Validating a Framework of Transportation Infrastructure Project Sustainability Measures

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Abstract

Purpose of this paper
Transportation infrastructure contributes significantly to any economy. However, the long-lasting nature of such projects is threatened if sustainability elements are not taken cognizance of during the planning and operation stages of the projects. The objective of the current study is to validate a structure of transportation project sustainability measures to evaluate projects and ensure continual delivery of intended benefits in the long run.

Design

Empirical data were collected using a field questionnaire survey developed from literature review and a preliminary qualitative inquiry. A total of 132 built environment professionals were included based on purposeful and snowball sampling techniques. A model-generating confirmatory factor analysis was undertaken to validate underlying structures of sustainability measures.

Findings

The findings validated that a four-factor structure, with eleven variables, could adequately measure transportation infrastructure project sustainability (PS). The CFA structure achieved construct, convergent and discriminant validity, with fewer variables than theorised and established in the exploratory factor analysis.

Value

The validated four-factor structure is envisaged to be beneficial to transportation infrastructure project stakeholders in better decision-making with regard to selecting worthwhile projects as well as monitor operational projects with the aim of delivering long-term benefits to generations of users.

Keywords: Confirmatory factor analysis, infrastructure, South Africa, sustainability, transportation

1. INTRODUCTION

Transportation plays an essential role in countries' competitiveness, through employment and income creation, balanced and livable spatial development, access to water and energy, and food security, and is critical for social inclusion and improved quality of life, enhances economic development and growth (Friedrich and Timol, 2011; Chen and Cruz, 2012; Vilana, 2014; United Nations, 2015). However, such projects are fraught with uncertainties, which if not considered during the planning of the projects and/or continuous monitoring to sustain intended performance, is detrimental to the immediate community and society. Sustainability performance across the life cycle of an infrastructure project is a crucial aspect in achieving the goal of sustainable development (Amiril, Nawawi, Takim and Latif, 2014). Sustainability enables sound economic development, job creation and productivity; enhances quality of life; and promotes a more efficient and effective use of financial resources (investors' margins) (Montgomery, 2015). However, sustainability of infrastructure is hampered by lack of finance, governance and policy problems, planning inefficiencies and technical capacity (Bueno, Vassallo and Chueng, 2015). This then behooves transportation planners, policymakers and indeed researchers to find ways to maintain sustainability of such projects. Therefore, research on transportation infrastructure project sustainability is paramount in order to ensure that projects continue to deliver intended benefits to generations of users.

Although previous studies have explored key sustainability and performance elements, the focus has been singularly on one aspect. For instance, Amiril et al. (2014) developed a framework for railway infrastructure in Malaysia while Gamalath, Perera and Bandara (2014) and Park, Mount, Liu and Xiao (2019) focused on environmental and social sustainability aspects, respectively. Yu, Zhu, Yang, Wang and Sun (2018) conducted a simulation analysis using system dynamics, but focused on effectiveness of transport policies. Further, Amiril et al. (2014) employed a literature review for their study and although Wai, Yusof and Ismail (2012) applied factor analytical techniques to determine important project success criteria, sustainability was regarded as a secondary factor. This is inadequate since failure to address sustainability risks on projects is likely to result in long-lasting and potentially irreversible impacts on wellbeing, health and the economy (Bhattacharya, Oppenheim, and Stern, 2015). Thus, for projects to be sustainable, there are key elements or conditions, which must be extant.

Therefore, with limited studies, which holistically cover sustainability elements, the objective of the study was to validate critical project sustainability (PS) indicators for transportation infrastructure. The study employs confirmatory factor analysis to validate the underlying structure of sustainability indicators (Okoro, Musonda and Agumba, 2019). The study provides a reliable tool for ex-ante and ex-post evaluation of transportation infrastructure projects in order to ensure that lasting benefits are obtainable for generations of users.

2. TRANSPORTATION INFRASTRUCTURE PROJECT SUSTAINABILITY MEASURES

A plethora of infrastructure sustainability indicators exists in different contexts and sectors. Rating systems and assessment tools (LEED, CEEQUAL, INVEST, GreenLITES, etc.) have been used. However, they focus on singular elements, either environmental, or economic assessments and therefore fail to fully address all components of sustainability holistically (Bueno *et al.*, 2015). They are also usually based on historical trends and relationships and thus could be biased (Lyons and Davidson, 2016). Essentially, sustainability assessment measures should possess representativeness to cater for the complexity of factors that must be considered in infrastructure sustainability (Cottrill and Derrible, 2015).

Sustainability integrates the useful operational life, technical or structural quality, project leadership, and natural resource management (Jeon, Amekudzi, and Guensler, 2010; Friedrich and Timol, 2011; Kaare and Koppel, 2012). A cornucopia of factors was therefore identified from extant literature as indicative of sustainability. These were used to develop variables (twenty-eight, grouped into six factors) (Table 2.1), comprising:

- socio-economic environment (SE1 – SE8) (including *there are no complaints about travel times; there are no complaints about user discomfort during travel; there are no complaints about inconvenience during travel; there is no competition between different modes of transport; property values have increased after the infrastructure was built; new business ventures have developed after the infrastructure was built; infrastructure is accessible by all including the disabled and elderly; demand for the infrastructure services is as expected);*
- financial factors (FI1 – FI3) (including *capital invested has been recovered; there are no complaints about maintenance resources; there are no complaints from investors about revenue*);
- condition of physical infrastructure (CI1 – CI4) (including *the infrastructure is in good condition; there are no complaints about the cleanliness of the infrastructure; there is no traffic overload; the infrastructure, in its present condition, is able to withstand common adverse weather*);
- safety and security (SS1 - SS5) (including *signage for safety is adequate; fencing (median) is in place for safety; security officers are visible; security cameras are in place; formalised sidewalks are in place for pedestrians*);
- stakeholder satisfaction (ST1 – ST5) (including *the needs of the stakeholders are satisfied; users are satisfied with pricing/charges; there are no operational problems; the actors are able to work in collaboration with other stakeholders; there is clarity of responsibilities among partners*, and
- service quality (SQ1 – SQ3) (including *management responds quickly to user complaints about infrastructure services; management responds quickly to user complaints about safety incidents; the infrastructure services (rides) are predictable*).

(Jeon *et al.*, 2010; Dhingra, 2011; Quium, 2014; Cottrill and Derrible, 2015; Pavlina, 2015; Litman, 2016).

3. METHODS

The study presents quantitative results from a sequential exploratory research approach, whereby the results from a qualitative multi-case study phase was used to develop, test and validate a framework of transportation infrastructure sustainability measures in the quantitative phase (Darke, Shanks and Broadbent, 1998). Data were amassed from 132 respondents selected through purposive and snowball sampling techniques, comprising Built environment professionals in the nine provinces of South Africa, involved in transportation projects, at the feasibility and/or operational stages. The respondents comprised 69% public and 31% private entity professionals. These were directors, deputy director and heads of departments (25%), project managers (15%), engineers (12%) and safety officers (10%), executive/deputy managers (8%), development managers/ agents (6%), feasibility study consultants (4%), quantity surveyors (4%), planners (4%), academics (3%), and technical assistants on projects (2%) on road, bridge, rail, airport and tunnel projects. Prior to data collection, ethical clearance from the university authorities and consent from the respondents' superiors, were obtained. The questionnaire, distributed by hand and online (email and google forms), sought information on a five-point Likert scale, with responses ranging from 1=strongly disagree to 5=strongly agree.

Data was analysed using AMOS software version 25, because it was able to read SPSS data as an input and accommodate plugins for automatic programming and building of a series of paths (Nokelainen, 2007). The maximum likelihood method (Carter, 2006). Preliminary considerations in terms of missing data (treated using mean imputation), sample size, univariate and multivariate normality and outliers (using univariate skewness and multivariate kurtosis (*Mardia's* coefficient), as well as Mahalanobis d-squared distance tests, which should be ≤ 1.0 and < 1.96, respectively, definability of the model (degrees of freedom, *df*, which should be positive (greater than 1), theoretical specifications, method of estimation (maximum likelihood), model fit criteria and modifications were undertaken (Byrne, 2001; Awang, 2012). A sample size of 132 was considered sufficient, with a ratio of 5 to 1 (Kenny, 2015). Seven outliers were deleted

The model-generating CFA was thereafter undertaken to determine the model of factors that best fit or represented the data underlying the theory. Hu and Bentler's (1999) two-index presentation strategy was adopted, using both absolute and comparative fit indices, including Comparative fit index (CFI) (close to 0.95 or ≥ 0.90), Relative chi-square (CMIN/df) (χ^2 *to df* ≤ 2 or 3). Standardised root mean square residual (SRMR) (> 0.05 to 0.08; the lower the better), and Root mean square error of approximation (RMSEA) (Close to 0.06; 0.08 – reasonable fit; > 0.10 – poor fit) (Hu and Bentler, 1999; Schreiber, Stage, King, Nora and Barlow, 2006; Iacobucci, 2010).

Other assessments for model suitability included examination of the standardised residual matrix (items with high correlations above 1.0), factor loadings or variance explained in the model ((squared multiple correlations below 0.5 were problematic items), and the modification indices (items that may be redundant in the model). Items were deleted iteratively and the model rerun, bearing in mind that item deletion may not exceed 20% of the total number of items and latent constructs should have at least two or three items. Statistical significance of the parameter estimates (squared multiple correlation and factor loadings less than 1.0, and the critical ratio values, akin to *Z* statistic greater than 1.96 at the 0.05 significance level) was also assessed (Byrne, 2006). Reliability and validity were also checked using Cronbach alpha, composite reliability (CR) and average variance extracted (AVE) and the results are presented in a later section.

4. RESULTS AND ANALYSIS

The CFA analysed the relationships between the latent constructs and their variables as presented in the input diagram in Figure 4.1, using the 125 cases remaining (data set with outliers deleted). The rectangles are the observed variables or indicators of each latent construct. The ovals represent the latent constructs. The error terms for each observed variable are represented as circles. These are residual or error variances, which uniquely cause response variations in the observed variables. The results of the model-generating CFA are presented hereunder.

4.1 Initial Project Sustainability Model Fit Analysis

The initial evaluation of the PS input model showed that there were no high correlations (exceeding 0.80) between the latent constructs. This indicated that there was discriminant validity for the PS input model. The model fit indices for the first run (Table 4.1) showed that the chi-square was significant (χ^2 =203.084; p=0.000), indicating that the postulated model was significantly different from the sample data. Other indices revealed that CMIN/*df*=2.860 (cut-off value= ≤ 2 or 3), CFI=0.888 (cut-off value= ≥ 0.90), SRMR = 0.0687 (cut-off value = > 0.05 to 0.08), and RMSEA=0.122 (cut-off value = 0.09). The CFI and RMSEA values indicated that the hypothesised model did not match the data. However, the SRMR, which informs on the degree of discrepancy between the hypothesised model and the sample data, was acceptable, indicating that the PS input model matched the data. Nevertheless, an examination of other output from this first run was undertaken to determine if the model fit could be improved.

4.2 Diagnostic Fit Analysis and Model Modification

An examination of the standardised residuals covariance matrix revealed that there were no high residual covariances (above 2.58). However, SE6 and SS1 covaried with four and three other items in the model, respectively, with values more than 1.0 and they were deleted successively. The model fit indices (Table 4.2) showed the results after the deletion. It was notable that the model fit improved significantly after the third run with CMIN/df = 1.986, falling below the recommended 2.0, CFI = 0.949, close to 0.95 (cut-off value > 0.90), RMSEA = 0.089 (cut-off value = < 0.09), and SRMR = 0.0586 (cut-off value > 0.05 to 0.08). Based on the two-index presentation strategy advocated by Hu and Bentler (1999), the model after the third run was observed to be an excellent fit to the sample data.

However, the item ST2 was found to have a low contribution of 34%, indicating that the item was contributing more error variance than explained variance in the model and it was removed and the test rerun. The final model (Figure 4.1), displayed acceptable fit (Table 4.1), with values within the recommended ranges: CMIN/df = 2.087 (cut-off value < 2 or 3), CFI= 0.95 (cut-off value > 0.90), RMSEA = 0.094 (cut-off value 0.09), and SRMR = 0.0570 (cut-off value > 0.05 to 0.08). These results indicated that the hypothesised PS model matched the sample data by 95% and with a residual value of 5.7%, the model can be deemed to be an excellent fit to the data. It was notable that approximately 20% of the number of items (three out of 14) were deleted, and this was observed to be permissible in a model-generating CFA (Byrne, 2001; Awang, 2012).

Table 4.1: Model fit indices for first and final PS model

Fit indices	Cut off value	Estimate (input model)	Estimate (final model)	Comment
Chi-square χ^2		203.084	85.579	
Degrees of freedom *df*	> 0 ; positive	71	41	Acceptable
Relative chi-square (CMIN/*df)*	≤ 2 or 3	2.860	2.087	Acceptable
Comparative fit index (CFI)	≥ 0.90	0.888	0.950	Acceptable
Standardised root mean square residual (SRMR)	> 0.05 to 0.08	0.0687	0.0570	Acceptable
Root mean square error of approximation (RMSEA)	< 0.09 – good fit < 1.0 – reasonable fit	0.122	0.094	Acceptable

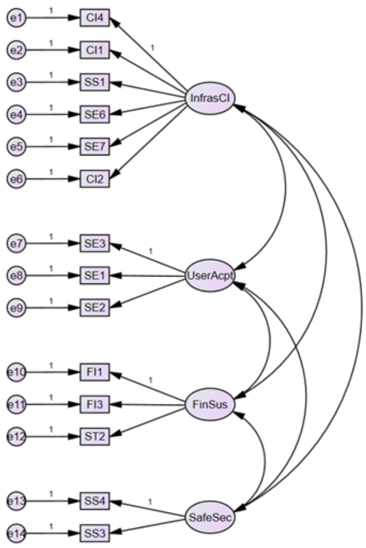

Figure 4.1: CFA input model

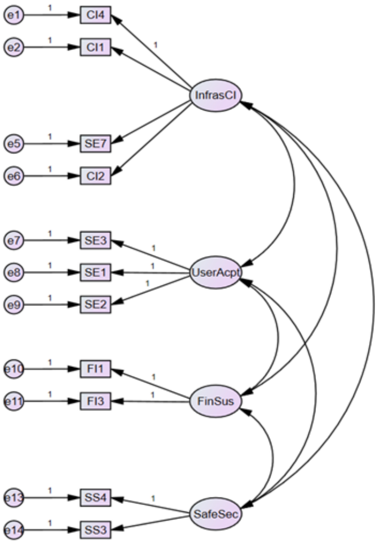

Figure 4.2: Validated model

4.4 Statistical Significance of Parameter Estimates

An examination of the factor loadings (regression weights), standard errors and critical ratio estimates was undertaken to determine if the model parameters were statistically significant (Byrne, 2006). The PS final measurement model parameters exhibited statistical significance with the squared multiple correlations values all less than or equal to 1.0 and therefore reasonable. The parameter estimates had high correlation values (above 0.4). The correlation values suggested a high degree of linear association between the indicator variables and their latent constructs, and therefore reasonable.

In addition, the critical ratio test statistic, analogous to Z scores, was used to test the significance of the parameters. The critical ratio, which is the parameter estimate divided by its standard error, had to be greater than 1.96 at the 0.05 significance level for it to be said to be statistically different from zero and considered significant. Table 4.2, containing the parameter estimates, showed that the critical ratio values were all above 1.96 and therefore statistically significant.

Table 4.2: Parameter estimates of the selected PS measurement model

Latent construct	Variable	Squared multiple correlations R^2	Factor loading (unstandardised λ)	Factor loading (standardised λ)	Critical ratio	Significant at 0.05 level?
Infrastructure	CI4	.559	1.000	.748	…	Yes

condition and impacts	CI1	.633	.972	.795	8.645	Yes
	SE7	.442	.822	.665	7.174	Yes
	CI2	.705	1.150	.839	9.100	Yes
User Acceptability	SE3	1.000	1.000	1.000	…	Yes
	SE1	.773	1.000	.879	…	Yes
	SE2	.808	1.000	.899	…	Yes
Financial sustainability	FI1	.548	1.000	.740	…	Yes
	FI3	.622	1.000	.789	…	Yes
Safety and security	SS4	.689	1.000	.830	…	Yes
	SS3	.717	.871	.847	7.454	Yes

… Values not determined due to unstandardised regression weight of 1.0

4.5 Reliability and Validity of the Project Sustainability Model

The piloting and reviews of the questionnaire by the researcher's supervisors and statistician refined the tool and increased face or content validity of the questionnaire. Including a variety of professionals and transport projects increased generalisability and reliability of the results. Statistically, internal consistency reliability of the measures before and after EFA was assessed using Cronbach's alpha test and values ranged from 0.76 to 0.84 (before) and 0.92 (N=14) (after), indicating good reliability. Discriminant validity was also achieved by the modification indices being below 15 and the inter-construct correlations were lower than 0.85 (Musonda, 2012; Ahmad, 2016). Discriminant validity was also achieved by the inter-construct correlation values being below the square root of the AVEs, as shown in Table 4.3. Unidimensionality of the CFA model was good with all factor loadings positive and above 0.5 (Awang, 2012). Composite Reliability (CR) and average variance extracted (AVE) tests for reliability and validity indicated that the confidence level of the CFA latent variables was good, with values greater than 0.6 and 0.5, respectively (Table 4.4) (Awang, 2012; Xue *et al.*, 2018). Convergent validity was achieved by the AVE values all being above 0.5. Construct validity was achieved by the model being of good fit, with all the fit indices within the recommended cut-off ranges.

Table 4.3: Discriminant validity for PS measurement models

Construct	Infrastructure condition and impacts	User acceptability	Financial sustainability	Safety and security
Infrastructure condition and impacts	**0.76**			
User acceptability	0.57	**0.93**		
Financial sustainability	0.73	0.44	**0.77**	
Safety and security	0.63	0.46	0.46	**0.84**

Table 4.4: Reliability results for selected PS measurement model

Latent construct	Item	Factor loading λ	CR (> 0.6)	AVE (> 0.5)	Comment
Infrastructure condition and impacts (n = 4)	CI4 CI1 SE7 CI2	.748 .795 .665 .839	0.762	0.585	Required level was achieved
User acceptability (n = 3)	SE3 SE1 SE2	1.000 .879 .899	0.926	0.860	Required level was achieved
Financial sustainability (n = 2)	FI1 FI3	.740 .789	0.765	0.586	Required level was achieved
Safety and security (n = 2)	SS4 SS3	.830 .847	0.839	0.703	Required level was achieved

5. DISCUSSION

The validated CFA four-factor solution revealed that critical transportation infrastructure project sustainability measures include:

- condition and impacts - including *ability to withstand common adverse weather*, *infrastructure is in good condition, accessibility to all including the disable and elderly*, and *no complaints about cleanliness*;
- user acceptability - including *no complaints about inconvenience during travel, no complaints about travel times,* and *no complaints about user discomfort during travel*;
- financial management factors - including *capital invested has been recovered* and *no complaints from investors about revenue;* and
- safety and security – including *security cameras are in place* and *security officers are visible.*

The above findings slightly align with Amiril et al. (2014) study, which found that in addition to the traditional iron-triangle consideration of social, economic and environmental sustainability aspects, the quality and functionality as well as project financing are critical sustainability elements. The criticality of the wide-range of factors, which emerged from the analysis, has also been emphasised. The condition of transportation infrastructure with regard to its ability to withstand poor weather conditions or natural disasters and being in good condition (generally) were identified as important performance measures for road infrastructure in South Africa (Friedrich and Timol, 2011). These views were also shared by Jeon et al. (2010) and Stapledon (2012) who emphasised the importance of technical and structural conditions and network capacity in sustainability assessments. Likewise, user acceptability was defined in line with the satisfaction of travel needs of the stakeholders including the end-users (Amiril et al., 2014; Yu et al, 2018). Safety and security were classified under social factors in Amiril et al. (2014) and Litman (2019). Nonetheless, given the range of objectives, impacts and options considered in transportation developments, which invariably affect different people in many ways, a variety of factors need to be considered in order to ensure that decisions are consistent with strategic long-term goals of sustainable transportation development (Litman, 2019).

6. CONCLUSION

Project sustainability was initially theorised to be measured by a six-factor structure comprising socio-economic factors, financial factors, condition of physical infrastructure, safety and security, stakeholder satisfaction and service quality, with twenty-eight items. However, the EFA indicated a four-factor solution including infrastructure condition and impacts, user acceptability, financial sustainability as well as safety and security, with fourteen items. Using a model generating approach to CFA, the primary focus was to generate a measurement model that best described the sample data, and as such, modifications were necessary based on the sources of misfit identified. Findings from the CFA, it was revealed that the four-factor structure established during the EFA could adequately measure project sustainability, albeit with fewer variables (eleven). This model achieved construct, convergent and discriminant validity and is therefore deemed reliable and generalisable in sustainability assessments of transportation infrastructure projects in South Africa. It is argued that some of the problems and challenges encountered in the operational stage of transport infrastructure projects could be mitigated by according considerable attention to sustainability factors before and after implementation or development of such infrastructure. The performance of transportation infrastructure projects can be sustained if attention is given to developing robust strategies to overcome or mitigate the impact of sustainability risks associated with the identified factors. It is notable that the relative importance of the factors was not presented in the current study. Future studies could be dedicated to establishing the relative importance of the measures as well as the relations among the variables.

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