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Evaluating Sustainability Rating System for California Infrastructure Construction Projects

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Abstract: The use of the sustainability rating systems in infrastructure construction projects is not as common in comparison to building construction projects. While the sustainability rating systems share some commonalities, they differ from one another in certain ways. Thus, project teams cannot make reliable decisions when choosing the best sustainability rating tools for a given infrastructure projects. The Department of Transportation (DOT) in several states are developing its own rating system to address the infrastructure sustainability, but not in the case of California. Therefore, this paper presents the statistical results on the important sustainability determinants that affects the success of meeting sustainability goals of infrastructure construction projects. The authors conducted an online survey using the structured questionnaires. The categories considered include site, water/wastewater, energy, materials/resources, environmental, and others. The statistical analyses such as Kruskal-Wallis and ANOVA are conducted using a total of 25 valid and complete data out of 59 surveys collected. The results demonstrate several factors under each of six major sustainable categories have received higher ranks than other factors. The results also show that a statistically significant difference can be found from water, energy, and environmental categories against the other category based on the pairwise comparisons.

Key words: Sustainability, Infrastructure, Assessment, Determinants, Quantitative analysis

1. INTRODUCTION

The transportation industry significantly contributes to greenhouse gas emissions, generating an average of 6 billion metric tons of carbon dioxide each year between 1990-2016. Carbon dioxide (CO_2) from fossil fuel combustion is responsible for almost all greenhouse gas (GHG) emissions from transportation sources. The transportation industry comprised of 29% percent of the total U.S. energy consumption in 2017. U.S. consumption of energy equated about 17% of the world's total energy consumption in 2016 (EIA 2018). It is evident the transportation industry has a significant impact on the environment and the consumption of natural resources. Transportation systems have considerable correlation to the quality of life. Therefore, implementation of sustainability transportation systems is necessary for present and future benefits. For example, transportation systems provide transportation for distribution of goods and services, access to health care and education, and personal mobility.

Transportation is the second-most energy-consuming sector in the United States out of five main energy consuming sectors including electric power, industrial, residential, transportation, and commercial (EIA 2018). Reducing energy use for transportation requires immediate action if we hope to ensure climate resilience and a livable future for future generation. There is an obligation to ensure distribution of resources for all people. The obligation refers to the right of all people equal share of materials, land, energy, water, and environmental quality. Sustainable development provides the needs of the present without compromising resources for future generations. One of the solutions for consuming less energy could be sustainable development in primary energy consumption sectors with the aim of limiting consumption of natural resources such that present needs are met while ensuring future generations' access to adequate reserves (WCED 1987). Black (2010) identified four issues to be resolved to maintain sustainable development in transportation systems, including consumption of limited resources, injuries caused by traffic congestion, heavy traffic congestion, and damage to the environment. Because of the profound impact that U.S. highways have on sustainable transportation efforts, it is essential to consider the perspective of the regulatory body governing highway projects. The Federal Highway Administration (FHWA) defines sustainability in highways as giving equal weight to environmental, economic, and social values. This definition means that sustainable highways are supposed to aim for safety, mobility, environmental protection, livability, asset management, and effective cost management in the life cycle of highways (FHWA 2018). Because the world's limited sources need urgent care, the construction industry has become more interested in sustainable development (Reeder 2010).

Many rating systems for the infrastructure and transportation projects have been developed and under development using the point-based system like the United States Green Building Council (USGBC)'s LEED system for building construction (USGBC 2018). However, the use of these sustainability rating systems in infrastructure projects, especially in the transportation sector, is not as common as in building design and construction. A sustainability rating system focused on transportation sector would improve environmental and sustainability factors in construction for transportation systems including airports, roads, highways. A focused transportation sustainable rating system would aim to address reduce consumption of limited resources, injuries and economic impacts caused by traffic congestion, damage to the environment while aiming to improve safety, mobility, environmental protection, livability, asset management, and effective cost management in the life cycle of highways. While there is limited industry guidance on sustainable transportation construction practices, several states have developed its own transportation rating system. Simpson (2013, 2014) compiled and compared ten rating systems to develop a framework for Colorado DOT, South Dakota DOT, Utah DOT, and Wyoming DOT. While the methods and criteria of these rating systems share some commonalities, they differ from one another in certain ways. It might be difficult for decision-makers to choose the best sustainability rating system for their project's evaluation. Thus, a thorough and comprehensive research in this area is needed, as it helps project teams make reliable decisions in the best sustainability assessment tools for a given infrastructure project. This paper aims to fulfill a gap in the literature by evaluating the most important sustainability determinants for California infrastructure construction projects so that transportation agencies, professionals, federal and local governments have the ability to make more effective and efficient decisions about which sustainability assessment tools is best fit for their projects.

2. RESEARCH OBJECTIVES AND METHOD

The objective of this paper is to determine the important sustainability determinates that affect the success of meeting sustainability goals of California infrastructure construction projects. In doing so, the authors created an online survey for the quantitative analysis to evaluate the sustainability characteristics that infrastructure industry professionals currently consider.

Statistical methods are used to analyze the quantitative analysis of 7-point Likert scale data for six major sustainable categories and their related factors. First, descriptive statistics such as the means, medians, and standard deviations were presented to describe the data distributions. Second, to verify the assumption of normality before performing a hypothesis test, the normality tests using Anderson-Darling test were conducted for each of the six major sustainable categories and criteria. If the p-value obtained from the normality test is greater than the significance level of 0.05, then the null hypothesis that the data follow a normal distribution is not rejected and it can be confirmed by the normality graph that shows the data points are relatively close to the fitted normal distribution line. Third, Bartlett's tests of homogeneity of variances are conducted to identify equal variances of interval-level dependent variables among six major sustainable categories that are independent variables. The equal variance tests examine the null hypothesis of no difference in variances between the sustainable categories. Fourth, based on the status of parametric assumptions such as normal distribution and equal variance, Kruskal-Wallis test was conducted to determine whether the medians of six major sustainable categories differ. The Kruskal-Wallis statistic helps us to test the hypothesis that all population medians are equal among categories. If the null hypothesis of equality of population medians is rejected, then the individual categories were compared using a pair-wise comparison. As an alternative test, one-way Analysis of Variance (ANOVA) was also considered because the survey data has 25 points for six major sustainable categories, which meet the sample size guideline. One-way ANOVA also performs very well with skewed and nonnormal distributions, and it has more power. Minitab 20, the latest version of one of the statistical software packages, was used for statistical analysis (Minitab 2020).

3. SURVEY DESIGN AND DATA COLLECTION

The authors designed an online survey questionnaire based on the information gathering from the literature. We used the Qualtrics program, which is a simple and secure web-based survey tool used to conduct survey research, evaluations, and data collection activities. The survey consists of four major components including background information, insights of existing sustainability rating tools and their applicability in California infrastructure construction projects, six major sustainability categories and their related factors, and open questions on performance measures and improvements. We used a 7-point Likert scale to effectively analyze their opinions on how important each category and factor are to sustainable infrastructure construction projects in California. The authors identified six major categories common to existing sustainable transportation rating systems including site-related category, water and wastewater-related category, energy-related category, materials and resources-related category, environmental-related category, and others category. The authors collected online survey data from October to December 2021. The total number of individuals who attempted the survey was 59 people. Of those 59 surveys, some respondents did not actually complete the survey as the data show that they started the survey but did not finish it, resulting in the progress rate of less than 100%. These incomplete survey data were eliminated from the data analysis. Of those 59 surveys, 25 respondents' surveys (42.4 %) have the validity as indicated as "True" in the survey once it was completed, and their responses were only used for the data analysis.

4. DATA ANALYSIS AND FINDINGS

4.1. Analysis on Existing Experiences of Infrastructure Sustainability Systems

To understand the respondents' background and prior experiences on existing infrastructure sustainability systems, the respondents were asked to answer the number of years working in infrastructure construction projects. Respondents used for data analysis possess an average experience of 17.96 years (SD = 9.95) with a median of 18 years. The respondents are classified as engineers/designer, construction managers, and government agency employees for 55.6%, 13.9%, and 30.6%, respectively. The average number of projects they used any sustainability rating systems available in the industry is 8.68 projects (SD = 3.95) with a median of 3 years.

The respondents had used Envision® the most, followed by, others and INVEST for 77.8%, 3.7%, and 18.5%, respectively. Four of 25 respondents used USGBC's LEED rating system and 1 of them adopted internal policy to use "low impact" concrete and asphalt having 30% fewer emissions. The respondents considered "meeting the commitment of the organization’s sustainability goals" as the major purpose of the usage for the sustainability rating systems for California infrastructure construction projects. The quantifications of the triple bottom lines have the percentages of 23.08%, 13.46%, and 11.54% for the environmental, economic, and social benefits, respectively. The respondents weighed the importance of obligation to funding source and others for 7.69% and 3.85%, respectively. The other includes that the requirement of the local agency needs to be considered and that the rating system can be used as a thought framework that integrates sustainability and environmental principles in all design phases.

The survey results demonstrate 44% of respondents do not agree the necessity of Caltrans' own sustainability rating systems as a standalone system, 20% of them neither agree nor disagree, and 36% of the respondents agree California DOT needs its own sustainability system. The response result triggers further questions regarding which of the existing sustainability rating tool fits best for California transportation infrastructure construction projects.

The respondents were asked to suggest the assessment methods when developing a sustainability rating system for California infrastructure construction projects. The responses indicate that the percentages for guidance manual, self-assessment, scoring system, third-party, and others for 28.8%, 25.0%, 23.1%, 17.3%, and 5.80%, respectively. The result means that most respondents think a guidance manual is needed to measure the sustainability of infrastructure construction projects. The respondents were asked to indicate in which stage the development of a sustainability rating system for California infrastructure construction projects is most beneficial. The result indicates that the rating system is most beneficial at the conceptual and design stages for 44% and 24%, respectively, while 32% of the respondents did not specify the any stages.

The measurement methods for development of a sustainability rating system for California infrastructure construction projects were asked to indicate from the prescriptive measures, performance measures, comparing to existing projects that were awarded, and others. The response showed that prescriptive measures and performance measures toward awarding credits are most beneficial at the percentages of 48.6% and 40.5%, respectively. Prescriptive measures require a project team to satisfy a certain standard to achieve the credits while performance measures require an entire structure or its elements to perform up to a pre-specified standard. Other opinion was that a comparative approach can be used to allow for unique credits to have a comparison metric. Also, all the credits need to have a limit on what can be claimed by considering direct impacts on the project vicinity. The respondents were asked to express the necessity of whether California DOT needs to incorporate innovation in design and regional priority into its own sustainability rating systems like USGBC's LEED system. 60% of respondents agree the necessity of Caltrans' own sustainability rating systems need to incorporate innovation in design and regional priority, 32% of them neither agree nor disagree, and 8% of them disagree it.

4.2. Analysis of Multiple Comparison among Major Category of Infrastructure Sustainability Systems

Six major categories of infrastructure sustainability systems considered in this survey were compared using the median values for categories if they are statistically equal or not. Kruskal-Wallis tests were used to determine whether the medians for each category differ because data does not follow normal distribution. Kruskal-Wallis statistic helps us to test the hypothesis that all population medians are equal among categories. If the null hypothesis of equality of population medians is rejected, then the individual categories are compared using a pair-wise comparison (Minitab 2020).

Table 1 shows the statistical results on Anderson-Darling tests for the normality. For Anderson-Darling tests for the normality, the null and alternative hypotheses are H_0: Data follow a normal distribution and H_1: Data do not follow a normal distribution, respectively. Since the p-values for all six major sustainable categories are less than the significance level of 0.05, we reject the null hypothesis that the data follow a normal distribution. The result suggests that non-parametric tests need to be used to analyze the data. Since the one-way ANOVA can tolerate non-normal data with only a small effect on the Type I error rate, it can be also considered a robust test against the normality assumption.

Table 1 also shows the statistical results on Bartlett's tests of homogeneity of variances. Bartlett's method is used even though this method is only accurate for normal distribution to examine the equal variance among six major sustainable categories. For Bartlett's tests for the equal variance, the null and alternative hypotheses are H_0: All variances are equal and H_1: At least one variance is different, respectively. Since the p-values for all six major sustainable categories are greater than the significance level of 0.05, we failed to reject the null hypothesis that all the variances among the data are equal. The result means that equal variance assumptions are met for parametric tests to analyze the data.

Table 1. Results of Normality and Equal Variances

Test	**Anderson-Darling**			**Bartlett's tests**		
Category	**Test statistics**	**P-value**	**Normality**	**Test statistics**	**P-value**	**Equal variance**
Site-related	6.804	<0.005	No	2.71	0.607	Yes
Water and wastewater-related	10.393	<0.005	No	5.09	0.278	Yes
Energy-related	11.269	<0.005	No	0.07	0.997	Yes
Materials and Resources-related	7.666	<0.005	No	1.08	0.898	Yes
Environmental-related	8.818	<0.005	No	0.60	0.963	Yes
Other	5.437	<0.005	No	0.55	0.908	Yes

Table 2 tabulates the statistical results on multiple comparisons for the median values for all six major sustainability categories based on the results obtained from the Kruskal-Wallis tests. For the responses of factors under each category, the hypotheses are Ho: The medians for all six major sustainability categories are equal and Ha: The median for all six major sustainability categories are not equal. A tie occurs because the same value is in more than one sample due to the nature of Likert scale data. Although the adjusted p-value usually shows more accurate result than the unadjusted p-value, the unadjusted p-value is used because it is always greater than the adjusted p-value and because it is considered the more conservative estimate. Also, note that if no ties exist in the data, the two p-values are equal.

For the responses of all six major sustainability categories, we have enough evidence to reject the null hypothesis because the observed significance levels of p-values are greater than $\alpha = 0.05$ with higher test statistics of H value. Therefore, we found that there is no sufficient evidence to conclude that at least one median value is different among all six major sustainability categories. The results recommend verifying that the test has enough power to detect a difference that is practically significant. Several ways to increase the power of a hypothesis test can be made in the future study, including (1) collecting more sample data that is the most practical way to increase power, (2) considering the usage of a higher significance level so that the probability that you reject the null hypothesis is increased, (3) selecting a larger value for the difference, (4) using a one-sided hypothesis, and (5) finding a way to decreases the standard deviation in the process (Minitab 2020).

Table 2. Results of Multiple Comparison for All Six Major Categories

Test Category	**Test statistic (H-value)**		**P-value**		
	Not adjusted for ties	**Adjusted for ties**	**Not adjusted for ties**	**Adjusted for ties**	**Difference among medians**
Site-related	6.24	6.75	0.182	0.150	No
Water and wastewater-related	4.52	5.18	0.345	0.269	No
Energy-related	2.29	2.62	0.682	0.623	No
Materials and Resources-related	2.05	2.24	0.727	0.692	No
Environmental-related	1.90	2.09	0.755	0.719	No
Others	2.53	2.76	0.471	0.430	No

An analysis of variance (ANOVA) is further conducted to compare the mean response values of six major sustainability categories to determine the difference in the extent to which respondents are weighing the importance levels. The ANOVA tests the null hypothesis that six major sustainability categories are drawn from populations with the same mean values. The authors assumed that respondents' response variable residuals are approximately normally distributed, the responses are independent, variances of populations are equal, and responses for the six major sustainable categories are independent and identically distributed normal random variables. The one-way ANOVA was used to test whether there is variation in preferences for mean values across six major sustainable categories presented in the survey. The null and alternative hypotheses are Ho: $\mu Ci = 0$ for all i, where i is category, and Ha: at least two mean values among six major sustainable categories differ. At a significant level of 0.05, the null hypotheses are rejected if the p-value is not greater than 0.05, meaning a sufficient evidence to show that the null hypothesis is not true.

Table 3 tabulates the ANOVA results for all six major sustainability categories. The One-Way ANOVA test yields a p-value of 0.001 less than $\alpha = 0.05$; therefore, we have a significant evidence to reject the null hypothesis. The result means that the mean value of one category differs statistically from that of other categories.

Table 4 shows the results obtained from Tukey simultaneous tests for the differences of means of six major sustainable categories. Tukey's multiple comparison test is used to determine which means among the means of six major sustainability categories differ from the rest by comparing the difference between each pair of means with appropriate adjustment for the multiple testing. At a significant level of 0.05, the null hypotheses are rejected because their p-values are less than 0.05, meaning a sufficient evidence to show the significant difference for the pairwise comparisons between others and water and wastewater-related categories and others and energy-related category. However, for the rest of the pairwise comparisons, at a significant level of 0.05, the null hypotheses are not rejected because their p-values are greater than 0.05, meaning a sufficient evidence to show that the null hypothesis is true.

Table 3. Results of ANOVA for Multiple Comparison of Six Major Categories

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	5	28.25	5.650	4.04	0.001
Error	719	1004.86	1.398		
Total	724	1033.11			

Table 4. Results for Differences of Means of Six Major Categories

Difference of Levels	**Difference of Means**	**SE of Difference**	**95% CI***	**T-Value**	**Adjusted P-Value**
Water vs Site	0.272	0.150	(-0.154, 0.698)	1.82	0.453
Energy vs Site	0.240	0.150	(-0.186, 0.666)	1.60	0.595
Materials vs Site	0.024	0.150	(-0.402, 0.450)	0.16	1.000
Environmental vs Site	0.096	0.150	(-0.330, 0.522)	0.64	0.988
Others vs Site	-0.362	0.159	(-0.814, 0.090)	-2.28	0.201
Energy vs Water	-0.032	0.150	(-0.458, 0.394)	-0.21	1.000
Materials vs Water	-0.248	0.150	(-0.674, 0.178)	-1.66	0.560
Environmental vs Water	-0.176	0.150	(-0.602, 0.250)	-1.18	0.848
Others vs Water	-0.634	0.159	(-1.086, -0.182)	-4.00	0.001 **
Materials vs Energy	-0.216	0.150	(-0.642, 0.210)	-1.44	0.700
Environmental vs Energy	-0.144	0.150	(-0.570, 0.282)	-0.96	0.930
Others vs Energy	-0.602	0.159	(-1.054, -0.150)	-3.80	0.002 **
Environmental vs Materials	0.072	0.150	(-0.354, 0.498)	0.48	0.997
Others vs Materials	-0.386	0.159	(-0.838, 0.066)	-2.43	0.145
Others vs Environmental	-0.458	0.159	(-0.910, -0.006)	-2.89	0.045 **

* Individual confidence level = 99.55%
** Statistically significant

5. CONCLUSIONS

The authors presented the statistical results on the important sustainability determinants that affects the success of meeting sustainability goals of infrastructure construction projects based on the survey with transportation industry professionals in California. Based on the results obtained from the Kruskal-Wallis tests, the median response values for the six major sustainability categories do not show any significant difference. The ANOVA results also show that no statistically significant difference in the mean response values can be found from the six major sustainability categories considered. Based on the pairwise comparison results, only others category showed the difference with water and energy-related categories. These findings mean that the categories are equally important determinants to the respondents for the successful implementation of sustainability in infrastructure construction projects in California.

While this paper presented an empirical contribution for development of a framework of California infrastructure sustainability rating system, several limitations remain. Some of the open research areas to address these limitations for the research community include a need to expand this survey to general constructors or subcontractors to incorporate their voices and compare them with the results obtained from this survey for infrastructure sustainability systems. Collecting more sample data, which is the most practical way, can increase power of a hypothesis test. A higher significance level needs to be considered so that the probability that you reject the null hypothesis is increased. Comparing the results needs to be made with other states' sustainability rating systems for the infrastructure construction projects.

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