sustainability

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Review

Sustainable Development Factors in Pavement Life-Cycle: Highway/Airport Review

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Abstract: Sustainability has gained as much importance as management in business. Sustainable pavement development as a business practice should involve making evaluations according to the triple bottom line in the pavement life-cycle. Despite the current approaches to evaluating the social as well as economic and environmental feasibility of pavement projects (involving highway and airport infrastructure), there has recently been a lack of consensus on a methodology to guarantee sustainability upon assessment and analysis during the pavement life-cycle. As sustainability is a complex issue, this study intends to further explore sustainability and elaborate on its meaning. The second step involves a general depiction of the major sustainability appraisal tools, namely cost-benefit analysis, life-cycle cost analysis, life-cycle assessment, multi-criteria decision-making, environmental impact assessment and social life-cycle assessment, and an explanation of their cons and pros. Subsequently, the article addresses the application of an organized methodology to highlight the main factors or concepts that should be applied in sustainable pavement development and, more specifically, in sustainable pavement management. In the final step, research recommendations toward sustainability are given. This study is aimed to assist decision-makers in pavement management to plan sustainability frameworks in accordance with probable boundaries and restrictions.

Keywords: sustainable pavement management; cost-benefit analysis (CBA); life-cycle cost analysis (LCCA); life-cycle assessment (LCA); multi-criteria decision-making (MCDM); rating systems

1. Introduction

The concept of sustainability dates back to 1972. The first international conference with the objective of analyzing special environmental concerns was held by the United Nations on the Human Environment in Stockholm. Just after this conference, the Brundtland Commission (1987) laid the foundation for the widespread reference to the concept of sustainable development. Simply put, sustainability can be described as development that serves the demands of the present day without compromising the needs of future generations [1]. The United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992 and the World Summit on Sustainable Development (WSSD) convened in Johannesburg in 2002 were two significant conferences related to sustainability [2]. During that period, the idea of sustainability outgrew the environmental phase to include socio-economic features [3]. Sustainability is defined by the American Society of Civil Engineers [4] as "*A compilation of environmental, social and economic circumstances that permits all the individuals of a community to handle plus improve its standard of living by giving them the same level of viewpoints for the predictable future without degrading the amount, characteristics or the presence of natural, financial and social sources.*" The Transportation Research Board (TRB) held a seminar in 2005 named "Integrating Sustainability into the Transportation Planning Process" and predicted sustainability as its most fundamental level.

Sustainability in the airport field is not unanimously explained by the aviation society. The Airport Cooperative Research Program (ACRP) explains airport sustainability as "*A deeper terminology that involves a large variety of techniques that can be applied to the organization of airports*" [5]. The Sustainable Aviation Guidance Alliance (SAGA) suggests that airport operators should realize the meaning of sustainability in the context of particular organizations or individuals, keeping in view the distinctive nature of the airport and its community. SAGA declared that sustainability includes vital elements under the "Triple Bottom Line"—Economic Growth, Social Responsibility and Environmental Stewardship [6].

Sustainability is a broad concept as every organization has its own definition and methodology and this means that sustainable development can entail unknown and ambiguous processes and activities. Moreover, most previous methods do not focus on all factors equally. This review offers a comprehensive look at the factors that should be considered in infrastructure and sustainable pavement development as well as the role of these factors in pavement management. The major certification tools, decision-making software and expert systems are introduced. Last but not least, restrictions during the pavement lifecycle are presented and recommendations are made.

2. Literature Review

In the 1990s, the idea of sustainability gained significance universally. Since then, advancements have been made in the infrastructure of sustainability [7–10]. Development of sustainability is mounting day by day with increasing demand owing to present levels of public analysis, planning and rules. Stakeholder concerns and the global pressure for sustainability have given rise to a sense of urgency [5,6,11–13]. Levin [14] claimed that sustainability is a broad concept and, most importantly, asked the question of how it can be achieved. Based on the Gatto's [15] theory, sustainability has three different definitions that are interrelated. To provide a better understanding, Figure 1 is drawn to show this correlation.

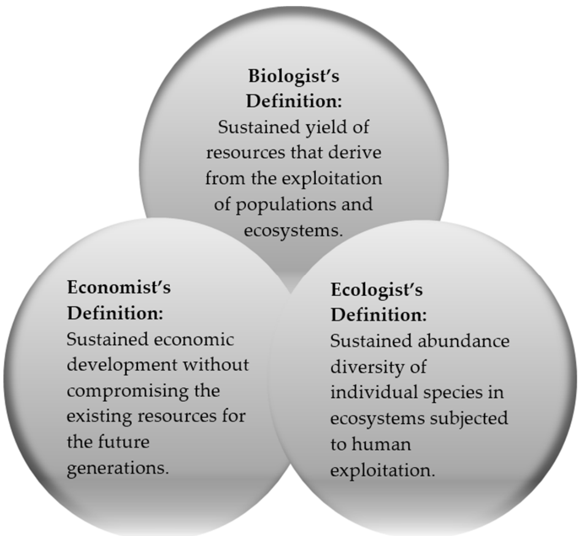

Figure 1. Distinct definitions of sustainability.

Researchers have reached consensus on the fact that sustainability revolves around the need to achieve economic and social development aimed at environmental protection. Nonetheless, there is so far no solid methodology that can be evolved in terms of sustainability. Many researchers have attempted to define sustainability in their own ways with the main ideas given to support the definition. According to Radermacher, as cited by Ciegis *et al.* [16], sustainability should include globalization, external effects, a long time period, policies to govern environmental matters, and a "cradle to grave" approach. Other groups of researchers have presented several different definitions of sustainability similar to Gilmour *et al.* [17] and Parkin *et al.* [18]. Most of these definitions revolve around the social and economic concepts and some are related to the environment. Ciegis *et al.* [16] argued that no single definition can cover the concept and the process of sustainability.

Airport stakeholders have also started seeking ways to achieve sustainability in order to increase the effectiveness of operations [19]. Implementing the concept of sustainability for airport pavement also revolves around environmental, operational, economic, and societal effectiveness and impacts on decision making. These are the same factors that govern every pavement lifecycle [5,11].

To enhance sustainability, governments have been taking several steps together with industrialists and the academia sector. The frameworks of sustainability and their feedback recording systems have been thoroughly described and implemented as well by Muench *et al.* [20], Mukherjee and Cass [21], and Zietsman *et al.* [22]. It is hardly possible to cover all the indicators of sustainability in the given broad range of international sustainability criteria, and no single measurement unit has been agreed upon yet [23]. Farsari and Prastacos [24] laid down a number of indicators of sustainability from some of the best-known international efforts in their study.

3. Sustainability Assessment

The International Federation of Consulting Engineers (FIDIC) [25] categorized sustainability evaluation tools into four groups. This study shows these groups on the basis of their origin and utility in Figure 2. This section provides a comparative study of the major methodologies employed for assessing sustainability. In this part of the literature review, the major assessment tools for measuring and evaluating sustainability are described in general.

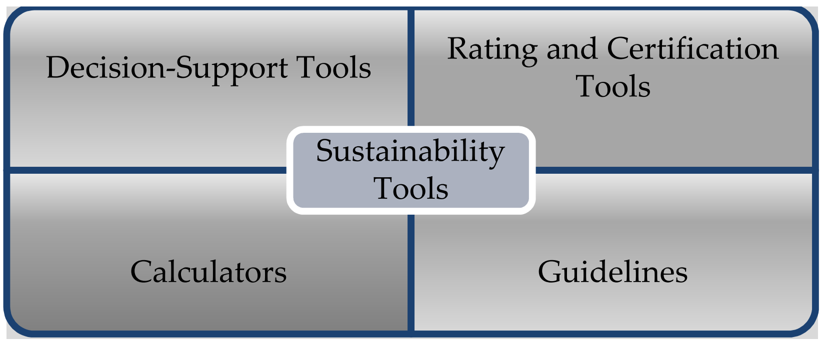

Figure 2. Sustainability tool categories.

3.1. Cost-Benefit Analysis (CBA)

Cost-Benefit Analysis is a commonly employed tool that provides significant assistance in the decision-making process. According to Browne and Ryan [26], CBA is normally used to evaluate finances of road construction in terms of congestion reduction advantages like reducing travel time and vehicle operating costs. To follow the CBA approach first, the potential expenses of pavement alternatives are estimated. Then, the probable advantages of each alternative are evaluated. At the end, all alternatives are compared based on the criteria of costs and benefits [27]. In the CBA approach, unlike LCCA, the costs are countered by the respective benefits, which assert higher costs for greater benefits. However, both of these approaches are feasible in terms of deterministic or probabilistic values. Several studies and research papers have been presented that examine various theoretical and practical approaches to CBA on similar grounds as Adler and Posner [28], Lamptey *et al.* [29], Boardman *et al.* [30], Tudela *et al.* [31], Gühnemann *et al.* [32], Calthrop *et al.* [33] and Hyard [34]. Furthermore, extensive research has been carried out to account for problems faced in the CBA evaluation process [35–37]. The European Commission refers to CBA as "common appraisal language" for comparing different projects [38]. Mouter *et al.* [39] referred to problems pertaining to cost-benefit calculation in non-monetized projects. The following problems were identified by Omura [40] after examining the role of CBA in the promotion or demotion of sustainable development:

- Attempting to evaluate non-economic parameters at the monetary level;
- Limited concern toward distributional equity;
- Presence of political bias in applying CBA.

3.2. Life-Cycle Cost Analysis (LCCA)

The basic objective of economic evaluation is to demonstrate that a selected project is dependent on the available finances [41]. In 1960, the American Association of State Highway Officials (AASHO) in its "Red Book" presented the concept of LCCA of pavement investment decisions, which further initiated the notion of pavement development financial assessment at the planning level. The Intermodal Surface Transportation Efficiency Act (ISTEA) called for the need to use life-cycle costs in the design and construction of bridges, tunnels or pavements in both city and state-wide level planning [42]. In the Final Policy Statement published in 1996, the stance of FHWA regarding LCCA was further explained, identifying LCCA as a helpful tool for decision makers. Ozbay *et al.* [43] stated that LCCA application would surely increase if the public and policy makers demanded better resource management.

LCCA is an economic method of evaluating financing alternatives intended to attain a comparative analysis of the overall cost-benefits of all possible options. The guideline provided by FHWA [44] comprehensively describes the use of LCCA in highway design and management. Walls and Smith [45] provided procedural directions and consultation regarding the application of LCCA in pavement design in the FHWA Interim Technical Bulletin. It also explains Risk Analysis, *i.e.*, a probabilistic approach for explaining ambiguities pertaining to the decision-making process. It was mentioned that like CBA, LCCA can be classified according to two approach types: deterministic and probabilistic. The LCCA arrangement essentially requires the following steps:

(1) The development of substituent management processes, an analysis time frame and condition triggers for maintaining the timing and performance of determined activities.
(2) Determining the cost of activities for both agencies and users considering the analysis time frame.
(3) Devising expenditure streams that may include discounted costs and computing the net present value (NPW) of every substituent process.

Figure 3 describes the concept of the probabilistic approach in LCCA. This approach surpasses the deterministic approach by allowing risk evaluation from the outputs. This is made possible by calculating the probabilities of each outcome represented by the parameter distributions. FHWA [46] presented the latest program, RealCost, as one of the several mechanisms devised for probabilistic LCCA. Another logic-based model was presented by Chen and Flintsch [47], which is aimed to structure the mechanisms for decoding various intrinsically unclear inputs. The model is intended to assist in the further development of the probabilistic LCCA approach.

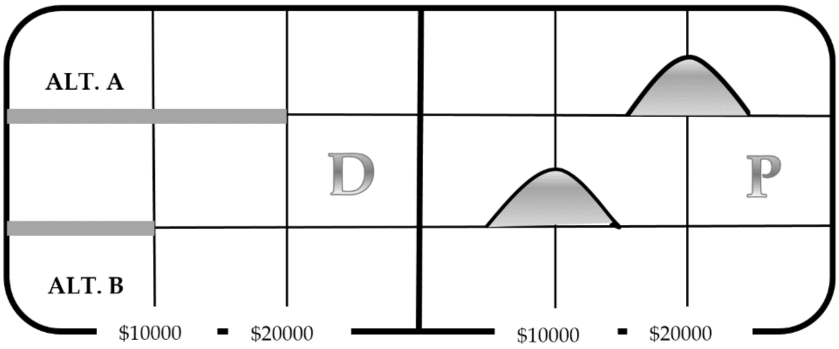

Figure 3. Deterministic vs. probabilistic method in lifecycle cost analysis (LCCA).

Some of the main drawbacks of employing the majority of existing LCCA models are:

- User costs are excluded in most evaluations [48];
- Preventive maintenance treatments in the policy-making process are ignored [49];
- Evaluating the uncertainty of input parameters is ignored [50].

3.3. Life-Cycle Assessment (LCA)

Life-cycle assessment analysis is one of the presently accessible methods to determine the effects of construction processes on the environment. It is a technique to evaluate the performance of a product, activity or a process from the perspective of its environmental influences in every step. The LCA is authorized and supervised by ISO 14040 for carrying out the various assessment processes. LCA is defined by the Society for Environmental Toxicology and Chemistry (SETAC) as an evaluation process aimed [51] to:

- Identify environmental issues by assessing the materials and energy consumed and released in the environment;
- Determine the effects of these materials and energy on the environment; and
- Ascertain possible methods for environmental development.

According to Muench *et al.* [20], the information collected through LCA databases is very helpful in providing input values for analysis. While this process affords ample information to determine the environmental influence of input parameters, no standard models have been devised to assist airport pavement engineers with conducting LCA. A study carried out by Pittenger [52] reflects that this analysis method is not currently practiced at airports. Moreover, the literature does not provide any assistance regarding the use of LCA in airports.

In the field of LCA for highways, different methodologies are employed to evaluate the environmental effects of LCA. Each method is characterized by significant and unique benefits and drawbacks. Treloar *et al.* [53] found that most presently available methods have one major drawback in their basic intention, which is to promote environmental responsibility among the construction industry rather than encourage environmental sustainability. More recently, various methods have been devised to employ the LCA approach in conducting environmental assessments, for instance by Stripple and Erlandsson [54], Santero *et al.* [55], and Bin Yu *et al.* [56]. The most comprehensive and agreed method incorporates material extraction, construction product manufacturing, the overall construction process, maintenance and operation, and recycling upon life cycle completion. Figure 4 graphically illustrates this life-cycle method of a highway pavement.

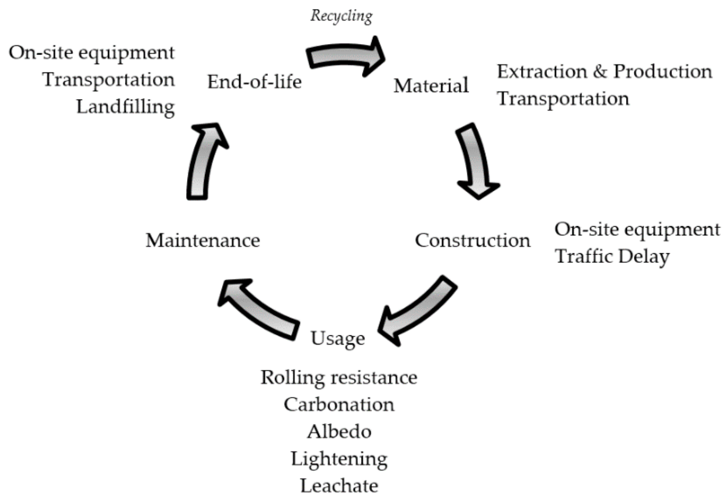

Figure 4. Main structure of a road life-cycle assessment.

Treloar *et al.* [53] asserted that the road construction process has an important role in determining the road's environmental impact. However, with the passage of time, other parameters such as manufacturing and vehicle use and maintenance became as notable as construction. Along with assisting researchers to evaluate and determine the environmental effects of the provided facilities, LCA also bears some drawbacks. Generally, the following are some of the major criticisms of LCA in the literature:

- Policy makers must establish standards for the evaluation process and indicate the potential consequences of activities, since environmental impact is not the main goal of decision makers. Therefore, they deal with rather complicated and incomprehensive models when carrying out assessments for private organizations;
- According to ISO standards, the actual LCA methodology does not account for result uncertainty, validation and robustness in the decision-making process [57];
- Some parameters like biodiversity or biological barrier effects are quite challenging. This is why they are often excluded from an LCA model [54];
- No standard LCA methodology is currently agreed upon. When employed for roads, the LCA is limited only to materials and engine alternatives for construction vehicles. The modules like usage and end of life have gained less attention in previous studies [55].

3.4. Multi-Criteria Decision Analysis (MCDA)

Beria *et al.* [58] defined Multi-Criteria Decision Analysis (MCDA) as a tool for selecting between various projects that have many variables, such as social, economic and environmental impacts. Several authors have recommended MCDA as the most suitable tool to assist with the decision-making process, e.g. Tudela *et al.* [31], Walker [59], and Janic [60]. Significant problems faced when employing multi-attribute decision making are multiple objectives, criterion limitations, and the use of weighting values to evaluate various criteria. The key problem in pursuing MCDA, which remains unresolved, is the difference between partial and objective decisions. The concept is referred to as "the black box" by Sayers *et al.* [61]. This problem arises due to differences in opinions among decision makers. Browne and Ryan [26] addressed this concept and its drawbacks. Three of the basic weaknesses indicated are:

- Qualitative evaluations with personal assumptions incorporated into standard postulations result in decision partiality [62,63];
- Concerns associated with incomparable parameters are not addressed in the decision-making process;
- The black-box effect on the whole process, which may affect result transparency.

Recently, a number of scholars have asserted that assimilating the multi-criteria and cost-benefit techniques may help attain absolute sustainability [26,58,64]. According to Beria *et al.* [58], MCDA is suitable for indirect projects, e.g., anticipation of subsidiary benefits, while the CBA is more appropriate for projects seeking direct and monetized costs and benefits. Beria *et al.* [58] supported this assertion by illustrating it through a decision support model that combines CBA and MCDA. Moreover, Gühnemann *et al.* [32] presented a new approach by integrating the CBA and MCDA methodologies from the perspective of a pavement infrastructure development program.

3.5. Environmental Impact Assessments (EIA)

In 1969, the Environmental Impact Assessment was developed by the National Environmental Policy Act (NEPA) and defined by the International Association for Impact Assessment [65]. The European Commission defined EIA as "*A procedure that ensures the consideration of the environmental repercussion of decisions before the final decision is being made*" [66]. According to Morgan [67], current practices in many countries assure there is still room for process strengthening despite the mechanical and organizational developments in the EIA over the past few decades. The four principal areas that can be improve EIA processes consist of follow-up, monitoring, range and estimation of EIA reports [68]. EIA does not specify the process of how a project underwent manufacturing but only educates on what needs to be done.

Estimating the influence of a pavement project to assist decision-making is defined as the intention of environmental impact assessment. According to USDOT [69], many airports and highways may necessitate environmental assessments in order to fulfill regulatory prerequisites. All powerful impacts like societal, environmental, operational and economic impacts are illustrated in the comprehensive review that is obligatory for existing pavement ventures. As stated by Meunch *et al.* [20], scope documentation and determination as well as collection of impacts are a central goal of the process.

The Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) are mentioned at the European level, where the former is a mandatory regulation for some civil schemes/programs that are likely to have notable impact on the environment. Although SEA and EIA are quite similar, they still differ on many levels. EIA is a plan applicable to a wide range of public and private projects and applied in certain projects, while SEA provides a few details although for more advanced feasibility levels. The EIA and SIA are regarded as the initial step towards sustainability impact assessment and the former must be integrated with other impact assessment tools.

3.6. Social Life-Cycle Assessment (SLCA)

Different approaches have been developed and employed to assess the social effects of projects. A study carried out by Jørgensen *et al.* [70] showed there are a number of insights of social impact assessment (SIA) with regards to social life-cycle assessment (SLCA) approaches. The study indicated that SLCA approaches are yet in developmental stages with room for further development. However, it was also asserted that including relevant consequences in the SLCA is necessary, as this might be helpful in rendering SLCA a dominant and effective decision support tool. The Centre for European Policy Studies (CEPS) and the Evaluation Partnership (TEP) conducted a study in order to explain, compare and examine various means of carrying out SIA. The study was also intended to provide recommendations for further improving the effectiveness of social impact assessment systems and analysis [71]. The study concluded that a need still exists for further development in European systems of social impact assessment. This area is less established than economic and environmental impact assessment, which has resulted in the absence of standard methods for assessing social and distributional effects of transport projects. Therefore, there is ambiguity as to whether to include them in major projects since their evaluation leaves a question mark. Social assessment requires considerable development and it has not become a part of the decision-making process. The European Commission [72] indicated that there is significant scope for social impacts in the area of impact assessment, but economic impact still receives most of the attention. SIA systems are faced with the following challenges in further improvement:

- The term "social impact" is not defined as per its broadness;
- Most social impact assessment systems are based on qualitative analysis methods, allowing for informational gaps. Hence, there is a need to develop quantitative methods of analysis.

As shown in Table 1, all assessment tools have particular benefits and drawbacks, and recognizing these will facilitate decision makers to use them properly.

Table 1. Strengths and weaknesses of appraisal tools.

Appraisal Tools	Strengths	Weaknesses
Cost-Benefit Analysis (CBA)	• Rigorous, transparent and formal. • It is common language, known and used worldwide. • Can be used to show economic efficiency. • Easy communication or results.	• Monetization process is questionable for some intangible aspects. • Does not consider any issue (distributional equity). • Still suffers from serious defects in practical implementation given the difficulty of quantifying various types of environmental costs and benefits.
Life-Cycle Cost Analysis (LCCA)	• Broad concept and comprehensive in economic efficiency. • Consider all direct and indirect costs during life-cycle. • Numbers of software are available to assist users. • The methodology is well-developed, user friendly and easy to communicate.	• Exclusion of user cost in some software. • Difficult to quantify and the values associated with user costs are often disputed. • In many existing pavement LCCA models is the non-consideration of preventive maintenance treatments as a criterion in strategy formation. • Uncertainty of input parameters in LCCA is considered complicated, and is therefore often ignored.
Life-Cycle Assessment (LCA)	• Transparent, well established and comprehensive • Scientists can include the consumption or production of resources like energy or carbon emissions, even if the products are moved to another geographic location or if changed from one form to another.	• Results obtained can be specific and it can be difficult to extrapolate out to all industries or all farms. • Very little inventory data may be available and best estimates are required. • Collecting this data is costly. • Boundaries are different from case to case (defining by researcher).
Multi-Criteria Decision Analysis (MCDA)	• Participation and legitimacy. • Allows qualitative measure. • Multi-disciplinary modelling approach. • Useful in developing social solutions.	• Use subjective qualitative assessment. • Black-Box nature of the methodology. • Issues surrounding the use of weights and how these might be obtained in practice. • Variations in how to combine scores and weights to give an overall project score.

Table 1. *Cont.*

Appraisal Tools	Strengths	Weaknesses
Environmental Impact Assessment (EIA)	• It is well established around the world, with presence in international law and lending institution standards. • The use of EIA at different level of decision-making is growing significantly. • There is a well-developed support infrastructure from professional groupings through to support unites in international agencies.	• There is concern in many countries over the poor quality of impact assessment information. • The resulting practice inertia provides a real challenge to the EIA community as the consequence of poor practice (delays, poor decisions, increased costs to proponents *etc.*)
Social Life-Cycle Assessment (SLCA)	• Broad concept and basic in social impact efficiency. • It has been implemented by using several different approaches. • Multi-disciplinary modelling approach.	• It has not been well-defined due to its broad concept. • Lack of appropriate tools to assess social impacts quantitatively rather than qualitative. • Has not been integrated to other approaches into decision making process. • There remains a considerable uncertainty surrounding what a social impact is and how to estimate it.

4. Pavement Life-Cycle Sustainability

The sustainability of pavement can be assessed by taking into consideration its design, implementation, construction, operation and maintenance [73]. Road safety factors, underlying objective achievement, transport capacity and maintenance are additional key points governing pavement life-cycle sustainability [74]. There are several practices that are collectively considered as requirements for sustainability [20], as shown in Figure 5. These practices involve information gathering and analysis during the planning process and designing stage to assist decision makers. Creating and implementing plans in real life are other practices necessary for a sustainable pavement life cycle.

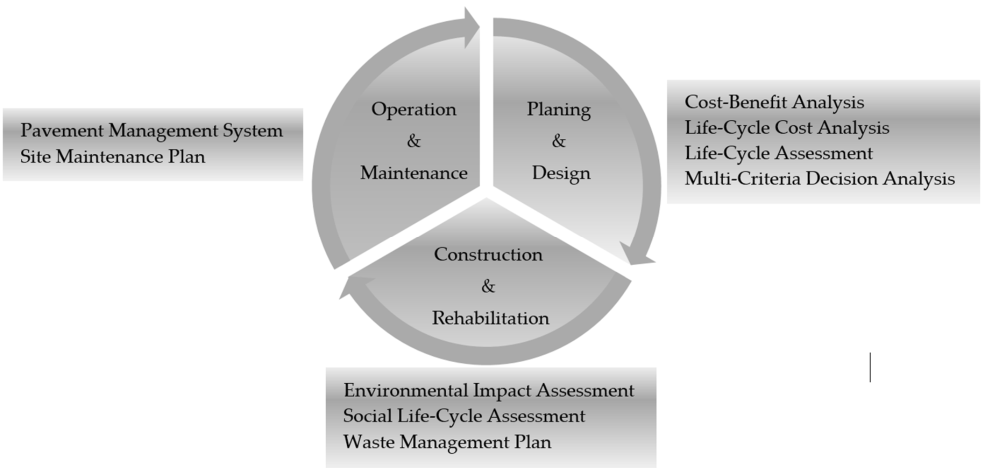

Figure 5. Fundamental practices for pavement life-cycle sustainability.

Not every practice pointed out in Figure 5 can be implemented to specific roads and airports, but the policy's sustainability can be selected either by users or certain stakeholders for their sustainability practice [19]. The implementation of sustainability and its evaluation can together yield a durable, cost-effective pavement based on the net benefits [75].

4.1. Planning and Design Considerations

Sustainability projects have greater influence on the phases of planning and design, as shown in Table 2. Most sustainability considerations are attributed to the first phase [20,76–78]. Moreover, at the planning level, sustainability activities involve forecasting and suggesting improvements to enhance service efficiently and safely. These strategies enhance project durability by minimizing cost, operational disturbance and environmental impact by supporting the design. Pavement sustainability policies and regulations can create hurdles in pavement design and may also interfere with newly developed strategies.

Table 2. Sustainability considerations during project planning and design phases.

Sustainability Benefit	Consideration
Quantify economic/operational impact	Cost-Benefit Analysis Life Cycle Cost Analysis
Quantify environmental impact	Life Cycle Assessment
Quantify sustainability impact	Multi-Criteria Decision Analysis

4.2. Construction Considerations

Sustainable construction can be explained as the process of construction that incorporates the primary matters of sustainable progress [79,80]. The construction process should be in accordance with several principles, including environmental responsibility, social awareness, economic profitability and wider community involvement [81]. The United Nations Environment Programme/International Environmental Technology Centre and The International Council for Research and Innovation in Building and Construction (CIB) presented the following definition of sustainable construction: "*... .a complete procedure intending to re-establish and preserve coordination between the natural and constructed situations, and form agreements that uphold and encourage human self-esteem and boost financial impartiality*" [82]. Although sustainable pavement life-cycle application mostly concerns the energy and material perspectives, the process of construction is the main focus in evaluating the sustainability of pavements [83].

Material extraction, construction equipment, transportation and waste recycling are enlisted in this stage of construction considerations. Monitoring the social effect of the entire energy input and emissions' release can also be added to the list. Moreover, few airports follow certain campaigns like "anti-idling campaigns" to check vehicle emissions and construction materials to enhance the effectiveness of sustainability [84].

4.3. Operations and Maintenance Considerations

Once infrastructure is in place, pavement management activities need to be implemented and major focus should be shifted to the preservation of pavement networks. If a pavement remains safe both structurally and functionally, it is tagged as a well-maintained pavement. In this regard, highly professional serviceability is required. If a pavement necessitates extra servicing during the maintenance phase, the structural capacity of the pavement is deemed to be below normal and such pavement requires rehabilitation rather than maintenance. Pavement evaluation and tracking are the principal activities in this phase. Maintenance strategies and prioritization can also help to predict pavement performance and its purposes, with the Pavement Management System usually being applied [85]. Managers appointed to observe pavements provide short/long term maintenance systematically and identify several steps to be taken for better pavement maintenance. The process is followed for both rigid and flexible pavements.

5. Sustainability Rating Systems and Decision Support Tools

5.1. Rating Systems and Certification Tools

The International Federation of Consulting Engineers (FIDIC) [25] specified that certification tools and rating systems are generally created by reliable governmental and private organizations in association with academic circles. They are expected to analyze, evaluate and arrange existing facilities on the basis of their manageability standards. Table 3 illustrates the most vital manageability certification tools generally used in the infrastructure and transportation fields.

Table 3. Different rating and certification tools.

Tool	Certifying Body	Sector	Country
ASCE	American Society of Civil Engineers	All *	US
CEEQUAL	Institution of Civil Engineers (ICE)	All *	UK
ENVISION	Institute of Sustainable Infrastructure (ISI)	All *	US
IS	Australian Green Infrastructure Council (AGIC)	All *	Australia
GreenLITES	New York State Department of Transport	Transport	US
Greenroads	University of Washington	Transport	US
I-LAST	Illinois Department of Transportation	Transport	US
INVEST	Federal Highway Administration (FHWA)	Transport	US
STARS	Portland Bureau of Transport	Transport	US

* All Infrastructures

Generally, when a project is considered for assessment with a rating system, it necessarily undergoes some minimum, mandatory prerequisites [86]. On the off chance that the project does not fulfill certain requirements, it will not be granted certification. At this point, the project can gain discretionary recognition related to every subdivision. Each rating system chooses the general mass for every classification and subdivision. The ratings of segments and subdivisions are collected and compared. Hence, the venture could guarantee the rating of accomplished recognitions. The correlation between transportation rating frameworks is outlined in Table 4.

Rating systems contain general components that can form part of the certification tools: systematic and strategic environmental performance, water, energy, materials, and innovation [87]. Figure 6 indicates that even though the appraisal tools have set weights and levels that mirror their own particular standards, all of them are in view of comparative operational methodologies. In Figure 6, the perpendicular arrangement represents the rate of total points.

Table 4. Comparison of Sustainable Transportation Rating Systems.

System	Rating Method	Max Point	Certification Level	Category
GreenLITES	Point system	60 points	Silver Gold Evergreen	Sustainable sites Water quality Material Energy Innovation
Greenroads	Point system	118 points	Silver Gold Evergreen	Project requirement Environment Material/Resources Construction Water quality Access/Equity Custom credits Pavement technologies

Table 4. *Cont.*

System	Rating Method	Max Point	Certification Level	Category
I-LAST	Point system	233 points or 153 items	Point system	Planning Design Environment Water quality Transportation lighting Materials Innovation
INVEST	Point system	68 criteria ranging 1–10	Bronze, Silver, Gold, Platinum	Planning/Process Development Project Transportation Management
STARS	Point System	200–600+ points	3 stars4 stars5 stars	Environment Material Innovation Climate/Energy Access/Equity Energy Transportation Water system.

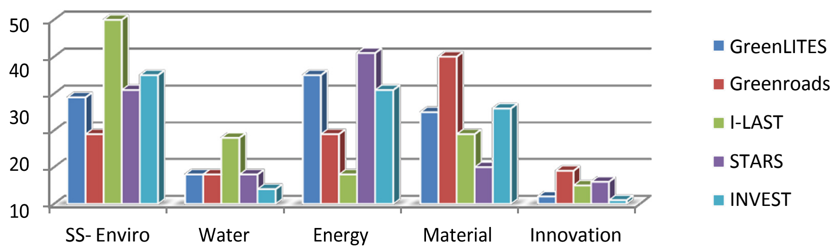

Figure 6. Rating system category percentage of total points.

A few scholars have criticized the rating system's utilization regardless of its expansion throughout the field of civil engineering, by stating that "they need clarity and impartiality in the standard choice and weighting process and are not in light of an institutionalized approach for implementation" [88]. Every rating system comprises a specific weighting methodology. Besides, every rating system functions as a free implementation metric with a specific common theory in assessing sustainability. Nonetheless, there must be some sensibly partiality because of the wide range of activities, area, externalities and other different characteristics. Restrictions and limitations with accessible maintainability assessment tools for infrastructural activities are not necessarily dissimilar by maintainability indicator frameworks for structures. Fernández [3] asserted that in spite of reasonable developments being customarily centered on structures, such rating systems additionally exhibit the following considerable problems:

- The prevalence of environmental characteristics while assessing pavement manageability;
- Uncertainty and subjectivity while choosing criteria, indicators and dimensions [89,90];
- The absence of support and participation from each stakeholder in the project life cycle;
- The number of indicators should mostly be low, but in existing system it is quite high.

5.2. Models and other Decision Support Tools

The International Federation of Consulting Engineers (2012) characterized various models as "Decision Support (DS) tools" and guaranteed they are appraised by systems that utilize multi-criteria analysis methods to survey the sustainability performance of distinctive strategies throughout the design stage assessment. Table 5 demonstrates some accessible DS apparatus for transportation, aviation and infrastructure.

Table 5. Sustainability Decision Support Tools & Guidelines

Tool	Certifying Body	Sector	Country
ASPIRE	ARUP & Engineers Against Poverty	All *	UK
HalSTAR	Halcrow	All	UK
INDUS	Mott MacDonald	All	UK
SPeAR	ARUP	All	UK
Tandem Empreinte	Egis	All	France
MAESTRO	Egis Avia and French Civil Aviation SNA	Aviation	France
SAGA	Sustainable Aviation Resource Guide	Aviation	US
Scottish Transport (STAG)	Transport Scotland	Transport	Scotland
WebTAG	DfT	Transport	UK

* All Infrastructures.

6. Sustainable Pavement Management System

Current pavement management methods are mostly in traditional methods, but adding sustainability to these practices entails so-called "sustainable pavement management". According to Hudson *et al.* [27], additional maintenance and rehabilitation of dilapidated pavements is a viable option from an economic point of view. In the wake of limited fund availability, it would be more appropriate to not only rehabilitate decaying structures but to also conserve pavements that are still in order to some extent. A pavement management system (PMS) involves maintaining pavements adequately, maximizing their function and utility, and extending their service life, thus reducing the spending requirements of pavements. It also ensures enhanced airport security and operation efficiency through judicious use of resources, and it has been implemented by various airports [85,91].

As far as airport pavement sustainability is concerned, it is essential to have an airport pavement management system (APMS) to emphasize on pavement construction, preservation, maintenance and also airport's pavement life-cycle cost analysis. According to Tighe and Covalt [92], the main objectives are to identify the maintenance needs of a pavement, select the best project from available options and implement that plan over a period spanning several years, and assess the long-term impacts of the scheme. Pavement management entails studying the system at various levels, including the strategic level, network level and project level [93]. The detail of these three levels of management, which builds upon Flintsch and Bryce's [94] study, is shown by Figure 7.

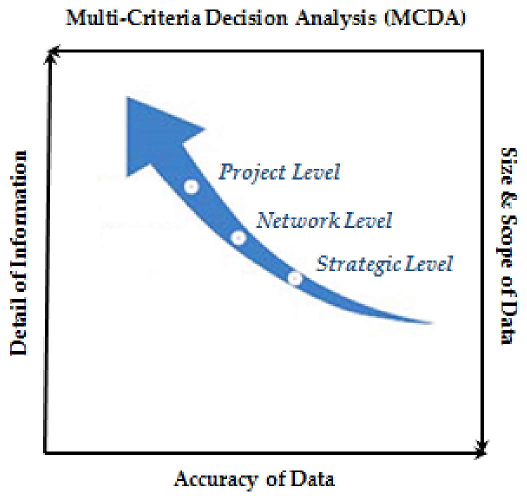

Figure 7. Decision levels in pavement management.

6.1. Implementing Sustainability in Pavement Management

6.1.1. Project Level

At the project level, the options of pavement design, construction model, material type as well as obstruction factor due to the proposed construction should all be reviewed and taken into consideration. For instance, Diefenderfer *et al.* [95] stated a discussion about pavement recycling methods used by the Virginia Inter-state, where it is attempted to reduce the use of building materials, cost and expenditure on projects, and project impact on the public.

Pavement type selection and design are fundamental concerns at the project level of pavement management. In general, this option is viewed from the perspective of life-cycle cost analysis, accessibility to different construction supplies, and local suppliers' knowledge about making use of the available material [96]. However, many more factors can be included and their trade-offs considered in order to make the pavement type selection process more sustainable. Fuel consumption, vehicle operating cost (VOC), discharge levels and time frame also differ for different pavements [97]. Diverse pavement types require different types of maintenance models and original or recycled materials, which will affect the estimate and review of sustainability [98]. Last but not least, what also needs to be considered at this stage is the impact of pavement surface type on lighting needs, carbonation, and urban heat island effect due to pavement albedo and carbonation [55].

6.1.2. Network Level

At the network level, establishing maintenance plans and prioritizing schemes in the context of the triple bottom line of sustainability is the hallmark of sustainable pavement management models. The objectives of network level considerations can be amended so that a multi-criteria approach is adopted in the process of requirement analysis and optimization to attain the highest or maximum results [99]; for example, multi-criteria approach advocated by Giustozzi *et al.* [100] to focus on the preventive aspects of maintenance at the network level.

Bryce *et al.* [101] utilized a probabilistic approach for the network level that is marked by uncertainty during the maintenance phase. For this purpose, Monte Carlo's simulation model was employed to make histograms of energy consumption for different stages of maintenance and rehabilitation along the pavement. To assess extra fuel consumption due to rough pavement structure, the methods introduced by Chatti and Zaabar [97] were used at the network level. While these methods have multiple possible outcomes, the greatest benefit is derived from the risk assessment involved in the process of pavement management.

6.1.3. Strategic Level

Strategic planning is a must in pavement management, whereby managers can set goals and objectives. The AASHTO asset management implementation guide [102] attaches great importance to strategic planning, because without defining plans and strategies, an organization cannot follow its missions and achieve its targets. Strategic planning enables the organization to lay down a plan regarding what the destination, mission and vision are and what funds and resources it has at its disposal to achieve the targets. It also enables enhancing workforce performance to ensure that the goals are being achieved. It is of great importance for an organization to inter-link its aims and targets with the level of achievement in attaining sustainable pavement management.

6.2. Expert Systems in Sustainable Pavement Management

These are computerized advisory programs that are among the most active research areas in artificial intelligence (AI), which function like human specialists when redressing a particular problem in a narrow domain [103]. These knowledge-based systems imitate human skills and judgement through the use of previously provided human experiences. These systems separate field of knowledge and maneuver, while characterizing the information and processing it clearly [104,105]. Computerized programs are more useful than human expertise because they are not temporary, can be easily documented and transferred, and are also cost effective. In the pavement management area, especially in preservation, maintenance and rehabilitation activities, applying expert systems is perhaps the most beneficial for decision makers and stakeholders [106].

Table 6 contains different models and methods evolved over a period of time for solutions to pavement management issues. These methods have been practiced since the early 1980s, but the fact remains open especially in airport infrastructure [107].

Table 6. Sustainable Expert System Application in Pavement Management

Expert System	Development Tools	Sector	Country
ROSE	EXSYS	Highway-Flex.	UK
SCEPTRE	EXSYS	Highway- Flex.	US
PRESERVER	OPSS	Highway-Flex.	US
ERASME	French Shell Insight 2 + Expert System Shell	Highway-Flex.	France
EXPERA	SAVIOR	Highway-Rigid	US
PARES	Mainframe	Highway-Flex.	US
PAVERS	Mainframe	Aviation-Both	US
AIRPACS	NA	Aviation-Rigid	US
PMAS	Pro Instant Expert Plus	Highway-Both	US/Canada
PMDSS	NA	Highway-Flex.	US

7. Discussion & Recommendations

With regards to pavement sustainability, it is evident from the present study that various practical concerns regarding the process linger. Also, it does not provide an explicit explanation and methodology for sustainability which was found to be too wide in scope [108]. This study offers the following suggestions by acknowledging economic, environmental, ecological and social development as the foundation for sustainability:

(1) The triple bottom line in sustainable pavement management is to balance the economic, environmental and social aspects as a parallel exercise to the main part of the design phase, followed by construction, maintenance and rehabilitation till the end of pavement life.

(2) Quantitative methods like CBA and MCDA do not normally come to terms with the requirements of the overall aspects of sustainability. Evaluating incommensurable goods like social and environmental features has been acknowledged as an unsettled CBA problem. On the contrary, the MCDA has been unable to separate the biased through subjectivity in the procedure despite containing all-inclusive criteria like social, environmental and economic aspects. Many opinions have emerged supporting techniques developed for transaction purposes. Also, a lot of comprise tools for the LCCA and the LCA have received support. Moreover, a number of techniques for handling societal effects are not fully developed but nonetheless get appropriate mention in research studies.

(3) It is hoped that in coming years, asset management (AM) plans will become an integral part of strategies regarding infrastructure management with a view to supervising asset investment, the overall show and responsibilities [84]. PMS/APMS upholding the AM, it will evolve over the life-cycle and develop into an advanced phase [85]. Pavement managers will get assistance from the improved techniques while examining the various pavement conditions both structurally and functionally to make decisions like when to repair pavements and how to improve safety levels with limited available resources.

(4) Though the environmental aspects receive significant attention in rating systems and are useful to grade, compare and rank particular projects, they cannot be applied in a real-world sense to construction projects, particularly pavement projects. Each existing model is based on different methods. Generally speaking, except for material management, an all-compassing approach is lacking in existing structures and methods.

(5) New technologies, especially for recycling materials, should come into practice to make pavements not only more eco-friendly but also more strongly-built to endure the effects of time and should be gainful and cost effective [48].
(6) Highly trained and efficient personnel, appropriate technological equipment for assembling information and data for assessment, quantifiable strategic objectives, maintaining clear objectives and goals, and management skills are key features that can guarantee successful, sustainable pavement management.
(7) For best practice, pavement managers should focus on the long term costs rather than short term costs while including the agency's and user's costs in appropriate probabilistic methods during various phases of life-cycle sustainability.

8. Conclusions

Sustainability is still considered as multi-disciplinary steps and difficult to explain for practical purposes. It is not obvious if sustainable development needs be considered as part of a trade-off or as an achievable optimum level. Bringing together the economic, environmental and social aspects while explaining the sustainability criteria is uncertain. Theoretically, it is considered important for the sustainability criteria to be made part and parcel of investment project assessments, but practically, this is not the case because sustainability is a wide-ranging and broad-based concept; moreover, there is no agreement among stakeholders regarding its application, especially in road schemes. Lots of efforts have been made in previous studies, especially focused on conception of sustainable transportation, but still there is lack of a standard framework in assessing progress toward sustainability.

Various assessment methods and techniques were discussed in this research to shed light on different pavement management projects and determining the sustainability assessment of the pavement life-cycle. However, the fact is that projects are examined in accordance with their business utility and determined by factors like the cost and expenditure involved, whereas the sustainability factor is not usually an integral part of the standard assessment process.

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