a more sustainable urban transport system.

5.2 BENEFITS OF GREEN AND SUSTAINABLE TRANSPORTATION

Green and sustainable transportation has several advantages, including advantages for the environment, human health, and the economy. Some of the main advantages of utilizing green transportation are given below:

Green transportation offers numerous environmental, economic, and social benefits. It produces little to no greenhouse gas emissions, helping to reduce air pollution and mitigate climate change. Sustainable transport modes such as bicycles, electric vehicles, and carpooling lower fuel and maintenance costs, resulting in significant economic savings. By reducing reliance on fossil fuels, green transportation supports a sustainable economy and promotes the growth of clean energy industries. It also improves public health and quality of life by minimizing exposure to harmful pollutants. Furthermore, green mobility options help reduce traffic congestion and decrease dependence on non-renewable energy resources, contributing to sustainable urban development.

5.3 ADAPTABLE CONCEPTS AND METHODS:

Case studies of best practices lead us to concepts like:

Sustainable transportation can be promoted through a combination of infrastructure development, policy measures, and public awareness initiatives. Dedicated bicycle paths, green cycle routes, and advance stop lines improve cyclist safety and convenience. Limiting private car use through social campaigns and restricting vehicle access to city centers helps reduce congestion and pollution. Affordable public transport services and free charging stations encourage the adoption of sustainable travel modes, including electric vehicles. Additionally, strong support for public transport, walking, and cycling creates accessible, healthy, and cost-effective mobility options, contributing to improved urban accessibility and environmental sustainability.

5.4 SUSTAINABILITY PARAMETERS:

The various studies lead us to draw various sustainability parameters as below:

1. Li, Hu &Beisi. Jia (2010)

The main parameters can be seen in the spear wheel form which have been originally derived from Arups spear Wheel.

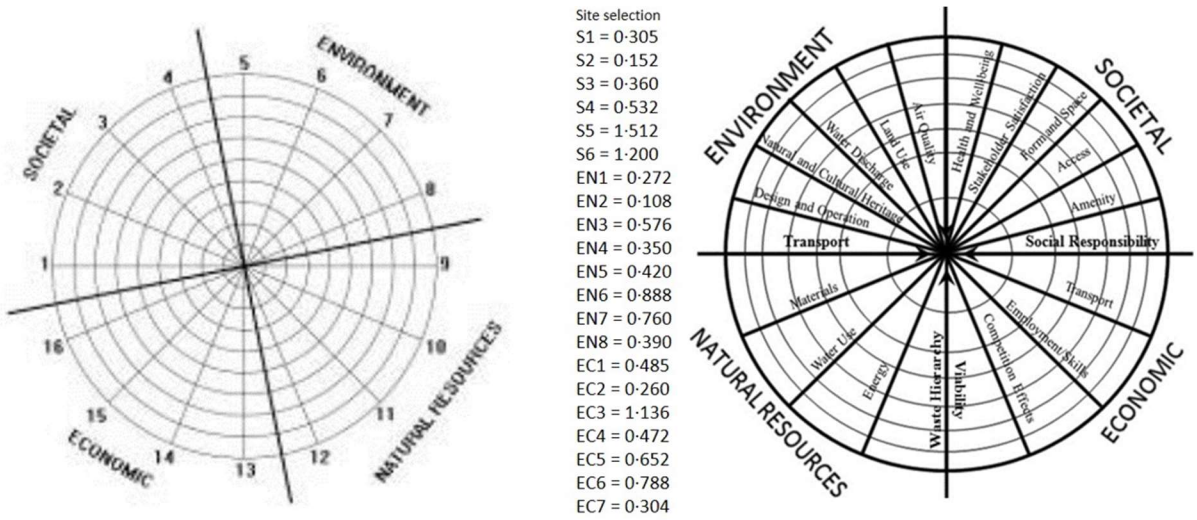


FIG 18: Framework system for sustainability assessment showing weighted and unweighted scores for 21 parameters.

2. J. MoskolaïNgossaha et al. (2017)

Sustainability assessment of a transportation system under uncertainty: an integrated multicriteria approach:

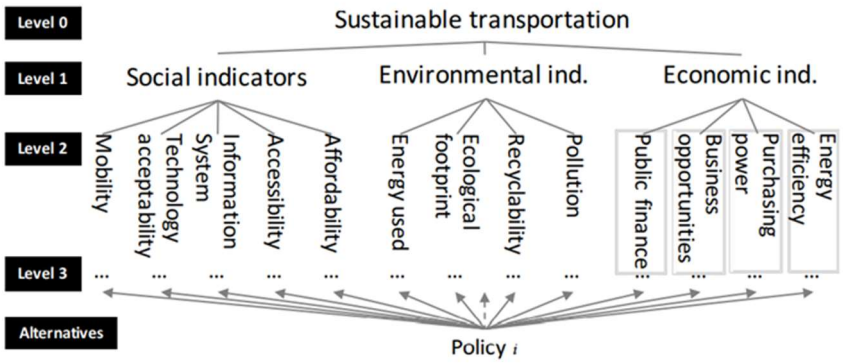


FIG 19: Partial View of the Sustainability Indicators Hierarchy (Source:Ngossaha, M., 2017)

3. YedlaS., et al., (2002)

Multi Criteria selection for Environmentally Sustainable Transportation System at Delhi-

Following parameters have been used with AHP :Energy efficiency (energy)- Energy saving potential, Emission reduction potential (ERP) (environment), Economic feasibility (cost) ,Technological preparedness/availability (technology), Implement ability/adaptability ,Barriers to the implementation of these options (barriers)

4. Mike Jenks Springer (2010)

Dimensions of Sustainable city- The methodologies employed to measure sustainability include:

The assessment of urban sustainability requires data collection across multiple dimensions. Environmental assessment utilizes environmental modelling, site surveys, biodiversity studies, and GIS mapping to evaluate ecological conditions. Social assessment relies on questionnaires, focus groups, and neighbourhood statistics to understand community needs and well-being. Economic assessment incorporates interviews, land and property market data, and economic models to measure financial impacts. Transport assessment employs activity diaries, field surveys,

accessibility analysis, and mode choice studies to evaluate mobility patterns and transportation efficiency.Statistical Methods such as AHP, PCA and Simulation for Optimization can be very helpful to arrive at analysis and assessment of sustainability due to improved accessibility systems applied for an intra city level.

5.5 GOVERNMENTALINTERVENTIONS

Governmental Interventions and actions can solve the problem and lead transportation towards sustainability by various ways as below: -

Sustainable transportation can be enhanced through policy and regulatory measures such as switching public transport to natural gas, replacing outdated taxis, and conducting regular vehicle emission inspections during licensing and on-road checks. Additionally, promoting non-motorized transport infrastructure and providing incentives for green and electric vehicles can significantly reduce pollution, improve mobility, and support environmentally sustainable urban development.

6. CONCLUSIONS

The review concludes that a sustainable urban form cannot be attained without enhancing the accessibility of urban areas because these two are highly interdependent and reinforcing. The results of the literature review indicate that the approach that is more holistic in terms of ensuring sustainability is accessibility-oriented planning, as opposed to mobility-related solutions. Compact urban development, mixed land use, and high density contribute to greatly decreased travel distances and reliance on personal vehicles, which, in turn, lead to a decrease in environmental effects and increased social equity.

The analysis further indicates that the multimodal and integrated transport systems which are aided by the transport systems such as public transport, non-motorized transport (NMT), and TOD are very important in improving accessibility. Analysis methods like AHP, PCA and GIS-based assessment techniques provide useful frameworks to analyze sustainability indicators and make decisions. In global cities, case studies have shown that policy interventions such as limiting the use of the personal vehicle, facilitating cycling infrastructure and fostering electric mobility could make a considerable impact on enhancing the sustainability of urban areas.

In conclusion, this study argues that sustainable urban development is a synthesis of an effective accessibility system, a properly designed urban form and the existence of appropriate governmental policies. Transportation and land use should be coordinated in order to attain environmental improvement, economical benefits and social equity.

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