

Article

Developing a Framework for the Sustainability Assessment of Urban Transportation and Its Implementation

Zaheer Abbas , Amer Aziz  and Rizwan Hameed

Department of City and Regional Planning, University of Engineering and Technology, Lahore 54890, Pakistan; dr.ameraziz@gmail.com (A.A.); drrizwanhameed@uet.edu.pk (R.H.)

* Correspondence: zaheerabbas@mnsuet.edu.pk; Tel.: +92-3002734301

Abstract

A sustainability appraisal framework helps to ensure the smooth sailing of various activities in transportation departments. A well-developed and flexible framework can serve as a primary tool for the evaluation of tasks in transportation departments. In this study, a framework for the sustainability appraisal of urban transportation is developed and its implementation is presented as a case study. As the transportation sector is placed within a wider context of sustainable development, the framework is based on a holistic approach considering transportation from a sustainable development perspective. The approach adopted for the implementation of the framework involves all stakeholders, including transportation departments and the community, in planning, decision-making, and bringing opportunities to guide the community and shape collective behaviors. By defining context-specific goals, objectives, inputs, and outcome variables, which inclusively represent sustainable development, the framework will be effectively utilized. The framework will also be useful to guide transportation departments to polish their vision, in addition to making policies, designing methodologies, and implementing measurement and monitoring systems for attaining the desired state of sustainability.

Keywords: appraisal framework; sustainable development; transportation system; holistic approach; indicator-based evaluation



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1. Introduction

A crucial element of sustainable development is achieving sustainability in the transportation system. Sustainability in the transportation system is essential, as transportation is a prerequisite for overall growth and a contributor to environmental difficulties and land use challenges [1,2]. Refs. [3,4] assert that sustainability cannot be achieved solely through design modifications, operational strategies, and transportation management; rather, a shift in mindset is essential for recognizing and evaluating potential solutions to transportation issues. The notion of sustainability in urban transportation planning is a dynamic field of study that has developed robust theoretical foundations, encompasses a wide array of activities in both public and private sectors, and includes operational instruments [5–7]. Transportation networks in urban planning must be built with sustainable development in mind.

Developed nations such as Australia, Canada, the United States, and many European countries possess well-defined sustainability frameworks that inform standards for transportation, exploration, and development [8,9]. Several renowned generic frameworks exist, including the “Pressure–State–Response” (PSR) model (often utilized for environmental

assessment), the “Balanced Scorecard” (for departmental performance management), and “The Natural Step” method (employed by firms to structure their sustainability initiatives). Likewise, certain practical frameworks within the transportation sector have attained recognition as brands, such as “The Smart Mobility Framework, Caltrans,” articulated as Caltrans’ vision for the 2025 California Transportation Plan; the “Gray Notebook” issued by Washington State DOT, USA [10]; and the “Transport and Environment Reporting Mechanism” (TERM) by the European Environmental Agency [11]. Conversely, others remain relatively obscure due to their limited application on a smaller scale. There is a necessity to build technologies that effectively serve transportation departments in urban areas of developing nations, which exhibit diverse population features, organizational dynamics, and cultural contexts.

The key terms used in the manuscript are defined here to bring clarity throughout the discussion. Goals are the broad intentions that express the desired direction of sustainable transportation; objectives are specific, measurable features linked to each goal that guide evaluation and implementation; indicators are quantifiable measures used to track progress toward objectives; input variables are the performance measures on the transportation department side; and outcome variables are public perception-based indicators.

2. Overview of the Concept and Carried out Research

The concept of sustainability or sustainable development received formal global recognition at the United Nations Conference on Environment and Development (UNCED) [12,13]. An often-referenced definition of sustainable development originates from *Our Common Future*, the report of the Brundtland Commission [14]. The international consensus on the definition of sustainable development encompasses three dimensions: economy, environment, and social fairness. It is essential to understand that the three Es [15] do not represent separate domains of human existence but rather serve as analogous descriptions for comprehensive perspectives to assess if progress is broadly sustainable [16]. The concept of dimensions of sustainable development lacks a rigorous scientific foundation. A method to connect these three Es is through a series of nested circles, representing equality, environmental, and economic dimensions. The economic sector operates inside a framework of social equality, just as society is encompassed by the natural environment. To illustrate the relationships among these sustainability dimensions, many representations may be employed, such as depicting the three dimensions as the sides of a triangle or as interlinked circles [17].

Sustainable transportation is broadly described as the principle of sustainable development when policies and activities are deemed “sustainable” through the adoption of conventional methods. In the literature and in operations, there are two distinct perspectives: one that considers transportation within a comprehensive framework for sustainability, and another that focuses primarily on transportation [15,17]. Upon examining the literature on sustainability, transportation systems are situated within a broader context of sustainable development. This method emphasizes the contributions of the transportation division and others to unsustainable development. Progressing towards sustainable development is unattainable without acknowledging the cumulative influence of all sectors, including transportation—a holistic perspective [13]. Conversely, “sustainable transportation” is articulated through the aspects of sustainability (the 3 Es—economy, society, environment) and is regarded as “a manifestation of sustainability within the transportation sector—Transportation centered view [17]”. A strategy for deciding whether to adopt a holistic vs. a transportation-centered perspective on sustainable development can be achieved by integrating the merits of both approaches [13]. This approach necessitates the articulation of sustainable transportation indicators at the system level within the context of global, national, and regional metrics.

The preliminary notion of integrating sustainability into the transportation sector is the triple bottom line. Issues of sustainable development can be analyzed via the lens of the three Es: environment, economy, and equitable society [18–23]. A comprehensive definition of sustainable mobility encompasses four fundamental components: substitution of transport modes, modal shift, a decrease in travel distance, and enhancement of efficiency [21]. These terms pertain to physical mobility (transportation) in addition to spatial, social, and economic aspects [24]. The definition and use of sustainability extend beyond technical advancement [25]. The advancement of sustainable transportation encompasses society, incorporating elements of economics, policymaking, planning, and civic engagement [25]. Previous studies indicate that the aims of sustainable transportation include enhancing safety, accessibility, and use of bicycles and walking, while also reducing ecological effect and costs [26]. Ref. [22] offers an alternative definition of sustainable transportation that aligns with a broader concept of sustainability: “transportation that meets current transportation and mobility demands without compromising the ability of future generations to fulfill those needs”. The American Association of State Highway and Transportation Officials (AASHTO) has established a set of 17 goals for sustainable transportation, encompassing mobility, safety, enhanced convenience, ecological consequences, and pollution reduction, among others [17].

2.1. The Sustainable Assessment Approaches

A literature review on “urban transportation sustainability assessment” indicated that “the study fails to encompass the complexity of sustainability in a comprehensive manner, resulting in inconclusive assessment outcomes in the academic literature, despite the application of various assessment methodologies” [27]. Various methodologies for evaluating sustainability in the transportation sector are presented in Table 1.

Table 1. Methods used for transportation sustainability-related assessments.

Sr. No.	Method	Assessment Phenomena	Source
1	Indicators or framework development	Evaluate various aspects of urban transportation systems	[28–34]
2	Multicriteria decision analysis (MCDA), modeling, and simulation	Assessment of policies and plans	[35–43]
3	Participatory data collection methods	Evaluation of public perceptions	[44–47]
4	GIS methods	Performance evaluations and built-environment evaluations	[48,49]
5	Statistical data analysis	Assessment of public transportation systems and service performance	[50–52]
6	Documentary analysis	Assessment of policies and plans	[53]

2.2. Identification of an Appropriate Framework and Global Practices

Four categories of frameworks integrate various contemporary planning and management practices: (i) transportation appraisal frameworks, which are national systems for evaluating transportation plans and projects; (ii) environmental policy review and reporting, conducted by organizations such as the OECD and the European Environment Agency (EEA); (iii) sustainability assessment, aimed at quantifying economic, environmental, and social impacts; (iv) performance management, where performance metrics are utilized to summarize outcomes and inform organizational decision-making. None of the frameworks are solely dedicated to the evaluation of sustainable transportation. Nonetheless,

their research elucidates how institutionalized environments and conventional practices partially allow certain elements while also necessitating others in the evaluation of sustainability within the transportation industry [13]. The framework's design must integrate an evaluation of both sustainability (type iii) and performance management (type iv) for transportation agencies, thoroughly addressing sustainability by embedding it into the organization's strategic planning and management initiatives. This adaptable framework is pertinent in contexts where various departments with intersecting objectives and functions must collaboratively address specific issues [17].

Numerous exemplary frameworks for sustainability assessment in transportation exist, such as Caltrans's Smart Mobility Framework, Green LITES, New Jersey Future in Transportation, Comprehensive Life Cycle Assessment for Sustainability, and the London Sustainable Freight Distribution Plan, which foreign transportation departments and agencies have implemented to integrate sustainability principles into transportation planning activities. Each practice reflects the critical priorities of the employing organization, such as rural economic development, climate change, and congestion reduction. The practices also include several phases of the transportation planning process. These practices implement several tactics employed by transportation organizations to attain sustainability goals and address deficiencies. Furthermore, these practices encompass all facets of sustainability within the transportation system (environment, economics, society, and system performance) when integrated with innovative strategies and methodologies, and they also encompass the entire continuum of planning and project development.

Recent research on frameworks for the sustainability assessment of transportation systems have used Artificial Intelligence (AI)-based evaluation models, data-driven indicator construction, and dynamic transport demand modeling. For example, ref. [54] proposed a framework that helps in transportation planning by bringing multiple metrics into one score and giving rankings and practical suggestions for system improvement. Ref. [55] developed a novel decision-making method called the "Iterative Data Envelopment Analysis (iDEA) model to assess transfer efficiency of public transportation for elderly people". Refs. [56,57] used explainable AI data envelopment analysis approaches to evaluate the efficiency of public transportation systems.

According to the preceding discussion, a comprehensive framework will encompass both sustainability evaluation and performance metrics. The proposed framework will be delineated as a conceptual structure comprising goals, objectives, and indicators pertinent to sustainability assessment, together with a mechanism for monitoring and benchmarking these indicators or establishing targets for comprehensive sustainability evaluation.

2.3. The Dynamics of Proposed Framework

The proposed framework adopts a holistic approach, specifically a sustainable development perspective, integrating sustainability assessment and performance management for transportation departments. This framework is particularly beneficial in contexts where organizations exhibit overlapping functions, as seen in developing countries. The framework delineates transportation sustainability objectives in accordance with fundamental sustainability principles. Additionally, the established methodology contributes to assessing public perception of governmental initiatives aimed at achieving sustainability in urban transportation. To use the framework practically, input variables are established to conduct case studies on chosen transportation departments to evaluate the existing level of sustainability, while outcome variables are constructed to gauge public perception of this state. Ultimately, a final sustainability score is calculated based on the scores of the input and outcome variables to assess the current status of sustainability in the transportation sector. The developed framework has been implemented to assess sustainable urban

transportation, using Lahore, Pakistan, as a case study. The approach employed for the framework, together with its implementation procedure, will assist transportation agencies in tackling sustainability challenges, rendering it pertinent and accessible.

3. Materials and Methods

The sustainability appraisal framework was developed through qualitative research, while its validation involved mixed-methods research, incorporating both qualitative and quantitative approaches. The flow of methodology was as follows: (1) selection of case study, (2) five pillars of the framework (identify a suitable framework, create general framework, validate and update the framework, test the framework through case studies, and create a mechanism for computing the sustainability score), (3) sample size and distribution, (4) collection of data, (5) analysis of data. The validation utilized a curated panel of experts and specific case studies (transport departments and public perception). The city of Lahore, Pakistan, was selected as a case study based on its rapid growth in population, passengers per kilometer, and involvement of various ministries and agencies in planning and infrastructure development, with overlapping responsibilities. The framework design is presented below.

3.1. Framework Design

The framework is distinctive in its aim to embrace a holistic approach to sustainable development, incorporating sustainability attributes, performance metrics, and public engagement with governmental activities towards sustainability. After conducting the literature review, a framework for evaluating sustainability within the transport system could be delineated through a formal structure of objectives, targets, and performance measures/indicators pertinent to sustainability. Another aspect of implementation is the formulation of methods to assess the indicators, establish benchmarks, and set targets. The aforementioned reduced version of a generic framework was constructed, with intermediary links for the validation and amendment of the framework, as illustrated in Figure 1. The formulation of the chosen overarching framework will proceed through the subsequent stages.

3.2. Sustainability Principles

The formulation of sustainability principles relied on the conventional definition of sustainability, particularly in relation to transportation systems and their associated departments. From the perspective of sustainable development, a collection of key principles includes the preservation of ecological and environmental systems, the promotion of economic development, the enhancement of quality of life, and the assurance of justice among demographic groups and across generations [22]. Four principal facets of sustainable development, as derived from *Our Common Future* [14], can be applied to transportation: (i) safeguarding enduring environmental sustainability, (ii) ensuring essential human needs, (iii) promoting intergenerational equity, (iv) fostering intragenerational equity [58].

The aforementioned criteria guarantee that transportation policies promote advancement towards sustainable development. The objectives must be connected to at least one of the sustainability principles listed below:

- (a) Enhancing quality of life;
- (b) Preserving environmental and ecological systems;
- (c) Advancing economic development;
- (d) Determining fairness among demographic groups and across generations.

Table 2. *Cont.*

Ensure		Reduce	
4.	Ensure that the system makes the best use of new and existing assets.	18.	Minimize the waste produced from transportation-related activities.
5.	Maximize user-friendliness and reliability of transport services.	19.	Reduce nonrenewable resource use and promote renewable energy to operate the transport system.
6.	Ensure a reliable transportation system, resilient to threats from all hazards.	20.	Minimize air pollution and greenhouse gases related to transportation.
7.	Ensure the development and operations of the transportation system favor economic development and prosperity.		
8.	Ensure investments in the transportation system are feasible economically.		
9.	Ensure transport for all regardless of location, age, gender, income race, or disability.		
10.	Ensure the transportation system involves all modes of transportation.		
11.	Ensure the transportation system offers access to the services essential to empower people to rise out of poverty, overcome social exclusion, and bring goods and services to the market, driving socio-economic growth.		
12.	Ensure integrated, comprehensive, and inclusive planning for transportation projects/systems.		
13.	Ensure that there are mechanisms to assess the sustainability of the transportation system.		

3.4. Objectives of Sustainability

Following the establishment of goals and their alignment with sustainability principles, the subsequent phase is to elucidate the sustainability principles and aims in relation to the objectives. The objectives will delineate the connection between the goals and the indicators, using appropriate indicators and performance metrics associated with each target. The paper “Well Measured—Developing Indicators for Sustainable and Livable Transport Planning” delineates many transport planning objectives that align with sustainability goals [59]. The objectives for this framework were established for each goal based on the literature and the National Transport Policy.

Each goal encompasses numerous objectives. The objectives of Goal No. 1 include enhancing travel safety and security, improving the safety of transportation infrastructure, ensuring safe travel for individuals and cargo across various modes of transport, and fostering a culture of safety. Correspondingly, objectives were delineated for all the aims.

3.5. Performance Measures

Based on the examined literature, performance measures were established using input and outcome variables, as delineated by [59]. Inputs refer to the resources allocated to particular activities, such as the amount of funding utilized for various modalities or tasks. Outcomes comprise final results, such as average travel speed, crowding and congestion levels, total miles traveled and mode share, user satisfaction, incidence of accidents and fatalities, energy consumption, and pollution emissions. Input variables were formulated to conduct case studies on specific transportation departments to evaluate the present state of sustainability, while outcome variables were established to gauge public perception regarding the current state of sustainability.

Multiple input variables and performance measures were established for each objective. For Goal No. 1, the performance measures include adherence to relevant international standards and regulations regarding transport safety, driver fitness and skills, vehicle standards and fitness, accident recovery protocols, safety audits for new or enhanced transport infrastructure projects, sufficient alternative transport infrastructure for pedestrians and cyclists, and institutional capacity for the design and management of the transport network system. Likewise, many performance metrics/input variables have been established for each objective.

Table 3 delineates 22 indicators/outcome variables categorized according to sustainable domains, namely safety, fairness, public transport efficiency, affordability, pollution, land use, governance, climate change/hazards, and heritage protection. Each indicator or outcome variable was associated with one or more of the established goals. The majority of the variables are qualitative and are transformed into quantitative measures by numerical ratings specified in the analysis section. A panel of experts was convened to assess and validate the following factors: (i) the selection and review of goals within the local context, (ii) the categorization of goals as functional or impactful, (iii) the connection of goals to established sustainability principles, (iv) the evaluation of specific objectives for each goal, interpreting sustainability principles and defined goals into objectives, (v) the examination of performance measures/variables and their classification as input or outcome variables.

Table 3. Mapping of outcome indicators with goals.

Area	Outcome Indicators			
Safety	Safe travel (free from accidents and thefts) G—1,6			
Equity	Adequate and safe facilities for pedestrians and cyclists (non-motorized transport) G—1,3	Accessibility for women (secure and comfortable travel for women) G—1,2,3,9,11	Transport facilities for disabled people G—1,2,3,9,11	Public transportation access from home, education, workplaces, and recreation places G—1,2,3,9,11
Public Transport Efficiency	Public transport adequacy (availability, particularly in peak hours) G—2,3,9	Public transport service quality (riding ease) G—2,3,5	Diversity in availability of modes of transportation and flexibility in changing mode G—10	
Affordability	Travel cost (travel cost per month). G—3,7,11		Travel time (average time spent on daily trips) G—2,5,6,7,11	
Pollution	Noise pollution (by transportation) G—14	Air pollution (by transportation) G—14,20	Numbers of private vehicles (car, bike, etc.) G—14,20	User adaptation and affordability of new technologies (e.g., hybrid, electric vehicles, etc.) G—14,16,19,20
Land Use	Land transport facilities (adequate roads and parking facilities) G—14			
Governance	Public participation in planning of transportation projects G—12		Resource efficiency (efficient use of government resources in transportation planning) G—4,5,8	
Climate Change/Hazards	Transport accessibility in all weather conditions G—6,15	Weather forecasts (timely and reliable predictions available to public) G—15	Early warning system (in case of any natural or manmade hazards) G—15	Emergency exits (public transportation and infrastructure) G—15
Heritage Protection	Protection of natural beauty, old buildings, and monuments during the execution of transportation projects G—17			

3.6. Questionnaire Design and Weighting Criteria

The last step involved designing the questionnaires used to conduct the case studies and assess the outcomes based on the chosen case studies. Distinct questionnaires were developed: one for transportation departments and another to assess public perception.

The first questionnaire was developed for transportation departments, encompassing key components such as goals, objectives, and potential indicators, including performance indicators and input variables. Respondents needed to evaluate each input variable and performance measure for importance and provide a rating on a scale from 1 to 5 individually. The significance of each performance measure/input variable was assessed according to scores assigned by respondents, ranging from 1 to 5, where 1 indicated unimportance and 5 indicated very high importance. Additionally, each performance measure/input variable was assigned a score to assess its current status, with scores ranging from 1 to 5, where 1 indicated the lowest status, 2 the second lowest, 3 the median, 4 the second highest, and 5 the highest. An average score for each goal was calculated by averaging the importance and rating scores provided by respondents for the associated performance measures and input variables linked to that goal. A weight was assigned to each goal according to the average importance score, ensuring that the total sum of weights for all goals was equal to one. To calculate the weighted score for each goal, the weights assigned to each goal were multiplied by their respective final rating scores.

The outcome variables for Questionnaire 2 were categorized under the sustainability areas of Safety, Equity, Public Transport Efficiency, Affordability, Pollution, Land Use, Governance, Climate Change/Hazards, and Heritage Protection. The literature summarizes 22 outcome indicators. Each outcome indicator is associated with one or more sustainable transportation goal, as presented in Table 3. The outcome indicators encompass all three dimensions of sustainable development: economy, equity (social), and environment. However, they are not distinctly categorized, as the three pillars often intersect.

The questionnaire was developed to assess the perceptions of various demographic groups residing in the city based on these outcome variables. The questionnaire consisted of three sections: Part A: Sociodemographic Characteristics of the Respondents. Part A addressed the variables of gender, age, education, mode of transportation, monthly income, and monthly travel expenses. Section B: Respondents' Perceptions Regarding the Effectiveness of Outcome Indicators. In Part B, the performance of each indicator was assessed using a five-point Likert scale to measure satisfaction. The respondents affirmed that the specific indicators were functioning adequately against five response options: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5). Part C: Respondents' Perceptions Regarding the Significance of Outcome Indicators. In Part C, the performance of each indicator was assessed using a five-point Likert scale regarding its importance. Participants were inquired regarding the significance of each variable. Five measurements were provided for the responses: not important (1), slightly important (2), moderately important (3), important (4), and very important (5). Using the importance and rating scores provided by respondents, an average score was computed for each performance measure/outcome variable. Subsequently, this score was associated with the goals established through the connection of each performance measure/outcome variable to one or more of the defined goals. A weight was assigned to each goal according to the average importance score, ensuring that the total of all weights was equal to one. The weighted score for each goal was determined by multiplying the weight of each goal by its final rating score. Two weighted scores were calculated for each goal: one derived from data collected from transportation departments/input variables and the other from data collected from public/outcome variables. The weighted scores for all goals were aggregated separately for input and outcome variables to facilitate comparison on a scale of 1 to 5.

3.7. Determination of the Sample Size

The questionnaire for transportation departments received responses from twenty respondents representing relevant stakeholder departments, namely the Traffic Engineering & Transport Planning Agency (TEPA) and the Transport Department of Punjab, including its sub-departments. This research employed a proportionate stratified sampling technique to ensure adequate representation of each section. Each department was treated as a distinct section, with the sample size determined proportionally based on the number of eligible respondents from each section. The respondents typically held managerial positions and were well-acquainted with the sustainability initiatives implemented by their departments. The initiative attained a response rate of 90%.

The sample size for the public perception survey was calculated using Cochran's formula [60]:

$$n_o = \frac{(t)^2 \times (s)^2}{(d)^2} = \frac{(1.96)^2 \times (1.25)^2}{(5 \times 0.03)^2} = 267, \quad (1)$$

where t = the value for the chosen alpha level (which represents the amount of risk the researcher is prepared to assume that the actual margin of error might be more than the allowable margin of error), s = the population's estimated standard deviation (or the scale's estimated variance deviation), and d = the allowable margin of error for the mean that is being estimated (adjusted for the number of points on the principal scale). Using the five-point scale, we set an alpha level a priori of 0.05, a level of acceptable error of 3%, and an estimated standard deviation of the scale of 1.25 (5/4). The current number of households in Lahore is 2,012,526 [61] and the required sample size was less than 5%; [60] correction formula need not apply.

Proportionate stratified sampling was employed to provide enough representation of each stratum in the selection of respondents. The acquired sample was categorized according to the number of zones in the City District of Lahore. Lahore District is divided into nine towns and Cantonments, and each town has a group of Union Councils, with a total number of 152 union councils including Cantonment areas. Similarly, the study employed a proportionate stratified sampling technique to ensure adequate representation of each section. Each town was treated as a distinct section, with the sample size determined proportionally based on the number of households from each section.

Table 4 demonstrates the socio-demographic profile of respondents for the above-mentioned sample size.

Table 4. Socio-demographic characteristics of respondents ($n = 267$).

Sr. No.	Variable	Statistics
1	Gender	63% male; 37% female
2	Age	62% between 15 and 35 years
3	Education	80% have at least secondary education
4	Mode of transport	35% public transport; 40% private mode
5	Income	49% (PKR 20,001–50,000)/month
6	Travel Costs	60% (PKR 2000–10,000)/month

4. Data Analysis

The findings indicate a sustainability score of 3.15 out of 5.0 for input variables, derived from data obtained from transportation departments, and a score of 2.68 out of 5.0 for end variables, based on public perception (Table 5).

Table 5. Goals and comparison of input and outcome variables.

Sr. No.	Goal	Input Variables				Outcome Variables			
		Importance	Rating	Weight	Weighted Score	Importance	Rating	Weight	Weighted Score
Functional Goal (Provide)									
1	Provide a safe transportation system (service and infrastructure) for users and the general public.	4.86	3.76	0.052	0.196	4.42	3.25	0.055	0.180
2	Provide an accessible transport system to meet the basic needs of the people.	4.71	3.33	0.050	0.168	4.50	2.94	0.056	0.166
3	Provide affordable and equitable transportation opportunities for all sections of society.	4.78	3.17	0.051	0.162	4.43	3.02	0.055	0.167
Functional Goal (Provide) Score out of 5.0		3.42				3.07			
Functional Goal (Ensure)									
4	Ensure that the system makes the best use of new and existing assets.	4.57	3.06	0.049	0.150	4.33	2.67	0.054	0.145
5	Maximize user-friendliness and consistency of transport services.	4.65	3.23	0.050	0.161	4.56	3.00	0.057	0.171
6	Ensure a reliable transportation system, resilient to threats from all hazards.	4.83	3.47	0.052	0.180	4.56	3.33	0.057	0.190
7	Ensure the development and operations of the transportation system support economic development and prosperity.	4.55	3.24	0.049	0.158	4.78	3.06	0.060	0.183
8	Ensure the investments in the transportation system are feasible economically.	4.72	3.33	0.051	0.169	4.33	2.67	0.054	0.145
9	Ensure transport for all, irrespective of location, income, gender, age, race, or disability.	4.83	3.37	0.052	0.174	4.42	2.83	0.055	0.157
10	Ensure the transportation system involves all modes of transportation.	4.67	3.11	0.050	0.156	4.00	3.00	0.050	0.150
11	Ensure the transportation system provides access to the services required to enable people to rise out of poverty, overcome social exclusion, and bring goods and services to the market, driving socio-economic growth.	4.83	3.33	0.052	0.173	4.53	3.03	0.057	0.172
12	Ensure integrated, comprehensive, and inclusive planning for transportation projects/the system.	4.70	3.33	0.050	0.168	4.00	2.67	0.050	0.133
13	Ensure that there are mechanisms to assess the sustainability of the transport system.	4.83	2.67	0.052	0.138				
Functional Goal (Protect) Score out of 5.0		3.21				2.92			
Impact Goal (Protect and Enhance)									
14	Protect environmental and ecological systems while developing and operating the transportation system.	4.71	2.97	0.050	0.150	4.60	2.07	0.058	0.119
15	Ensure the transport system adapts to climate change.	4.58	3.44	0.049	0.169	4.17	3.00	0.052	0.156
16	Enhance taxation and subsidies (minimize taxation and/or maximize subsidies for cleaner technologies).	4.56	2.78	0.049	0.136	5.00	1.67	0.063	0.104
17	Ensure the planning of the transport system considers heritage protection.	4.50	3.42	0.048	0.165	3.67	3.00	0.046	0.138
Impact Goal (Protect And Enhance) Score out of 5.0		3.15				2.37			
Impact Goal (Reduce)									
18	Minimize the waste generated from transportation-related activities.	4.42	2.94	0.047	0.139				
19	Reduce nonrenewable resource use and promote renewable energy to operate the transport system.	4.73	2.23	0.051	0.113	5.00	1.67	0.063	0.104
20	Minimize transportation-related emissions of air pollution and greenhouse gases.	4.28	2.81	0.046	0.129	4.67	1.67	0.058	0.097
Impact Goal (Reduce) Score out of 5.0		2.65				1.67			
Overall Framework Score out of 5.0		Σ	93.31	1.00	3.15	79.95	1.00	2.68	

4.1. The Gap Between Initiatives and Perception

The weighted average score for the functional goal of provision is 3.42 out of 5.0 for input variables, derived from data collected from transportation departments, and 3.07 out of 5.0 for outcome variables, based on public perception. The weighted average score for the functional goal (ensure) is 3.21 out of 5.0 for input variables, derived from data collected from transportation departments, and 2.92 out of 5.0 for outcome variables, based on public perception.

The weighted average score for the impact goal (protect and enhance) is 3.15 out of 5.0 for input variables, derived from data collected from transportation departments, and 2.37 out of 5.0 for outcome variables, based on public perception. The weighted average score for the effect goal (reduce) is 2.65 out of 5.0 for input variables, derived from data collected from transportation departments, and 1.67 out of 5.0 for outcome variables, based on public perception. Figure 2 illustrates the comparison of the weighted average scores between the input and result factors.

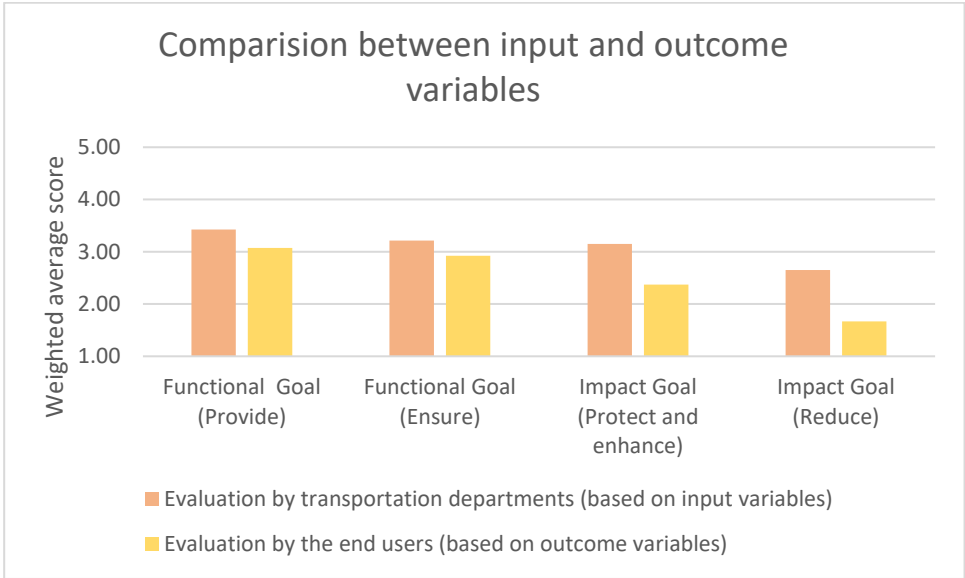


Figure 2. Comparison of Weighted Average Scores Between Input and Outcome Variables.

Figure 3 presents a comprehensive comparison of the weighted average scores for the input and result factors. The five-point scale comprises five segments, each delineating a specific stage of sustainability. Part 1 is described as unsustainable (0–1), Part 2 as moderately unsustainable (1–2), Part 3 as marginally sustainable (2–3), Part 4 as moderately sustainable (3–4), and Part 5 as sustainable (4–5). The data obtained from the transportation departments (input variables) indicates a score of 3.15 on a scale of 5.0, signifying moderate sustainability. The public opinion outcome factors indicate a score of 2.76 on a 5.0 scale, signifying marginal sustainability. The mean of the final weighted scores for the input and result variables is 2.95 out of 5.0, indicating a condition of marginal sustainability.

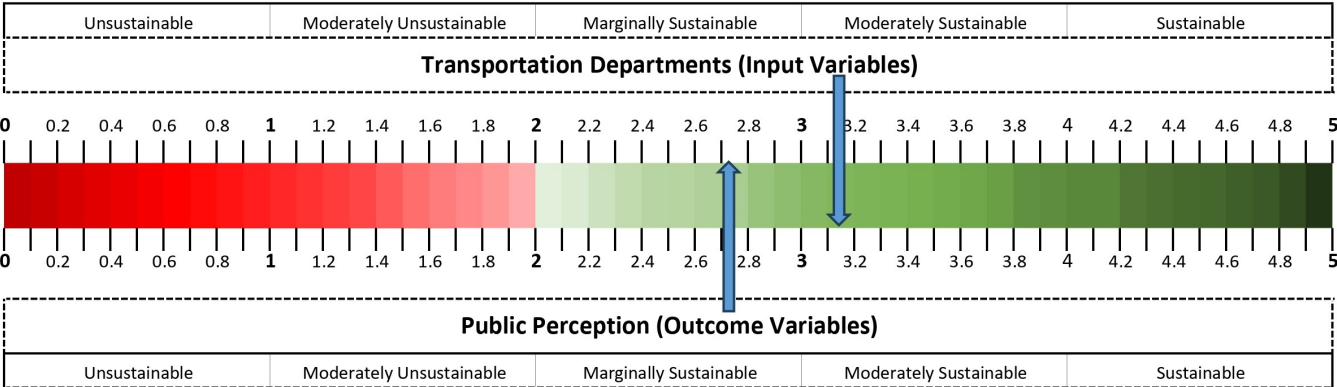


Figure 3. Overall comparison of weighted average scores between input and outcome variables.

4.2. Statistical Analysis

Regression analysis is performed by taking sustainability as the dependent variable and goals (20 numbers) as independent variables. The regression plot and equation are presented in Figure 4.

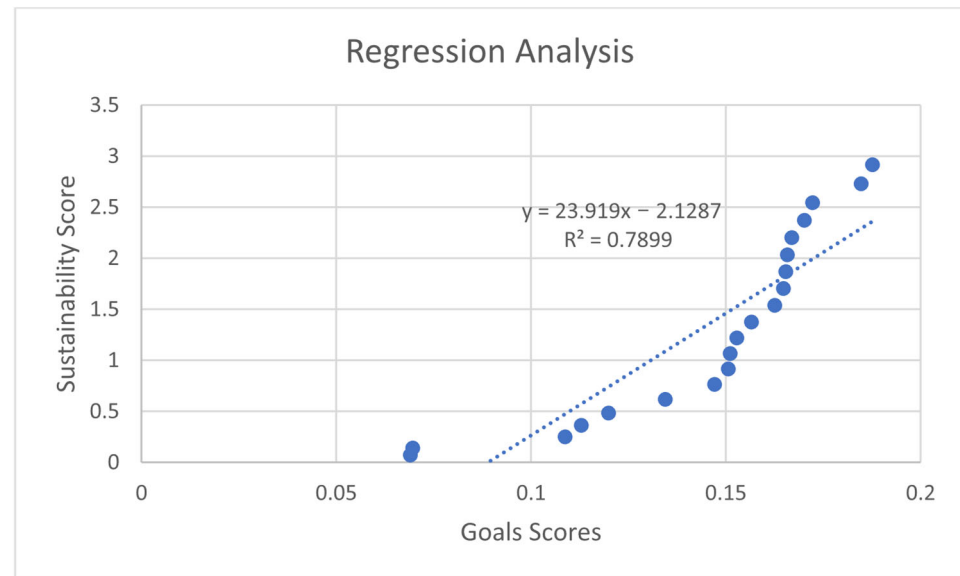


Figure 4. Regression analysis of sustainability and goal scores.

With a Multiple R value of 0.891, the results show a reasonably strong linear relationship between the sustainability score and the goal score, as well as a high positive correlation between the two. With a coefficient of determination (R^2) of 0.7899, it was shown that variations in goal score account for around 78% of the variability in the sustainability score. With an F-statistic of 66.00 and a Significance F value of 2.95×10^{-7} , the ANOVA statistics offered more evidence in favor of the model's validity. This demonstrates that the regression model is statistically significant at the 0.05 level, meaning that there is very little possibility that this association would have happened by accident. With a 95% confidence interval between 19.82 and 33.73, the positive coefficient is statistically significant ($p = 2.95 \times 10^{-7}$). This implies that the association has practical significance in addition to being statistically significant.

Besides quoting R^2 , the regression assumptions were performed to verify the validity of the diagnosis. The model consisted of one predictor; therefore, multicollinearity was not applicable. The plot of residuals revealed that the residuals were not heteroscedastic, and the normal probability plot evidenced that the residuals were normally distributed. Additionally, no outliers were identified to have the ability to influence the results, as the residuals remained within the acceptable limits. This shows that the results of the regression analysis are statistically good.

Reliability and Validity of Indicators

Cronbach's alpha was used to test the grouped indicators in order to check their internal consistency. Coefficients of reliability were above 0.70 ($\alpha = 0.79\text{--}0.87$) in all the domains and were therefore acceptable, indicating strong reliability [62]. Exploratory Factor Analysis (EFA) testing was performed to confirm construct validity. A Kaiser–Meyer–Olkin (KMO) measure of 0.81 and significant Bartlett's Test of Sphericity ($X^2(210) = 1345.6$, $p < 0.001$) indicated that it was appropriate to factor analyze the data. Eight factors—safety, equity, affordability, governance, environment, land use, efficiency, and resilience—which explained 78 percent of the variance were identified [63,64].

5. Results and Discussion

This study sought to provide a framework utilizing indicators for the sustainability assessment of an urban transportation system. This document delineates comprehensive instructions for the development of a particular sustainability appraisal methodology for transportation departments. The established framework for evaluating sustainability in transportation systems is predicated on a formal structure of goals, objectives, and indicators/performance metrics utilized for sustainability assessment. Defining the goals, objectives, and performance indicators for assessing sustainability in the transportation sector within the broader framework of sustainable development enables the achievement of sustainability evaluation.

The indicators and performance measurements are delineated within a two-tiered hierarchical framework. The highest level is characterized by outcome indicators that align with the sustainability objectives in the relevant domain and represent the community's experience of sustainability within the transportation system. The lowest level is characterized by input factors that offer insights into potential measures or strategies for enhancing sustainability within a transportation system. The established framework can be characterized as follows:

1. The framework is predicated on a holistic viewpoint, specifically the sustainable development paradigm, aimed at enhancing the economic, environmental, and social performance of the transportation sector without adversely affecting the performance of other sectors.
2. The framework evaluates sustainability and performance management concurrently for transportation departments, making it beneficial in regions where organizations have overlapping functions, such as in developing countries.
3. The framework is able to gauge public sentiment regarding governmental measures aimed at achieving sustainability in urban transportation. The public perception derived from outcome variables throughout the framework's implementation phase will validate the allocation of suitable resources established during the planning phase.
4. In its third aspect of implementation, the framework achieves the development of procedures to assess the indicators, establish benchmarks, or set targets.

The research used this paradigm in Lahore City, Pakistan, and assessed the existing transportation network's sustainability status using data gathered from transportation departments and public perceptions. The results indicate a satisfactory score for the functional objectives, namely in providing and ensuring; nonetheless, public perception suggests a necessity to enhance the parameters to elevate the score for functional objectives associated with ensuring. Conversely, substantial effort is required to boost the scores associated with impact goals, namely protection, enhancement, and reduction.

Functional goals (provide): Each goal was assigned significant weight and importance by transportation departments (avg. weighted score 3.42) and the public (avg. weighted score 3.07). Both groups provided relatively high ratings; however, the public's scores were comparatively lower than those of the transportation departments. The rationale for this is that although metro trains, metro buses, and public transportation services are available, the metro bus and orange line only cover a limited part of the city and require expansion into a network rather than remaining as isolated lines.

Functional goals (ensure): Each goal received significant weight and importance from transportation departments and the public, with transportation departments assigning a relatively high rating (avg. weighted score 3.21); however, the public's score was comparatively lower (avg. weighted score 2.92) than that of the transportation departments. The rationale for this is identical to that concerning the provision of public transportation, such as metro trains and buses, which only service a limited segment of the city and require

expansion into a comprehensive network rather than isolated lines. Goal No. 13 was not directly associated with public perception; hence, this goal was assessed solely based on the ratings provided by transportation departments.

Impact goals (protection and enhancement): Each goal received significant weight and relevance from transportation authorities (avg. weighted score 3.15) and the public (avg. weighted score 2.37), particularly Goal No. 16, which focuses on minimizing taxation and subsidies for cleaner technologies, which was emphasized in public responses. Nonetheless, the ratings assigned by the transportation departments, and especially from the public, were comparatively inferior to the scores for the functional objectives. The city's environmental conditions need improving, particularly its air quality index, which ranks among the highest globally. It is essential to support greener technology, advocate for electric vehicles, upgrade the current bus fleets, and improve the regions served by public transportation.

Impact goals (reduction): Each aim received significant weight and relevance from transportation departments and the public. Nevertheless, the ratings assigned by the transportation departments (avg. weighted score 2.65), and especially from the public (avg. weighted score 1.67), were comparatively lower than those for the functional objectives. Given the lowest public perception (1.67) for Goal No. 20 and Lahore's high air quality index there is a need to reduce transport-related emissions by promoting retrofitting fleets and deploying electric buses. It is essential to subsidize cleaner technology, diminish nonrenewable resource use, upgrade the current bus fleet, and improve the regions served by public transit. Goal Number 18 was not directly associated with public perception; hence, this goal was assessed solely based on the ratings provided by transportation departments.

The substantial difference between departments' ratings and public perception within the context of this case study reflects structural and service-level challenges. First, due to fragmented public transport coverage, large residential and employment zones remained underserved. Therefore, the departments evaluate these initiatives positively, but the public perceives limited advantages in daily mobility. Secondly, accessibility and affordability remain critical. Most of the public relies on motorcycles and para-transit modes due to insufficient reach of public transport. This highlights why the public perception of goals related to accessibility and equity are significantly lower than the departments'. Thirdly, as Lahore is among the world's most polluted cities, departments may consider planned projects and policy commitments in their scoring, but the public ratings reflect traffic congestion, smog, and poor air quality.

This research paper suggests ways for enhancing transportation sustainability from this perspective. Its insights aim to enhance the current status of sustainability and concentrate on the advancement of critical elements within transportation systems.

The following recommendations address the identified deficiencies:

1. Initially, the notion of sustainable transportation must be recognized. Transportation infrastructure and services must be designed as a cohesive network within the city, rather than offering specific services limited to one or two routes, transitioning from a corridor strategy to a network approach. Investments in transportation networks must also be economically viable. Strategic objectives, both long-term and short-term, must align to achieve the desired condition of transportation sustainability.
2. Secondly, robust coordination among all levels of government—national, provincial, and local—is essential for the efficient utilization of resources and the achievement of sustainability goals. Additionally, a process must be established to evaluate the sustainability of the transportation system.
3. Third, it is essential to sustain the current infrastructure and bus fleet, necessitating the allocation of sufficient finances. It is essential to reduce taxation and provide incentives to encourage greener technology and the use of electric vehicles. Both

natural and anthropogenic heritage must be safeguarded throughout the planning and implementation of the transportation system.

4. Finally, all stakeholders, including land use control departments, environmental agencies, transportation departments, and relevant private sector entities, must engage with the transportation department. Furthermore, the engagement of public opinion in transportation planning is a crucial element for successful projects.

By adhering to the principles outlined in this article to develop a targeted sustainability appraisal framework for transportation departments, these departments can refine their organizational structure within a local context. The assessment results will assist transportation departments in enhancing their organizational structures and processes with a greater emphasis on sustainability, as well as improving decision-making, planning, and operations.

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Abbreviations

The following abbreviations are used in this manuscript:

PSR	Pressure–State–Response
TERM	Transport and Environment Reporting Mechanism
EEA	European Environmental Agency
UNCED	United Nations Conference on Environment and Development
AASHTO	American Association of State Highway and Transportation Officials

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