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ENHANCING SUSTAINABILITY IN HIGHWAY INFRASTRUCTURE: RISK ANALYSIS MODLES

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ABSTRACT: Transportation infrastructure issues are at present attracting attention in North America due to their maintenance and rehabilitation needs. Although there is recognition of their role in sustainability of cities, regions and the country, the poor physical condition of infrastructure will not enable these facilities to fulfill their sustainability role. The location and design of highway infrastructure were guided mainly by functional considerations rather than using these as instruments of sustainability. In addition, for good reasons, the initial cost was subjected to scrutiny, but this occurred at the expense of the important role of life cycle cost in shaping economic parameters of sustainability. A number of sustainability rating schemes have become available around the world. The development, improvement, and promotion of the ENVISION tool for planning and rating infrastructure projects has much potential to improve sustainability including a formal recognition of the importance of life cycle analysis. To go beyond the current state of knowledge, research is needed in the identification of cost overrun variables through factor analysis, models of cost overruns, and treating risk and uncertainty in life cycle analyses. Cost overrun models are reported in the paper and inferences are drawn on the use of these models as a part of treating risk on a life cycle basis. This will be a contribution towards enhanced infrastructure planning and management, including the informed application of tools for planning and evaluation of highway infrastructure projects.

1. INTRODUCTION

Well-designed highway infrastructure in good condition is essential for serving the socio-economic environment. Also, it is expected that planners and designers of highway infrastructure attempt to minimize environment impacts. Related to these requirements in planning infrastructure is to make it sustainable. In order to guide the profession in the sustainability direction, the Institute for Sustainable Infrastructure (ISI) (https://www.sustainableinfrastructure.org/) in association with the Harvard Graduate School of Design's Zofnass Program advanced the Envision program (Black & Veatch 2017) .

The Envision was developed for the purpose of improving the sustainability of infrastructure projects. This tool can be used during planning, design, construction, or at all phases of a project. A large number of sustainability metrics are to be used. These are intended to guide infrastructure investments to become cost-effective, energy efficient, and adaptable to long-term future conditions (Black & Veatch 2017).

For realism and effective application of Envision, risk in initial cost estimates as well as in life cycle costs should be formally treated.

1.1. The Importance of Infrastructure Cost as A Sustainability Factor

If cost estimates of an infrastructure project are subject to overruns and the decision to accept the project for implementation is made without knowledge and analysis of such overruns, the economic and financial sustainability of the project will be adversely affected. Also, due to flawed decision to accept the project and allocate scarce resources to it will adversely affect other projects that are competing for financial resources.

Studies on initial cost of infrastructure show that public and private sectors spend many billions of dollars in the provision of new infrastructure around the world (Flyvbjerg, holm, and Buhl 2003). Also, the required rehabilitation for maintaining serviceability and extending life of infrastructure is very costly. This issue is well appreciated at present due to highway infrastructure improvement needs that will cost hundreds of billions of dollars in North America.

Infrastructure projects face a high degree of risk due to many reasons, that span planning, design and implementation phases. Of course, the complexity of construction process and procedures is well known to the industry. Infrastructure projects can encounter two major risks, namely cost overruns and late completion times. These impact overall project performance (Flyvbjerg, Holm, and Buhl 2002). It has been a challenge for infrastructure project teams to manage and estimate schedules and costs of complex projects (Sangrey et al. 2003). In order to take the initial decision for any construction process of large/mega projects, there is a need to have accurate budget estimates (Ward 1999). Costing methods, rising costs due to inflation, and insufficient information analysis are some causes of cost overruns in large/mega projects (Akpan and Igwe 2001).

In another study by Flyvbjerg and his colleagues on cost overruns of large projects, it was found that among 258 large/mega projects in several countries, almost 90% of project costs were underestimated. Also, on average, actual costs were 28% higher than estimated costs and any increase in the size of the project caused an increase in the cost overruns. According to (Washington State Department of Transportation 2014), increased cost overruns were noted to exist under following situations: large-sized projects, high risk projects, complex projects, and projects with many bidders.

Having accurate estimated cost is the most important factor that contributes to the success of project cost management from its initiation phase to completion phase. Initial cost estimates, even though they are inaccurate, become the basis of all other future costs for the project team in construction process. Consequently, the project success is measured by comparing the initial cost estimates to the final project costs (Hester, Kuprenas, and Chang 1991).

The issue of inaccuracy in costing is not limited to initial cost of a project. Frequently, under estimation of future costs results in the inability of the owner (mainly public agencies) to cope with timely maintenance and rehabilitation tasks. This leads to substantially higher costs of upgrading the quality of infrastructure than would be the case if care was exercised in costing the entire life cycle and attempts are made to treat risk in all phases of the life cycle.

2. PROBLEM DEFINITION

2.1. The Sustainability Issues

Transportation facilities serve transportation demand and integrate the fabric of society. In serving its intended functions, socio-economic and environmental effects occur that are not always positive. Also, a notable characteristic of infrastructure is that these are expensive and frequently cost-over-runs are experienced.

At the time of planning new infrastructure, criteria for location of new facilities, design, evaluation and implementation are to be defined. When rehabilitations/renovations are to be studied, the use of appropriate factors is necessary. Although sustainability concerns have been acknowledged around the world following the Brundtland Commission report of 1987 (WCED 1987), comprehensive well-defined criteria were generally not applied to location, design and evaluation of new large transportation (including highway) projects. Also, infrastructure rehabilitation decisions generally ignored sustainability criteria.

The Brundtland Commission report defines sustainable development as the “development which meets the needs of the present without compromising the ability of future generations to meet their own needs.” In the case of sustainable transportation, most definitions of sustainable transportation (ST) presented by various governmental and non-governmental organizations are nested on the idea of sustainable development and are trying to balance its three pillars: economic, social, and environmental objectives of society (Khan et al. 2006; Litman and Burwell 2006; Marsden et al. 2007; OECD 2009; Perks et al. 2006).

Recently, as a result of cooperation of the Institute for Sustainable Infrastructure (ISI) and the Zofnass program of Harvard University, the ENVISION rating scheme was developed. It is very comprehensive (the latest update has 64 criteria that cover a number of relevant subject areas) (ISI 2017). However, its application requires detailed methods that are yet to be developed. Notable examples are risk analysis of first cost overruns, and cost estimates for maintenance and rehabilitation. That is, risk analysis of life cycle costs requires methodological attention. Although attempts have been reported in risk analysis of transportation (including highway) infrastructure, there is a need to go beyond previous research by developing advanced methods and to tailor their application to support application of ENVISION and other similar rating schemes.

2.2. Cost Overruns

Estimating project actual costs has been a great challenge in infrastructure large/mega projects because of the project's complexity and the difficulty in identifying the associated risks in the phases of project life cycle. Because the base cost of the project represents up to 80% of total project cost, identifying and analyzing the critical risk indicators should be done by involving all parties participating in the project. These risks have great impact on infrastructure cost growth and schedule growth. Therefore, by identifying these risks, project estimators should quantify risks and deal with them. If the problem of cost overrun remains untreated, it will bring unanticipated and unexpected impacts to the project as well as the infrastructure industries.

Among other sustainability factors, this research is an attempt to highlight the critical factors of cost overrun risks in transportation infrastructure industry and investigates the impact of these risks in project life cycle. There is a need to define factors and their associated risk in developing models for life cycle costing of infrastructure in support of economic parameters of sustainability.

3. COST OVERRUNS RISK ANALYSIS IN TRANSPORTATION INFRASTRUCTURE PROJECTS

Cost overruns have been shown to occur in a significant number of transportation investment projects especially in mega projects such as railways, tunnels, and bridges. According to (Kaming et al. 2012) cost overrun is very common in infrastructure construction projects and studies show that in some countries by the time a project is completed the actual cost is much higher than the estimated costs. Most of the pervious literature illustrated cost overruns causes in transportation capital projects; however, few of them mentioned how to estimate the risk associated with cost overruns and how to incorporate risk estimates into project assessment.

The objectives of this analysis are to develop methods for estimating cost overruns risk as well as to find out ways to include it into project decision-making. Therefore, we propose distribution fitting models to determine the probabilities of cost overruns.

3.1. Assessing the Risk of Costs Overrun

Cost overrun is defined as the difference between the actual cost and the planned/estimated budget. The project's actual cost is the total funds that the spending agency has actually paid for the project's construction. The project's planned budget is the money assigned to the project prior to its commencement. There is another estimate that is produced prior to initiating construction.

In this analysis, we begin by defining a Cost Overrun Ratio (COR) as the ratio of actual costs to planned budget. To illustrate more, if the actual cost is (2.5$) billion and the budget for a project is (2.0$) billion then COR = 1.25; if the actual cost is (0.5$) billion and the planned budget is (1.0$) billion then COR = 0.5(<1), which means no cost overrun. However, we define the cost overrun risk in three levels. $S1$= Low risk of cost overrun ($COR \leq 1$) (i.e. no risk), $S2$= Medium risk of cost overrun ($1 < COR \leq 1.2$) and $S3$= High risk of cost overrun ($COR > 1.2$).

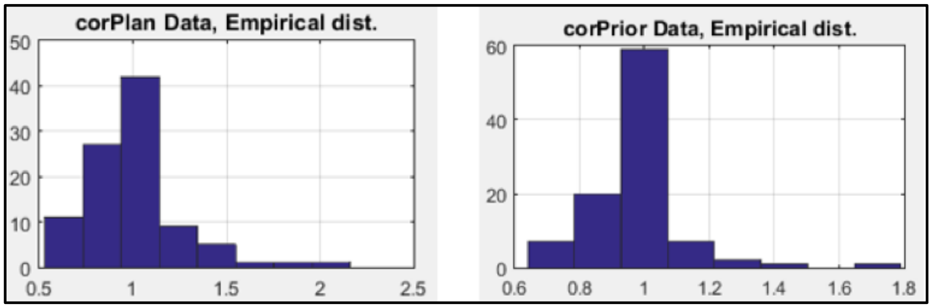
The main purpose of the analysis is to identify a probability distribution model that best explains the distribution of the COR.

3.2. Probability Distributions Fitting Models of Cost Overrun

A best fit analysis was conducted with MATLAB and Excel on two data sets, (COR at planning phase and COR prior to construction phase) consisting of about 100 projects from British Columbia. Budget at planning phase is the approved budget at the end of planning phase and the beginning of design. The budget prior to construction (estimated cost) is the approved budget to start construction.

In order to model the cost overrun value for a given project, we need a pool of distributions from which to select the best fit model. Since the COR data is continuous, the candidate distributions must all be continuous and thus to be well suited to model the cost overrun. However, Figure 1 shows the distribution shapes of the empirical data for (COR at planning phase and COR prior to construction phase).

Figure 1. Histogram of COR at planning phase and prior to construction phase.



The histograms are not symmetric and appear to be slightly skewed. Based on this observation, it is very unlikely that the sample data could come from a normal distribution. It could also be the case that the cost overrun during the planning phase and prior to construction phase is more likely to be low or medium than high. To study this further, we will find the theoretical distributions that best fit these empirical distributions.

3.3. Determine the Distribution Function

3.3.1.Cost Overrun Analysis (Budget at Planning Phase Data)

After running the best fit analysis, we arrive at the following five best fit distributions with the corresponding parameters values. These distributions are Cauchy, Normal, Log Logistic, Gamma, and Log Normal.

The parameters of each distribution determine the shape of the distribution. The Log likelihood (LL) value measures the goodness of fit of the empirical histogram to the theoretical distribution. Hence, as the sample data histogram becomes similar to the model distribution, the (LL) increases or gets higher.

Table 1 below summarizes the best fit analysis results. Three best fit tests are used to assess the quality of the fitted distributions (log likelihood (LL), Kolmogorov–Smirnov (KS) test, and Chi-square test).

Table 1.Goodness of Fit Statistics (Budget at Planning Phase Data)

Quality criteria (Best of fit)		Distribution				
		Log Logistic	Log Normal	Cauchy	Gamma	Normal
Log Likelihood (LL)		9.3518	6.2199	8.4886	4.2946	-3.4364
Chi-square test	P-value	P=0.023	P<0.05	P<0.01	P<0.005	P<0.000
Kolmogorov–Smirnov test	P-value	P=0.034	P<0.05	P<0.01	P<0.005	P<0.000

Chi-square and Kolmogorov–Smirnov (KS) tests are like the Log likelihood (LL) value. They just measure the goodness of fit of a model. As the Chi-square and KS values get higher, the histogram and theoretical shape become more and more similar (Montgomery and Runger 2010). The p-value is the probability that the empirical data deviates from the distribution model by chance alone. As the p-value gets smaller, it becomes unlikely that the distribution fits the available data (Montgomery and Runger 2010). We should then expect the p-value to be relatively high when the histogram is very close or similar in shape to the model. However, based on the goodness of fit tests, Log-logistic distribution appear to fit the data pretty well.

Next, we compute the probability that COR is low (less than 1), medium (between 1 and 1.2) or high (more than 1.2) for the fitted distributions above. The results of COR probability are given in Table 2.

Table 2.COR Probability (Budget at Planning Phase Data)

COR	Observed	Log logistic	Log normal	Cauchy	Gamma	Normal
$S1 = \mathrm{COR} \leq 1$	61.85 %	58.74 %	55.9 %	56.74 %	54.4 %	51.0 %
$S2 = 1 < \mathrm{COR} \leq 1.2$	24.74 %	21.63 %	26.23 %	27.1 %	17.24 %	13.91 %
$S3 = \mathrm{COR} > 1.2$	13.4 %	19.61 %	17.88 %	16.2 %	28.4 %	35.1 %

The log logistic model predicts that there is about 58.7% of chance that the COR will be small, 21.6% of chance that the COR will be medium and about 19.6% of chance that the COR will be high. Thus, according to the log logistic model, it is more likely to expect a small (low) cost overrun during planning phase of the project. The normal distribution predicts a 35.1% probability of observing a high COR value in the planning phase. The log logistic model fits the data better than any other model.

3.3.2.Cost Overrun Analysis (Budget Prior to Construction Phase Data)

Table 3 below summarizes the best fit analysis results. Three best fit tests are used to assess the quality of the fitted distributions (log likelihood (LL), Kolmogorov–Smirnov (KS) test, and Chi-square test).

Table 3. Goodness of Fit Statistics (Budget prior to construction Phase Data)

Quality criteria (Best of fit)		Distribution				
		Cauchy	Log Logistic	Log Normal	Gamma	Normal
Log Likelihood (LL)		73.5438	64.5232	54.7627	53.8181	49.3246
Chi-square test	P-value	$P=0.076$	$P<0.06$	$P<0.01$	$P<0.01$	$P<0.005$
Kolmogorov–Smirnov test	P-value	$P=0.059$	$P<0.05$	$P<0.01$	$P<0.01$	$P<0.005$

We note that the p-value gets smaller as the distribution shifts from the Cauchy model to the normal model. It is thus unlikely that the normal distribution fits the available data. The Cauchy distribution followed by the log logistic appear to fit the data pretty well. Next, we compute the probability that COR is low (less than 1), medium (between 1 and 1.2) or high (more than 1.2) for the fitted distributions. The results of COR probability are given in Table 4.

Table 4.COR Probability (Budget Prior to Construction Phase Data)

COR	Observed	Cauchy	Log logistic	Log normal	Gamma	Normal
$S1 = \mathrm{COR} \leq 1$	65.97 %	60.9 %	58.8 %	60.9 %	59.4 %	57.8 %
$S2 = 1 < \mathrm{COR} \leq 1.2$	29.89 %	26.0 %	31.0 %	33.0 %	34.6 %	36.3 %
$S3 = \mathrm{COR} > 1.2$	4.12 %	13.11 %	10.2 %	6.14 %	6.02 %	5.9 %

The Cauchy model predicts that, for the prior to construction phase data, there is about 60.9% of chance that the COR (cost overrun) will be small, 26% of chance that the COR will be medium and about 13.11% of chance that the COR will be high. So, it is more likely to expect a small (or low) cost overrun during prior to construction phase of the project. We note that the estimated probabilities for this data set are much closer to one another.

4. ROLE OF RISK ANALYSIS IN ENHANCING ECONOMIC PARAMETERS OF SUSTAINABILITY

Sustainability criteria are performance measures or indices of measurement capable of defining the degree to the sustainability goals/objectives have been attained. These criteria/performance measures (or rates in the ENVISION language) are used for infrastructure design & evaluation. Although economic sustainability factors continue to be important, infrastructure investment decisions should take into account social and environmental factors.

The state of the art in the economic evaluation of transportation systems has improved considerably over the years. The benefit-cost analysis methodology has already been refined for application to mutually exclusive alternatives of a given system, based on net present worth (NPW) on total investment and their associated incremental approaches. However, the evaluation process needs to be better refined from a sustainability perspective.

Specifically, in the context of sustainable transportation, there is a need for:

- Information on how to deal with impact-incidence (the equity – i.e., distributional issues)
- Knowledge on how to quantify or at least to express in qualitative terms, factors that do not enter in benefit-cost analysis,
- Information on methodology for incorporating strategic economic, social and environmental impacts in the evaluation of the mutually exclusive alternatives.

It is essential to incorporate relevant economic, social and environmental effects of transportation systems in the planning, design and evaluation tasks. Also, the perceived needs and concerns of all relevant interest groups should be considered. The evaluation of alternatives, including do-nothing (if applicable), has to be based on all criteria, whether formally or informally, in order to establish their relative value to society. On the basis of the evaluation results, the choice of an alternative is made for implementation.

Economic evaluation of mutually exclusive alternatives can be carried out in the form of a benefit-cost analysis. The best alternative can be identified on the basis of net present worth (NPW) of total investment. For sustainable transportation systems, the following types of criteria have to be incorporated in the evaluation framework.

- Criteria that can be quantified in dollar terms (e.g., cost of congestion, induced employment)
- Non-dollar type of criteria that can be quantified in their measurement units but it is difficult to impute a dollar value (e.g., network effect of strategic importance, noise and emissions)
- Criteria that can be expressed in subjective ordinal terms (e.g., social impacts such as community cohesion)

The economic parameters of sustainability can be enhanced if risk and is formally treated in cost-effectiveness of infrastructure investment and asset management decisions within the overall framework of working with all sustainability-related criteria as defined by the ENVISION scheme. This can achieved by developing methods that can take into account risk in life cycle costs and integrate results with other criteria (rates) defined by ENVISION.

4.1. Decision-Theoretic Model

Decision-theoretic models will be developed that will treat cost levels as probabilistic and initially, the method will work with the criteria that can be quantified in dollar terms. As a follow-up, the method will be extended in the form of a comprehensive methodology which can treat uncertain factors and will use utility theory in order to establish an overall expected value score for each alternative. This methodology will be based on the principles of multi-attribute utility theory. It will enable the treatment of uncertain cost overruns, multiple evaluation criteria, differential weighting of criteria, diminishing marginal utility property (if applicable), and risk averse/neutral/risk seeking viewpoint of the decision-maker.

A major challenge in the incorporation of the sustainable transportation criteria is the important task of quantifying their achievement levels (i.e., impacts) or expressing these in qualitative terms. Although there may be much temptation to assign effectiveness scores or to attribute qualitative statements in a subjective manner on the basis of a general knowledge of the study area, there is much merit to initiating special studies for obtaining the necessary information that could be used as a basis for predicting criteria achievement levels.

Weights can be used as indicators of relative importance of corresponding evaluation criteria. Also, can be used to convert criteria ranks to weights. On the other hand, criteria weights can be expressed as rates on a continuous scale of (1 to 5).

The level of achievement of a criterion, originally measured in its raw units (e.g. dollars) or in some cases expressed subjectively (e.g., excellent, very good, good, etc.), can be mapped on a relative value or utility scale of (0 to 1.0).

The criteria achievement levels quantified in their original units are obtained from analysis of alternatives. In the absence of such information, these can be expressed subjectively on the basis of surveys and judgment. As for life cycle costs, their present worth or equivalent annual worth can be found by using standard cost estimation and discounting methodologies. Criteria weights, noted above, can be used to modify achievement levels. In the utility-theoretic methodology, utility functions relate raw values of criteria achievement with their worth to the stakeholder(s).

The starting point for the application of the Decision Model is to work with life cycle economic factors. These can be expressed as the Expected Net Present Worth [EXP.(NPW)]. Although the decision model can formulated on the basis of utilities, most analyses work with impacts that can be quantified in dollar terms. The variables of the decision model as applied in this research are alternatives (A1, A2, A3), the states of cost overruns (S1, S2, S3), and the NPW for each A & S combination.

The states of cost overruns are defined as follows:

- S1 = Low risk of cost overrun (COR ≤ 1) (i.e. no cost overrun).
  (1.0) was used with probability P1
- S2 = Medium risk of cost overrun ($1 < \text{COR} \leq 1.2$).
  (1.2) was used with probability P2
- S3 = High risk of cost overrun (COR > 1.2).
  (1.5) was used with probability P3

Decision based on Expected Net Present Worth shows on Eq.1 as follows:

$$[1] \quad \mathrm{E}\,(\mathrm{NPW_i}) = \sum\nolimits_{\mathrm{j=1}}^{\mathrm{n}} [\mathrm{NPW_{ij}} \times \mathrm{P_j}]$$

Where:

E ($\mathrm{NPW_i}$) = the expected Net Present Worth of alternative $\mathrm{A_i}$; i = 1, 2,…, m
$\mathrm{NPW_{ij}}$ = the NPW of alternative $\mathrm{A_i}$, under state of nature $\mathrm{S_j}$; j = 1, 2,…, n
$\mathrm{P_j}$ = probability of state of nature (COR risk level) $\mathrm{S_j}$

In this life cycle risk analysis problem, three mutually exclusive alternatives (i.e., A1, A2, and A3) for a highway transportation project “A” are to be evaluated. The data for this risk analysis problem are sourced from three references. The first one is Federal Highway Administration (FHWA) (1998), “Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Decisions”, U.S. Department of Transportation, Publication No. FHWA-SA-98-079. The second reference is a research report on cost overruns published by the University of British Columbia. The third source of information is a report on Cost-Effectiveness of Highway Investment written for the Ministry of Transportation of Ontario.

Table 5 shows the present worth (PW) of costs ($M). Table 6 shows lifecycle Expected Net Present Worth E(NPW). The probabilities for the occurrence of S1, S2 and S3 shown in Tables 5 and 6 are based on Cauchey’s probability distribution function, sourced from the University of British Columbia research report.

Table 5. Lifecycle Analysis Present Worth (PW) of Costs ($M)*

Alternative	S1 (Cost overrun multiplier = 1.0)	S2 (Cost overrun multiplier = 1.2)	S3 (Cost overrun multiplier = 1.5)
A_1	96.750	109.38	128.325
A_2	94.25	108.05	128.750
A_3	95.315	109.579	130.975

*@ 4%, 35 years of analysis. Alternatives A1 has 3 rehabilitations and Alternatives A2 and A3 have two rehabilitations. Σ (Initial cost + cost of rehabilitation cycles + routine maintenance cost + user costs) in present worth @ 4% interest/discount rate. Cost overruns multipliers are obtained from the B.C. paper.

Table 6. Lifecycle Economic Evaluation NPW & (Expected NPW) ($M)

Alternative	S1 P(S1) = 0.42	S2 P(S2) = 0.55	S3 P(S3) = 0.03	EXP(NPW)
A_1	34.25	21.62	2.67	26.356
A_2	36.75	22.95	2.25	**28.125+**
A_3	35.685	21.421	0.03	26.770

+ Choice based on life cycle economic evaluation

The criteria that could be measured in dollar terms are used to carry out the cost-benefit analysis. The results of cost-benefit analysis as well as information on three additional criteria/impacts are shown in Table 7.

The "equity of costs and benefits" was quantified as a percentage of members of a committee of experts that indicated the achievement of the equity criterion by each alternative (an assumption). Here, 70% of committee members thought that A1 meets the equity criterion whereas 90% of committee members indicated A2 and 60% voted for A3. The infrastructure integration (or connectivity/accessibility) index values are assumed to be estimated by network analysis. The greenhouse gas impact indicator is based on gms of emissions per passenger-km.

Table 7. Highway Life Cycle Analysis: Mutually Exclusive Alternatives and Performance Scores (Selected Envision Criteria)

Alternative	Life cycle cost ($M in PW)	Life cycle cost of do-nothing** ($M in PW)	Life cycle (NPW)+ ($M)	Equity and Social Justice ++	Infrastructure integration connectivity/ accessibility index #	Greenhouse gas Emissions ##
A_1	96.750	131.000	34.250	70	30	197.7
A_2	94.250	131.000	36.750	90	60	87.0
A_3	95.315	131.000	35.685	60	90	111.5

****** Agency and user cost of existing route (with inadequate capacity and low quality of ride).

+ NPW = [PW Life cycle cost of "do-nothing" – PW Life cycle cost of alternative]. Relates to Envision's Economy criterion. Leadership (LD 3.3 Conduct a life cycle economic evaluation)

++ Relates to Envision's Community Criterion. Quality of Life (QL 3.1 Advance equity and social justice)

Connectivity and accessibility index; related to Envision's Resilience criterion. Climate and Resilience (CR 2.6 Improve infrastructure integration)

Relates to Envision's Emissions Criterion. Climate and Resilience (CR 1.2 Reduce Greenhouse Gas Emissions)

The transformed values are shown in Table 8. For NPW, equity and GHG impacts, linear (normalized) transformations are used. In the case of connectivity/accessibility, a diminishing marginal utility function is used. Next, criteria weights are defined on a scale 1 to 5: NPW 2, equity 2, connectivity/accessibility 3, and GHG emissions 3. The final utility scores are presented in Table 9

Table 8. Evaluation based on utility theory (relative value scores assigned to criteria)

Alternative	Expected (NPW) Million $ (@4%)*	Expected NPW (in relative value units)	Equity and Social Justice	Infrastructure integration/ Connectivity & accessibility	GHG reduction	Sum of utility scores
A_1	26.356	0.94	0.78	0.39	0.44	2.55
A_2	**28.125+**	1.00	1.00	0.71	1.00	**3.71++**
A_3	26.770	0.95	0.67	1.00	0.78	3.4

\+ Choice based on life cycle economic evaluation

++ Choice based economic, social and environmental criteria (utility values)

Table 9. Evaluation based on weighted utilities

Alternative	Expected (NPW)	Expected NPW (in relative value units) (Weight=2)	Equity and Social Justice (Weight=2)	Infrastructure integration (Weight=3)	GHG reduction (Weight=3)	Sum of weighted utility scores
A_1	26.356	1.88	1.56	1.17	1.32	5.93
A_2	**28.125+**	2.00	2.00	2.13	3.00	**9.13++**
A_3	26.770	1.90	1.34	3.00	2.34	8.56

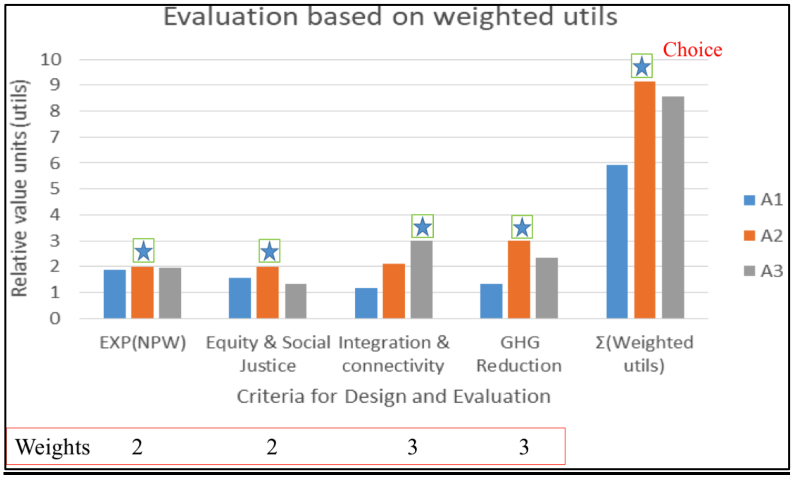
\+ Choice based on life cycle economic evaluation.

++ Choice based on weighted economic, social and environmental criteria (weighted utility values)

5. DISCUSSION ON ROLE OF RISK ANALYSIS

(1) The results shown in Figure 2 suggest that the use of infrastructure integration & connectivity criterion (i.e. a proxy for resilience) alone would lead to alternative A3 as the choice. However, alternative A2 is the choice under all other criteria.
(2) Alternative A2 is the choice on the basis of sum of weighted utility scores.
(3) The final results reflect the philosophical, theoretical, and practical facets of risk analysis in support of evaluation of alternatives and making infrastructure investment decisions.

Figure 2. shows the best alternative based on weighted utility values



6. CONCLUSION

Cost overrun is a common phenomenon in transportation infrastructure investments. It has been shown to occur in a significant number of transportation investment projects especially in mega projects, where a small amount of cost overrun can translate into heavy financial risks. Furthermore, overruns occur in projects of all types such as railways, tunnels, and bridges. Rail projects are prone to it more than are other types of investment.

In the above analysis, there could be a difference between the risk of costs overrun estimated prior to construction phase and the risk that is estimated at the planning phase. The estimation of COR becomes more accurate when additional information becomes available. Moreover, risk analysis should be implemented continuously at the entire project life cycle including planning stage, construction, operation and maintenance.

In conclusion, the main point of this paper is to highlight the importance of incorporating the risk of cost overruns in the evaluation and decision-making of transportation infrastructure projects. This will result in selecting better projects.

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