DEVELOPMENT OF AN IMPROVED CRITERIA TO EVALUATE ACCESSIBILITY TO PUBLIC BUS TRANSPORT SYSTEMS IN A SUSTAINABLE PERSPECTIVE

Thisaiveerasingam Thilakshan

198066D

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

May 2021

DEVELOPMENT OF AN IMPROVED CRITERIA TO EVALUATE ACCESSIBILITY TO PUBLIC BUS TRANSPORT SYSTEMS IN A SUSTAINABLE PERSPECTIVE

Thisaiveerasingam Thilakshan

198066D

Thesis submitted in partial fulfillment of the requirements for the degree
Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

May 2021

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other university or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as article or books).

Signature: Date: 28.05.2021

T. Thilakshan

The above candidate has carried out research for the Master's thesis under my supervision.

Name of the supervisor: Prof. J.M.S.J. Bandara

Signature of the supervisor: Date: 28th May 2021

ABSTRACT

Sustainability is a universal concept applied in all industries and services to instigate a base of responsibility in an individual and collective manner. The need to promote the concept and hold stakeholders responsible and answerable is the current core in terms of incorporation of sustainable practices.

The concepts of sustainability in transportation especially with respect to accessibility is evaluated using available tools that are more biased towards qualitative measures and comparisons between routes, transit systems or cities and regions are difficult or biased towards opinion. The study deals with the relationships in relation to the SDGs and more precisely the 169 targets which elaborate the SDGs in a focused manner. The analysis provides rise to relationship/links directly and indirectly in identifying targets related to sustainable transportation and linking the targets more precisely with the five dimensions of sustainable transportation as stated by the United Nations for better understanding and relationship establishments.

The need for a better measure for the context of understanding accessibility levels to transportation mainly in the context of public transit (bus) services in cities in an urban environment was identified and this study evaluates the factors that needs to be concerned in affecting the concept of 'ease of access' in a sustainable platform. The evaluation of the available sustainable transportation measures, models and tools give a comprehensive understanding of the avenues that had been considered and the quantitative and qualitative disparity that exists among the existing indicators. Thus, the need for a more representative and quantifiable measure of accessibility to public transit services in the urban context is identified. The research study presents a critical review in existing literature and identifying research gaps in paving the path in achieving a quantitatively enriched index with qualitative support.

Sustainable Urban Transit Accessibility Scorecard (SUTAS) is proposed considering all available parallels in developing a more effective measure for policymakers and researchers to identify the accessibility quotient to public transit systems available while improving the measure further to accommodate different regions, cities, routes into respective levels of comparison. The incorporation of the indicators was done in line with highlighting the accessibility quotient and striking a fine balance with giving a fair space with the other dimensions of sustainable transportation. This inclusiveness has facilitated further strengthening the scope of the improved criteria to be with strong quantitative outcomes. A number of majorly qualitative indicators are also incorporated which enhance the scope of the improved criterion. The indicators have been set to provide a single SUTAS value for analysis. The study in detail further elaborates on how every indicator can be improved to increase the validity of their individual score in highlighting their parameters. Thus the developed SUTAS is able to assess the accessibility quotient to public transit (buses) in an urban context both in terms of individual city assessment through a timeline and in comparison amongst cities.

The pilot phase of the scorecard has been carried out using case studies and the outcomes have been informative and hence applicable. The scorecard is further refined along with real case applications to introduce a comprehensive procedure that will be a standard method in terms of evaluating accessibility to public transit systems in the urban scenario. Thus, the purpose of SUTAS is to support urban zones to improve sustainable transportation and its related challenges through proper analysis and understanding in a platform where cities of different context can be compared and contrasted to support each other.

Keywords: Sustainable Transportation, Accessibility, SDGs, Scorecard, Indicators

DEDICATION

I dedicate this dissertation to **Prof. J.M.S.J. Bandara**, my research supervisor and mentor who gave me this opportunity and guided me throughout the research study until completion.

T. Thilakshan

Department of Civil Engineering,

University of Moratuwa.

28.05.2021

ACKNOWLEDGEMENT

I would like to acknowledge many people who supported me to complete the research successfully.

I am especially in debt for life to **Prof. J.M.S.J. Bandara**, Senior Professor of the Department of Civil Engineering, University of Moratuwa, who supervised and guided me throughout the entire research study.

I wish to thank the support given by the Department of Civil Engineering, University of Moratuwa and its academic and non-academic staff members. Special mention to **Prof. S.A.S. Kulathilaka**, the current Head of Civil Engineering Department in providing all administrative support when required.

I would also like to thank all the lecturers in Transportation Engineering Group in addition to my supervisor, including **Prof. W.K. Mampearachchi**, **Dr. H.R. Pasindu**, **Dr. G.L.D. de Silva** and **Dr. Loshaka Perera** who helped me both academically and otherwise during my time as a researcher.

Further I would like to express my gratitude to my research progress committee members including **Dr. A.G.T. Sugathapala** (Chairman of the panel) for his extensive comments and guidance on my research and **Dr. J.C.P.H. Gamage** (Research coordinator), for her guidance to improve my research findings. I would like to provide a special mention to the postgraduate course coordinator, **Mrs. Melani Jayakody** for her continuous administrative support and my **fellow research assistants** in Transportation Engineering Group during the period of 2019/2020 for their constant help and guidance throughout the research period.

Finally, I must thank my parents who were supportive and had helped throughout the period of the study.

T. Thilakshan

Department of Civil Engineering,

University of Moratuwa.

28.05.2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MDGs – Millennium Development Goals

SDGs – Sustainable Development Goals

SUTI – Sustainable Urban Transport Index

STPI – Sustainable Transport Performance Index

SUTAS – Sustainable Urban Transport Accessibility Scorecard

1 INTRODUCTION

1.1 Background

The world is moving at a pace that has prioritized development agendas with less concerns on the adverse impacts to the environment and the future generations. The basic requirements of people are being met at the cost of exploitation of natural resources in a rapid pace. It is in this overall scenario that the United Nations and concerned organizations has given utmost priority to include the concept of Sustainability in all aspects of life. The concept of Sustainability is defined as per the framework it is related with, but the core meaning of the concept remains the same.

Mega and Pederson (1998) defines the concept of sustainability as the harmony and equity extended into the future, an endless journey with care with a continuous effort to for harmonious co-evolution of environmental, economic and socio-cultural goals.

It is into this concept that development is introduced to make the latter more viable and friendly to the community and environment. Thus, Sustainable Development is the meeting of the present needs without compromising the ability of future generations; measured according to the three dimensions (social, economic and environmental dimensions of sustainable development (WCED, 1987). It is obvious that the present is affected by the decisions and resulting actions of the past and thus any decisions and related actions taken in the present must be in terms with the consideration of the impacts for the future. It is anyhow in the near past that people and organizations realized the danger of the past and present actions into the future which needs to be balanced out and reversed with the adoption of Sustainability into every decision and related actions.

The inclusion of sustainability in development helps in balancing the economic, social and environmental aspects giving importance to its short-term and long-term consequences. Transportation is a prime tool to facilitate development on mankind from the discovery of the wheel to current inventions in the transportation framework. It is important to note that the positive impact of transportation has drastically been surpassed by the negative aspects to the environment and the people. Transportation has had a vital role in helping human developments in a national and international platform facilitating the movement of people, goods and services with ease. Thus, it became an important part of the human cycle. It was not until the recent decades that the positive outcomes of transportation were preceded by the negative impacts which became globally recognized. The impact on climate change, the overall pollution percentage and the use of fossil fuels were among the few highlighted aspects that required the transportation industry to reframe its entire network and operations in a sustainable perspective.

The basis of sustainable transport planning highlights on the avenues in which transportation and its related decisions influence people requiring more inclusive responsible decision making in transportation (Litman, 2019). Thus, the importance of sustainable transportation is emphasized. Further, the concept of sustainable transportation is defined and broken down into many sub groups by many organizations and past research outcomes. The United Nations (2015) recognizes five dimensions of sustainable transportation: Accessibility, Affordability, Safety, Security and Environmental Concerns. Every dimension is evaluated in the study and their importance in the national and international framework is discussed.

The absence of a sustainable perspective in actions and decisions encouraged the United Nations to introduce a set of goals with a defined set of sub-goals/targets and indicators incorporating the main issues faced by mankind on a global perspective. The Millennium Development Goals (MDGs) was set to be achieved for a period of 15 years from 2000 which was succeeded by the SDGs (Sustainable Development Goals) listed to be accomplished by 2030 post analysis of the MDGs and the global scenario as of 2015. The study analyzes the 17 SDGs and 169 targets along with their indicators which constitutes the global problems to a larger extent. Thus, the 169 targets which were an extension to the 17 goals were related to the five dimensions of sustainable transportation as identified by the United Nations. The sustainably more viable dimensions are rated from high to low in terms of a conceptual study with their impact to achieving the SDGs in a direct or indirect manner identifying the importance of accessibility.

Accessibility is an important aspect of transportation which is generally defined as the ease of reaching destinations, goods, activities, and services: which can be defined as reaching opportunities with ease (Litman, 2018). The indicators of accessibility include performance indicators such as time and money spent to reach a particular service or activity or the associated travel costs (Duranton and Guerra, 2016). Litman (2013) explains the shift of perspectives in transportation planning from a traffic-based analysis to a mobility-based analysis to an accessibility-based analysis. Litman (2013) and Litman (2018) mention on the concept of accessibility with available indicators to measure the concept and its potential impact on sustainable transport decision making and implementations. The research gap of being able to not incorporate many of the factors in a single measure is identified comprehensively with many of the evaluations focusing on mobility rather than the overall accessibility component in transportation.

Public transport along with NMTs (Non-Motorized Transport) is considered as the pillars of sustainable transport that need to be focused in the near future to overturn the negative aspects of transport to be more friendly in terms of ‘to the future generations’ and the environment. Palmateer, Owen and Levinson (2016) state on the ways and means of how public transit increases mobility (including mobility for non-drivers and increase affordability, reducing traffic and parking congestion) and accessibility in different aspects of transport, establishing role of public transport in the sustainable transportation framework.

The importance of "having access" (accessibility) to public bus transport systems is established in a sustainable perspective with a criterion in our study to measure the accessibility quotient to public bus services in the urban context. This leads to the outcome of a measure which can measure the above mentioned in a quantitative manner with the ability of individual city comparison (dependent on the city's' improvement or downfall of the measured aspect with time) or comparison within a number of cities.

It must be clearly stated that improvements are suggested in the study so that the outcome can be more consistent. The sustainable factor is the platform utilized in building up the criterion with the indicator set. It can be described as the scenery included in a beautiful photograph. It is very important to have a meaningful scenery for the outcome to be effective (appealing) and that is how the concept of sustainability and the inclusion of sustainable transportation framework is adopted in the study of developing an improved criterion to evaluate accessibility to urban public transit. The evaluation development is carried out in the background of the concept of sustainability. Taking into consideration the concept of sustainability, sustainable transportation and accessibility with the measures available, the requirement for a new measure to assess accessibility especially with a more quantitative shade is thus identified.

Thus, an improved criteria called Sustainable Urban Transportation Accessibility Scorecard (SUTAS) is developed as an Accessibility Evaluation Tool for Urban Public Transit in a Sustainable Framework to assist policy decision makers to understand the scenario in detail. In a scenario where public transportation projects are implemented without a proper background of the possible impacts and the absence of evaluating which region needs potential investment over the other, this tool will assist policy makers to evaluate and understand individual and comparative scenario helping in making more meaningful and impactful decision outcomes. The shortcomings in reviewed studies with respect to having an inclusive accessibility indicator is established with many of the indicators/measures considering only public transport parameters in a qualitative perspective. The absence of mode parameters other than travel speed or travel time, economic concerns, walkability, environmental attributes to reach an access point and related accessibility constraints is mainly identified as gaps which needs to be catered in an improved criterion.

1.2 Initial Definitions

This part gives a basic explanation of the main terms used throughout the research study. The study revolves around these concepts and thus a clear idea of the terms was required to be given in advance, resulting in the inclusion of the definitions in brief. These are direct definitions which are further elaborated in detail throughout the body of the research study. These can be highlighted as keywords in the research and thus a brief definition is required for better understanding of the scope of the research.

Criterion - Criterion is a standard or principle by which something is judged, or with the help of which a decision is made (Oxford Learners' Dictionary)

Accessibility - Accessibility is the physical ease of gaining access to services, goods and destinations, basically facilitating the concept of transportation. This is the utmost goal of most transportation activity (except the small percentage of travel with no desired end points) (Litman, 2018)

Public Transport (PT) - PT is a system of vehicles that operate on predefined routes usually with fixed fares and scheduled timeframes at regular times and are used by the passengers (Cambridge Dictionary) (eg: buses and trains)

Indicator - A variable selected to exhibit an important characteristic of a system or a wider phenomenon of interest (Gudmundsson and Regmi, 2017)

Sustainable - a method of using a resource or harvesting resources which results in the resource being not depleted or permanently damaged, making it available to future generations without any compromise (Merriam-Webster)

Sustainable Transportation – A term which identifies and establishes the need of transportation to be functioning in par with the concept of sustainability

1.3 Scope of Study

This study initially focusses on the importance of accessibility in sustainable transportation in comparison with the sustainable development goals (SDGs). After an overall analysis, the study focusses on developing a criterion to evaluate accessibility to public bus transport systems. The set of indicators are to be identified and developed with the objective of assessing individual performance of a city over a period of time and comparison of cities at a given point of time with the criterion value. This can be further narrowed to route level analysis in further development stages of the criterion with further fine tuning to the criterion based on any practical shortcomings/suggestions identified in the pilot and implementation phase.

1.4 Objectives

The objectives of the research are as follows:

- Identification of transport related SDG targets that are related to accessibility in the context of sustainable transportation
- Study of current methods in evaluating SDG targets and sustainable transportation, corresponding indicators and shortcomings of the methods related to evaluating accessibility
- Development of an improved criteria to evaluate accessibility to public bus transport systems in a sustainable perspective

1.5 Outcomes

The dissertation consists of the following outcomes:

- Identification of the measures available for assessing sustainable transportation and accessibility have a higher qualitative shade
- Identification of the major dimension (among the five dimensions of sustainable transportation) and their importance to achieve sustainability in terms of the SDGs and the targets either directly or indirectly
- Identification of the indicators with their individual descriptive characteristics which have a major influence to measure accessibility to public bus transport systems in the urban scenario
- Development of a criterion incorporating the indicators identified to evaluate accessibility to public transit in the predefined sustainable framework

1.6 Arrangement of the Dissertation

The structure of the dissertation is as described below:

Chapter 01 describes the background of the particular study including the concept of sustainability and the importance of transportation in the context of sustainability. Further an insight is provided into the scope of the study, the structure of the study, the exact study objectives and the anticipated outcomes.

Chapter 02 covers the literature review highlighting the current situation in terms of sustainable transportation and accessibility in general, highlighting on the importance of access to public transit and the available measures to assess the accessibility quotient. Identifying the importance of different parameters and their impacts on accessibility to public transit has been carried out identifying their significance and potential in inclusion as a potential indicator for the criterion. Further the parameters are not adopted as per their availability in literature but modified and given leverage depending on their directness of impact to the study objective and the qualitative

/quantitative aspect. Further the importance of the SDGs in sustainability and the possibility of a route to assess sustainability via a conceptual study of the SDGs in transport and accessibility in particular is established which has paved the way for chapter 3. The justification and criteria in selecting the indicators out of the many potential indicator candidates is mentioned in chapter 4 followed by the explanation of SUTAS (the developed criterion) and expected further developments.

Chapter 03 deals with a conceptual study analyzing the relationship between sustainable transportation and SDGs in order to establish a more concrete understanding of the inter connections. Even though it is accepted that transportation is interrelated with achieving the SDGs (impacting the goals directly or indirectly) very less study or analysis on a relationship perspective has been conducted in the academic framework which has been catered into the study.

Chapter 04 introduces and elaborates on ‘Sustainable Urban Transit Accessibility Scorecard’ (SUTAS), the proposed final outcome from the research study criteria to evaluate accessibility to public transit systems in a sustainable perspective. The chapter further analyzes the set of indicators resulting from post complete study of the available measures/index, factors affecting relating subject areas and their shortcomings as well as novel considerations. The new criterion expects to approach the concept in a quantitative perspective providing the industry with a better measure for analysis.

Chapter 05 depicts the outcome of SUTAS for a city to be used as an individual comparison tool to measure a city’s development in terms of accessibility to public transport in a sustainable framework. The chapter calculates SUTAS initially using hypothetical (but practical) set of values to observe its performance and possible outcomes in an individual and collective manner. The chapter depicts a reliable pathway of the measure to analyze an individual city or in comparison with a number of cities via the two case studies assessing both the ten and five indicator sets of SUTAS elaborating the reason to assess the measure in two perspectives of a five and ten indicator set. Spider Chart depictions are utilized to represent the hypothetical data outcomes to ensure more clarity and precision can be obtained in analyzing and decision making.

Chapter 06 concludes the research thesis with a summary of the study and related outcomes, further providing recommendations for development of the study and the developed criterion ‘SUTAS’.

2 LITERATURE REVIEW

Any research study needs to be initiated with an overall literature study and analysis which helps in achieving a clear insight on the study area with available developments and methods that can be utilized and incorporated for an effective outcome. The literature study review mainly engages in understanding the branches of the study including sustainability, sustainable transportation, accessibility and sustainable development goals while understanding the options available in the development of a quantitatively sound measure.

2.1 Sustainability and Sustainable Development Goals (SDGs)

Along with the introduction (Section 1.1) which defines and discusses sustainability via the study of Mega and Pederson (1998) and WCED (1987), there are different perspective definitions stated by researchers and organizations based on their expertise and the background involved. Basically, the term arose with a need for inclusion of moral ethics in the verge of global discontent towards the irresponsible byproducts and focusing merely on short-term monetary benefits.

The real idea of the term ‘Sustainability’ can be extracted when the word is divided into two: ‘Sustain’ + ‘Ability’. The basic concept of the ability to sustain in this world is enriched by the concept of sustainability.

Corporate social responsibility and corporate sustainability became initial points of discussion to be included in par with technological and economic development. The term ‘Development’ is defined as the process in which someone or something evolves or changes and becomes more advanced (Cambridge Dictionary). It was very unfortunate to witness development to be a negative trigger for the environment and future of human existence. Thus, sustainable development is not a burden but the way forward balancing commerce and the community. Sustainability is a mandatory inclusion in the current world scenario and it is evident that countries are involved in enhancing the concept which needs to be further accelerated in a global platform to reap impactful benefits to the community. The importance of flexible and adaptable nature of the related systems is important for sustainable development.

The mantra of committing to sustainable development can be identified by the following (ABCD concept):

- **A**dvocate for sustainable development
- **B**alance social, economic and environmental priority
- **C**onserve and protect resources
- **D**evelop sustainable development solutions

The major commercialization of the concept has made the concept somewhat unstable. The harsh reality of the situation is well established in the fully air-conditioned fully illuminated automated teller machine slots in banks which claim to enhance sustainability via not providing a receipt hardcopy for the transaction or the painting of a wall green in color and naming it a green building without having a first-hand understanding of the concept and its impact on the environment, economy and society (social): the three fundamental dimensions of sustainable development (Thilakshan and Bandara, 2019).

The initial global platform created by the United Nations (UN) was the inclusion of the Millennium Development Goals to be achieved by all the member nations and world's leading development organizations in a fifteen years' time span. Even though the word 'sustainable' was not often utilized, the MDGs enhanced the concept. The eight UN MDGs are listed as shown in Figure 01.

Figure 01: Millennium Development Goals (Global Goals, 2019)

The then UN secretary general Ban Ki-moon stated that the MDGs has supported in uplifting more than one billion people out of extreme poverty, to enable more girls to attend school than ever before, to make inroads against hunger and to help in safeguarding our planet. While acknowledging the immense development via the work put in achieving the MDGs, he further stated that they were expecting to complete the MDGs and 2015 was an important year of success with respect to the outcomes. He mentioned on forging a bold vision for sustainable development, including a set of effective sustainable development goals and an aim for a new, globally acceptable climate agreement. (The Millennium Development Goals Report, 2015). The MDGs report (2015) acknowledged uneven achievements and shortfalls in many areas highlighting the need to continue in the new development timeframe. Thus, the successor of MDGs was introduced in the global scenario as the Sustainable Development Goals (SDGs) from 2000 to 2015.

The Agenda for Sustainable Development adopted by the world leaders to be achieved by 2030 in September 2015, officially came into force on the 1st of January 2016. It can be utilized as a global road map for sustainable development. The Agenda is a set of 17 SDGs with 169 targets (and 244 indicators) stimulating actions to transform the world to a resilient and sustainable path. The 2030 SDGs' Agenda forefronts in facilitating ways and means to end all forms of poverty, tackle climate change and fight inequalities, while making sure that "no one is left behind" (Partnership on SLoCaT, 2018). The 17 SDGs are listed as shown in Figure 02.

Figure 02: Sustainable Development Goals (IED, 2019)

With the introduction of the SDGs, Sri Lanka pledged its commitment to achieve the set goals and targets along with other world member nations. Not ever before have world nations and leaders shown effective response and efficient policy decisions unanimously across a universal and broad policy agenda in a similar manner. The path is laid together towards sustainable development dedicated collectively to accelerate international development and bring about a "win-win" situation which can bring massive positive outcomes to member nations and the world collectively. The ability of the member nations to work freely in exercising full permanent sovereignty utilizing their economy and national frameworks according to their individual frameworks without any direct or indirect complications offer the SDGs as a positive platform for all countries to actively be able to get involved.

The figure 03 depicts the 17 SDGs grouped into five themes/subgroups namely: People, Planet, Prosperity, Peace and Partnerships. The perspectives of the 5Ps considers the United Nations Sustainable Development Goals are as listed below (ICAA, 2018).

- People (to ensure human wellbeing)
- Planet (to sustainably manage the planet for the present and future generations and to protect the planet)
- Peace (to work towards more peaceful, fair and inclusive societies)
- Prosperity (to promote social, economic and technological prosperity in harmony with nature)
- Partnership (to strengthen the global solidarity)

Figure 03: Sustainable Development: The 5Ps (Santiago et al, 2018)

In concern to the concept of introducing 'goals' into the global platform by the United Nations, a Harvard Business School MBA study on goal setting stated the following assessment regarding the importance of goals for sustainable effective outcomes. The class which was graduating was queried a specific question about the specific goals in life. The query presented in concern was on relation to whether they had written their goals and laid forward a plan for their attainment, before their graduation and using the feedbacks it was established that 84% of the class had no goals at all while 16% of the class had a set of written goals. In this background, an analysis ten years' post-graduation was that the 16% of the class who had a written goal were making twice or more as much economically as compared with the 84% of the remaining who had no set of specific goals at all. This particular study outcome and similar studies prove that people are driven towards a target or goal rather than reaching an unplanned final destination. Thus, the SDGs post the MDGs have to treated as focused driving frameworks to attain sustainability in the best possible way covering all aspects to be considered for sustainable change and development.

While the SDGs represent an ambitious plan to be achieved by 2030, the 169 targets are a direct enhancement of the objectives of each goal which helps the stakeholders in gaining a clearer vision to focus on their future strategies.

The Sustainable Development Council of Sri Lanka is the national body with evaluating and monitoring the organizations that are working towards achieving the SDGs by 2030. The Main Roles and Responsibilities of the council include to act as the national focal agency in reporting, coordinating and facilitating of the commitments to implement the national commitments to achieve the SDGs by 2030 for Sustainable Development and the SDGs followed by island wide formulation and review, issuing necessary guidelines, promoting sustainable development in all levels of the community while not falling short for adoption to new mechanisms and innovations in the sector.

2.2 Sustainable Transportation: Concept, Measures, Models and Indicators

Transportation can be elaborated as

- public transfer or conveyance of passengers or goods (with a commercial enterprise perspective) (Merriam-Webster)
- means of conveyance or travel from one place to another

Transportation was, is and will be a vital tool in the development of humankind. It had been an important catalyst in development in the economic, social and cultural perspectives. But the adverse impact in the last few decades have been a prime point of discussion. Miller, Barros, Kattan and Wirasinghe (2016) state on the importance of an effective transportation network as an important driver for social and economic development of cities highlighting the series of challenges created by transportation towards achieving sustainability.

It is important to understand the complexity of the impacts of transport systems and to deal with the complexities in an integrated manner. It is due to non-efficient solutions and planning and implementation with very short term mind sets that have led to miss the integration of transport systems converting the system to be more complex in a national and global perspective. The dynamics of transport systems are impacted by the certain considerations including urbanization and urban–rural integration, demographic changes, global supply chain and trade logistics, and digital connectivity.

Currently, complex transport systems require a holistic approach for a sustainable outcome.

Transport supports high mobility demands and assist in socio-economic development but has resulted in certain negative outcomes such as high motorization levels, congestion, resource consumption and emissions. The E^3ST (Energy Efficiency and Environmentally Sustainable Transport System) is a strong concept adopted with the virtues of sustainability to attain an interconnected transport framework. In line with the 5Ps of SDGs, the objectives of E^3ST can be reflected via the 5Is and 5Cs framework among the other ways to present the sustainable transport objectives, and the mentioned framework the "**5 Is and 5 Cs**" is one such approach as in figure 04.

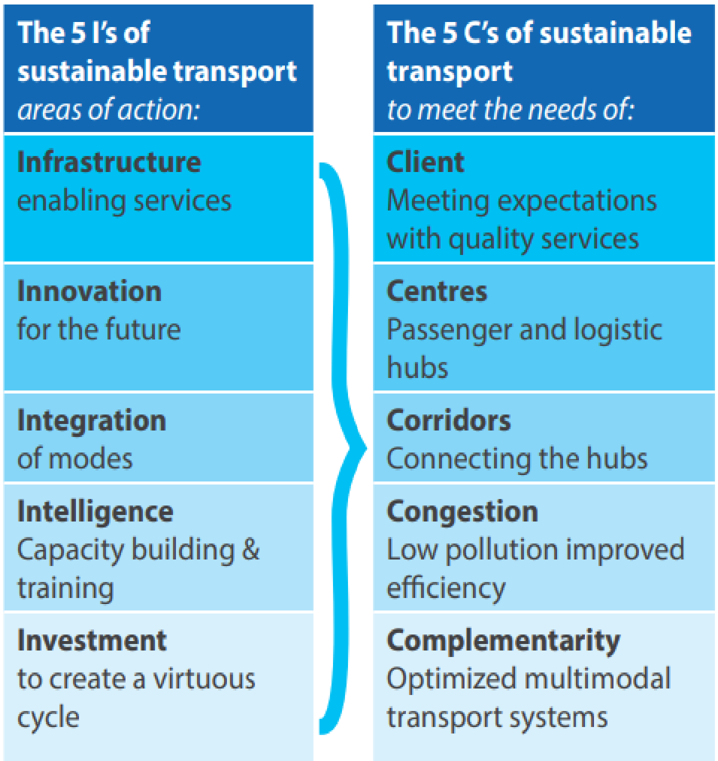


Figure 04 : 5 Is and 5 Cs (UN -Mobilizing Sustainable Transport for Development)

The "A-S-I Approach (Avoid/Reduce – Shift – Improve)" is a sustainable approach in transportation better than the conventional "Predict – Provide – Manage Approach". The perspective of A-S-I is to ensure the accessibility – mobility – connectivity is not compensated via sustainable alternatives and novel approaches. It is important to offer the transport user a number of modes/options to travel from a place to another ensuring quality and no major compromises establishes a sustainable framework with easy access to the goals of SDGs by 2030.

Being a cross cutting sector, the importance of making transportation 'sustainable' or responsible to the society which increased focus of the concept of sustainable transportation. It is in this context that the current sustainable transportation framework drifts towards the achieving of the SDGs by 2030 as a major stakeholder. Thus, the importance of analysing the sustainable transportation concept and related assessing methods is understood while narrowing down to the concept of accessibility and its measures. Ramani et al (2011) highlights on a sustainability assessment framework for transportation agencies supported with a comprehensive study on the available key transportation concepts in a sustainable framework. It consists of a five step process as listed below:

1. understanding sustainability
2. transportation sustainability goal development
3. development of the related objectives
4. development of the performance measures
5. performance measure application

Greenroads (Greenroads Rating System is a guided manual for managing and measuring sustainability on infrastructure projects like bridges, streets, rails, highways etc.) basically forecasts the fate of transportation stating that sustainability will be the next great game in terms of transportation which becomes serious business when you tend to maintain score. Among the many definitions for Sustainability (1 below) and Sustainable Transport (2,3 below), listed are a few of the widely used.

1. Centre for Sustainability (2004) states sustainability as the capacity for prolongation into the future in a long term perspective. Basically it is on any specific thing that can go on being done on an indefinite basis that can termed as sustainable. Thus anything that cannot go on indefinitely is termed unsustainable.

2. A Transport System which is sustainable is one that is affordable, accessible, safe and environmental-friendly (ECMT, 2004)

3. Environmentally Sustainable Transportation is one that does not negatively impact health of the public or eco-systems while ensuring to meet the needs for access consistently with the inclusion of renewable resources in a responsible manner considering their regeneration rates and utilization of non-renewable resources considering the regeneration rates of the substitutes which are renewable in nature (OECD, 1998)

In an overall scenario a Sustainable Transportation System (CST, 2005) is described to be a collective outcome of the following:

- Offers choice of modes of transport, affordable, support vibrant economy and operates efficiently

- Minimize the consumption of non-renewable resources to the level of sustainable yield, limit the waste and emissions within the planet’s ability to absorb them, minimizes the use of land and production of noise and reuses and recycle its components

- Facilitates the needs of individuals and societies to be fulfilled in a safe environment, with equity within and between generations and consistent with the health of human and ecosystem

Hart (1997) states that potential indicators available must showcase the difference of sustainability in an urban or suburban area in relation to a rural town. The same applies in the case of sustainable transportation and its elements. Zheng et al (2011) discuss on selected economic indicators including affordability, mobility, finance equity and resilience for sustainable performance evaluation. In terms of social aspect indicators for sustainability: Human Development Index, Quality of Life Index, Prosperity Index and Quality of Living Survey are available via literature.

Table 01 represents the set of indicators available to measure sustainable transportation. The indicators are further categorized as per the three aspects: Social, Economic and Environmental concerns. Two adjacent sets of indicators by Litman (2019) and United Nations (2017) are considered and the similar indicators categorized as per the three dimensions are depicted using notational matching (using same symbols to indicate similar indicators). The indicators and the notational comparisons are depicted in Table 01.

Table 01: Sustainable Transportation Indicators

(Litman, 2019)	(United Nations, 2017)
Economic Indicators	
Affordability #	Costs of transportation to consumers/ customers #
Commute Time	Transportation-related health costs
Crash costs *	Accidents related costs *
Land Use mix	Non-renewable resources and energy supplies depletion
Congestion delay $	Traffic congestion $
Facility costs π	Transport related facility costs π

Transport diversity	
Modal share	
Electronic communication	
User Satisfaction	
Freight Efficiency	
Vehicle Travel	
Crash costs	
Land use planning	
Environmental Indicators	
Air pollution *	Air pollution *
Climate change emissions $	Global climate change $
Noise pollution #	Noise pollution #
Water pollution ^	Water pollution ^
Land use impacts π	Consumption of land/urban sprawl π
Habitat protection ¥	Disruption of ecosystems and habitats ¥
Habitat fragmentation ¥	Introduction of exotic species
Resource efficiency	Light pollution
	Depletion of the ozone layer
	Release of hazardous /toxic substances
	Solid wastes
	Vibration pollution
	Visual intrusion and aesthetics
	Hydrologic impacts
Social Indicators	
Safety *	Accidents *

Community livability #	Declining community livability/community partitioning #
Disabilities $	Mobility inequalities / barriers for the disadvantaged $
Children’s Travel $	Wastage of Time
Cultural preservation	Human health impacts (physiological and psychological)
Non-drivers	Inequalities related to negative health and environmental impacts
Affordability	Visual pollution
Fitness	
NMT Transport	
User rating	
Inclusive planning	

It is evident that affordability, cost due to accidents and congestion delay related costs are common indicators in both economic based indicator scenarios. The climate change factor, water pollution, noise pollution, air pollution, land use patterns, biodiversity related parameters are common environmental indicators in both scenarios. Indicators on safety (accidents), disadvantaged and livability are common in terms of the two sets of sustainable transportation indicators.

The Table 01 gives an overall perspective of the indicators available in the sustainable transportation scenario and the common indicators identified provide a better platform for consideration in further analysis. It is in this perspective that a criterion is developed to assess accessibility to public transit in a sustainable perspective termed as SUTAS (Sustainable Urban Transport Accessibility Scorecard). The review throughout the chapter helps in reviewing available studies and measures with regard to accessibility in transportation and identifying the research gaps in narrowing down to a set of indicators. The basis of indicator selection is mentioned in chapter 4.

NRTEE (1996) proposes a set of eight guiding principles on which transition strategies are proposed to be built on to achieve sustainable transportation systems.

Principle 1: Access

Principle 2: Equity

Principle 3: Health and safety

Principle 4: Individual Responsibility

Principle 5: Integrated Planning

Principle 6: Pollution Prevention

Principle 7: Land and Resource use

Principle 8: Fuller Cost Accounting

Kirk et al (2010) developed a framework to evaluate regional sustainable development which consists of six sustainability principles and 38 indicators in the Twin Cities Metropolitan region. Certain of the 38 indicators which represent the essence of sustainable transportation are Access to transit, Accessibility to Non-work related opportunities, Housing and Transportation Accessibility, Job Accessibility, Walkability, Vehicle Miles Travelled (VMT) per capita, Transportation Reliability, Transportation Safety and Public Safety. World Bank - Global Mobility Report (2017) evaluates the performance of major modes of transport and categorized into four aspects in relation to the SDGs as follows: Universal Access, Efficiency, Safety and Green Mobility. Roughton et al (2012) state on the Non-Motorized Transport Performance Indicators. Zietsman and Ramani (2011) discuss on a developed sustainability performance measurement framework based on the recommended goals as follows.

1. Basic Accessibility
2. Safety
3. Equity / Equal mobility
4. System Efficiency
5. Security
6. Prosperity
7. Economic Viability
8. Eco-systems
9. Waste generation
10. Resource consumption
11. Emissions and air quality

Considering Basic Accessibility (1), it is not favorable in adopting the indicator into a criterion/measure as basic accessibility is the ability of people to reach goods and services which are only basic or essential (this includes education, employment, medical care, basic shopping etc) which limits the scope of the study and complicates the measure leading to omission of trips which are not considered essential.

SUTI - Sustainable Urban Transport Index is a measure developed under the purview of UN ESCAP to support in summarizing, tracking and comparing the performance of Asian cities with respect to sustainable urban transport and the related SDGs (UN ESCAP, 2017). This is one of the most frequently used index and is based on the ten indicators for which data needs to be collected using a given set of guidelines for every individual indicator. The number of indicators is of a lesser number in order to reduce the efforts needed to collect and analyze data for the index. Inclusion of data for all ten indicators will lead to the calculation of the index and display a review of the performance of transport systems and policies of the considered city, along with comparisons with different cities as well. It is vital that each considered city collects required data for the same ten indicators and follows the same methodology as described in this guideline to enhance comparability of results across cities. Certain indicators may require comparatively higher amount of effort and time than others to collect and produce comparatively.

For certain indicators such as distance, direct cost, time and information pre-calculated periodically; data can be more or less available in a document or database immediately, but others may need the collection of certain data backed by calculation and further analysis. Most indicators will need much more effort than just looking up a for a required data number in the available archives. Indicators with the involve most work or most challenges for each city or which of the offices will be needed to be involved cannot be foreseen in advance and thus depends on how the city is organized in a local and national level within their perimeter and a city's existing data and previous study data collection efforts making indicators involving 'hectic large manual data collection, complex calculations, loss of periodic data completely or in random timeframes and absence of people with basic knowledge for data collection and indicator formulation' difficult to calculate and process. Thus, the study focusses largely on accessibility as it has been identified as an important parameter in almost all the evaluation systems that are being used.

An initial set of 14 Sustainable Transportation Performance Indicators (STPI) are designed to show movement of transportation in Canada towards or away from sustainability. This scenario has been reviewed in the case of the Sri Lankan context and with certain alterations as per the characteristics of the country can be used to evaluate the sustainable quotient in terms of transportation. The main concern on the STPI is the increase amount of weightage towards energy use and energy intensity which caters the environmental perspective of the sustainable transportation concept but not fulfil the other aspects for a balanced measure.

Table 02 depicts the individual indicators of the two measures (SUTI and STPI) and a notational comparison of the similar indicators. The two indicators represent the sustainability quotient in regards to transportation which indeed represents the accessibility quotient to a certain extent (accessibility is one of the main dimensions of sustainable transportation: explained later in the chapter).

Table 02: Comparison of Sustainable Transportation Indicator: SUTI & STPI

	SUTI (Sustainable Urban Transport Index)	**STPI** (Sustainable Transportation Performance Indicators)
1	Air quality #	Use of fossil fuel energy for all transport #
2	Greenhouse gas emissions from transport #	Greenhouse gas emissions from all transport #
3	Convenient access to public transport service	Index of emissions of air pollutants from road transport #
4	Traffic fatalities per 100.000 inhabitants *	Index of incidence of injuries and fatalities from road transport *
5	Public transport quality and reliability	Total motorized movement of people
6	Affordability – travel costs as share of income	Total motorized movement of freight
7	Operational costs of the public transport system	Share of passenger travel not held by land-based public transport
8	Investment in public transportation systems	Movement of light-duty passenger vehicles
9	Extent to which transport plans cover public transport, intermodal facilities and infrastructure for active modes	Rate of use of urban land
10	Modal shares of active and public transport in commuting	Length of paved roads
11		Index of relative household transport costs
12		Index of the relative cost of urban transit
13		Index of energy intensity of the road vehicle-fleet #
14		Index of emissions intensity of the road-vehicle fleet #

The SUTI provides a more varied set of indicators with more precision (diverse in the context of sustainable transportation dimensions) than the STPI. Liu Zhenmin (Under-Secretary-General for Economic and Social Affairs, UN) states in the introduction of the SDG Report 2019 highlighting climate change as being the most urgent area for action along with a dedicated SDG for Climate Action (Goal 13) along with expansion of renewable energy which is reflected in the STPI set of indicators.

Rodier and Spiller (2012) summarizes the Performance Indicator Framework and list Access, Proximity, Choice and Congestion as the Performance Indicator for travel. The Required Model Data for the Access Performance Indicator consists of travel time/cost by mode, origin and destination, area, activity type and time of day. Wilbur Smith Associates (2008) state on the Transport Performance Index in the context of India consisting of the following factors.

- Public Transport Accessibility Index
- Service Accessibility Index
- Walkability Index
- Congestion Index
- City Bus Transport Supply Index
- Para-Transit Supply Index
- Safety Index
- On-street Parking Interference Index
- Slow Moving Vehicle Index

Out of the above indices, Public Transport Accessibility Index (PTAI), Service Accessibility Index and Walkability Index are related to accessibility (Higher the index, better is the accessibility). PTAI is calculated as the inverse of the average distance to the nearest transit station. Basically this is a direct calculation which can give a rough idea of accessibility to public transit but is far from the real case scenario depiction as there are many factors other than distance which influences public transport accessibility. Service Accessibility index is calculated as the percentage of work trips accessible within 15-minute time and 30-minute time for each city which basically approaches the concept in the land-use pattern perspective. Walkability Index basically values the performance of pedestrian infrastructure taking into consideration the availability of foot path on major corridors and the overall facility rating by pedestrians. This approach is good and is expected to be considered in the development of the criterion.

Indicators in terms of the five dimensions of sustainable transportation are identified as listed below (along with a number of factors to assess each of the dimension) (United Nations, 2015).

1. Accessibility
    a. Infrastructure Density
    b. Infrastructure Quality
    c. International Transport
    d. Burden of border crossing
2. Affordability
    a. House transport spending
    b. Price of transport
    c. Transport public investment
    d. Transport private investment
3. Security
    a. Terror threats
    b. Criminal Activities
4. Environment
    a. Transport Energy consumption
    b. Emission of local pollutants and greenhouse gases
    c. Local pollutants
    d. Noise from transport
5. Safety
    a. Road fatalities
    b. Impaired driving, seat belt use and speeding
    c. Active level crossings

Thilakshan and Bandara (2019) discuss on the five dimensions of sustainable transportation as stated by the United Nations and access them individually with the 57 targets of SDGs which have a direct or indirect affiliation to achieve the SDGs by 2030 in the sustainable transportation sphere. The study shows the highest impactful dimension to be accessibility with a 32% weightage to achieve the SDGs in the context of sustainable transportation directly or indirectly which has been comprehensively analyzed in chapter 3. The study gives a novel perspective in dealing with sustainable transportation and related SDGs.

It is evident from the study that the present tools are more qualitative in nature and results are subjective. Thus the need for a more inclusive (representing the parameters influencing accessibility with an essence of other dimensions of sustainable transportation impacting accessibility) tool with a quantitative approach can be identified. Apart from accessibility the other four dimensions will be considered separately and combining the five dimensions together can give rise to effective comparisons using a spider web approach or similar graphical representations.

2.3 Accessibility, Public Transit and Further Analysis

The importance of giving prominence to public transportation is discussed as the most viable sustainable solution and investing on public transit options have been proposed to be more viable. Public Transportation modes along with non-motorized transport modes such as walking and cycling are globally promoted especially in the context of developed countries and the developing countries are following but in a rather slow pace. Thus, the importance of accessibility for passengers to reach these public transportation modes (buses in this case) is established in the study with a sense of sustainability and responsibility. The following Transport Planning Objectives are referred to support Sustainable Goals by Litman (2019).

- Transport System Diversity
- Affordability
- System Integration
- Efficient Pricing and Prioritization
- Resource Efficiency
- Operational Efficiency
- Land Use Accessibility
- Comprehensive and Inclusive Planning

Miller et al (2016) states public transportation to be a key component in building sustainable cities. The study further provides a comprehensive literature review of sustainability analysis for public transit and analyses the sustainability quotient of transportation systems emphasizing the need for better indicators in the related study areas. The scope of accessibility is considered in the perspective of an individual and important dimension of sustainable transportation. It is observed of a visible paradigm shift to an accessibility-based transport planning scenario from a mobility-based transport planning framework. Gliderbloom and Riggs (2015) states on reduction of speeds, reduction of crime rates, increase property values, increase non-motorized travel among the many pros of having a well-connected road network.

Accessibility is a factor to be concerned with the opportunity of an individual or type of person at a given location possess, to participate in a particular activity or set of activity and mention the factors affecting accessibility including mobility, transport options, land use and affordability (accessible to all economic groups).

Fransen et al (2015) discusses on public transport enabling the less privileged segments of the population with special mention to those with no private/owned vehicle to take part in activities that are deemed normal as per the society they live in. Currie (2010) mentions on a combined indicator to evaluate access to public transport stops and relative service. Fransen et al (2015) further state on available accessibility measure concerns that do not provide insight into whether people are transported to their desired activity location with a fair travel time at the time of day required and not provide importance to public transit provision that can be compensated by local availability of amenities. Delmelle and Casas (2012) assume a constant velocity to construct a routable network for public transport travel. In concern to wait and transfer time, usually there is an under estimation of overall journey travel time. Fransen et al (2015) measures the accessibility labels to key destinations for socio-spatial population groups at regular time intervals and compute these levels over different peak and off-peak timeframes on weekdays and weekends. Conventional approaches to accessibility include 'person based', 'location based' and 'infrastructure based' measures.

Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) is a tool developed to assist in accessibility planning by introducing a planning support tool that can be utilized to inform transport planning and strategic land use. The study states that if public transport is to offer a real alternative transport mode choice to the car, there is a need for a new approach to planning and evaluating public transport accessibility, which takes into account the transport network and also assess the integration of this network with land use and the consequent activity opportunities in terms of public transport there is an overall concern as to the appropriate public transport accessibility benchmark for metropolitan areas.

A brief description of the SNAMUTS Composite Index indicators are as follows:

- Service Intensity
  The measure basically evaluates the operational input required to provide the service levels across a system. Basically the indicator is affected by the relevant authorities and operators to provide resources to operate the system efficiently.
- Closeness Centrality CC
  It basically accesses the ease of movement. A value is calculated based on the travel impediment (travel time/service frequency) between two predefined nodes on a selected network.
- Degree Centrality DC
  It is the number of transfers which is needed to travel between any two points/centres in a network.

It must be noted that better DC and CC is denoted by lower values which depict higher public transport accessibility.

- Network Coverage Indicator NCI
  NCI basically locates the zones with a comparatively poor service standard by assessing the land use patterns. It calculates the percentage of jobs and residents within accepted walking distances (800m to rail, ferry etc. and 400m to a bus service) to atleast one public transport service and depicts this in relation to the total number of jobs and residents in the considered area.
- Contour Catchment Indicator
  The indicator measures the average percentage of jobs and residents which can be reached from every node by a public transport in a thirty minutes or less timeframe. It is calibrated to reflect on parameters such as density of the urban spaces, public transport speeds and the considered node spacing.
- Betweenness Centrality
  This dynamic approach calculates the geographical distribution of opportunities with respect to travel in the nodes and route segments. The frequent and quick nature of modes between considered points are pointed out to be more attractive while the performance of different modes in attracting passengers can be understood via the indicator.
- Network Resilience
  The indicator determines the ratio of the potential opportunities with respect to travel patterns and the available capacity obtained from the service frequency and the passenger capacity of the modes in service.
- Nodal Connectivity NC
  NC is a measure of the possibility of the nodes to function as potential hubs in the considered network. It considers the number of travel undertaken within a time period on available modes in different directions. It highlights the multi-directionality of the elements in the network along with the capacity of the modes and the user selection preferences.

Based on an overview of SNAMUTS, it is a support tool to assess accessibility in multimodal urban transport systems which has been utilized mainly in the Australian scenario for comparison of cities in individual and overall perspectives. It does not give an individual score and is a more graphical comparison with a potential for a better sustainable approach.

Walkability is a mode highly valued in accessibility analysis as itself is a mode of choice and supports other modes (Litman, 2018). Further reducing the distances to destinations and having sustainable transport choices increase the overall functionality of a city making accessibility to goods, services and activities easy from any given location at any given point of time. Litman (2018) discuss on the importance of public transit improvements and highlight their influence on increases in mobility and accessibility. Thus, accessibility-based planning applies in the current context way more than conventional planning. The Access to Destinations (Litman, 2018) research platform developed tools and data seta to quantify accessibility considering multiple transport choices and land use development patterns. The study showed centralized population and job opportunity to increase the overall accessibility. The MTA Initiative (Moving to Access) aims to promote socially focussed, access first approach to planning, services, investments and transportation policy.

Access Scores utilize the different GIS mapping tools to measure people's transport demands (Litman, 2018), the accessibility to work and non-employment activities by various modes and locations. The comparative advantage of this method is the numerical depiction and display in heat maps. Urban Accessibility Explorer is a mapping system which measures the number of activities that a particular region resident can reach within an allocated given time frame. The tool enhances policymakers, planners and other concerned factions to easily evaluate transportation systems.

Thus it is evident that a shift from a conventional perspective of assessing transport planning using average travel speeds and roadway level of service to considering improved mobility to non-drivers, improving alternative modes, efficient pricing, energy conservation, improved safety, accessible land use improvements etc in assessing accessibility in a sustainable perspective is the present and future of transportation and its indicators. The identifying of the indicators to be included in the criterion is thus paramount.

The concept of connectivity is highly complicated with other transportation concepts such as accessibility and mobility which needs to be differentiated and elaborated to understand the connectivity value of a certain region and compare with previous values over a period of time or with adjacent towns with similar parameters at a given point of time. It is important to consider different connectivity levels being intentionally applied to different modes (filtered permeability) (Cozens and Hillier, 2008).

Further the connectivity in terms of public transport (bus services) is calculated and a comparison with the connectivity index in terms of the road network is performed. Consistent connectivity is absolutely vital to the functioning of smart and sustainable cities (Hayes, 2020). Types of connectivity measures are as follows: (Handy et al, 2003).

- Block Density
- Block Length
- Intersection Density

- Street Density
- Block Size
- Connected Node Ratio
- Grid Pattern
- Link Node Ratio (Connectivity Index - CI)
- Effective Walking Area
- Pedestrian Route Directness

Basically all these measures help in valuing connectivity based on the individual attributes such as road network segments, walkways, urban sprawl etc. Connected Node Ratio and Link Node Ratio (Connectivity Index - CI) are considered to obtain a basic understanding for the indicator development but is more general in nature conceptually to the objective of this study and is slightly altered to bring in the main concept of public transport access leading to the Public Transport Accessibility Index (PTCI).

A complete transportation network represents the ability to reach a particular location with a number of routes and modes available to select from depending on the travel requirements. VTPI (Victoria Transport Policy Institute) (2017) defines connectivity as the density of connection in road or path networks and the directness of the links. Further a network with good connectivity consists of many short links, minimal dead ends (cul-de-sacs) and numerous intersections. VTPI (2017) depicts the connectivity pattern showing the increase in connectivity and the impact on decrease of travel distance and increase of route options. The concept of connectivity is applicable both within a particular area (internally) or between two or more area (externally).

Connectivity is a subjective concept and depends on other parameters such as speed, distance, modal choice etc. It is important to note that increased connectivity means increased accessibility, but increased accessibility needs not necessarily represent a good connectivity network. The different street patterns play a major role in defining the connectivity of a particular area. Street connectivity reduces vehicle travel by providing alternative modes for choice and reducing the travel distances between destinations as well. Apart from accessibility, the resilience factor is increased in par with connectivity minimizing the hindrances when a particular road connection is closed and needs detour.

Taaffe and Gauthier (1973) states connectivity as the degree of connection between vertices whereas Robinson and Bamford (1978) defines the concept as the degree of completeness of the links between nodes. Dill (2004) mentions the importance of state street connectivity as a key element in neighbourhood design and encourages more grid like networks where the high connectivity will have lesser distance and increase usage of non-motorized travel and access to public transit. It is important to decide on the method of connectivity measurement and the level of depth in the analysis depending on the nature of the analysis such as linking travel behaviour to urban form and public policy/decision making.

The basis of the first indicator considered for the criterion is based on the network connectivity concept. Ewing (1996) proposes 1.4 as a good connectivity index value. The value does not reflect the length of the links and the calculation is simple and direct in terms of the network. The greater the CI value, more the connectivity. A maximum score (completely connected network) is of 2.5 while a score above 0.75 is usually desired. The direct measure in a particular road network will ensure that the value depicts the real nature of the road connections including number of links and intersections and the multiple number of route options available.

Studies which have been reviewed are in the context of road network and none have considered public transit networks. It must be noted that all roads do not cater to public transit services and thus a more refined index to consider public transit is adopted in this particular study. Considering the comprehensive study, it is vital to represent connectivity in a public transit perspective within the SUTAS framework.

The basic idea of the availability of a road network will assist people to move from a place to another is primitive in terms of having a mode to transfer. Except for non-motorized modes, public transit is required as a basic entity to reach basic needs and wants and thus availability of a service in a segment makes it more valuable compared to a road segment not serviced by public bus services. This aspect needs to be reflected via an indicator as the availability of a service to assess accessibility to the service promoting the ethos of sustainable transportation and development.

The importance of analysing catchment areas was important in considering the inclusion and development of a related indicator for the improved criterion. Catchment area inclusion is important as a strong decision tool in mass transit planning (Andersen and Landex, 2008). The accuracy of the catchment area analysis depends on the area considered and the related method utilized. There are two methods in catchment area analysis: namely, Circular Buffer Approach and the Service Area Approach Method. The Circular Approach Method considers the Euclidean distance to decide the catchment. The limitations of this method include inclusion of physical barriers in the catchment, availability of access path considerations which is minimized to a certain degree using a detour factor. The Service Approach Method identifies a certain point in each link of the network considering the impedance of the link and interpolating the points to from a polygon which represents the catchment area.

Mendis and De Silva (2020) analyse on the accessibility to the proposed Light Rail Transit from Fort to Malabe with respect to different modes of transport. The study uses Conveyal Analysis to study the public feeder services considering the corresponding catchment areas. Thus the potential bus catchment areas are identified and compared with the current bus network showing poor accessibility to the LRT access points. Thus new bus routes or rerouting bus systems with the requirement to ensure access is well assessed in the study highlighting the need to increase the catchment area.

A Well designed transit route is vital for the overall transit network in being able to cope with urban transport issues such as congestion. Location of stops is a main concern in transit route design. Basically, optimum intersection spacing in deciding service access points locations are considered identifying two main parameters: to minimize the passenger travel time and to maximize the number of passengers (Luo et al, 2020). Further the stop locations influence the service accessibility and operator's efficiency with respect to fuel and fleet size. Li and Bertini (2008) states on utilizing stop spacing model to reduce operating cost and increase transit accessibility. Further concerns prevail on bus stops located in close proximity to each other increasing service time and operation costs. Reduction in number of stops on the other hand can make the transit service inaccessible and reduce the total catchment area within a region/city which may lead to loss of passengers indirectly increasing affordability and alternative mode selections.

The Highway Design Manual (2012) by the Oregon Department of Transportation: Chapter 12 on Public Transportation Guidelines states that the bus stop locations are mainly decided based on needs of the passengers, maximize passenger convenience and maximize catchment areas. Basically the number of stops on a particular transit network will be proportional to the rate urbanization and pedestrian/people movements. Thus, optimum spacing is dependent on the area transit segment and the related land use patterns.

In terms of optimum spacing (Guidelines for the Design and Placement of Transit Stops (2009) - Washington Metropolitan Area Transit Authority), a greater distance between stops helps reducing operating time and provide a rapid ride. But this leads to a higher walking distance requiring optimum distance to fall within the maximum walkable distance to a transit service. Therefore, stops need to be located in an accessible distance which is mainly dependent on identifying the catchment area via an effective method and provide a distance far enough to assist buses decelerate less and move rapidly. Thus, the evaluation of catchment is important in the accessibility to public transit as it facilitates to understand the available demand and location of stops with a win-win scenario for both the user and operator.

Bocarejo and Oviedo (2012) states on the accessibility framework as a concept representing a complex concept including several dimensions which includes temporal, spatial, social network, societal, economic, political, personal and mobility disadvantages among different segments of society. Frye (1989) mentions on the adaptations that can to the then existing public transport vehicles (which has unfortunately not been considered or disregarded in implementation frameworks especially in developing countries such as Sri Lanka) such as better handrails and lighting, lifts on buses, lower steps, a split step entrance, and the "kneeling" bus concept which lowers the step height. The adoption of a conducive environment for wheel chair users and physically challenged other groups are yet to be implemented. Improved staff training and staff availability aimed at helping the disabled traveler are available at developed countries but still a long way ahead in terms of developing countries until and unless policy makers understand the importance of inclusiveness in a national framework. Accessibility in a sustainable perspective for public transit needs to consider the disadvantaged user access scenario and reflect the real case scenario in possible avenues for providing atleast an inclusive assured better tomorrow to all.

PTALs (Public Transport Accessibility Levels) is a measure of the accessibility from a particular location to a particular mode of public transport considering walk access time and the service availability, measuring the density of public transport network at any location within greater London (Transport for London, 2010). PTAL is categorized based on 6 levels starting from Low Accessibility to High Accessibility. The output of PTAL is listed as a set of accessibility based indices for a range of locations and spatially mapped. PTAL takes into account the following aspects in its calculations:

- Time taken to Walk from POI (Point of Interest) to Public Transit Service Access Points (SAPs)
- Number of services available within the catchment
- Reliability of the service modes available
- Level of service (LOS) available at the SAPs

The measure in the negative perspective does not consider

- Speed/Utility of accessible services
- Ease of interchange
- Passenger count and seating availability of public transit

High PTAL values highlight good access scenarios (and vice versa) and is developed mainly within the London parameters which will require fine tunings as per any other locations/cities. The main concern in regards to access to public transit is the absence of many aspects which will impact the accessibility levels including affordability, safety, security and the environmental concerns among the others in the measure.

In terms of ‘Service Satisfaction Measure’, previous studies were important to consider and develop a methodology for the indicator. Parasuraman et al (1985) mention the importance of achieving and sustaining the quality of products and services. The study discusses access, communication, competence, courtesy, credibility, reliability, responsiveness, security, tangibles and understanding the customers the ten main determinants of service quality. The ten determinant service model can be adopted into further sharpening the factors to attain a good public transit service model via the indicator. Corazza and Favaretto (2019) state on the importance of transit as one of the backbones of sustainable mobility while highlighting the importance of attractiveness of public transits. It is an important indirect influencer in terms of accessibility to public transit which is a strong candidate in inclusion for the criterion.

Studies on service access points are vital in understanding the broader factor affecting accessibility to public transportation in detail. Alexander et al (1977) highlight of how bus stops are often dreary because it is often set down independently with very little thought to the experience of waiting in the stop and to the relationships to its’ its surroundings. Bus stops and its surroundings can be an important concern in the overall perspective and its evident that the authorities are less concerned in bus stop performance levels but in simply adding bus stops when and where it is possible to include one in the road network without favorable study. Karou and Hull (2012) have identified lack of provision of a shelter and seating at bus stops as limitation in terms of accessibility to public transport.

Ohmori et al (2014) states the importance of providing a better surrounding to passengers in terms of waiting for a bus in a bus stop. The analysis of the passengers’ waiting behavior in the study showed the passenger mindset in the bus stop influenced by waiting time, activity engagement in the bus stop, time constraints at destinations and the environment of the bus stop. The importance of providing a positive environment in a bus stop will increase the attraction towards public transit. Prathibaa and Gunasekaran (2016) discusses of planning of bus stops for safe and efficient passenger boarding and alighting. The experience of the environment thus impacts the user perspective in his/her access to public transit and to select a public transit for commuting.

Wong et al (2018) state on urban areas experiencing increasing automobile use, resulting in congestion and long hours of commuting. The outcomes of the severity and duration of traffic congestion has greatly increased pollutant emissions and degradation of air quality. The study further highlights on public transit commuters being exposed to pollution more than car commuters because they are in the open air during the walking period along the road to reach a stop/terminal or commuter using the public transport.

OECD (2019) highlights on the impact of emissions from transport which have grown faster than any other sector over the last 50 years, accounting for approximately 23% of global CO_2 emissions. Transport related CO_2 emissions could increase by 60% globally by 2050 if the mobility patterns are not changed rapidly. But the concern is that the issue itself is impacting on the solution mechanism, providing a non-friendly environment to the potential public transit user to reach a stop. The importance of maintaining the air quality within a range not impacting the people exposed is vital and their values impact on the selection of mode choice. Thus, the future of accessibility is dependent on the air quality of a particular region/city and needs to be considered in any measure or criteria.

Safety in transportation and public transportation was analyzed in detail to identify impacts and importance in the overall index framework. Even though the modes of walking and cycling (which is a part of the public transport mode selection pattern of the majority users) are comparatively high risk per mile causality rate modes, studies such as Rojas Rueda et al (2011) argue on the health and fitness benefits which is seen to have more positive outcomes but highlight on provision of separate tracks to widen the scope of safety.

Litman (2014) states that safety along with security are serious concerns and elaborate on the safety concerns of public transport showing risks decreases as transit level increases. Cafiso et al (2013) evaluates the perceptions and subject knowledge of bus managers on safety issues and the potential effectiveness of different technologies in achieving higher safety standards. The study further identifies automatic door opening, bus materials, start inhibition and internal architecture as top concerns in relation to the safety of bus passenger. Intersection crossing and hard braking were considered to be factors of high-risk concerns. Joewona and Kubota (2005) states on the importance of public transport safety mainly considering the larger scale/greater number of passengers in comparison to the few or mostly one car rider/user. Further the user is the most important stakeholder of any mode and his or her safety is of utmost importance. Understanding and awareness of driver and user safety in public transportation is an important variable in improving safety.

The National Public Transportation Safety Master Plan (NPTSMP) (FTA, 2017) is an important study material in terms of identifying the importance of having a set of considerations to ensure public transportation safety is maintained at high standards. The Federal Transit Administration US undertakes the following rules to improve the public transport standards. They are

- Public Transport (PT) Safety Program rule

- State Safety Oversight rule
- PT Safety Certification Training Programme rule
- PT Agency Safety Plan rule
- Preventing Transit Worker Assault rule

NPTSMP states that improving safety performance with the PT industry is a collaborative effort that requires participation of number of partners at all levels of the transit industry including

- Federal Government
- Regional Entities
- States
- Tribal Governments
- Local Government Entities
- Transit Providers of all size in both rural and city areas

Farida (2018) discuss on the public transport service categorization (especially in the case of public buses) as moderate in safety and comfort whereas emphasizing the involvement of relevant government and other private stakeholders to provide the required and adequate facilities to reach higher standards of public transport quality. Litman (2014) makes a fair argument on how a train or bus crash often makes it to the national headlines often with national and international media coverage whereas fatal automobile crashes even though occurring in a way larger number is usually underreported.

The comprehensive review of safety in respect to public transit and transportation in general is to understand the importance of safety (and also security) in the accessibility framework. Being two of the main dimensions of sustainable transportation, it can be evaluated via review of previous studies of their individual importance and the indirect impact of safety on the accessibility component. Safety is a valid indicator which can be included in the criterion development and is exclusive of other parameters in general.

Thus, any accessibility-based planning indicators developed must reflect the concept of sustainable transport in a vital manner. Transport Accessibility is the avenue to identify the most efficient way to link the origins and destinations, reduce congestion, create liveable neighbourhoods with sustainable transportation and provide street designs that enhance different modes of transportation. Thus, the above literature analysis has given a clear understanding of sustainable transportation and accessibility.

It is in this basis that a set of indicators in SUTAS have been identified for the adoption of an improved criterion to be in par with the study objectives.

2.4 Summary of the Chapter

The chapter highlights the current situation in terms of sustainable transportation and accessibility in general, highlighting on the importance to access to public transit and the available measures to assess the accessibility quotient. The importance of different parameters and their impacts to accessibility to public transit has been carried out identifying their significance in including them as a potential indicator. Further the parameters are not adopted as per their availability in literature but modified and given leverage depending on their directness of impact to our objective and the qualitative /quantitative aspect. Further the importance of the SDGs in sustainability and the possibility of a route to assess sustainability via a conceptual study of the SDGs in transport and accessibility in particular is established which has paved the way for chapter 3. The justification and criteria in selecting the indicators out of the many potential indicator candidates is mentioned in chapter 4 followed by the explanation of SUTAS (the developed criterion) and expected further developments.

3 IDENTIFICATION OF RELEVANT SUSTAINABLE TRANSPORTATION LINKS TO SDGs

The importance of the concept of sustainability and the convergence of the concept with transportation for a future friendly development can be identified via the overall study of the concept and their relevant branches in chapter 02. Further the importance of SDGs in the current global scenario and the responsibility of the world especially the member nations including Sri Lanka to achieve the SDGs by 2030 is highlighted. But the relationship between sustainable transportation and SDGs need to be established via a more concrete understanding of the inter connections.

3.1 SDG Targets and Sustainable Transportation

It must be acknowledged that even though sustainable transport is not represented or mentioned individually by a specific SDG in the Agenda, the need for its contribution is well included in a direct or indirect perspective within the scope of the SDGs framework, mainly in relation to cities and human settlements, health, infrastructure, energy, food security and climate change. The contribution of Transport and related infrastructure is very important in achieving most, if not all, SDGs.

The 2030 Agenda states that sustainable transport systems, along with global access to affordable, reliable, sustainable and modern energy services, quality and resilient infrastructure, and other policies that increase productive capacities, would build concrete economic foundations for all. Certain SDGs are impacted directly while others have indirect impacts. Transport contributes directly to five targets on energy efficiency (Target 7.3), road safety (Target 3.6), urban access (Target 11.2), sustainable infrastructure (Target 9.1) and fossil fuel subsidies (Target 12.c) highlights that transport in a sustainable framework is essential to pave way in achieving a wide variety of SDGs. Agricultural productivity (Target 2.3), sustainable cities (Target 11.6), air pollution (Target 3.9), climate change adaptation (Target 13.1), reduction of food loss (Target 12.3), access to safe drinking water (Target 6.1) and climate change mitigation (Target 13.2) are a number of other targets where transport contributes in an impactful manner (Partnership on Sustainable Low Carbon Transport, 2018).

The first global Sustainable Transport Conference was convened post understanding of the global importance of sustainable transportation by the then UN Secretary-General Ban Ki-moon on the 26th and 27th of November 2016 in Ashgabat, Turkmenistan. This is an important event to identify the seriousness and impact of sustainable transportation on the global scale and to achieve the SDGs by 2030. The second united nations global sustainable transport conference was scheduled in Beijing, China from the 5th to 7th May 2020. The event was postponed due to travel precaution measures due to Coronavirus (Covid-19). It will provide a platform to pay more attention on the opportunities, solutions and challenges towards achieving the objectives of sustainable transport and is expected to pave a more clear path for sustainable transport to be a major contributor in achieving the objectives for sustainable development by 2030.

Seven of the 17 SDGs include one or more targets that addresses transport. The most relevant goals and targets are as listed (ITDP, 2015) below which can be referred to in the link: http://www.statistics.gov.lk/sdg/application/publications/book.pdf (page 23-35).

Goal 2

Goal 2 Targets: **2.3 2.a.**

Goal 3

Goal 3 Targets: **3.6. 3.9.**

Goal 7

Goal 7 Targets: **7.3. 7.a.**

Goal 9

Goal 9 Targets: **9.1. 9.4. 9.a.**

Goal 11

Goal 11 Targets: **11.2. 11.6. 11.7. 11.a.**

Goal 12

Goal 12 Targets: **12.c.**

Goal 13

Goal 13 Targets: **13.2.**

The ITDP (2015) is one of the many studies in which the most relevant targets for transport are identified as listed above. The need to identify the links in terms of different studies and organizations is important in building linkages between sustainable transportation and SDGs. The need to quantify the links to a possible level which can be recognized in the academic perspective and thus a conceptual approach is adopted in the research to quantify the links.

3.2 Identification on links for a conceptual study

The 17 SDGs are listed in Table 03 along with their individual number of targets and the number of targets in relevance to transportation (Holzwarth, 2015).

Table 03: List of UN SDGs along with their number of targets

Goal No.	Goal Identification	Number of individual targets	Number of targets in relevance to transportation
1	No Poverty	7	5
2	Zero Hunger	8	4
3	Good Health and Well-being	13	3
4	Quality Education	10	4
5	Gender Equality	9	4
6	Clean Water and Sanitation	8	4
7	Affordable and Clean Energy	5	2
8	Decent Work and Economic Growth	12	4
9	Industry, Innovation and Infrastructure	8	4
10	Reduced Inequality	10	2
11	Sustainable Cities and Communities	10	6
12	Responsible Consumption and Production	11	4
13	Climate Action	5	1
14	Life Below Water	10	1
15	Life on Land	12	1
16	Peace and Justice Strong Institutions	12	1

17	Partnerships to achieve the Goal	19	7
Total count		**169**	**57**

Considering the studies in the aspect of SDGs and transportation, it is important to identify the specific links and the individual targets linked to sustainable transportation both directly and indirectly. Thus, via Holzwarth (2015), it is evident that 57 out of the 169 targets (33.7% which is approximately 1/3rd) have either direct or indirect linkages to be achieved in 2030 through assistance of transportation. To make the linkage more precise and meaningful in the study, the identified targets are further classified based on the five dimensions of sustainable transportation depicted in Table 04 (Holzwarth, 2015). It must be noted that the individual connections to one or more of the five dimensions with respect to every target was established via comprehensive literature analysis and expert opinion as depicted in Table 04.

Table 04: Identified Links of SDG targets with sustainable transportation factors

Sustainable Transportation Factors	**Accessibility**	**Affordability**	**Safety**	**Security**	**Environmental Concerns**
SDG Targets related to Sustainable Transportation					
1.1		×			
1.2	×	×			
1.4	×				
1.5					×
1.b		×			
2.1	×				
2.2	×	×			
2.3	×	×			
2.a	×				
3.4					×
3.6			×		
3.9					×
4.2	×	×			

4.3	×	×			
4.4	×	×	×	×	×
4.5	×				
5.2				×	
5.4	×				
5.5	×				
5.6	×				
6.1	×				×
6.2	×				
6.3					×
6.6					×
7.1		×			×
7.3					×
8.2	×	×	×	×	×
8.4					×
8.5	×	×	×	×	×
8.a	×				
9.1	×				
9.4					×
9.5	×	×	×	×	×
9.a	×				
10.1		×			
10.2	×				
11.1	×				
11.2	×	×			
11.3	×	×	×	×	×
11.6					×
11.a	×				
11.b				×	×
12.1	×	×			×
12.3	×				
12.4					×
12.c					×
13.2					×
14.1					×
15.1					×
16.3	×	×	×	×	
17.3	×	×	×	×	×
17.6	×	×	×	×	×
17.9	×	×	×	×	×
17.11	×				
17.14	×	×	×	×	×
17.17	×	×	×	×	×
17.19	×	×	×	×	×

Table 05: No. of targets linked to individual targets (analysed from Table 04)

No. of SDG Targets related to Sustainable Transportation	No. of targets in relation to every dimension				
	Accessibility	Affordability	Safety	Security	Environmental Concerns
57	*36*	*23*	*13*	*14*	*29*

The listed targets in Table 04 can be referred to in the link 'http://www.statistics.gov.lk/sdg/application/publications/book.pdf' (page 23-35)' as and when required.

The conceptual linkages of the targets identified with the five dimensions of sustainable transportation using literature and individual target analysis gives the corresponding values of the impact of every individual dimension in the achieving of the SDGs by 2030 considering the 57 targets identified. It is important to have an elaborated understanding of the targets considered in the Table 05 based on which analysis was carried out to link them individually with one or more dimensions. Thus, the following elaboration of the targets identified in relation to transportation is listed below (Holzwarth, 2015).

Goal 01

1.1 Transport cannot be separated from socio-economic development

1.2 Transport provides the ability to reach to reach vital opportunities including employment and other financial assistance

1.4 Transport gives access to all people with no discrimination with affordability to the mode being a factor of concern

1.5 Transport is a major contributor to climate change, requiring sustainable alternatives for the betterment of the environment and the industry itself

1.b Transport planning and design increases the advantages of improved mobility and inclusive growth to all

Goal 02

2.1 Transport with high reliability ensures access to market opportunities for both consumers and producers

2.2 Transport and agricultural logistic chains gives high access avenues to nutritious and affordable food for all

2.3 Logistic chains have a direct impact on agricultural productivity, market accessibility and farmers' earnings through time, energy and cost savings

2a Availability of reliable transport options give a platform to outreach agricultural extension, technology and knowledge with ease

Goal 03

3.4 Air Pollution has been listed as one of the main risk factors for non-communicable diseases

3.6 Considering the extent of fatalities and related injuries form traffic accidents, the need to consider the aspect with high concern is necessary

3.9 Air Pollution, the reason for premature deaths of an estimated 3.7 million people is mainly (one of the) fueled by the transport sector

Goal 04

4.2 Availability of affordable and reliable transport to reach educational facilities

4.3 Availability, reliability and affordability determine the right for all to access quality education

4.4 Transport itself is a wide platform for learning, research and development

4.5 Equal access opportunities to all via transport encourages the equality in terms of education

Goal 05

5.2 Safety in transport and its relevant measures is required to improve the security for women and girls

5.4 The need to cater to the specific transport requirements of women is vital in terms of the society

5.5 In terms of women, transport acts as an enabler to engage in public life, social interactions and reach employment opportunities with minimal hardships

5.6 Health access for women of all ages and backgrounds is enabled by transport

Goal 06

6.1 Transport affects water both in a positive and negative perspective: ensuring access to water sources and impact the fresh water sources mainly via pollution

6.2 Access to sanitation is vital and can be facilitated via transport

6.3 Transport impacts water quality adversely mainly in terms of emissions affecting water source and the usability of water

6.6 Transport and related infrastructure adversely impact the ecosystems

Goal 07

7.1 The excessive demand by transport for fossil fuels and the need for cleaner energy to be incorporated in transport is mainly focussed upon

7.2 Increase of vehicle efficiency in fuel usage in transport needs to be considered

Goal 08

8.2 Transport and related planned logistics are required for increase economic productivity

8.4 The main concern of sustainable transport deals with a low carbon future

8.5 Transport itself generates a large number and variety of job opportunities

8.a Transport is vital in movement of goods and related services within the country and beyond the country as well

Goal 09

9.1 An efficient transport framework is a major tool for socio-economic development with an equal access usage opportunity

9.4 Transport can be a major game changer in terms of minimizing carbon usage

9.5 Transport is developing with time and technology incorporating innovations such as ITS

9.a Providing a platform for combined development in transport with sustainable adaption in a local and international perspective

Goal 10

10.1 Transport reduces in equality within the community giving access to essential services in an affordable perspective

10.2 Incorporation of large-scale transport development projects reducing the urban-rural divide providing access to the majority with lack of access.

Goal 11

11.1 Transport provides access to basic services and wider opportunities with minimal discrimination

11.2 Transport is a major form of asset to the related community/ organization/ government

11.3 Transport and sustainable incorporation in transport contributes vitally in achieving urban sustainability

11.6 Transport is a major contributor in terms of air pollution and related fatalities

11.a Transport helps and provides a platform for intra-city and inter-regional transport connectivity

11.b Integrated transport framework help in increased efficiency, effectiveness and flexibility of transport systems

Goal 12

12.1 Incorporation of sustainable consumption and production in transport helps in decrease of consumption of resources while improving accessibility.

12.3 Food waste and food losses can be minimized via improvement of rural transport and related infrastructure and services

12.4 Transport related combustion of fossil fuels contribute majorly to air pollution

12.c The increase of fossil fuel prices with no subsidies encourage users to move to sustainable alternatives

Goal 13

13.2 Transport is responsible for more than 20% of the global CO_2 emissions requiring alternative sustainable options

Goal 14

14.1 Maritime transport has a negative impact on the environment, especially on the marine environment

Goal 15

15.1 Transport contributes adversely in degradation of terrestrial ecosystems and biodiversity including forests, deserts and land segments

Goal 16

16.3 The post conflict zones in the national and international areas can be rehabilitated with a major involvement by transport

Goal 17

17.3 17.6 17.9 17.11 17.14 17.17 17.17 All related targets mainly establish inter connections with sustainable transport to the global community in terms of capacity-building, finance, trade, technology, policy coherence and multi stake partnerships, and data, accountability and monitoring.

In the above list of targets which are influenced by transportation, the targets that are impacted by accessibility as indicated in table 04 are 1.2, 1.4, 2.1, 2.2, 2.3, 2.a, 4.2, 4.3, 4.4, 4.5, 5.4, 5.5, 5.6, 6.1, 6.2, 8.2, 8.5, 8.a, 9.1, 9.5, 9.a, 10.2, 11.2, 11.3, 11.a, 12.1, 12.3, 16.3, 17.3, 17.6, 17.9, 17.11, 17.14, 17.17 and 17.19 whose elaborations have also been discussed above in the list of targets affecting sustainable transportation.

The 244 SDG indicators have been accepted as the indicator framework to act as a management tool to assess the implementation and progress of the SDGs in the national and the international scenario. The 244 global indicators frameworks were developed by the Inter Agency and Expert Group on SDG Indicators and accepted at the 48th session of the United Nations Statistics Commission (Status of SDGs Indicators in Sri Lanka: Department of Census and Statistics, 2017)**.** Amongst the 244 indicators it must be noted that certain of the indicators either directly or indirectly reflect the importance of working towards sustainable transportation and transport accessibility. These indicators pave the way in developing sustainable indicators which solely represent the concepts in transportation. Listed below are indicators related directly to the context of accessing accessibility:

1.1.1 Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural)

1.4.1 Proportion of population living in households with access to basic services

9.1.1 Proportion of the rural population who live within 2 km of an all-season road

9.1.2 Passenger and freight volumes, by mode of transport

11.2.1 Proportion of population that has convenient access to public transport, by sex, age and persons with disabilities

11.3.2 Proportion of cities with a direct participation structure of civil society in urban planning and management that operate regularly and democratically (subjective on direct link to transport accessibility)

16.1.4 Proportion of population that feel safe walking alone around the area they live

There are many indicators which indirectly incorporate the accessibility factor along with other parameters in assessing developments towards achieving the SDGs.

The Figure 05 is a graphical representation of the conceptual study. The Accessibility dimension shows the highest impact in achieving the SDGs via direct or indirect ways and means, with a '36 out of 57' weightage (which values at 32% contribution to the total of 33.7% contribution of transportation in achieving the SDGs). This reassures the importance of accessibility to achieve the overall objectives effectively. The next dimension with a larger impact is identified as environmental concerns with a 25% weightage. The hierarchy is followed by affordability (20%), security (12%) and safety (11%). These quantitative rankings in a conceptual study acts as an initiating point for further extended analysis and discussion in relation to sustainability. The main concern in this hierarchy is the requirement to analyze the safety component further to understand and evaluate the exact positioning due to its high-level impact in the field of transportation and individual impact more precisely to the overall scenario.

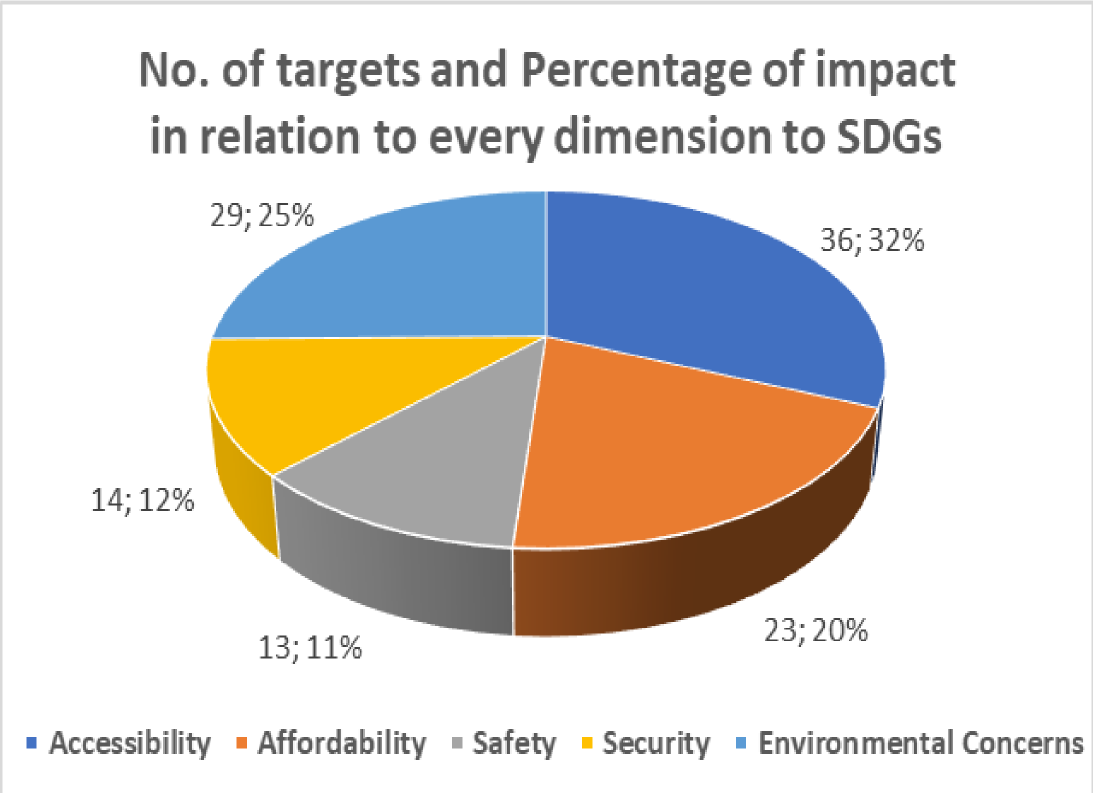


Figure 05: Number of targets and percentage of impact in relation to every dimension to SDGs

3.3 Summary of the Chapter

The chapter deals with a conceptual study analyzing the relationship between sustainable transportation and SDGs in order to establish a more concrete understanding of the inter connections. Even though it is accepted that transportation is interrelated with achieving the SDGs (impacting the goals directly or indirectly) very less study on a relationship study has been conducted in the academic framework which has been catered to in the study. The relationship building between sustainable transportation and SDGs directly or indirectly with the 169 targets leads a different perspective into the approach to enhance sustainability in transportation and understand the effect of transportation on achieving the SDGs by 2030. The base for the study has been identified in chapter 2 via a critical review of concepts and parameters which has helped in establishing the conceptual study. The chapter has created a strong platform of the positioning of accessibility in relation to sustainable transportation and further evaluating each target which are directly or indirectly associated with accessibity. The chapter 4 utilizes the outcomes from chapter 2 and chapter 3 in coming up with an improved criterion in line with the study objectives.

4 AN IMPROVED CRITERION

The identified research gaps and objectives of the research result in the development of an improved criterion which is elaborated in the chapter. The criterion is named as the ‘Sustainable Urban Transit Accessibility Scorecard’ which shall be referred to as ‘SUTAS’. The set of indicators are listed with the background developed from the previous chapters and the individual indicator descriptions and the calculation of SUTAS is represented in the chapter.

4.1 SUTAS - ‘Sustainable Urban Transit Accessibility Scorecard’

Sustainable Urban Transit Accessibility Scorecard (SUTAS) is the proposed final outcome index from the research study criteria to evaluate accessibility to public transit systems in a sustainable perspective. Initially bus transport is considered to build up the index and trial the statistical approach before expansion to other public transit modes. Other public transit modes such as Train and LRT systems could be included in the SUTAS to expand from the initial public bus transport systems.

Basically the conceptual framework in the selection of the indicators was in terms with the study conducted by Gudmundsson and Regmi (2017) in developing the SUTI measure. The steps include

- Identification and tabulation of the available indicators from literature
- Identify parameters which have a direct or indirect impact to accessibility to public transit
- Identify the core of the measure and consider the indicators that will be a fit in terms of data collection and analysis
- The final adjustment of indicators based on expert advice and workshops and a pilot study with an international interference. (Expected to be processed in the latter development phase)

SUTAS development been carried out with more or less equal considerations to all accessibility relating aspects to public bus systems in a sustainable perspective. It is vital that data collected in different cities for comparison need to follow the same course of action to be compatible and accurate. SUTAS has been initially put forward with the ten indicators filtered with some basic considerations.

- Basketing a set of indicators that is not take a negative toll to collect, but is available with an acceptable degree of reach
- The overall representation of sustainability, public transit accessibility and the amalgamation of both the concepts via the scorecard
- Following a final method to reduce the complexity of the outcome and showcase an efficient outcome

A group of indicators is selected post complete study of the available measures/index, factors affecting relating subject areas and their shortcomings. Individual indicators were assessed by their appropriateness to measure accessibility to public transit in an urban perspective, considering similar measures which can be adopted with fine tunings and incorporation of new parameters affecting the accessibility and attraction of people for public transit usage. The final outcome measure from ten indicators is selected post complete study of the available measures/index, factors affecting relating subject areas and their shortcomings. Individual indicators were assessed by their appropriateness to measure accessibility to public transit in an urban perspective, considering similar measures which can be adopted with fine tunings and incorporation of new parameters affecting the accessibility and attraction of people for public transit usage.

It is developed to help in parallel comparison and assessment of cities in a sustainable perspective with a more quantitative weightage in its outcomes. There are more than hundreds of indicators available in the transportation framework which mainly revolve around a number of main issues in different perspectives. Thus, these ten indicators are mainly selected in terms of reflecting the dimensions of sustainable transportation, weighing highly on the impact for accessibility to public transport and compare and contrast with expert opinion and indicator data availability.

It is evident that a large number of indicators have been brought down to the most appropriate ten due to the practicality in obtaining data for every individual indicator to be considered for the index. It is important to select a group of indicators that are appropriate and fall in line with the study objectives. The main aspect revolves around the selected measure having a high inclusion towards the accessibility component to public transit in an urban context while covering all the dimensions of sustainable transportation in the best possible way. This approach is a new conceptual method of analysing the dimensions with respect to sustainability and then building a measure considering the outputs of the study, comprehensive literature analysis and understanding the study objectives.

Indicators which are to be selected for the criterion in the data collection process will have standard formats including a description of the particular indicator, its reason of selection in the overall study space, the unit, maximum and minimum values along with any further guidance as and when required. Among these indicators proposed for the scorecard, certain indicators will have direct results available whereas certain data retrieval can be more complicated which needs to be identified in the process of collection of itself and will differ from one collection scenario to another. The initial set of indicators thus identified from the elaborated study and review for SUTAS are as follows:

1. Public Transport Connectivity Index
2. Network - Transit Service Ratio

3. Service Accessibility Ratio
4. Disadvantaged User Access Rating
5. Total Access Time
6. Service Satisfaction Measure
7. Stop / Terminal Performance Level
8. Aesthetic Experience Measure
9. Air Quality
10. Safety Measure

It is important to identify the attributes on each of these indicators before elaborating on their individual calculations. Understanding the base in which the criterion needs to be formulated on a public transport access framework perspective, certain indicators are direct measures or accessibility whereas others are indirect contributors.

1. Public Transport Connectivity Index – Direct Impact to Accessibility
2. Network - Transit Service Ratio – Direct Impact to Accessibility
3. Service Accessibility Ratio – Direct Impact to Accessibility
4. Disadvantaged User Access Rating – Direct Impact to Accessibility
5. Total Access Time – Direct Impact to Accessibility
6. Service Satisfaction Measure – Indirect Impact to Accessibility
7. Stop / Terminal Performance Level – Indirect Impact to Accessibility
8. Aesthetic Experience Measure – Indirect Impact to Accessibility
9. Air Quality – Indirect Impact to Accessibility
10. Safety Measure – Indirect Impact to Accessibility

Depending on the way of analyzing and the nature of data with the individual explanation/understanding of the indicators elaborated in the chapter, the quantitative or qualitative nature can be identified.

1. Public Transport Connectivity Index- Quantitative
2. Network - Transit Service Ratio - Quantitative
3. Service Accessibility Ratio - Quantitative

4 Disadvantaged User Access Rating - Majorly Quantitative

5 Total Access Time - Quantitative

6 Service Satisfaction Measure - Qualitative

7 Stop / Terminal Performance Level - Qualitative

8 Aesthetic Experience Measure - Qualitative

9 Air Quality - Quantitative

10 Safety Measure – Quantitative

Depending on the impact to accessibility to public transit and the quantitative/qualitative aspect, one can either utilize only the direct impact indicators which are quantitative or utilize the entire set providing an overall idea of the accessibility consisting of majorly quantitative and qualitative indicators. Thus, this decision lies on the user of the scorecard depending on the required outcomes, available data and other related parameters.

The indicators are a testimony of being quantitatively strong considering the importance a qualitative perspective too represented by three valid indicators, this diversity in an indicator is vital in a measure for incorporation of accessibility within the sustainable framework. It must be noted that a hypothetical study has been utilized to understand and evaluate individual indicators with a framework to attain a single SUTAS value complicit to comparison of a following city of a period of time or the comparison between cities in a considered timeframe.

It has also been given due importance to extract the accessibility oriented quantitative indicators to analyse on its validity and to compare and contrast on identifying the way forward in selecting the most apt measure from this study. Thus, the above listed shall hereforth be referred to as SUTAS 10 and the listed five set of indicators with a majorly quantitative outlook and direct impact to accessibility in a sustainable framework consisting of five indicators will be the SUTAS, the improved criterion of the study.

SUTAS

A Majorly Quantitative Accessibility Measure

1 Public Transport Connectivity Index- Quantitative

2 Network - Transit Service Ratio - Quantitative

3 Service Accessibility Ratio - Quantitative

4 Disadvantaged User Access Rating - Majorly Quantitative

5 Total Access Time - Quantitative

The main aspect in SUTAS 5 is the quantitative aspect in terms of evaluation. A case study has been carried out (Chapter 5) to identify to potential, constraints and the practicality of SUTAS.

Table 06 provides a side by side comparison of SUTAS and SUTAS 10 with another of the two available indicators discussed in the study. SUTI and STPI are selected to a comparative analysis via a notational matching along with supported color matching to identify to the similarities in concepts of the indicators and their differences. Table 06 has a varied representation in terms of the indicators in the background of sustainable transportation. The need for a quantitatively naïve and accessibility conscious indicator is well represented via SUTAS. SUTI needs to be more inclusive to the accessibility component whereas it has been already established of STPI being more biased in terms of environmental parameters in general. The outcome of the study objectives requires a viable *sustainably strong accessible* measure in terms of public transit. SUTAS is expected to be developed further based on studies and study outcomes. It is important to understand that the main framework is analyzing accessibility to public transit within the framework of sustainable transportation.

It is very important to note that the study outcome requires an improved criterion to evaluate accessibility to public bus transport systems in a sustainable perspective. Thus after a comprehensive study of the available measures, affecting parameters and understanding the background of the formulation of SUTAS (both SUTAS and SUTAS 10), it is important to propose a measure as the final outcome of the study.

The final outcome to be proposed as the improved criterion is the SUTAS 10 (hereforth referred as the SUTAS) is the improved criterion to evaluate accessibility to public bus transport system considering

- Representation of Accessibility and the overall sustainable transportation
- Majorly Quantitative Indicators
- Incorporation of Qualitative Indicators
- Covers the Five Dimensions of Sustainable Transportation (directly or indirectly)
- Backed by Expert Opinion

Table 06: Side by side comparison of SUTI, STPI and SUTAS (and SUTAS 10)

SUTI	STPI	SUTAS "10"	SUTAS
Air quality #	Use of fossil fuel energy for all transport #	Network Connectivity Ratio +	Network Connectivity Ratio +
Greenhouse gas emissions from transport #	Greenhouse gas emissions from all transport #	Network - Transit Service Ratio	Network - Transit Service Ratio
Convenient access to public transport service +	Index of emissions of air pollutants from road transport #	Accessibility Ratio +	Accessibility Ratio +
Traffic fatalities per 100.000 inhabitants *	Index of incidence of injuries and fatalities from road transport *	Service Satisfaction Measure >	Total Access Time +
Public transport quality and reliability >	Total motorized movement of people	Stop / Terminal Performance Level >	Disadvantaged User Access Rating +
Affordability – travel costs as share of income ^	Total motorized movement of freight	Air Quality Measure #	
Operational costs of the public transport system ^	Share of passenger travel not held by land-based public transport	Disadvantaged User Access Rating +	Environmental Concerns #
Investment in public transportation systems	Movement of light-duty passenger vehicles	Safety Measure *	Accessibility +
Extent to which transport plans cover public transport, intermodal facilities and infrastructure for active modes	Rate of use of urban land	Total Access Time +	Safety and Security *
	Index of relative household transport costs ^	Aesthetic Experience Measure	Affordability ^
	Length of paved roads +		Public Transport Quality >
Modal shares of active and public transport	Index of the relative cost of urban transit ^		
	Index of energy intensity of the road vehicle-fleet #		***Indicators highlighting Accessibility +***
	Index of emissions intensity of the road-vehicle fleet #		

1. Public Transport Connectivity Index - PTCI

This indicator is included to depict the public transport network topography via **"How well is the city public transport network connected?"** scenario. Thus, the concept of facilitating accessibility to the public transit systems is highlighted through the result outcome on the overall SUTAS index.

The number of nodes in the city transport network per square kilometer is a vital element in accessibility indication (Maria and Nicola, 2019). The Network Connectivity Ratio is calculated via the basic **equation (1.1)** which this is existing and represent overall accessibility of a city and you are suggesting PTCI to represent public transit accessibility.

$$\text{Network Connectivity Ratio (NCR)} = \frac{\text{Number of transport links}}{\text{Number of transport nodes}} \tag{1.1}$$

where definitions of the terms used is given below.

- Link - Any portion of a transport defined by a node at each end or at one end.
- Node - The terminus of a transport or the intersection of two or more links.

Network Connectivity Ratio depicts how well the road network is connected and is the number of network links divided by the number of nodes in a particular study area. Basically when the number of link increases, the connectivity of a network increases.

Network is basically defined by the prevalence of a combination of nodes and links. Basically in network analysis, even if there is a dead end it is represented by a node. Every link has two have distinctive nodes. In network analysis, the street network can be grid, hub and spoke (radial), linear or tree which has their individual characteristics. In considering a network structure (especially in public transit), there can be a centralized, decentralized or distributed network with individual characteristics.

It is evident that buses do not operate on all roads and links with buses operated needs to be considered. The PTCI is developed considering the bus stops as the nodes and the bus network links as the road network links depicted via the basic **equation (1.2).** Basically, the PTCI is based on the concept of the NCR concept but modified to accommodate stops as nodes and links based on bus/PT routes and stops. In terms of a node, it should have at least two bus routes crossing for consideration in the measure. It must be important that the bus stop is in usage and is not abandoned due to concerns such as no demand or absence of shelter etc. Further the route must be approved by a relevant authority to be considered in as a link as a standard route to be included in the PTCI.

$$\textbf{PTCI} = \frac{\textbf{Number of bus network links}}{\textbf{Number of bus stop nodes}} \tag{1.2}$$

PTCI in the current index scenario has incorporated all bus stops along certain network segment. The con of this method is that one can arbitrarily introduce stops along the segment and manipulate the index according to their requirements. Thus, it is expected to only incorporate the points where two or more buses/public transit intersect to avoid such discrepancies that may occur.

It is important that the sustainable quotient of a city is heavily dependent on the public transport availability and the impact of non-motorized transport which can only be encouraged with high connectivity standards. Thus, this indicator which seems to be simple in the outside has a high depiction of importance in terms of road connectivity, public transport connectivity and related accessibility. Depending on the index value, it can be identified whether the network is more of a centrifugal network or centripetal network.

It must be noted that in developing to other public transit modes such as railways, a station can function as a node in the place of the bus stop. A similar approach can be incorporated to other urban public transit modes too in the development phase.

Further understanding on the methodology of the indicator is presented via the case study discussing the applicability and improvements.

2. **Network - Transit Service Ratio**

This SUTAS indicator caters the public bus transport service (in this case) availability in considered region/city which is the main core of the developed index. The indicator is a representation of the ratio of availability of bus services in the road networks of a particular city/town and considers the service spread in a particular area. The roads to be considered in comparison is initially differentiated by the type of road which is expected to be developed based on the number of vehicular and pedestrian movement for consideration purposes. It is further expected to incorporate the number of bus routes and the service frequency via adjustment factors. Initially road networks will be incorporated in analysis which can be expanded to all transit routes. Even though the indicator seems simple, the availability of service can be well established within an urban city or town and the need for rerouting of certain services or introduction of new services can be understood.

The perspective in regards is as to **"What is the proportion of road networks which are served by public bus service/s?"** calculated by **equation (2)**. Thus,

Network (Road) – Transit (Bus) Service Ratio

$$= \frac{\textbf{Number of kilometers serviced atleast by one public bus route}}{\textbf{Total number of kilometers in the considered road network}} \qquad \textbf{(2)}$$

Considerations in terms of the indicators include

- Bus service at least every 20 minutes (Minimum service standard - SNAMUTS)
- Excluding residential streets, only considering collector, distributer and arterial roads (which can be more narrowed down to eliminate all roads (less than 1 km) with dead ends due to absence of clear definitions of residential streets)

The nature of the indicator was well established via the studies presented at the latter part of the study. The case study presented a platform to apply the indicator and further development avenues. Basically a value close to 1 will indicate a better availability in terms of bus services whereas a value close to 0 will highlight the need for further new bus routes to be added or extended in the road network (absence of bus services in majority of the road segments).

3. **Service Accessibility Ratio**

This indicator highlights the accessibility to the available bus service points from any given location in the city. The approach of the indicator is **"What is the land area covered by the bus route buffer zones?"** scenario is considered to calculate the indicator as shown in **equation (3)**. It is important to note that if a public bus transport system is not/poorly accessible the passengers are not/rarely encouraged to use the available public transport. These can be preventing factors which needs to be given high priority to develop a public transport friendly urban environment. Indicator two may seem to be similar but it focusses on the availability of a bus service along a road network. Indicator 03 takes into account the availability and appropriateness in locations of service access points which is a vital element to use the available bus service.

The indicator is a representation of the catchment area to measure the level of accessibility. It basically incorporates the character of bus stops in a particular region reflecting their location distribution and accessibility quotient to users. The factors in the catchment area criteria mainly constitutes of the walking (or any other mode) distance to access a particular public mode, level of service of the corridor etc. Even though an initial buffer of 500 m is considered, improvements can be adopted to make the indicator more effectively representative.

The latter method requires a more elaborative network for analysis. Thus consideration of a 500m buffer parallel to the bus route makes it practical for analysis and includes less complexity in the process. Location of bus stops is subjective and does not have a defined distance which can be considered in further development of the indicator.

Considerations in terms of the indicators include

- The 500m buffer is as per the UN recommendations (considered within a radius of 500m of a particular bus stop) (SDG report UN, 2019)
- Total square kilometers excluding water bodies

Service Accessibility Ratio

$$= \frac{\textbf{Number of square kilometers covered under the 500m buffer}}{\textbf{Total square kilometers of the considered city}} \quad (3)$$

As per the indicator more are covered as buffer represent better access. It must be noted that when two catchment buffers overlap the people in the particular common area have better access. In the situation of a perpendicular road section to the two parallel road with overlapping buffers, a third overlap can be experienced. This represents a further better accessibility scenario. Thus, these cases are expected to be incorporated in the indicator for better accessibility analysis. Indicator 2 basically identifies the availability of bus services and the need for more, whereas this particular indicator (3) evaluates the catchment area of the bus routes in operation evaluating their route and bus stop locations in terms of passenger attraction in the accessibility perspective.

4. **Disadvantaged User (Physically Challenged/Elderly etc.) Access Rating**

SDG target 11.2 highlights the importance of convenient access to public transport by all groups of users irrelevant of sex, age and person with disabilities. It is completely a different aspect of accessibility which needs to be included in the times of equality and inclusiveness which is one of the most important concerns in sustainability. Thus, the point of concern expected to be highlighted via the indicator is as to **"How comfortable are the disadvantaged/disabled in terms of reaching specific bus stops/terminals and using the service?"**. It is an amalgamation of the ease to reach the service point/bus stop and the ease of entrance and exit from the bus (access into the service). This indicator is in line with SDG indicator 11.2.1 which calculates the proportion of population that have convenient access to public transport, by sex, age and person with disabilities. Further the UN Habitat states that cities which have convenient access to public transport, including access by persons with disabilities are more preferred in the global context in comparison to others with less access provisions to its passengers of all avenues. The **equation (5)** shows the method to measure the 'Disadvantaged User Access Rating'.

Disadvantaged User Access Rating = **(5)**

(a) percentage of pavement systems/roadways which are friendly for the disadvantaged/disabled (0.5 weightage)
(considering the network of the city in consideration)

+

(b) percentage of inclusion of disadvantaged/disabled facilities measure available in public buses in operation (0.5 weightage)

(considering the number of buses in operation)

Considerations in terms of the indicators include

- calculated via in-site analysis (comparing the ease of facility to the disadvantaged to the total pavement system of the city) (the distance value may be available in certain local/national authorities)
- calculated in relation of buses with disadvantaged (exit-entrance-travel) facilities to the total number of public buses operated in/from/through the particular city

Fraction of accessible buses/trains in the fleet and access to stops and terminals are other viable measures that can be used in the development phase of the particular indicator.

5. **Total Access Time**

The SUTAS indicator reveals **"How long does it take to use the bus service from a specific point?"** in terms of the passenger. The indicator is a quantitative inclusion with respect to inclusion of the time parameter in reaching a stop/terminal and the time spent to gain access for the particular public transit service. It is expected to develop the measure especially with concerns to development of a mechanism for waiting time calculation for a specific route and an area in a considered network. Even though it seems to reflect service accessibility, the indicator is a reflection of the time perspective in using a public transit/bus service irrespective of the catchment area (incorporating trip generators and significant locations) in access to a public transit service via its service access point.

The total access time is calculated using the **equation (6).**

$$\textbf{Total Access Time} = \textbf{Walk Time} + \textbf{Average Waiting Time} \qquad \textbf{(6)}$$

Terms in detail:

- Walk time is the distance from Point of Interest to Service Access Point (SAP) which is basically a measure of time using average walking speed (calculated using average walking speed of 1.4 m/s and the corresponding distance) (walking speed average value of 1.4 m/s and (max distance of 500 m)
- Average waiting time is the average time in concern to passenger arrival to SAP to bus arrival. (min 5 to max 20)

The minimum total access time was calculated considering a minimum distance of 28 m (assumption based on average observations value in western province) and a corresponding waiting time of 5 minutes (The maximum value – maximum distance of 500 m and time of 20 minutes). In future interpretation of this indicator, in terms of comprehensive application of the indicator and the criterion, it is recommended to use the minimum total access time as **0** (the perfect situation – both walking time and waiting time is 0). In terms of the maximum value (upper boundary), the total access time is **30** minutes (as recommended in the SDGs). This is a combination of walking time and waiting time where the time values are independent as long as their total is 30 min. (eg: Waiting time can be 0 and Walking time can be 30 min (2.25 km at a speed of 1.25 m/s) or Waiting time can be 30 min and Walking time can be 0 min or any other variable scenarios given that the total is 30 min).

6. Service Satisfaction Measure

The qualitative approach on the indicator focusses on the service satisfaction of the public transit service. It is very important that the passenger or end user is happy with the service. The rate of satisfaction is very subjective depending on the geographical, economic and social positioning of the service. The satisfactory factors have been adopted for initial inclusion from SUTI and is expected to be developed into a quantitative value. The basic single word that would represent the idea of the indicator is to assess the 'Quality' of the service in a user of perspective. This indicator brings in quality and reliability along with a number of other factors which are to be taken into consideration in building up the indicator. (Basically, it is on **"How happy/satisfied are the people/users with the available public bus service in the particular city?"**)

- Frequency of the service
- Punctuality (delay)
- Comfort and cleanliness of vehicles
- Safety of vehicles
- Personnel courtesy
- Fare level

The user satisfaction should be conveyed using an ordinal (Likert) scale listing the above-mentioned factors individually thus coming up with an overall satisfaction value. Comfort and cleanliness and personnel courtesy are majorly qualitative whereas others can be analyzed in a majorly quantitative perspective as well. A five-point scale is incorporated to measure the factors with the following corresponding categories:

- Dissatisfied
- Partially dissatisfied
- Neutral
- Partially satisfied
- Satisfied

It must be mentioned that considerations to filter the parameters based on retrieving available information by monitoring or observation is better than querying all of the above parameters to the user. The minimum and maximum values were extracted using the assistance of the SUTI indicator. It will be less practical in terms of involvement and time constraints. Thus it is expected to tabulate parameters like the service frequency, safety of vehicles and fare levels via observatory analysis and data study. After summing up all the responses from the survey, the average satisfaction level of every individual category can be generated. Using the average value, an overall satisfaction value can be derived to be used in SUTAS. This indicator not only provides a final indicator result for the index but also help in realizing the problem of the indicator performance evaluating which of the above factor/s need to be improved in a particular city and in an overall national and international scenario to increase the service satisfaction rate of its passengers.

7. Stop / Terminal Performance Level

Based on literature review and analysis, the study identifies the need to recognize bus stops as a crucial element to improve bus services. The indicator will be developed further incorporating a quantitative approach to assess the performance levels. Thus it must be stated that importance in terms of experience of waiting is to consider the vibe of a bus stop. To elaborate, studies have found that passengers unconsciously multiply their wait time by a factor of 1.2 to 2.5 while having a negative stay/feeling at a stop.

The indicator question in this regard will be **"What is the performance level of available bus stops/terminals?"** and is recommended to be identified via observatory analysis with predefined parameters or characteristics. The three components of the level calculation will have individual ratings from 1 to 5 as shown in **equation (4)** which needs to be collected from all variations of people using the bus stop.

$$\text{Stop / Terminal Performance Level} = \text{Experience of waiting (1 to 5 rating)} + \text{satisfying infrastructure (1 to 5 rating)} + \text{information availability of buses (1 to 5 rating)} \quad (4)$$

Experience of waiting is expected to be obtained as a rating outcome from the passenger whereas the satisfying infrastructure and information availability can be rated as per observation of the considered bus stops. A documentation of every bus stop in terms of seating, restrooms, cleanliness of the station/stop, street width and related parameters, traffic density, noise levels, availability of greenery and any other entertainment related activity will be utilized in identifying a common mechanism to rate the bus stops in general. It is important to note that different stops have different levels of facilities in its composition. This is a basic measure to measure the levels which will be developed with more accurate analysis techniques. This initial indicator will be further individually developed with a set of guidelines to improve validity and comprehensiveness.

8. Aesthetic Experience Measure

The indicator is a value depicting the experience to reach the bus stop/terminal and investigating whether it classifies as a satisfying/friendly/comfortable experience. Basically, the level of satisfaction of passengers in the course of reaching the bus stop/terminal for bus service usage. This is a subjective comparison of the measure in terms of a friendly atmosphere urging passengers to have a 'happy' and 'content' walk to the service access point. (The 'Feel-good-factor')

Consideration in terms of the indicators include

- To be measured in a rating perspective based on in-field experience (initially a scale of 1 to 5 is to be used in a qualitative perspective in the index and will be developed individually considering all factors of concern in the perspective of a passenger accessing a public transit)

The measure is an introduction of the way forward and shall be developed in further phases of the study.

9. Air Quality

This indicator is an indirect measure related to accessibility mainly incorporating the conducive environment for the passenger in reaching the public bus stop, while waiting for the bus and while engaging in the bus service. Thus, this can be calculated as the air quality measure in the particular city (the point of selection for air quality in an important location eg: city main bus terminal vicinity – (Colombo Bastian Mawatha Bus stand)) in terms of data collection (This measure does not consider the inclusion of green transport concept where the bus needs to be a nonpolluting element which will be perceived in further developments of the index to attain an overall sustainable outcome via the SUTAS indicator).

The indicator deals with the problem statement of "**Is the environment exposed to the passenger reaching a bus stop/terminal conducive in terms of the environmental perspective?"**.

The **Annual mean levels of fine particulate matter (PM10) in the air (population weighted) compared to the health threshold** shall be calculated for the value in regards to this measure.

- Minimum value (worst) is 150 and maximum value (best) is 10 (for PM10) (UN ESCAP, 2017)

It must be noted that in the urban scenario, there is varied air quality in different locations and development phases need to incorporate these aspects to consider the number of varied locations, a criterion for the locations chosen for air quality analysis and the frequency of bus services. There needs to be a weighted phenomenon according to demand as all locations do not represent similar demand and bus service patterns in comparison to the main network lines. As the index highlights the sustainable perspective, it coincides with the SDG 11.6 (by 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality, municipal and other waste management) and the UN habitat has exclusively recommended PM concentrations as an indicator in measuring air quality in cities.

10. Safety Measure

Safety and Security are two important dimensions in terms of sustainable transportation. Public transportation selection constitutes of factors ranging from reliability, affordability to the utmost selection point of safety. In a time where public transportation is being over doomed as a point of no safety and security, the study focusses on the accident perspectives with data analysis. Litman (2014) describes public transportation as a relatively safe (low crash risk) and secure (low crime risk) transport mode. There are perspectives in which the safety risks of transportation are evaluated.

The sustainable transportation concept widely embraces nonmotorized modes of transport (NMTs) and Public Transportation as effective alternatives to personal use motorized transport modes. Based on extensive review (included in detail in the literature review), the basic problem statement of **"How safe is it to use a bus service?"** is expected to be incorporated via the following measure.

$$\textbf{Safety Measure} = = \frac{\textbf{Total Number of fatal public transit (bus) related accidents}}{\textbf{Total Number of total fatal accidents}}$$

Initially fatal accidents are incorporated and is expected to be separated by the categories of accidents in development phases and weighted as per their individual impacts on the accessibility aspect. The minimum value is decided based on the best possible scenario of no fatal accidents and the maximum value is retrieved considering the statistics of bus related fatal accidents in the last ten years and narrowing it down to regional values. The indicator is a way forward (in an initial point of concern due to considerations in potential restrictions of data availability, which can be narrowed down in further analysis corridors) to ensure the sustainable transportation values are represented in a public transport safety perspective. If the pattern of risk is not showing a decrease with years, the argument of 'nothing being done' or 'nothing effective being done' to ensure the safety of the modes are increased and accidents and other related incidents are decreased, an immediate alternative approach is needed in relation to public transit and the transportation framework.

4.2 Normalization

It is obvious that the ten indicators of SUTAS are calculated using varied units. Thus, it cannot be directly combined to come up with one single index. Thus, these indicators need to normalized. The process of Normalization is to make variables comparable to each other and thus the indicators can be brought into one align set of values to obtain a single index value. Many research outcomes, reports, data analysis such as Mingers and Meyer (2017), Benini et al (2014), Biran (2019) have utilized normalization in the analysis framework to obtain desired outcomes. Therefore, linear rescaling for normalization is incorporated in the building of the SUTAS index. This facilitates the indicators to have a linear scale from 1 to 100.

The equation (7) is used for the composite index design.

$$Z_{i,c} = [(X_{i,c}) - (X_{min,i}) \ / \ (X_{max,i}) - (X_{min,i})]*100 \quad (7)$$

where,

- Z is the normalized indicator X for topic I and city c.
- X_{min} is the lowest value of the indicator in actual unit, whereas X_{max} is the highest value

The maximum and minimum values are defined in par with literature reviews on performance measures and expert advice (ratio/value when inversely proportional to the criteria is considered – minimum and maximum values are interchanged). In this composite index design and development, it is necessary to weigh each element that needs to be combined. The initial option in the SUTAS scenario is considering equal weigh scenario which is expected to be further developed based on analysis as to certain with high or lower weigh influencing the final index. Initially a 0.1 value is given to every indicator in terms of their individual weightages.

In this scenario, the final SUTAS score is calculated as in equation (8).

$$\text{The final SUTAS score} = \sqrt[10]{i1 * i2 * i3 \ldots \ldots . i10} \quad (8)$$

Considering outcomes from previous analysis and considerations, the geometric mean option was selected as in equation (8) to aggregate the outcomes from the ten indicators to a single value.

The inclusion of weighted geometric mean is considered in development stages of the index as shown in the equation (9). This helps in given the required weightages to individual indicators considering their individual impact to accessibility to public transit in comparison to others.

$$\text{Weighted Geometric Mean} = \text{Antilog} \frac{\in W \log x}{\in W} \quad (9)$$

This has not been applied in the study as of now and is expected to calculate SUTAS, post fine tunings and further development of the indicators using the weighted geometric mean for more refined set of values for comparison and analysis.

4.3 Summary of the Chapter

The chapter introduces 'Sustainable Urban Transit Accessibility Scorecard' (SUTAS), the proposed final outcome index from the research study criteria to evaluate accessibility to public transit systems in a sustainable perspective. The chapter further analyzes the ten indicators resulting from post complete study of the available measures/index, factors affecting relating subject areas and their shortcomings as well as novel considerations. The new criterion expects to approach the concept in a quantitative perspective providing the industry with a better measure for analysis.

5 SUTAS ANALYSIS & RESULTS

5.1 The SUTAS Comparative Outcomes – SUTAS 10

Study 01 – Hypothetical Study – Method Verification

The SUTAS 10 measure for a city can be used as an individual comparison tool to measure a city's development in terms of accessibility to public transport in a sustainable framework. It is also a valid measure to compare cities using the SUTAS 10 value in terms of analysis and understandings for different requirements in a transportation perspective. Thus, the SUTAS 10 is initially utilized using hypothetical (but practical) set of values to observe its performance and possible outcomes in an individual and collective manner. Spider Web Chart depictions are utilized to represent the hypothetical data outcomes to ensure more clarity and precision can be obtained in a two dimensional graphical representation of the values. As explained in chapter 4 (4.3), the requirement to make variables comparable to each other and alighting the indicators into one align set of values to obtain a single index value has been attained by normalization process as indicated in table 07. This has facilitated the indicators to have a linear scale from 1 to 100.

The higher increase of value depicts a positive impact on the indicator reflecting in the index. There are certain indicators* such as Air Quality and Total Access Time where the higher values depict a negative impact and thus in streamlining into a single value, this factor must be concerned (ratio/value is inversely proportional to accessibility). Thus, the maximum value (numerically) is incorporated as the minimum boundary and minimum value (numerically) is incorporated as the maximum boundary in calculation which streamlines the impact effectively. In future developments with respect to the inverse indicators other than the switch of minimum and maximum values, the normalized values calculated can be deducted from 100 and the specific value can be incorporated. Both methods eliminate the negative (inverse) impact on the criterion.

Note: The minimum values and maximum values represent the lower and upper bounds of each indicator.

Table 07: SUTAS 10 Indicators and Corresponding Parameters (Individual City)

SUTAS Indicator No.	SUTAS Indicators	Units	Weights	Values		Real Values	Normalization Values
				Minimum	Maximum		
1	Public Transport Connectivity Ratio	Index Value	0.1	1.0	2.5	2	67
2	Network - Transit Service Ratio	Value	0.1	0	1	0.7	70

3	Service Accessibility Ratio	Value	0.1	0	1	0.3	30
4	Disadvantaged User Access Rating	Value	0.1	0	1	0.2	20
5	Total Access Time*	Seconds	0.1	320	1557	677	71
6	Service Satisfaction Measure	% satisfied	0.1	30	95	55	38
7	Stop / Terminal Performance Level	Value	0.1	3	15	7	33
8	Aesthetic Experience Measure	Value	0.1	1	5	3	50
9	Air Quality*	µg/m3	0.1	10	150	101	35
10	Safety Measure	No. of fatalities	0.1	0	1	0.12	12

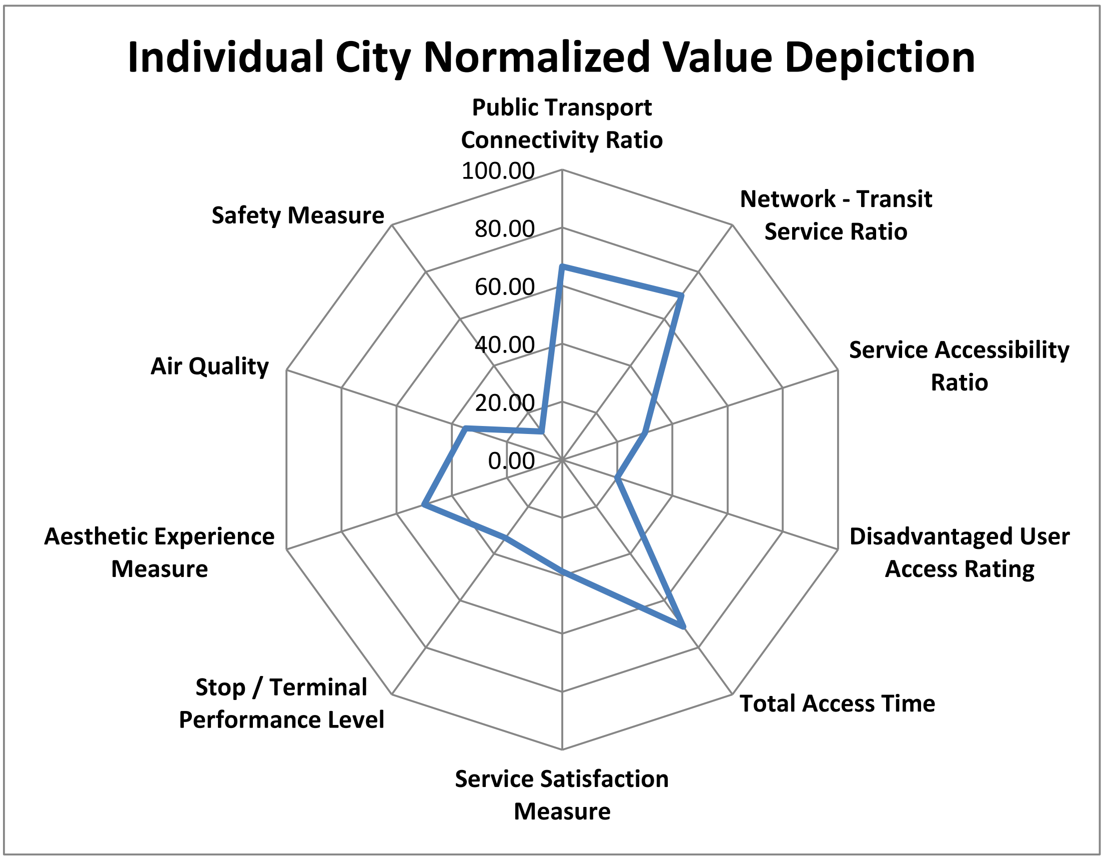


Figure 06: Spider Chart of Individual SUTAS 10 Indicators Depiction

Table 07 shows the SUTAS 10 Indicators and the corresponding parameters including the units and the minimum and maximum values which were derived from literature and expert opinion. Every indicator is given a 0.1 weightage (equal weightage) which could be changed with further analysis in the future to give more prominent indicators a larger share of impact in the index outcome value as explained in 4.3. The real values considered for the initial study (hypothetical set of values) and the corresponding normalization values of individual indicators are listed subsequently. This has helped to demonstrate the application using normalization in the criterion development.

Thus, the SUTAS 10 (Geometric Mean) of 37.14 is valued for the city. Figure 06 shows the indicators and their positions which can support in understanding the comparison in one depiction using the spider web chart. It is important to calculate the theoretical maximum and minimum values of the SUTAS 10 tool to understand the positioning of the calculated values. (The maximum SUTAS 10 value is 100 and the minimum SUTAS 10 value is 0)

Table 08: SUTAS 10: In City Comparisons using Hypothetical Values

SUTAS Indicator No.	SUTAS Indicators	Real Values				Normalization Value			
		City 1	City 2	City 3	City 4	City 1	City 2	City 3	City 4
1	Public Transport Connectivity Ratio	1.3	2	1.4	2	20	67	27	67
2	Network - Transit Service Ratio	0.3	0.4	0.7	0.7	30	40	70	70
3	Service Accessibility Ratio	0.5	0.4	0.6	0.6	50	40	60	60
4	Disadvantaged User Access Rating	0.3	0.2	0.4	0.4	34	29	35	51
5	Total Access Time	711	532	632	564	68	83	75	80
6	Service Satisfaction Measure	52	49	53	63	34	29	35	51
7	Stop / Terminal Performance Level	6	7	10	9	25	33	58	50
8	Aesthetic Experience Measure	2	3	2	3	25	50	25	5033
9	Air Quality	111	102	93	97	28	34	41	38
10	Safety Measure	0.22	0.25	0.16	0.12	22	25	16	12

Table 08 depicts the second scenario where comparison among cities is being processed using hypothetical values along with the basic parameters of the individual indicators. The corresponding normalization values required for the calculation of the index. Table 09 depicts the SUTAS 10 value for the four cities for comparison and ranking where a clear hierarchy has been established. Thus, this is an efficient measure in comparison of cities to access public bus services in a sustainable perspective. Figure 07, the spider chart with the values help in comparison of every individual indicator in terms of the four cities and the overall depiction in a single chart.

Table 09: SUTAS 10 Values based City Rankings on Access to Public Bus Transport

Rank	SUTAS 10 Index	Name
1	48.06	City 4
2	40.11	City 2
3	39.80	City 3
4	31.29	City 1

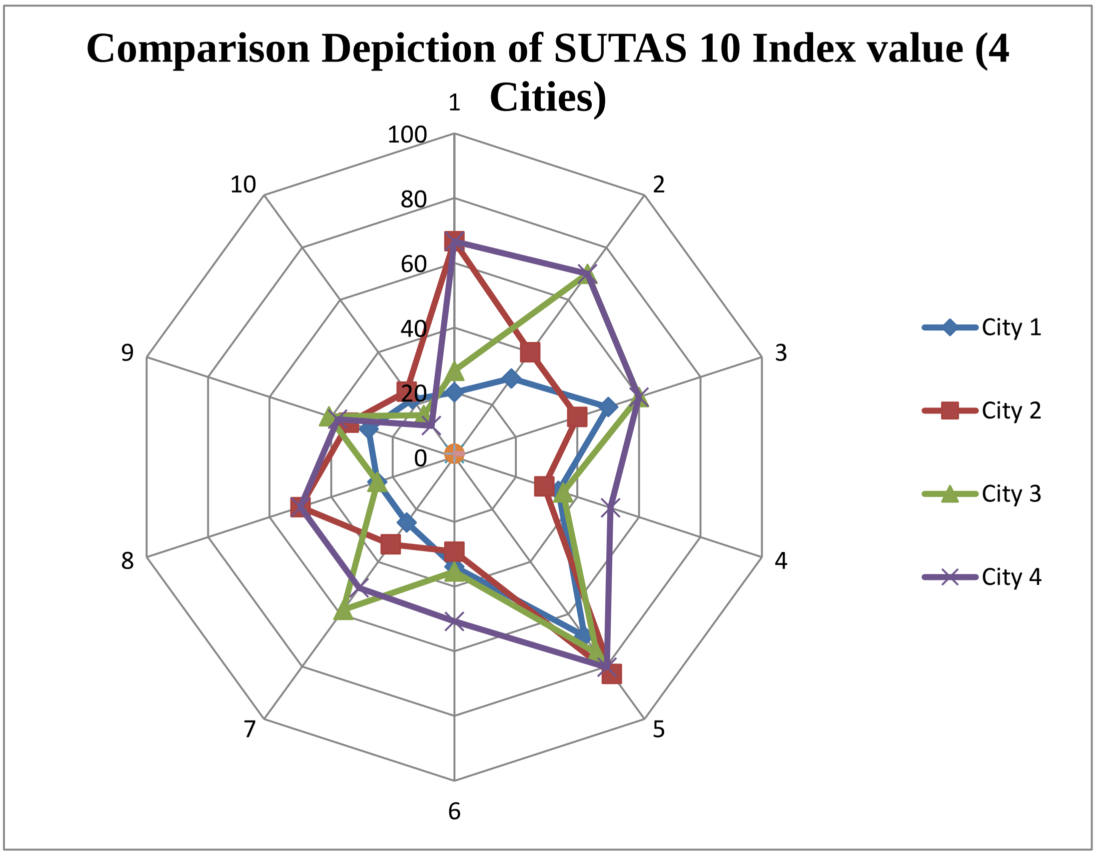


Figure 07: Spider Chart of Comparison Depiction of SUTAS 10 Index value (4 Cities)

Thus the individual city and 4 city comparison of the SUTAS 10 indicator using the hypothetical study validates the methodology incorporated to compare and contrast cities individually and among a number of cities. This comparison is both feasible via the SUTAS 10 value comparison of the hypothetical study and the spider web depictions which give a clear graphical representation. The next scenario is the application of the developed criterion in a real case study scenario which has been applied and analyzed in the following section.

The outcome from the SUTAS study indicates a comprehensive approach with the consideration of ten indicators. The data collection labor and the qualitative influence of the criterion can be identified as concerns from the SUTAS 10 analysis. The SUTAS 10 thus can be utilized to get an overall idea of accessibility to public transit in a highly sustainable background. Thus it is completely dependent on the person/organization who use this measure whether they need a comprehensive outcome for comparison and evaluation or a direct and quantitative measure to assess accessibility to public transit such as SUTAS (5). Thus, the following case study utilize SUTAS in relation to five towns which can provide with a highly quantitative direct measure and helps the user of which indicator he/she must go for depending of the requirements of the project and related parameters.

5.2 Study 02 – CASE STUDY (Application of the developed indicator in a Real Case Comparative analysis of five towns)

The five indicator SUTAS was analyzed in a model study considering five urban and sub-urban towns in the Western province of Sri Lanka. With certain restrictions, data for the study was collected from google maps using its travel time predictions and google street view. The cities have been selected on the diversity in population, road connectivity, geographic positioning and economic and social conditions. Further the case study elaborates the methodology of how every indicator is calculated in the real case scenario. Three of the selected cities (**Malabe**, **Homagama** and **Padukka**) are located in the Colombo District, **Ingiriya** belongs to the Kaluthara district and **Bopitiya** is located in the Gampaha district. Figure 08 depict the location of five towns in the western province whereas table 10 gives a description of the five towns considered for the case study. The administrative boundaries of the towns were considered to demarcate the boundaries of each town apart from available data availability.

Table 10 – Summarized Description of the five towns

Town	Location	Description
Homagama	• On the A4 Highway	• Urban town with access to by both bus and train services in terms of public transit

		• Served by a number of bus services including inner and outer provincial routes
Padukka	• To the south of the A4 Highway	• Sub urban town • Population of approximately 8000 • 33 kilometers from the capital city • Served by a number of bus services • Main station on the Kelani valley line
Ingiriya	• Intersection junction of the Rathnapura Panadura, Ingiriya Padukka and Ingiriya Bulathsinhala roads • Situated in the Kaluthara district in close proximity to the Sabaragamuwa province	• Diverse economic, social and cultural backgrounds
Malabe	• On the New Kandy Road (Kaduwela Road) • Approximately 10 km from the capital city of Colombo	• Had seen an immense boost in terms of trip attraction and generation due to the establishment of a number of educational institutions with high student volume and subsequent increase of land value
Bopitiya	• Situated in the coastal line	• Approximately 8 meters above the sea level • Close proximity to the main airport of Sri Lanka (15 to 20 minutes' travel time in average) • Facilitated for all main activities by the main towns of Jaela and Negombo

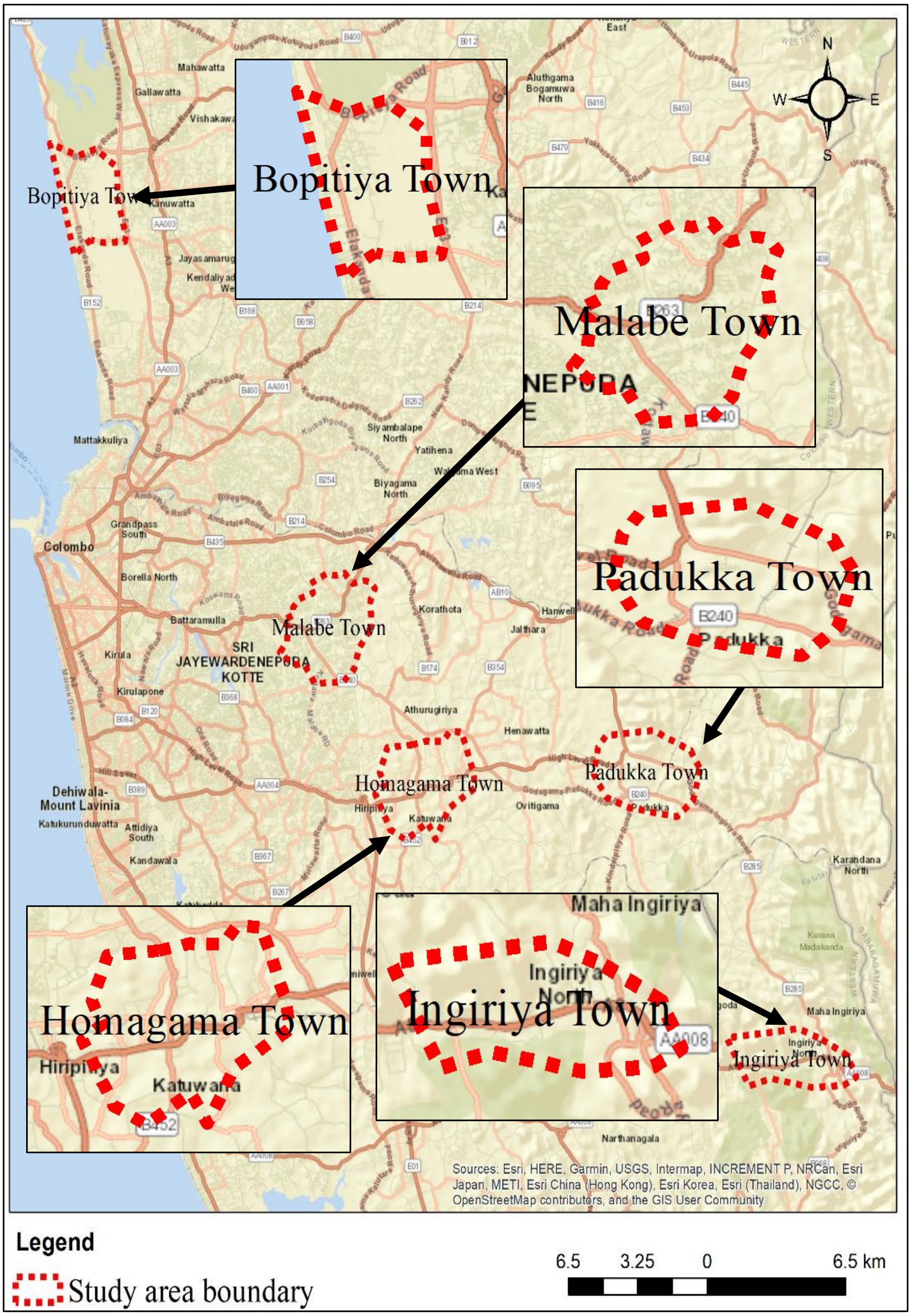


Figure 08 – Study Area Boundary with the five-town depiction

Thus, the five towns will be analyzed in terms of their individual road connectivity and public transport connectivity to analyze their individual nature of connectivity and further compare and contrast in relation to other parameters.

1. **Network Connectivity Ratio | Public Transport Connectivity Index**

The Connectivity Index 'CI' method or the Link Node Ratio is utilized in this study to identify the road connectivity scenarios of the five identified town ships. The values identified in the study will give an overall understanding of how behavior varies with geographical position and other parameters in general. Thus, the number of links and the number of nodes of the individual towns is analyzed using the GIS position to facilitate the identification of the number of nodes and links.

The Road Connectivity Index (RCI) is calculated for the five towns **as a ratio of the number of links and the number of nodes.** The RCI value is listed in table 10 below. Considering the RCI value, the towns are ranked in the table according to their connectivity in terms of the road network as shown in table 11.

In a similar approach, the Public Transport Connectivity Index (PTCI) is calculated substituting **the road nodes by the bus stops** (the particular points where commuters can transfer from one route or one service to another) **and the road links by the road network links** as shown in table 12. It must be noted that the bus stops on either side of the road had been amalgamated as a single bus stop on the network for analysis purposes. Both the figures utilized for the RCI and PTCI calculation and their respective nodes and links of every individual town via the ArcGIS software are represented for all five towns in the figure 09. RCI is calculated to get an idea of the road connectivity pattern to these five town and an adjacent understanding with the PTCI values which are utilized in the indicator considering the public transport aspect of the developed indicator.

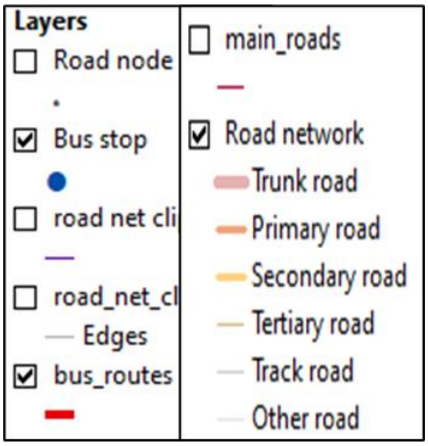
Table 11 – RCI Values

Town	**Number of Links**	**Number of Nodes**	**RCI**	**Rank**
Homagama Town	883	807	1.09418	2
Padukka Town	371	342	1.0848	3
Ingiriya Town	131	116	1.12931	1
Malabe Town	2542	2389	1.06404	5
Bopitiya Town	323	300	1.07667	4

Table 12 – PTCI Values

Town	Number of Bus Stops	Number of Bus Network Links	PTCI	Rank
Homagama Town	34	30	1.133	4
Padukka Town	46	43	1.070	5
Ingiriya Town	16	14	1.143	3
Malabe Town	46	36	1.278	2
Bopitiya Town	11	8	1.375	1

The PTCI values tabulated for the five towns provide a clear understanding of the availability of Service Access Points (SAPs) in the bus network links which is important in ensuring that the availability of a bus service in a particular route must be complimented by the positioning of SAPs at the right locations. The values for the five towns have been ranked on the basis of the indicator values where Bopitiya (1.38) has the best public transport connectivity index followed by Malabe (1.28) and Ingiriya (1.14). The RCI calculation has been performed as tabulated in table 10 to get a better understanding to observe the variations in comparison to PCTI (clearly witnessed by the rank column of both the tables). This shows that even though the road connectivity is high (via RCI value: Ingiriya - Rank 1) it needs not be the same case with the PTCI of the same town (Rank 3) (considering the case study of the five towns). The main reason for this difference in the two indices reflects that the availability of road segments in a particular region does not necessarily represent a good public transit connectivity. Thus, it implies the need for more public transport (bus) routes assigned to road segments without related services (considering related parameters as well).



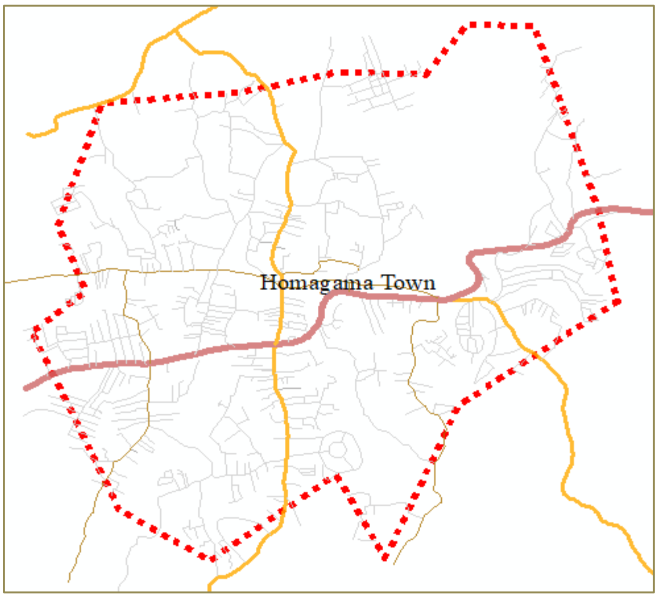


Figure 9.1 – RCI Analysis (Number of Links and Nodes): Homagama

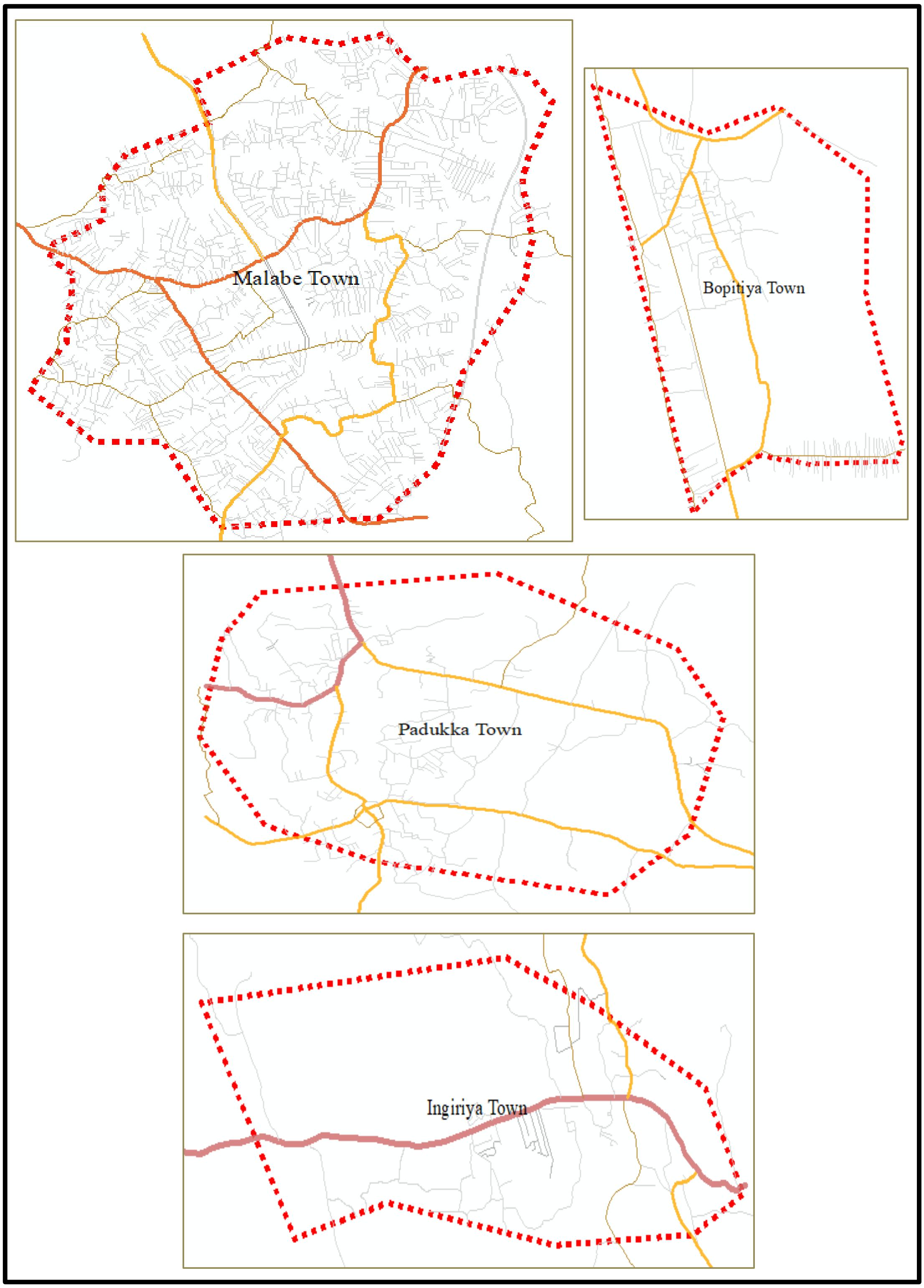


Figure 9.2 – RCI Analysis (Number of Links and Nodes): Malabe, Bopitiya, Padukka, Ingiriya

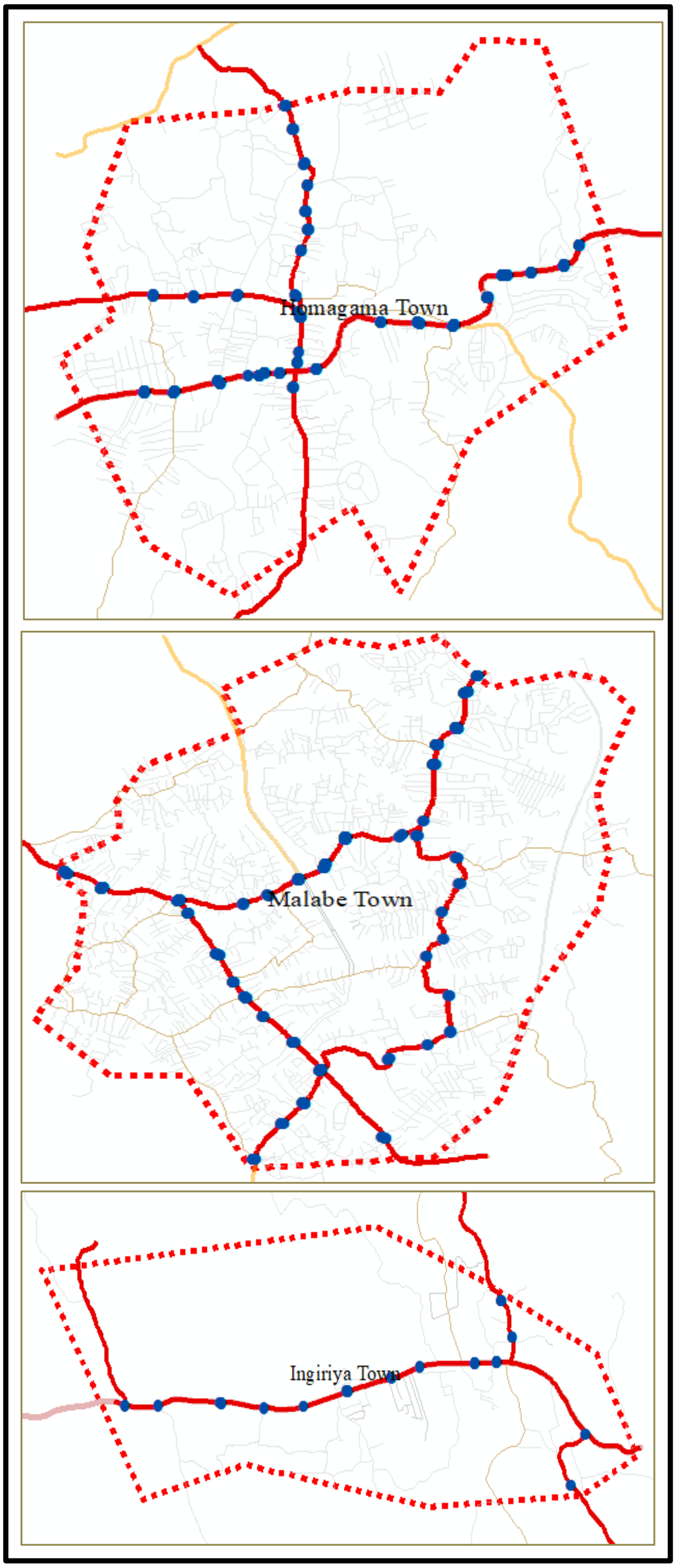


Figure 10.1 – PTCI Analysis (Number of Bus Network Links and Bus Stops): Homagama, Malabe and Ingiriya

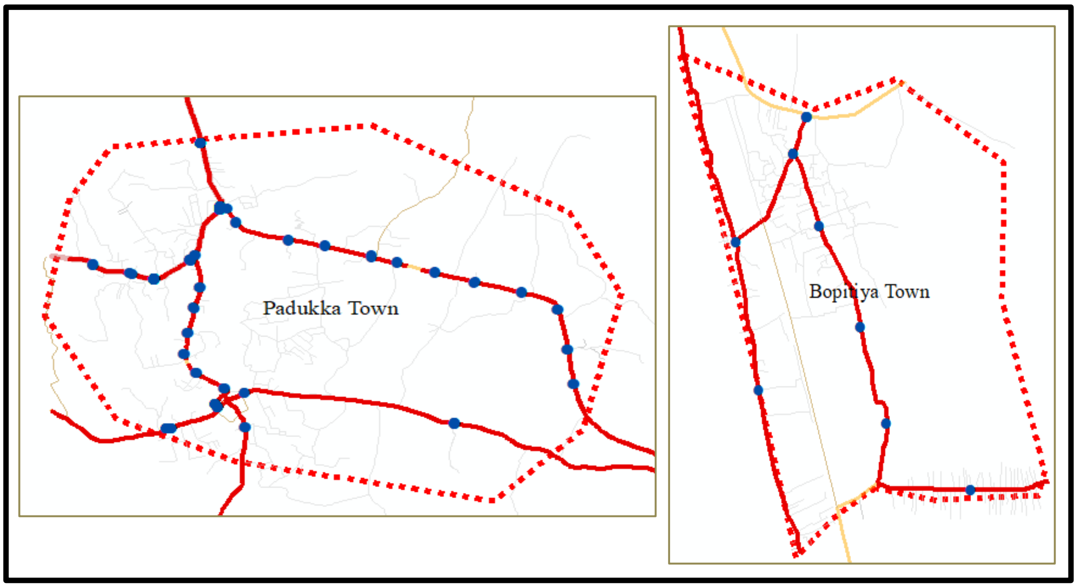


Figure 10.2 – PTCI Analysis (Number of Bus Network Links and Bus Stops): Padukka and Bopitiya

2. Network - Transit Service Ratio

Indicator 02 'Network - Transit Service Ratio' indicates the **ratio of the length of roads serviced by at least one bus service** (with certain limitations as mentioned in the indicator description) **to the total length of the available main road networks in the considered region**. The five towns are thus analyzed using the ArcGIS software and tabulated as in table 10. The figure 10.1 and 10.2 represented under the first indicator analysis itself was utilized (via the red line road section) to calculate the bus route length required for the Network – Transit Service Ratio calculation for every individual town scenario. The road length also was derived from the software results of the considered for analysis purposes.

Table 13 - Network - Transit Service Ratio

Town	Bus Route Length (km)	Road Length (trunk, primary, secondary, tertiary) km	Network - Transit Service Ratio	Rank
Homagama	8.93	17.01	0.53	4
Padukka	12.86	14.98	0.86	1
Ingiriya	6.83	9.78	0.70	2
Malabe	11.93	32.56	0.37	5
Bopitiya	10.26	16.02	0.64	3

Table 13 depicts the value of 'Network Transit Service Ratio' for the five towns considered. The values depict Padukka to have a higher score (which depicts availability of bus service (reliability aspect) along with the importance of public transport level spread in a particular town area) compared to the other four in comparison. It is followed by Ingiriya (0.698) and Homagama (0.52). The case study has not only been able to validate the methodology but also help in realizing potential developments and shortcomings of each indicator in general (such as the ability to other public transit modes as well).

Note: The case study has reflected the need to give a value to the number of routes available which needs to be quantified in the development stages.

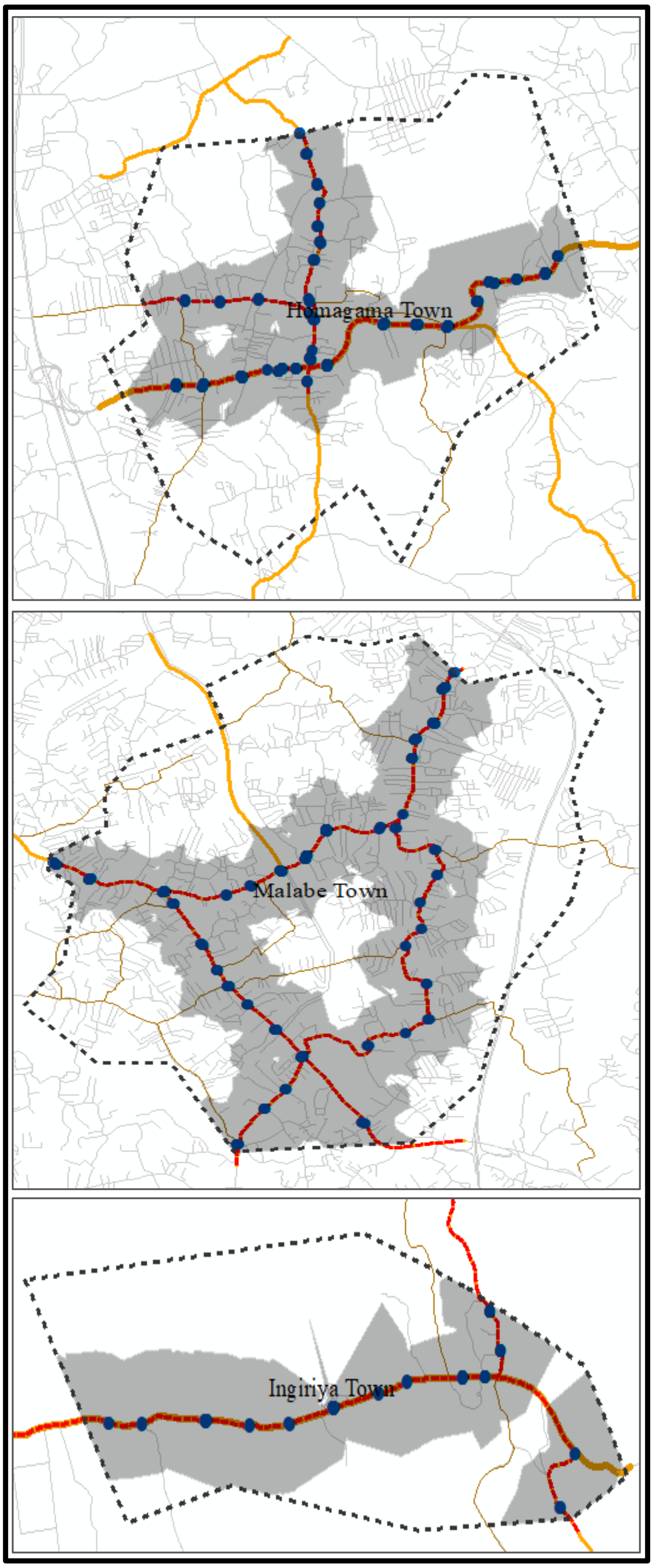
3. Service Accessibility Ratio

Indicator 03 assesses the positioning of the five towns in relation to access to the bus stops/terminals. The bus stops have been buffered **using the circular buffer approach and the ratio has been depicted for the five towns considered**. The main concern is locating bus stop/terminal locations which can be carried out manually, with the help of google maps or available shapefiles from relevant authorities. The following figures 11.1 and 11.2 of the five town show the buffered area using the ArcGIS software through which the table 14 values were obtained for calculation of the indicator. It must be noted that in future development phase of the indicator it must be considered to adopt a parallel section buffer to the both sides of the road due to the subjective nature of the bus stops in a road section (especially in the local context).

Table 14 – Service Accessibility Ratio

Town	500m service area sq. km	Total study area sq. km	Service Accessibility Ratio	Rank
Homagama	5.38	13.79	0.39	5
Padukka	7.12	13.29	0.54	1
Ingiriya	5.27	10.32	0.51	2
Malabe	6.44	13.63	0.47	3
Bopitiya	4.35	10.00	0.44	4

The main component of accessibility to a public transit mode is thus established via this particular indicator. In comparison of the five towns, using the ArcGIS software for analysis purposes as depicted in the figure 11 (11.1 and 11.2) below of the five towns Padukka was the best town in terms of accessibility for public (bus) transportation. The least value of 0.39 was calculated from Homagama which was the



largest of the towns in terms of area. The circular buffer method proved to be applicable in this comparison framework and is expected to be analyzed further using other buffer approaches as well to develop the indicator.

Note: The case study has seen many overlaps which increases the accessibility quotient as overlaps create more options and availability scenarios for public transport users. The overlaps create a choice space which needs to be incorporated in development stages of the indicator.

Figure 11.1 – Service Accessibility Ratio Analysis (Buffer Area sq. km and Total Area Sq. km): Homagama, Malabe and Ingiriya

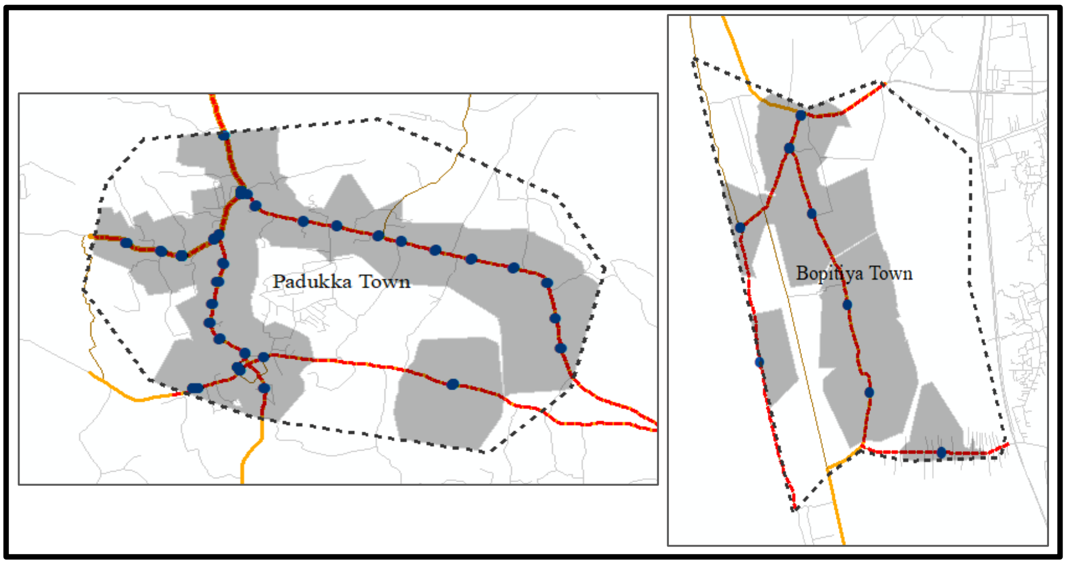


Figure 11.2 – Service Accessibility Ratio Analysis (Buffer Area sq. km and Total Area Sq. km): Padukka, Bopitiya

4. Disadvantaged User Access Rating

Table 15 - Disadvantaged User Access Rating

Town	Disadvantaged User Access Rating
Homagama Town	0.2
Padukka Town	0.2
Ingiriya Town	0.2
Malabe Town	0.2
Bopitiya Town	0.2

Indicator 04 is an important indicator which represents equality to the disadvantaged users and the national values in terms of cities/towns are very poor in terms of the indicator. Considering the percentage of pavement systems/roadways which are friendly for the disadvantaged/disabled users which have been obtained by observatory outcomes (better in terms of available updated data from relevant authorities) and percentage of inclusion of disadvantaged/disabled user facilities measure available in public buses in operation (Data obtained via relevant Public Transport Authorities), the table 15 has been formulated.

The basic values of both indicators for all five towns in general were of the lowest in value. Thus 0.2 was valued (0.1+0.1) for each town which highly represented the need to develop the indicator further to quantitatively express a value that represented the practical scenario of each town more precisely (will be developed in the latter stages).

5. Total Access Time

Table 13 is an elaborative depiction of the indicator calculation for the five towns considered for the case study. Both the access time for bus stops from points on interests and the waiting time to use a bus service available from the stop has been combined in attaining a single value for the individual towns in consideration. Due to the corvid situation, the time for the walk time and average waiting time were obtained via google maps. The initial case study consisted of selecting three prime locations within the town boundaries which were main trip generation points. The indicator will be further developed with a framework of the places to be considered within a region for analysis purposes. Further the study will be carried out after corvid in the manual method as well to compare and contrast the pros and cons for further development.

Initially from literature (Dar es Salaam Transport Policy and System Development Master Plan: Technical Report 6 - Traffic Surveys and Analysis), major activity generators were identified. Types of building uses to be considered are listed below (The study states the exclusion of religious places such as churches and mosques):

1) Government (public sector) office building
2) Private sector office building (including mixed tenants)
3) Commercial building (shopping center, restaurant, etc)
4) Residential building (apartment)
5) Mixed use building (mix of residential, office and/or commercial uses)
6) Hotels

Residential buildings and mixed use building are majorly covered in the third indicator 'Service Accessibility Ratio'. Hotels is not a frequent point especially in the towns of the national context. According to the person count in the study government buildings have a larger people movement and thus two government buildings are included in the case study of the five towns. Thus (the location depends on the town: geographically and demographically),

1) Government (public sector) buildings (includes **government** hospitals, ministries, post office, police station etc)
2) Government (public sector) buildings (includes government schools, universities, police station)
3) Private sector office building (including mixed tenants) or Commercial building (shopping center, restaurants (with a high customer movement), market spaces)

Note: Basically when there is more than one entity, the organization/point where the highest people movement is recorded needs to be considered. (eg- the school with the average number of students and staff, the government institution with highest people in and outs). Usually the selection can be changed based on location, but in comparison scenarios the selection needs to be consistent.

Table 16 – Total Access Time

Town	Walk Time min	Walk Time sec	Average Waiting Time min	Average Waiting Time sec	Total Access Time sec	Total Access Time sec
Homagama Town						680
Homagama Base Hospital	2	120	15	900	1020	
Homagama Maha Vidyalaya	1	60	10	600	660	
New Shamil Textiles Building	2	120	4	240	360	
Padukka Town						650
Padukka Divisional Hospital	3	180	8	480	660	
Siri Piyarathana Central College	2	90	8	480	570	
Padukka Fair / Market	2	120	10	600	720	
Ingiriya Town						500
Ingiriya District Hospital	1	60	7	420	480	
Gamini Central College	1	60	7	420	480	
Ingiriya Sathosa	2	120	7	420	540	
Malabe Town						380
Dr. Neville Fernando Teaching Hospital	1	60	7	420	480	
Boys' School - Malabe	3	180	3	180	360	
Arpico Super Store	2	120	3	180	300	
Bopitiya Town						520
Epamulla Sub Post Office	1	60	8	480	540	
Loyola College Branch - Bopitiya	2	120	7	420	540	
Cargills Food City, No. 1 Bopitiya	1	60	7	420	480	

Table 16 shows Malabe to have the least total access time which shows the effectiveness of the public transportation access points and the routing of bus services. It is followed by Ingiriya, Bopitiya and Padukka in terms of the indicator value comparisons. Homagama records the highest value of total access time which reflects the need to reroute and relocate bus services and stops at necessary locations after further elaborative analysis. (But it must be noted that the five towns considered have performed quite well in terms of the 'Total Access Time' indicator which is positive in terms of the national context)

Table 17 - SUTAS outcome from the case study

Town	SUTAS value	Rank
Bopitiya Town	41.059	1
Malabe Town	36.049	2
Ingiriya Town	35.708	3
Padukka Town	31.579	4
Homagama Town	30.363	5

Thus a final SUTAS calculation of the five calculation is tabulated in table 17 with a ranking of the five towns considered in the case study. It must be noted that this value gives an overall understanding of the accessibility to public bus services in a comparative analysis where Bopitiya is of a high value and Homagama attaining a least score which recommends authorities to reroute and reconsider bus routes and bus locations for better service provision to the passengers in the lower ranked towns of the case study in a sustainable transportation framework.

This case study provides a practical perspective on the measure with a filtered indicator set of five in a critical perspective. Thus, the above assessment of the indicator is an inclusive approach which provides a clear quantitative perspective of the objectives of the study. The five other indicator (Service Satisfaction Measure, Stop / Terminal Performance Level, Air Quality, Safety Measure and Aesthetic Experience Measure are complimentary to the five indicators and gives a more comprehensive approach resulting in a ten indicator analysis. This basically revolves in the objectives of the person or organization who/which are adopting the indicator and on the basis of the available data and required outcomes the five set quantitative indicator SUTAS can be adopted or continue with the ten indicators recommended in the study for a comprehensive analysis of a considered region/section.

It is expected to further refine the measure 'SUTAS' with a regional, provincial, national and global perspective. It is vital to engage relevant authorities and get maximum support and sponsorship with government and non-governmental institutions. **SUTAS is definitely a step ahead in assessing accessibility in a sustainable perspective within the transportation framework** and is expected to be developed further in par with global standards.

5.3 Summary of the Chapter

Chapter 05 depicts the outcome of SUTAS for a city to be used as an individual comparison tool to measure a city's development in terms of accessibility to public transport in a sustainable framework. The chapter calculates SUTAS initially utilize using hypothetical (but practical) set of values to observe its performance and possible outcomes in an individual and collective manner. The chapter depicts to pathways of the measure to analyze an individual city or in comparison with a number of cities. Spider Chart depictions are utilized to represent the hypothetical data outcomes to ensure more clarity and precision can be obtained when analyzing and in presentation.

6 CONCLUSIONS AND RECOMMENDATIONS

It is important to have measures to provide an understanding of a certain parameter in context of its own value over a certain period of time or comparison of values measured in different comparable avenues. Thus, transportation has different measures to calculate different attributes. In the same manner, sustainable transportation too has been analyzed in details and certain measures have been in forefront in analysis and comparison. SUTI and STPI have been main measures which have been elaborated and compared in the previous chapters in detail.

The evaluation of the available sustainable transportation measures, models and tools give a comprehensive understanding of the avenues that had been considered and the quantitative and qualitative disparity that exists among the existing indicators. Comparison of the index and relevant indicators demonstrate the similar and varying nature especially using the colour matching scenarios. One common scenario that can be observed is the unanimous selection of indicators based on the considered city or region and the fundamental requirements catered by the developers. It is in this arena that SUTAS has been developed as a potential measure to evaluate accessibility to public transit in a sustainable perspective.

The research was designed in three stages to validate the SUTAS model. The initial conceptual study of identification of transport related SDG targets that are related to accessibility in the context of sustainable transportation. The outcome of having a higher percentage of impact of accessibility in achieving SDGs in relation to the targets which directly or indirectly was identified. Thus, accessibility in the case of sustainable transportation required a better effective and quantitatively sound measure. It was essential to study of the available methods in evaluating SDG targets and sustainable transportation, corresponding indicators and shortcomings of the methods related to evaluating accessibility before developing a new measure. Thus, a comprehensive review was done to analyze the important indicators, method adopted in selecting indicators and the vacuum in terms of accessibility as a main part of the available measures.

Particular problems arise in lower-income countries, where good data (e.g. on modal split, or a comprehensive inventory of informal public transport services) may not be available. Some specific issues of public transport accessibility are present beyond the broad indicators described (e.g. barriers presented by heavily-trafficked main roads, gradient, or specific to certain user groups (e.g. the elderly)). The study is expected to be developed further with inclusion of modal shares of public transport and non-motorized modes.

In a scenario where, sustainable transportation has been proved to be a major force factor in achieving the SDGs by 2030, the indicators and measures helps in understanding the positioning of the concept in local, national and international levels. Indicators provide the space for assessment and betterment of the work undertaken and individual indicators developed can be tuned to suit local scenarios in assessing the level of sustainable transportation and its dimensions. SUTAS is an initial development of an improved criteria to evaluate accessibility to public bus transport systems in a sustainable perspective. The comprehensive sustainable framework has been analyzed with SDGs being considered as the global framework to achieve sustainability. Therefore, the measure is expected to be utilized in regional, provincial and national level analysis via pilot studies. The results are expected to further show the fine tunings required in the indicators.

The SUTAS 10 is a comprehensive package with a combination of quantitative and qualitative indicators having a sustainable measure to calculate accessibility considering other aspects of sustainable transportation as well. The five indicator SUTAS is a refined set of majorly quantitative indicators which focusses on accessibility to public transit. SUTAS 10 is supported by a pilot study with the final SUTAS value and contrast and comparisons performed to depict the complete outcome of the developed measure. Further a real scenario case study is performed on SUTAS indicator to identify any drawbacks or major changes which proved to be effective and is expected to be applied on a larger scale in future. Finally, the outcomes of the research study can be used in developing a better sustainable transportation framework and SUTAS is expected to be a vital part in ensuring access to public transit with maximum sustainability.

REFERENCES

- V. Mega and J. Pedersen, “Urban sustainability indicators,” Dublin, Ireland, 1998.

- World Commission on Environment and Development, “Our common future,” Oxford: Oxford University Press, 1987.

- T. Litman, “Well Measured - Developing Indicators for Sustainable and Livable Transport Planning,” Victoria Transport Policy Institute, 2019.

- United Nations, “Transport for Sustainable Development: The Case of Inland Transport,” 2015.

- T. Litman, “Evaluating Accessibility for Transport Planning - Measuring People’s Ability to Reach Desired Goods and Activities,” Victoria Transport Policy Institute, 2018.

- G. Duranton and E. Guerra, “Developing a Common Narrative on Urban Accessibility: An Urban

- Planning Perspective,” Moving to Access, Washington, Brookings Institution, 2016.

- T. Litman,” The New Transportation Planning Paradigm,” *ITE Journal*, 2013.

- C. Palmateer, A. Owen and D.M. Levinson, “Accessibility Evaluation of the Metro Transit A-Line,” Accessibility Observatory at the University of Minnesota, 2016.

- H. Gudmundsson and M.D. Regmi, “Developing Sustainable Urban Transport Index,” Transport and Communications Bulletin for Asia and the Pacific, 2017.

- United Nations, “The Millennium Development Goals Report,” 2015.

- Global Goals Research for Sustainability, https://globalgoalsproject.eu/what-were-success-factors-of-the-millennium-development-goals/, 2019.

- Alvany Maria dos Santos Santiago, Pamela K. Robinson and José Celio Silveira Andrade, “Corporate social responsibility: An approach to peace?”, African Journal of Business Management, 12(23):692-701, December 2018.

- The Institute of Entrepreneurship Development (iED), https://ied.eu/blog/sustainable-development-goals-and-the-2030-agenda-how-ied-supports-sdgs/, 2019.

- SLoCaT - Partnership on Sustainable Low Carbon Transport, “https://www.transformative-mobility.org/partners/slo-ca-t-partnership-on-sustainable-low-carbon-transport,“ 2018.
- ICAA,“https://icaa.pt/en/news/112/icaa-commited-with-ic-5p-for-the-future,” 2018.
- Department of Census and Statistics Ministry of National Policies and Economic Affairs, “Status of Sustainable Development Goals Indicators in Sri Lanka: 2017,” 2017.
- P. Miller, A.G Barros, L. Kattan and S.C. Wirasinghe, “Public transportation and sustainability: A review,” *KSCE Journal of Civil Engineering*, Issue 3/2016, 2016.
- T. Ramani, J. Zietsman, H. Gudmundsson, R.P. Hall and G. Marsden,” Framework for Sustainability Assessment by Transportation Agencies,” *Transportation Research Record Journal of the Transportation Research Board*, 2011.
- Center for Sustainability, www.c4s.info, The Future of Transport, Transportation Research Laboratory, 2004. (www.trl.co.uk)
- ECMT (European Conference of Ministers of Transport), “ECMT Annual Report 2004,” 2004. (https://doi.org/10.1787/9789282103463-en)
- OECD (Organization for Economic Co-operation and Development), Project on “Environmentally Sustainable Transport,” Report on Phase 2, 1998.
- CST, “Definition and Vision of Sustainable Transportation,” Canadian Centre for Sustainable Transportation, 2005.
- M. Hart, “Evaluating Indicators: A Checklist for Communities,” Johnson Foundation Zheng, 1997.
- NRTEE, “Draft Canadian Government Sustainable Transportation Principles,” National Round Table on Environment and Economy, “OECD International Conference,” Vancouver Canada, 1996.
- K. Kirk et al., “Framework for Measuring Sustainable Regional Development for the Twin Cities Region,” University of Minnesota Center for Urban & Regional Affairs and Center for Transportation Studies, 2010.
- The World Bank, “Sustainable Mobility for All - Global Mobility Report 2017,” 2017.

- C. Roughton, et al., “Creating Walkable and Bikeable Communities: A User Guide to Developing Pedestrian and Bicycle Master Plans,” Center for Transportation Studies at Portland State University, 2012.
- J. Zietsman and T. Ramani, “Guidebook for sustainability performance measurement for transportation agencies,” 2011.
- UN ESCAP, “Sustainable Urban Transport Index Data Collection Guideline,” Bangkok, 2017
- C. Rodier and M. Spiller “Model-Based Transportation Performance: A Comparative Framework and Literature Synthesis,” 2012
- Wilbur Smith Associates, “Study on traffic and transportation policies and strategies in urban areas in India- final report,” Ministry of Urban Development, Government of India, New Delhi, 2008.
- T. Thilakshan and J.M.S.J. Bandara, “Identification of Relevant Sustainable Transportation Links to Sustainable Development Goals (SDGs) in the National Context,” 113th Annual IESL Sessions 2019, pp. 341 – 348, Colombo, 2019.
- Transport for London, “Annual Report and Statement of Accounts 2009/10,” 2010.
- K. Fransen K, T. Neutens, S. Farber., P De Maeyer, G. Deruyterand F. Witlox “Identifying public transport gaps using time-dependent levels,” *Journal of Transport Geography,* vol. 48, pp. 167-187, 2015.
- B.H.A. Mendis and G.L.D.I De Silva, “Analyzing the Geographical Catchment of Fort-Malabe LRT by Access Modes”, MERCon 2020.
- G. Currie, “Quantifying spatial gaps in public transport supply based on social needs,” *Journal of Transport Geography,* 18(1), pp. 31-41, 2010.
- E.C. Delmelle and I. Casas, “Evaluating the spatial equity of bus rapid transit-based accessibility patterns in a developing country: The case of Cali, Colombia,” *Transport Policy, Elsevier*, vol. 20(C), pp. 36-46, 2012.
- ITDP (Institute for Transportation and Development Policy), “2015 ITDP Annual Report,” 2015.
- S. Holzwarth, “Analysis of the transport relevance of each of the 17 SDGs” United Nations, 20, 2015.

- V.C. Maria and F. Nicola, “A Methodology to Evaluate Accessibility to Bus Stops as a Contribution to Improve Sustainability in Urban Mobility,” *Sustainability*, 11 (3): 803, 2019.
- Victoria Transport Policy Institute, “Roadway Connectivity: Creating More Connected Roadway and Pathway Networks,” 2017.
- E.J. Taaffe and H.L. Gauthier, “Geography of Transportation,” Englewood Cliffs, Prentice-Hall INC, 1973.
- H. Robinson and C.G Bamford, *Geography of Transport*, Macdonald and Evans, USA, 1978.
- J. Dill, “Measuring network connectivity for bicycling and walking,” *Joint Congress of ACSP-AESOP*, pp. 1-20, 2004.
- R. Ewing, “Best Development Practices; Doing the Right Thing and Making Money at the Same Time,” Planners Press, 1996.
- J. Gilderbloom and W. Riggs, “Two-Way Street Conversion Evidence of Increased Livability in Louisville,” *Journal of Planning Education and Research*, 2015.
- P. Cozens and D. Hillier “The Shape of Things to Come: New Urbanism, the Grid and the Cul-De-Sac,” International Planning Studies, 13(1), pp. 51, 2008.
- J. Hayes, “Smart cities are only as good as their connectivity,” 2020.
- S. Handy, R. Paterson and K. Butler, “Planning for street connectivity: getting from here to there,” Chicago, IL: American Planning Association, 2003.
- J. Andersen and A. Landex, “Catchment areas for public transport,” Environmental Science: WIT Transactions on the Built Environment, 2008.
- M. Corazza and N. Favaretto, “A Methodology to Evaluate Accessibility to Bus Stops as a Contribution to Improve Sustainability in Urban Mobility,” *Sustainability*, 11(3):803, 2019.
- A.P. Parasuraman, V. A. Zeithaml and L. Berry, “A Conceptual Model of Service Quality and its Implication for Future Research (SERVQUAL),” *Journal of Marketing*, 49: pp.41-50, 1985.
- C. Alexander, S. Ishikawa and M. Silverstein, “A Pattern Language: Towns, Buildings, Construction,” New York: Oxford University Press, 1977.

- S. Karou and A.D. Hull, “Accessibility measures and instruments,” 2012.
- N. Ohmori, T. Hirano, N. Harata, and K. Ohta, “Passengers' waiting behavior at bus stops,” in *Traffic and Transportation Studies: Proceedings of the 4th International Conference on Traffic and Transportation Studies (ICTTS '04)*, pp. 157–164, 2004.
- K. Prathibaa and K. Gunasekaran, “Planning of Bus Stops for Safe and Efficient Passenger Boarding and Alighting,” International Journal of Engineering and Technical Research V5(06), 2016.
- D. Rojas-Rueda, A. de Nazelle, M. Tainio and M.J. Nieuwenhuijsen, “The health risks and benefits of cycling in urban environments compared with car use,” *health impact assessment study*, 2011.
- S. Cafiso, A. Di Graziano and G. Pappalardo, “Road safety issues for bus transport management,” *Accident Analysis and Prevention*, 60, pp. 324–333, 2013.
- T.B. Joewono and H. Kubota, “User Perceptions of Private Paratransit Operation in Indonesia,” *Journal of Public Transportation*, 10(4), 2007.
- FTA (Federal Transit Administration) U.S. DEPARTMENT OF TRANSPORTATION, “National Public Transportation Safety Plan,” 2017.
- I. Farida, “Public transport service relating to safety,” *IOP Conference Series Materials Science and Engineering*, 434(1):012195, 2018.
- J. Mingers and M. Meyer, “Normalizing Google Scholar data for use in research evaluation”. *Scientometrics* **112,** 1111–1121, 2017.
- Lorenzo Benini, Lucia Mancini, Serenella Sala, Simone Manfredi, Erwin M. Schau, Rana Pant. “Normalisation method and data for Environmental Footprints”, 2014.
- H. Biran, M. Kupiec and R. Sharan, “Comparative Analysis of Normalization Methods for Network Propagation”. METHODS article, https://doi.org/10.3389/fgene.2019.00004, 2019.
- OECD (2019), *Accelerating Climate Action: Refocusing Policies through a Well-being Lens*, OECD Publishing, Paris, https://doi.org/10.1787/2f4c8c9a-en.

- Li Ping Wong, Haridah Alias, Nasrin Aghamohammadi, Nik Meriam Nik Sulaiman, Hualiang Lin and Jinshun Zhao, “Commuting on Public Transport: Health Risks and Responses”, 2018.

- Frye, A “Advantages and Disadvantages of Special Transport Services for the Handicapped. Comparisons with the Adaptation OF Public Transport Vehicles. Viewpoint of Transport Policy”, The ECMT Seminar, Berlin, 1989.

- Bocarejo S., J. P., Oviedo H., D. R. “Transport accessibility and social inequities: a tool for identification of mobility needs and evaluation of transport investments. Journal of Transport Geography”. 24, pp. 142–154, 2012.

- Xiaoling Luo, Wenbo Fan ,1 Yangsheng Jiang,1 and Jun Zhang, “Optimal Design of Bus Stop Locations Integrating Continuum”, Journal of Advanced Transportation 8872748, 10 pages, 2020.

- Li Huan and Bertini Robert, “Assessment of an Optimal Bus Stop Spacing Model Using High Resolution Archived Stop-Level Data”, 88th Annual Meeting of the Transportation Research Board, 2011.

- Oregon Department of Transportation, “The Highway Design Manual”, 2012.

- Washington Metropolitan Area Transit Authority, “Guidelines for the Design and Placement of Transit Stops” 2009.