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Sustainability Assessment of Roadways through Economic and Environmental Impact Life Cycle Analysis

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ABSTRACT: In a sustainable cities' environment, the role of "green" roadways is a critical component to assure the minimal impact in the ecosystem and the well-being of citizens. Sustainability principles can be applied to roadway construction and rehabilitation. They can provide quantifiable means of identifying alternative construction strategies with the least environmental impact and cost. Such objectives can be achieved through economic and environmental impact analysis of sustainable construction design alternatives. This paper presents the steps of an analysis involved in assessing and comparing alternative sustainable solutions by quantifiable means. Sustainability metrics are used for identifying the rating of each alternative and the best sustainable construction strategy. The suggested methodology provided here in can be used to develop an optimization function to identify feasible alternative solutions based on user inputs that generates the higher reduction in cost and environmental impact loads

KEYWORDS: Sustainability, life cycle analysis, environmental impact analysis, sustainability

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I. INTRODUCTION

Objective of roadway sustainability towards the development of "green" citiesis to limit the waste of resources and materials [1, 2], and minimize the impact on the environment. Roadway sustainability involves several stages: assessment of alternative recycled materials in regards to the specific highway applications,evaluation of feasible pavement design alternatives, identification of proper maintenance and rehabilitation methods in time, preservation practices, use of recycling and waste materials, and lifecycle analysis. Several methods of sustainability assessment have been proposed for the various infrastructure components [3, 4, 5, 6, 7].These include analysis and credits for raw/virgin material conservation, use/ reuse of recycling materials and by-products, implementation of life cycle analysis for better allocation of resources, assessment of air quality andemissions, water quality and noise reduction, and effective energy use. In terms of roadway recycling and use of waste products in highway applications several methods and materials have been explored over the years [8, 9, 10, 11, 12]. The proper use of these methods and materials require a careful assessment of the current roadway conditions [13, 14] and a thorough economic analysis of design alternatives through life cycle analysis over the design period [15, 16]. Once feasible alternative rehabilitation design solutions have been selected, sustainability metrics can be used to compare them and identify the best design. The steps of the proposed methodology are presented below.

II. METHODOLOGY & STEPS OF SUSTAINABILITY ANALYSIS FOR ROADWAYS

The first step of the analysis (Step 1) involves the identification of the project site based on "network level" analysis in regards to the conditions of the highway system. Such an analysis is carried out by highway engineers looking at the entire network and identifying which locations and roadway sections are in need of repair and/or replacement. This stage typically involves a systematic assessment of the condition of the highway network through management systems (i.e., Pavement Management Systems, PMS) that are now in place throughout the US [17]. Once the project site has been identified, the current roadway condition has to be assessed to a further extend and detail. Such step involvesdetailed condition surveys, (i.e., at the "project level"), identifying the type of defects on the existing roadway and thus collecting data for rating the condition of the roadway. Objectives of such surveys and analysis are to: (i) assess the homogeneity of the different roadway sections involved in the specific project by considering in-situ variability between sections [18] in terms of structural design and construction materials (Step 2); and, (ii) assess the roadway condition in order to identify structural and functional deficiencies (Step 3). Thus, such steps involve execution of detailed and accurate pavement condition surveys, at the "project level," that may include distress surveys (and/or roughness, bearing capacity and pavement friction measurements). Such data can then be used to assess the overall pavement condition through rating condition indices, for example Pavement Condition Index, PCI, and/or other indicators). These methods have been standardized throughout the years from the various highway agencies [19, 20].

Based on the condition of the pavement structure, proper rehabilitation techniques and materials are identified (Step 4) including in-situ materials and applicable recycling alternatives [21], assessment of the availability of waste products (ex-situ materials), and, applicable permeable/impermeable surface layers to the specific project [22, 23]. The possibility of using available waste materials and by-products from any pertinent demolition and rehabilitation of roadside structures, or the use of waste materials available in the region could provide significant environmental benefits assuming their use can provide economic benefits as well as improvements in both structural behavior and long-term performance [9, 10, 11, 12]. Overall objective of such reuse of materials is to address environmental concerns, reduce the waste of materials and resources, save energy, reduce costs, and improve the quality and performance of roadway materials and structures.

Step 5 involves the development of pavement structural analysis for identifying required pavement structural thicknessesbased on the selected materials, traffic levels and site-specific environmental conditions [24, 25]. Such analysis will provide an initial assessment of material quantities and construction costs (Step 6). Cost estimation requires the use of construction cost data available in the specific region and reflecting local construction practices. An example of such cost information is published regularly in RSMeans construction cost data[26].Life cycle cost analysis (LCCA)is then used [15, 27, 28]for the design period (Step 7) and the environmental impact of each alternative is assessed in terms of greenhouse emissions (GHG) energy and water consumption, hazardous waste generated, and other pertinent parameters [27, 29, 30].

In addition to the environmental benefits, sustainability metrics are used in order to rank with a score the benefits of each sustainable alternative and reward best practices (Step 8)[4, 5, 6, 7, 31]. Finally, optimization analysis can be used (Step 9) to select the best/ optimum solution among the various alternatives considered for a specific project/ case study. In summary, the steps of the methodology are listed next:

- Identify project site location for rehabilitation (site specific characteristics and materials);
- Survey current roadway/pavement condition;
- Rate roadway/pavement condition;
- Identify applicable pavement recycling methods, available recycled materials (in-situ) and waste products (ex-situ), and possible permeable/impermeable surface layers applicable to the project;
- Compare pavement structural design for conventional strategy (i.e., no recycling)andalternative sustainable strategies;
- Calculate conventional and recycled/waste material quantities and costs for each strategy through life cycle cost analysis;
- Develop life cycle analysis of environmental impacts for conventional andsustainable strategies;
- Estimate sustainability credits and compare sustainable strategies to conventional one.
- Identify bestsustainable strategy throughoptimization analysis.

III. SUSTAINABILITY ANALYSIS CASE STUDY

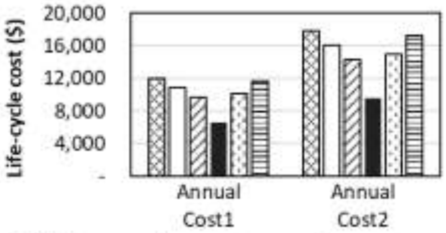
Life cycle cost analyses involve all costs associated with the roadway construction during the entire performance period and it includes initial construction, routine maintenance and future rehabilitation. Such analyses are based on the cost of materials, labor and transportation, to and from the construction site, and using economic indicators of the value of construction costs spread over time through the discount rate. Two approaches of economic analysis may be used for comparing the different sustainable alternative strategies, net present value (NPV)and uniform annual cost (UAC)[15]. The major input parameters that are included in such sustainability analysis areas follows:

- Physical dimensions of roadway project;
- Virgin and recycled materials available from the construction site and the region;
- Thickness requirements based on traffic and materialsused;
- Performance period
- Local materials processing cost and pertinent construction actives;

- Discount rate;

These inputs may include physical features of the roadway project, such as length and width of travel lanes, shoulders, embankments; characteristic of virgin and recycled materials available in the region and the construction site; thickness requirements based on structural analysis to address traffic and material properties used in generating the alternative sustainability solutions; performance period for the analysis; cost of materials, processing, labor, equipment and transportation for the region; and discount rate.

PaLATE [27] is one of the available tools developed for sustainability analysis and was used in the current study. The selected example included a concreteroadway system with two structural layers (a Portland cement concrete, PCC, slab and a granular base layer, GAB) for a two-lane roadway7.32 m wide and 1.6km long. The layer thicknesses for each sustainable alternative was calculated using the AASHTO 1993 pavement design method [24]with aninitial design service life of 20 years and a performance period of 40 years,and one major rehabilitation. Five sustainable alternative strategies were considered in addition to the reference one, referred to herein as the “Reference” strategy where only virgin materials were used (i.e., no recycled materials). The five sustainability strategieswere as follows. “Strategy 1-50% RCA,” with50% recycled concrete aggregate (RCA) in the concrete layer and 100% RCA in the granular aggregate base (GAB); “Strategy 2-100% RCA,” with100% RCAin concrete and 100% RCA in base layer; “Strategy 3- 40% RAP” with 40% recycled asphalt pavement (RAP)as aggregate in concrete and 100% RAP in the base layer; “Strategy 4-100% RAP” with100% RAPin concrete and 100% RAP in the base layer; and “Strategy 5-20% FS” with20% foundry sand (FS) in concrete and 100% RCA in the granular base. Such alternatives were selected representing available recycled materials in the vicinity of the project site and producing acceptable material properties and performance as reported in the literature and past roadway projects [8, 10, 12]. The economic analysis module of PaLATE was used to calculate the life cycle costof roadway construction (i.e., including cost and transportation of materials, labor and equipment for the construction, maintenance and rehabilitation), and the results are shown in Figure 1. In all cases, the alternative sustainable strategies provided a lower cost in relation to the “Reference” strategy when only virgin materials were used. In some cases the savings were in the order of +40%, indicating thus that use of recycled materials on roadway construction can provide significant economic savings.



	Annual Cost1	Annual Cost2
▧ Virgin	$10,858/year	$16,053/year
☐ RCA 50%	-9.6%	-9.9%
▨ RCA 100%	-19.3%	-19.9%
■ RAP 100%	-44.8%	-46.3%
⬚ RAP 40%	-15.7%	-16.2%
⊟ FS 20%	-2.7%	-2.8%

Figure1:LCCA based on UAC for sustainability alternatives
Note: Annual Cost 1 (at a 3% discount rate), Annual Cost 2 (at a 6% discount rate).

The environmental module of PaLATE was used to assess the life cycle environmental impact of several alternatives.The analysis included a study of energy and water consumption, air emissions (i.e., greenhouse gas), fume pollution, as well as the discharge of metals and organic contaminants (including the polycyclic aromatic hydrocarbons). As it can be seen from the concrete layer results of Figure 2, potential benefits of reducing the environmental impact in relation to the “Reference” strategy depends on the type and amount of recycled materials used in each case. While the difference in environmental effects between alternative strategies may seem small in some cases, it should be considered that these analysis are based on a 1.6km length of roadway. Thus, such effect could be significant in function of the size of the construction project. In terms of hazardous waste reduction, CO_2 and NO_x emissions, fume pollution (PM_{10}), as well as energy consumption, the 40% RAP and 100% RAP alternatives (i.e., Strategies 3 and 4) provided the highest reduction. For the FS 20% (i.e., Strategy 5), as well as the 50%RCA and 100% RCA options (i.e., Strategies 1 and 2) the environmental effects were comparable to the “Reference” strategy.

In each alternative sustainable strategy the material production has the higher impact on the environmental effects (i.e., energy, water, emission) followed by transportation and construction processing. Example of such effects are shown in Figures3 and 4. Material production involves abundant chemical reactivity as well as physical processing activities like milling, crushing, heating, etc. Transportation mainly refers to transporting existing materials to landfill and hauling new materials to the construction site. Processing is related to the equipment used in construction and rehabilitation stages, such as paving, full-depth reclamation, rubblization, etc. Similar analyses in regards to the base layer of the roadway structure were considered as well.

In order to identify the best sustainable strategy, both economic and environmental effects should be considered. In such an analysis a relative weight of each parameter should be considered. BE^{2}ST-in-Highways^{TM} is a sustainability metrics tool that considers such effects, and thus was used to conduct the current analysis [31]. An example of such weighting factors is shown in Table 1. The weights can be adjusted to reflect the policy of each agency, as well as the reality of each region in terms of what parameters of sustainability are more important than others. In the current study, an economic and environmental impact analysis was conducted to assess the effectiveness of each sustainability strategy to meet specific targets that an agency can identify (Table 2).

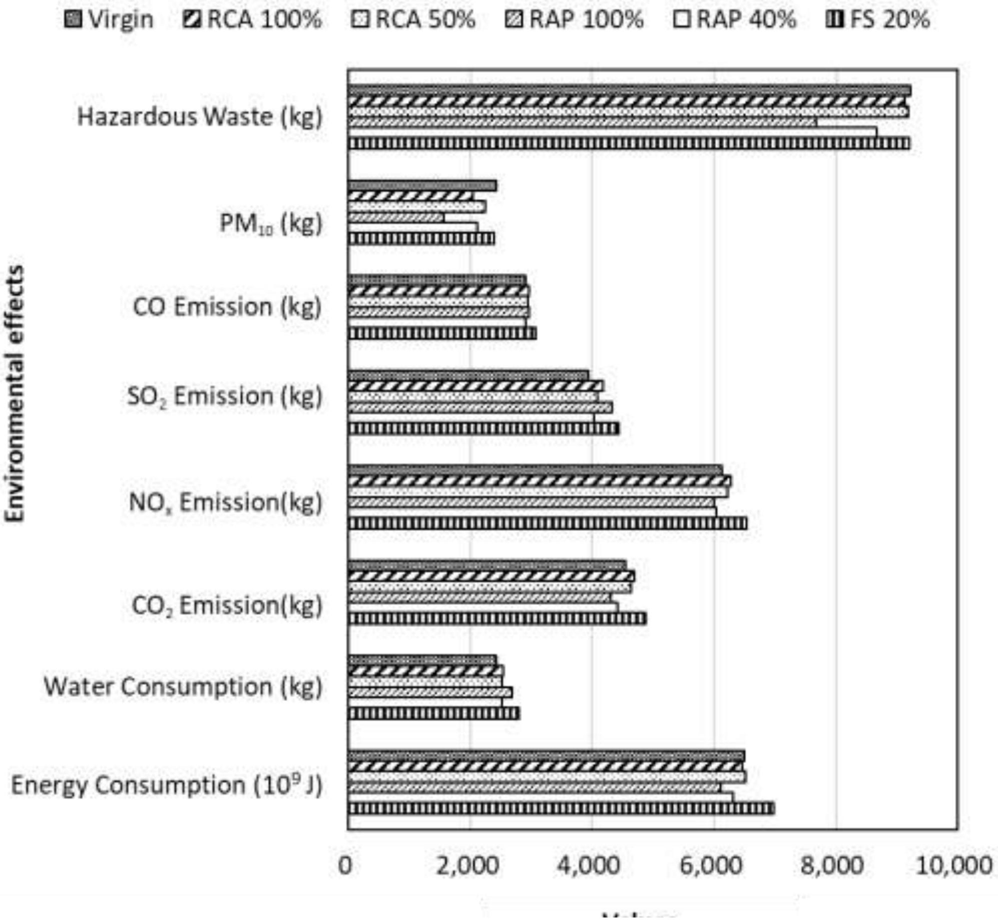


Figure 2: Life-cycle environmental analysis of concrete layer.

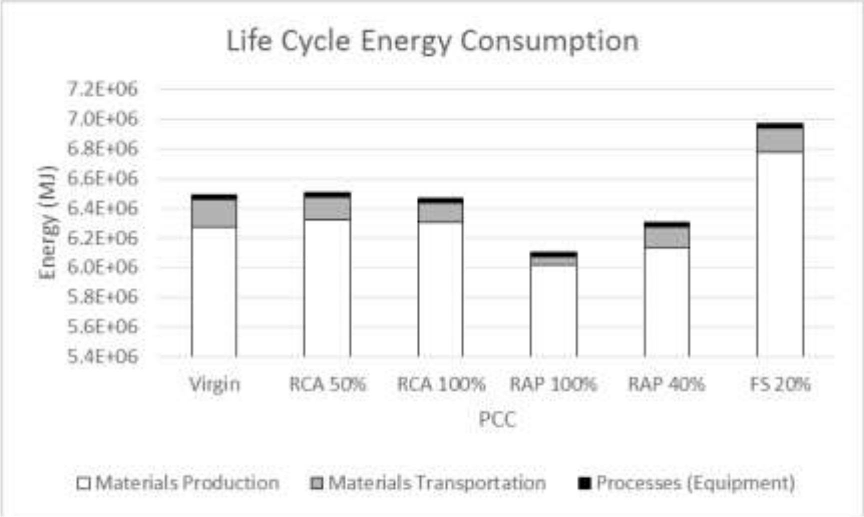


Figure 3: Life-cycle energy consumption pertinent to concrete layer.

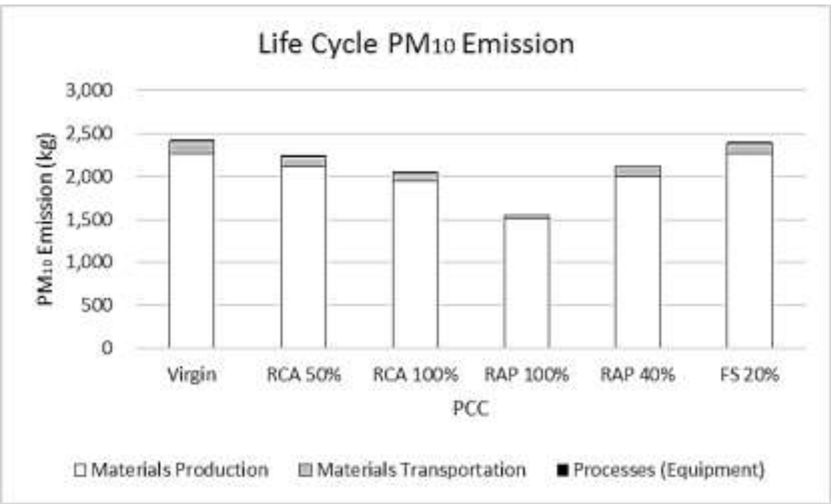


Figure 4: Life-cycle PM_{10} emissions for concrete layer.

In addition to the life cycle cost analysis (LCCA) the environmental effectsare accessed in BE^2ST-in-Highways^{TM}through energy consumption,global warming potential (GWP) through CO_2emissions,social carbon cost (SCC), water consumption, in-situ recycling, ex-situ recycling, traffic noise, and hazardous waste. SCC is the cost to reduce global warming, often used by highway agencies to enforce sustainable construction, andis based on $/ Mg of CO_2emissions [31].This sustainability metrics approach assigns points in relation to the ability of each strategy to reduce cost and environmental impact. In the example of Table 2, "Strategy 4" is awarded with 1 point if energy is reduced by 10% in relation to the "Reference" strategy, and 2 points if energy reduction of 20% is achieved. Similarly target values for the remaining sustainability assessment components are used (Table 2).Such targets can be adjusted to reflect the objectives and policy of each agency and reflecting the reality of each region. Positive performance in terms of sustainability is the degree of achievement in reducing the consumption of resources, reducing the generation of gas and hazardous waste, cutting down the costs, and increasing recycling rate. Positive performance impliesthat more environmental benefits are gained, while negative performance means more environmental loads are caused.This approach is similar to several of the sustainability metrics tools available today, including the well acceptedLeadership in Energy and Environmental Design (LEED) system for green building [3].The results in Table 2 reflect theeconomic and environmental impact analysis of the combined effects of the concrete and base layers for the roadway structurepertinent to "Strategy 4." As data reveals, there is a significant reduction in both economics and environmental impact from the "Reference" strategyin which no recycling materials were used. The results for each strategy can be visually represented with anAmoeba graph (Figure 5)to provide a quick and visual assessment of the effectiveness of the specific strategy in addressing the sustainability targets, and to identify which areas need to be addressed the next time around a new alternative sustainability strategy is generated. As mentioned above, noise component was not used in the current analysis.

The total rating for each strategy was then calculated from the sum of scores obtained by multiplying the level of compliance in regards to the sustainability targets (as those shown in Table 2 for Strategy 4) multiplied by their relative weights (Table 1). “Gold” sustainability label was awarded for a total score between 100 and 90, “silver” for a score between 90 and 75, and “bronze” for a score between 75 and 50. A score of less than 50 implies the pavement strategy is not considered as “green,” like in the case of the “Reference” strategy where only virgin materials were used with no recycling. The sustainability scores for all the strategies are listed in Table 3.“Strategy 4- 100% RAP” was the only one awarded the “gold” label and thus represented the best sustainability strategy for this project. When multiple sustainability alternatives need to be considered for the same project or multiple projects, an optimization function should be developedso as to save time and effort conducting such analysis, generating all feasible alternatives and identifying the optimum solution in each case (Figure 6). Objective of the optimization function is to identify feasible alternative solutions based on user inputs that generates the higher reduction in cost and environmental impact loads. Such a function can be identified based on the identified sustainability criteria and targets like those defined in Table2.

Table 1: Weighting System

Sustainability Indicators	Weight Factors (%)
Energy	10.00
Global Warming, GWP	10.00
In situ Recycle	15.00
Ex situ Recycle	15.00
Water Consumption	10.00
Life Cycle Cost, LCC	15.00
Social Carbon Cost, SCC	10.00
Hazardous Waste	15.00
Total	100.00

Table 2:BE^{2}STSustainability analysis results for“Strategy 4.”

Criteria	Unit	Target	Reference Strategy	Sustainable Strategy 4	Percent Reduction	Score
Energy Use	MJ	>= 10% Reduction (1 pt)	15,213,544	10,463,405	31.22%	2.00
		>= 20% Reduction (2 pts)				
Green House Potential, GWP	Mg	>= 10% Reduction (1 pt)	1,066	739	30.68%	2.00
		>= 20% Reduction (2 pts)				
In situ Recycling	CY	>= 10% Recycling Rate (1 pt)	0.00	0.5000	50.00%	2.00
		>= 20% Recycling Rate (2 pts)				
Ex situ Recycling	CY	>= 10% Recycled Content (1 pt)	0.00	0.4268	42.68%	2.00
		>= 20% Recycled Content (2 pts)				
Water Consumption	kg	>= 5% Reduction (1 pt)	5,381	4,434	17.60%	2.00
		>= 10% Reduction (2 pts)				
Life Cycle Cost LCA	$	>= 10% Reduction (1 pt)	1,097,804	609,609	44.47%	2.00
		>=20% Reduction (2 pts)				
Social Carbon Cost, SCC	$	>= $19,750/mi Saving (1 pt)	$69,290.00	$48,035.00	$21,255	1.08
		>= $39,500/mi Saving (2 pts)				
Hazardous Waste	kg	>=5% Reduction (1 pt)	21,811	15,722	27.92%	2.00
		>=10% Reduction (2 pts)				

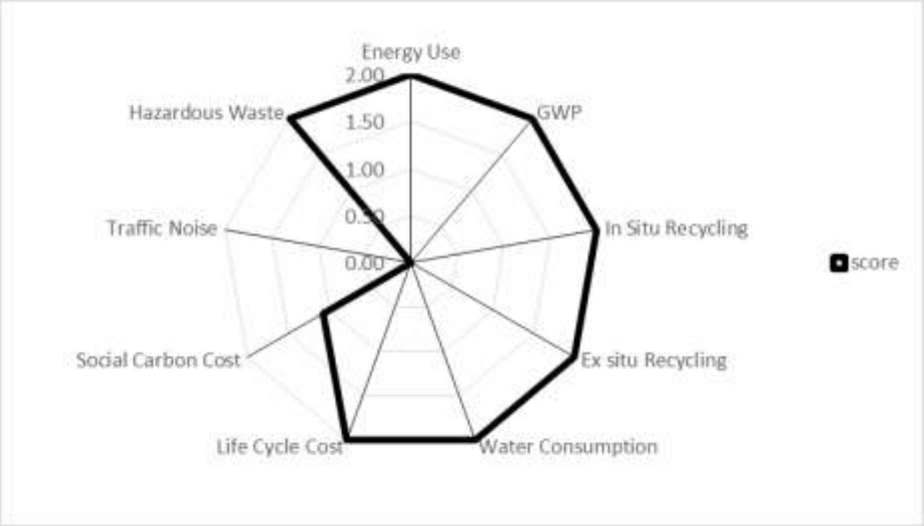


Figure 5: Amoeba graph for sustainable "Strategy 4."

Table 3: Rating of BE^{2}ST-in-Highway rating for alternative sustainability strategies.

Sustainable Alternative	Score/ Label
"Strategy 1-50% RCA"	70% / Bronze
"Strategy 2-100% RCA"	50% / Bronze
"Strategy 3-40% RAP"	73% / Bronze
"Strategy 4-100% RAP"	93%/ Gold
"Strategy 5-20% FS"	58% / Bronze

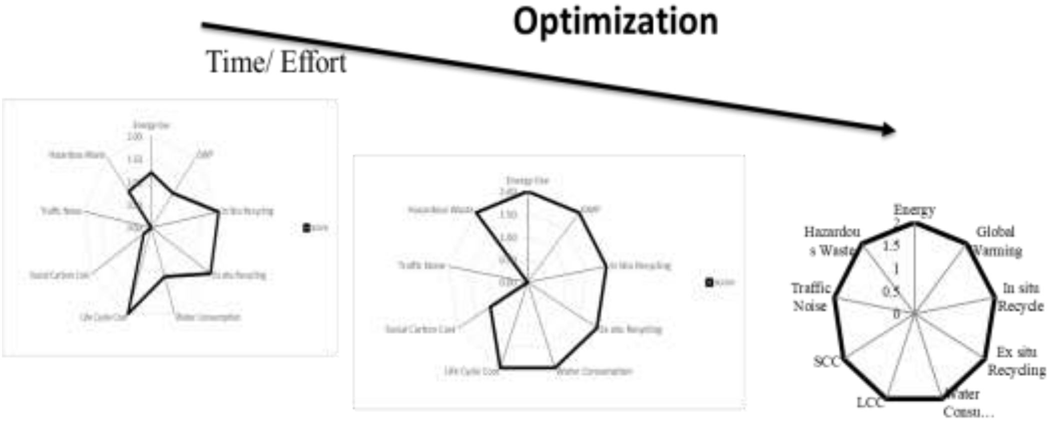


Figure 6: Optimum strategythrough optimization

IV. CONCLUSIONS

Sustainability has received significant attention over recent years by the industry, academia, highway agencies and the general public. Sustainability principles applied to the design, construction, maintenance and rehabilitation of civil infrastructure can provide significant benefits in safeguarding natural resources, minimizing the impact in the natural ecosystem and providing potentially economic benefits. This paper presented a methodology for developing sustainable strategies for roadway construction. The various steps of the methodology were presented with particular emphasis on the life cycle economic and environmental impact analysis, as well as sustainability metrics and rating. Results from a case studywere presented so as to demonstrate how economic and environmental impact analysis can provide quantifiable means for comparing alternative sustainability strategies for roadway construction. When multiple sustainability alternatives need to be evaluated, the development of an optimization function is recommended so as to save time and effort in assessing all feasible alternative strategies and identifying the optimum solution. The methodology and analyses presented herein are adaptable and transferable to other regions for sustainability assessment of roadway construction.

REFERENCES

[1]. Federal Highway Administration, FHWA. Sustainable Highways Self-Evaluation Tool: Compendium of System Planning and Processes, Project Delivery and Operations and Maintenance Criteria—Pilot Test Version, 2011.

[2]. Goulias D., Roadway Sustainability for Smart Cities, 4th IEE Smart Cities Symposium, May 24-25, 2018.

[3]. U.S. Green Building Council, USGBC, Leadership in Energy and Environmental Design, LEED, 2013.

[4]. Bevan, T., L. Reid, A. Davis, T. Neuman, K. Penney, S. Seskin, M. VanZerr, J. Anderson, S. Muench, C. Weiland, T. Ramani, J. Zietsman, J. Crossett, C. Crocker, and J. Schulz. INVEST: Sustainable Highways Self-Evaluation Tool. Version 1.0. Federal Highway Administration, 2012.

[5]. Institute for Sustainable Infrastructure, ISI, Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design. Envision, Version 2.0. A Rating System for Sustainable Infrastructure. 2012.

[6]. Muench, S. T., J. L. Anderson, J. P. Hatfield, J. R. Koester, and M. Söderlund. Greenroads Manual. Vol. 1.5. University of Washington, 2011.

[7]. New York State Department of Transportation, NYSDOT. GreenLITES Draft Operations Certification Program. 2012.

[8]. Transportation Research Board, TRB, NCHRP Synthesis 435. Recycled Materials and Byproducts in Highway Applications, Vol.1- 6. 2013.

[9]. Goulias. "Design, Behavior, and Benefits of Highway Materials Using Recycled Tire Rubber," Beneficial Use of Recycled Materials in Transportation Applications, Air & Waste Management Association, Vol. 114, pp. 545-552. 2003.

[10]. Kim H., Goulias D., Shrinkage Behavior of Sustainable Concrete with Crushed Returned Concrete Aggregate,CCA. ASCE Materials Journal. Vol 27, Issue 7. 2015.

[11]. Upadhyaya S., Goulias D., Obla K. Maturity-Based Field Strength Predictions of Sustainable Concrete Using High-Volume Fly Ash as Supplementary Cementitious Material." ASCE Journal of Materials Vol 27 Issue 5, 2015.

[12]. Khosravifar S., Schwartz C., Goulias D. Mechanistic Structural Properties of Foamed Asphalt Stabilized Base Materials." International Journal of Pavement Engineering. Vol 16, Issue 1. 2015.

[13]. Federal Highway Administration. FHWA, Distress Identification Manual for the LTPP Program, 4th edition, Washington, DC. , 2003.

[14]. America Society ofTesting and Materials, ASTM, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys, ASTM D6433. 2018.

[15]. Federal Highway Administration, FHWA. Improving Transportation Investment Decisions through Life-Cycle Cost Analysis. 2013.

[16]. American Concrete Pavement Association, ACPA. Life-Cycle Cost Analysis: A Tool for Better Pavement Investment and Engineering Decisions. Engineering Bulletin EB011. 2011.

[17]. Federal Highway Administration, FHWA. Guidelines for Development and Approval of State Data Quality Management Programs, 2018.

[18]. Scott M., Goulias D. Effective use of GPR Data in PMS for Identification of Homogeneous Sections with Uniform Pavement Thickness & Assessing Thickness Variability: A Multi-Scale Approach. 9th International Conference on Managing Pavement Assets, May 18-21, 2015.

[19]. Cafiso S., Di Graziano A., Goulias D., Delfino M., D'Agostino C. Assessing the Relationship between Pavement Roughness and Distress Surveys for Data Collection in PMS. 98th Transportation Research Board Annual Meeting. January 13-17, 2019.

[20]. Federal Highway Administration, FHWA. Practical Guide for Quality Management of Pavement Condition Data Collection. 2013.

[21]. Transportation Research Board, TRB, NCHRP Synthesis 421, Recycling and Reclamation of Asphalt Pavements Using In-place Methods. 2011.

[22]. American Concrete Institute, ACI, Report on Pervious Concrete, 522R-10. 2010.

[23]. National Ready Mix Concrete Association, NRMCA, Portland Cement Pervious Concrete Pavement: Field Performance Investigation on Parking Lots and Roadway Pavements. 2007.

[24]. American Association of State Highway and Transportation Officials, AASHTO, Pavement Design Guide, 1993.

[25]. Transportation Research Board, TRB, National Cooperative Highway Research Program (NCHRP). 2004. Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. 2004.

[26]. RSMeans, Building Construction Costs. 2018.

[27]. Recycled Materials Resource Center, RMRC, Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects, PaLATE, 2003.

[28]. International Organization for Standardization, ISO. Environmental Management: Life Cycle Assessment, Principles and Framework. Standard 14040. 2006.

[29]. Mukherjee, A., Stawowy B., Cass D. 2013. Project Emission Estimator: Tool for Contractors and Agencies for Assessing Greenhouse Gas Emissions of Highway Construction Projects. Transportation Research Record Journal Vol 2366 pp 3-12. 2013.

[30]. Wang, T., I. Lee S., Harvey J., Kendall A., Lee E., Kim C. UCPRC Life Cycle Assessment Methodology and Initial Case Studies for Energy Consumption and GHG Emissions for Pavement Preservation Treatments with Different Rolling Resistance. Research Report UCD-ITS-RR-12-36. 2012.

[31]. Recycled Materials Resource Center, RMRC. Building Environmentally and Economically Sustainable Transportation-Infrastructure-Highways. BE^{2}ST-in-Highways User's Manual. 2012.

D Goulias" Sustainability Assessment of Roadways through Economic and Environmental Impact Life Cycle Analysis" International Journal of Computational Engineering Research (IJCER), vol. 08, no. 12, 2018, pp 01-08