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Beyond project governance. Enhancing funding and enabling financing for infrastructure in transport. Findings from the importance analysis approach

Ibsen Chivatá Cárdenas[1]
Department of Construction Management and Engineering, University of Twente, The Netherlands.

Hans Voordijk[2]
Department of Construction Management and Engineering, University of Twente, The Netherlands.

Geert Dewulf[3]
Department of Construction Management and Engineering, University of Twente, The Netherlands.

Based on the examination of the transactions made in 58 case study projects, we have developed probabilistic causation models that include relationships hypothesised from exhaustive literature reviews. These models contain relationships that relate a number of significant project variables to transport infrastructure project performance. Here, we report on the use of the Importance Analysis approach to identify the most significant factors linked to variables measuring project performance. Such an approach is used in combination of Bayesian Networks and Sensitivity Analysis. Some variables that resulted important to achieve cost, time, and revenue expectations in transport infrastructure projects are identified. These include factors other than those related to project governance but linked to the funding and financing schemes in a project and its context of implementation. Additionally, we analysed how projects in the BENEFIT database responded to the effects of the European economic crisis in 2008. The results indicated that some actions were implemented at some instances during the crisis time. Specific factors that appeared to be sufficiently robust to face the economic crisis were found.

Keywords: *cost overrun, project governance, funding and financing schemes, causal modelling, uncertainty in projects.*

1. Introduction

The business models for enhancing funding and enabling financing for infrastructure in transport (BENEFIT) research project aims to provide policy makers and providers of funding and financing with extensive comparative information on the advantages and limitations of different funding schemes for transport infrastructure projects. Further, the analysis of business model options and project governance schemes to enhance transport infrastructure projects performance is also part of the research. From exhaustive literature reviews reported in Roumboutsos et al. (2015), and articles in this journal special issue, conceptual models have been developed in which a number of project factors dealing with the environment of project implementation, project governance, project business models, and funding and financing schemes were identified and related to the performance of transport infrastructure projects. Thus, using this antecedent

[1] IceBridge Research Institute. 170001, Manizales, Colombia E: ibsen_13@icloud.com
[2] P.O. Box 217, 7500 AE Enschede, The Netherlands, T: +31534894214 E: j.t.voordijk@utwente.nl
[3] P.O. Box 217, 7500 AE Enschede, The Netherlands, T: +31534892581 E: g.p.m.r.dewulf@utwente.nl

research and with the purpose of informing decision making, we aim, with the research reported in this paper, to identify those significant factors that most influence the performance of transport projects. The proposed research also includes an analysis of how these significant factors can inform responsive actions to face potential economic crisis (e.g. European economic crisis in 2008) affecting infrastructure projects. To this end, we have used records on transactions made in 58 European projects and deployed the comprehensive set of factors identified in the BENEFIT research project. This is worth making since in spite of important theoretical developments have been reported investigating critical factors affecting infrastructure project performance, e.g. Eriksson and Westerberg (2011), Li et al. (2012), Chen and Manley (2014), the latter authors focused partially on the issues of procurement and project governance, and did not consider variables such as the influence of the environment of project implementation, project business models, and funding and financing schemes.

The remainder of this paper is divided into four sections. In the next section, the analysis approach is described. In Section 3, we provide some details about the probabilistic model developed. A discussion of the results and conclusions are reported in the final two sections.

2. Importance Analysis overview

For the proposed research, we have used Importance Analysis (IA). IA was first introduced by Andsten and Vaurio (1992). IA is an ideal means to identify dominant factors that most influence the occurrence of a given variable. IA is ultimately aimed at providing information that supports management decisions; more specifically, supportive information to derive appropriate remediation measures or interventions. Appropriate measures are those that successfully either avoid or mitigate failure, or contribute satisfactorily to the materialisation of desired goals. In principle, these measures should act upon those critical factors that most influence the occurrence of a given output. In our research, to conduct the IA we used an approach which combines Bayesian Networks (BN), and Sensitivity Analysis (SA). These tools are especially powerful when it comes to conducting exhaustive analysis of interactions of factors. Anderson and Vastag (2004) showed that, by using BNs, some of the seatbacks of the traditional approaches to causal analysis (i.e. Structural Equation Modelling, SEM) could be addressed, and this motivated us to use BNs to develop the proposed models. For instance, BNs are able to deal with non-linear relationships, which is a constraining limitation of SEM. Further, SEM methods are parametric in function and distribution, thereby assuming normality, which is not an issue for BNs. Furthermore, when data is very scarce about a relationship, it can be specified in a probabilistic fashion in BNs whereas this is challenging with the SEM approach. Likewise, Borgonovo and Plischke (2016) have reported that SA is an ideal method to evaluate models.

BNs are essentially a tool for modelling the relationships between variables, and for capturing the uncertainty in the dependencies between these variables using conditional probabilities (van der Gaag, 1996). These conditional probabilities can be learnt under certain conditions from small data sets as shown by Onisko, Druzdzel and Wasyluk (2001). Bayesian Networks models are evaluated using traditional tests reported by Anderson et al. (2004) and Lee and Moore (2014). Such tests include independence tests to check marginal and conditional independence among factors in the models, marginal log-likelihood estimation, which is used to assess the goodness of fit of the data, and cross-validation to verify the capability prediction of the models developed. Note that in this approach, models might include relationships of variables confirmed by rejection of the hypothesis of independence for each marginal and conditional relationship (using for instance a cut-offs $p < 0.05$). The choice of an optimal model is mainly done by the assessment of its marginal log-likelihood value in conjunction with the prediction accuracy (Anderson et al., 2004) estimated with the leave-one-out procedure reported by Lee and Moore (2014).

SA is the study of how the uncertainty in the output of a mathematical model or system (whether numerical or otherwise) can be apportioned to the various sources of uncertainty in its inputs (Saltelli et al, 2008). In our study, Borgonovo's (2006) measure δ is used as a sensitivity indicator. This is an alternative approach that examines the global response of a model's output by looking at the whole output distribution changes as modifications are introduced into de input variables (Borgonovo, 2006). Borgonovo's measure was tested in Borgonovo (2006) and in Borgonovo et al. (2011) with numerical and analytical tests showing reliable results in terms of ranking relevant factors. Borgonovo's measure was first used in BNs by Cárdenas et al. (2014).

The Borgonovo sensitivity analysis renders rankings that can be represented by graphs as shown in Figure 1. The graph in Figure 1 presents those factors that have the largest normalised effects on the occurrence of an output factor in a model.

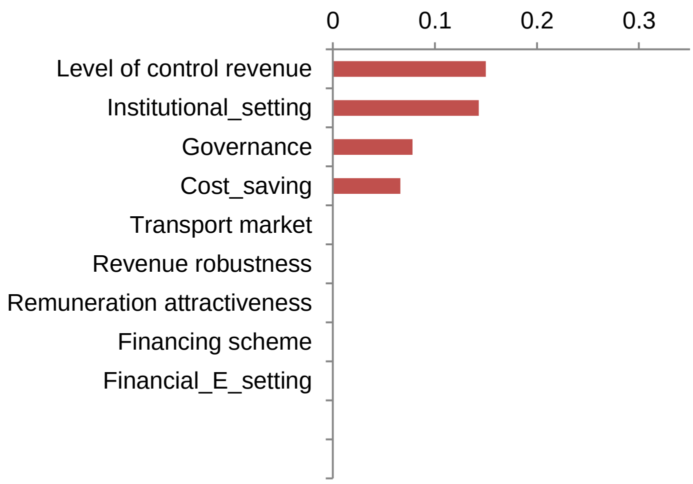


Figure 1. Ranking of factors and their impact on the occurrence of a given output variable

A more comprehensive description of the analysis approach advocated here is reported in Cárdenas et al. (2017).

3. Identification of critical factors linked to project outcomes

3.1 Factors considered in this study

The performed analysis consisted of determining the most relevant variables linked to a set of predefined output variables. The models analysed here considered some plausible interactions among input factors. The factors and their relationships were initially derived and hypothesised from exhaustive literature reviews available from Roumboutsos et al. (2015) and articles in this journal special issue. In Table 1, we described roughly each of the factors considered.

Table 1. Factors considered in this study

Factor	Description
Institutional setting	The institutional setting factor captures aspects such as the political stability and absence of violence, control of corruption, and voice and accountability of a country. The institutional setting variable also measures the legal and regulatory framework in terms of the rule of law and the regulatory quality. Finally, this factor covers the issue of "public sector capacity".

Table 1. Factors considered in this study

Factor	Description
Financial economic setting	This factor is equivalent to the "growth competitiveness index" as developed and validated by the World Economic Forum
Availability/Reliability (IRA)	This factor combines two variables, namely (i) reliability (% time of disruptions during operation) and (ii) availability (% of availability) of operations.
Governance	The variables incorporated in the governance factor consider aspects of project governance such as the early involvement of the contractor in the design and estimation of costs, procurement procedures, integration of design and construction, the incentives and disincentives regime, risk allocation, contract flexibility, and actions that allow the contracting party to maintain bargaining power during possible renegotiations (Cárdenas et al., 2017).
Cost saving	"Cost saving" factor can be described to be measuring the ability to avoid or reduce cost overruns. It covers aspects such as the capability to construct, monitor, operate, innovate, and plan of the all parties involved.
Level of control of revenue	It measures the capability of the all parties involved to secure revenue for a project when facing traffic demand changes. Such capability is linked to the control of influences of competing or complementary transport infrastructure projects.
Revenues	It measures the capability of the all parties involved to secure revenue for the project when facing traffic demand changes. Unlike "Level of control of revenue", this factor measures the capability of incorporating revenue sources other than those from transport services.
Remuneration attractiveness	Reflects the attractiveness of the remuneration scheme for investors and includes costs coverage (income streams) and risk of income measurements.
Revenue robustness	It measures the ability to cover the project costs from the revenues generated by or for the project.
Transport market efficiency & acceptability	Composite indicator reflecting the political attractiveness of the project funding scheme from the perspectives of the efficiency of utilization of the transport infrastructure (allocative efficiency) and the acceptability of the funding scheme for voters.
Financing scheme	The "Financing scheme" factor considers the impact of the financing structure to the project based on the cost of funds of the various sources of capital. It is based on a variation of the concept of the "Weighted Average Cost of Capital".

The set of output variables shown in Figure 2 are labelled as "cost", "time", "traffic", and "revenue". More details about the variables considered for this analysis are provided in the Appendices to this paper.

3.2 Data used for the analysis

The data from which the models are developed consist of records on 58 European projects. The records were collected from a review of the pre- and post- contract transactions and were complemented with personalized semi-structured interviews held with the management of the projects. Detailed descriptions of the projects are available from the public online BENEFIT database (2017), see reference list. Appendix B depicts the basic characteristics of the projects.

Although this dataset is large, the number records is still insufficient to enable one to develop models with more domain values (i.e. classes discretising the possible values a variable can take, "degrees of freedom") than those indicated in Appendix A. It would be desirable to have more degrees of freedom attached to each variable but this would be counterproductive with the current data limitations for reliable inference purposes. However, the proposed model can be enhanced as new information becomes available from further research.

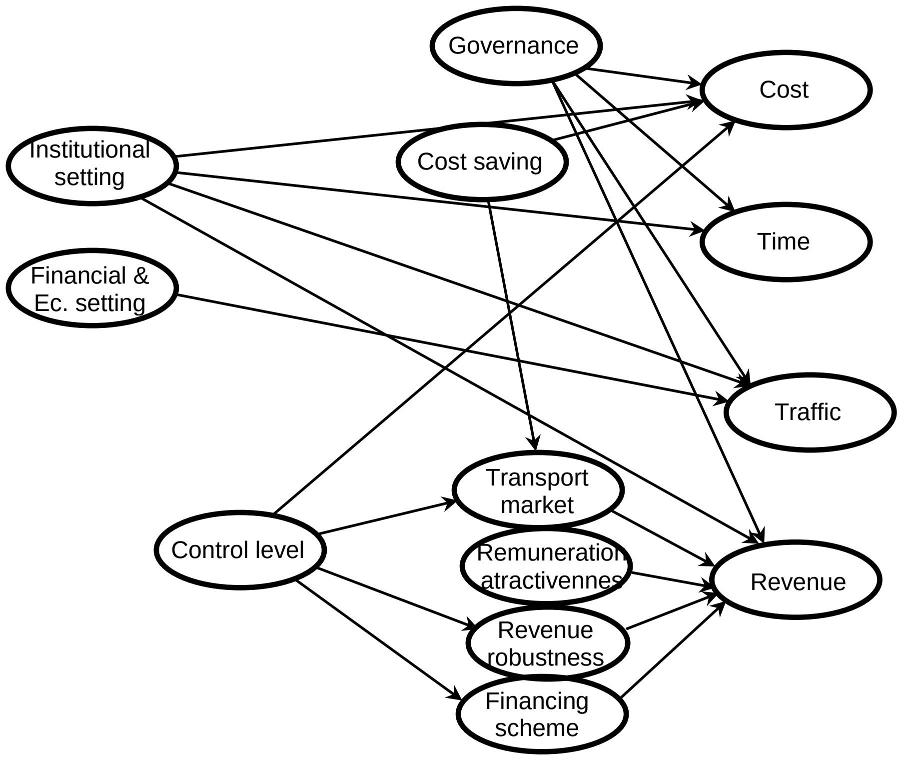


Figure 2. Structure of the most optimal model developed

3.3 Analysis set up

A number of analyses were run with data sets with different sizes as shown in Table 2. Note that, one of the interests in this stage of the research was also to identify the effect of the economic European crisis in 2008, and to assess how projects coped with it. To this end, various IAs were conducted. Unfortunately, more analyses with different, and smaller data sets cannot be carried out. Such additional analyses would not provide accurate results. Our approach is constrained by the size of the data subsets. According to Onisko, Druzdzel, and Wasyluk (2001) tests, the number of records to be used for Bayesian Networks should be bigger than 50 records. The remaining data subsets available, representing subsamples of the total sample of infrastructure projects, contains less than 50 records.

Appendix C depicts metrics of the analyses 1 to 12 conducted as mentioned in Table 2. These metrics provide information on the quality of the modelling.

Table 2. Analyses conducted and the respective dataset deployed

Analysis #	Objective of the analysis "Identification of factors relevant to …"	Data size*/number of project cases	Description
1	Cost	90/36	All the records available & projects awarded before crisis (2008) Model 1, M1
2	Time		
3	Traffic	83/33	
4	Revenue		
5	Cost	54/25	All the records available & projects completed before crisis (2008) Model 2, M2
6	Time		
7	Traffic	59/22	
8	Revenue		
9	Cost	59/22	All the records available & projects completed after crisis (2008) Model 3, M3
10	Time		
11	Traffic	45/21	
12	Revenue		
13	Cost	28/15**	All the records available & projects awarded after crisis (2008) Model 4, M4
14	Time		
15	Traffic	18/10**	
16	Revenue		

*Each data set size excludes records (snapshots) at award time.
** Data sets not analysed due to their small size

4. Results and discussion

In Tables 3 to 4 results are presented per outcome and data sample tested. The graphs present those factors that have the largest normalised effects on the occurrence of an outcome in the models. In the graphs in Tables 3 to 4, the numbers on the upper horizontal axis indicate the estimated value of Borgonovo's importance measure. A relatively high value of Borgonovo's importance measure indicates that the output variable (outcome) is highly sensitive to the analysed variable. If the measure is relatively low, the output will be fairly insensitive to the associated factor. In the graphs, factors are ordered according to their importance measure.

Table 3. Results obtained with respect to the outcome: COST

Graph	Sample
	Awarded before crisis Relevant Indicators: 1. Level of control of revenue 2. Institutional setting 3. Governance 4. Cost saving Insignificant indicators (δ <0.05): Independent Indicators: 1. Transport market 2. Revenue robustness

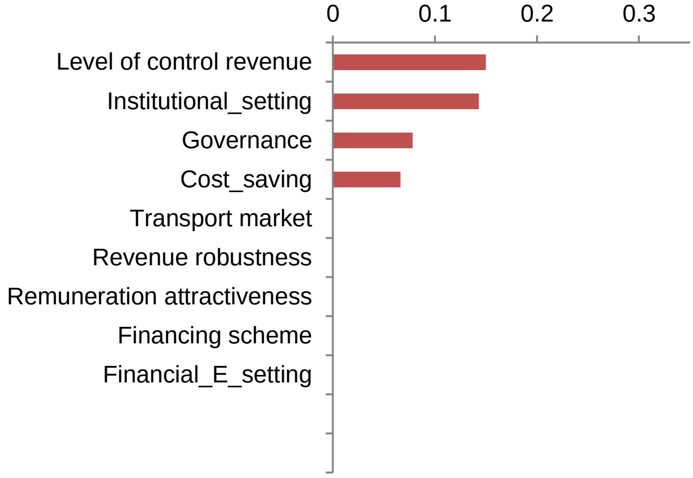
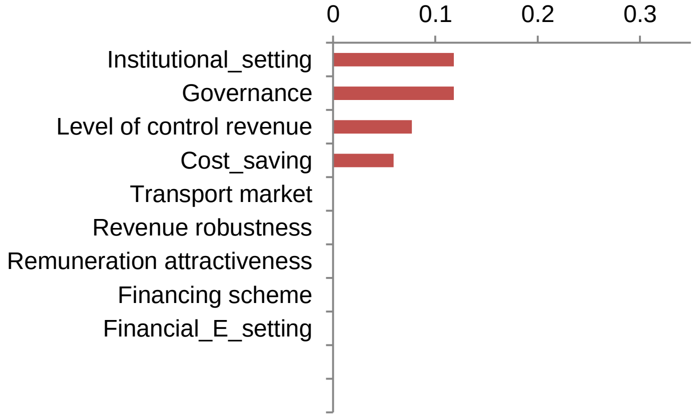
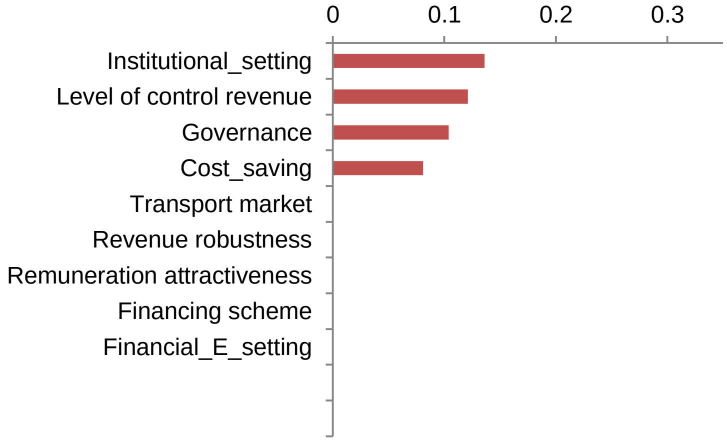
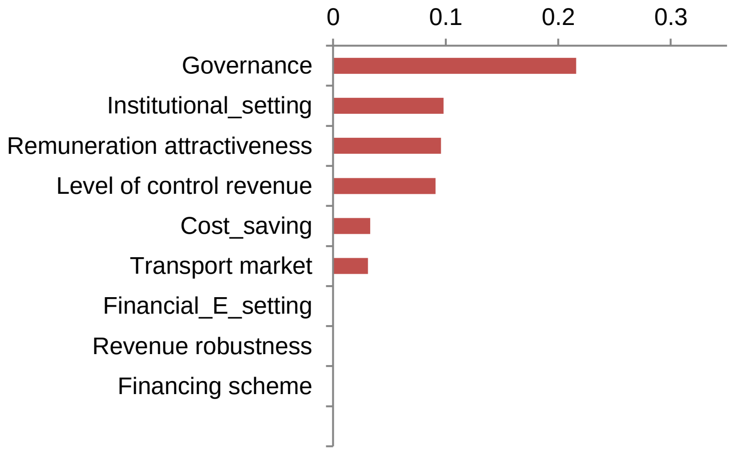
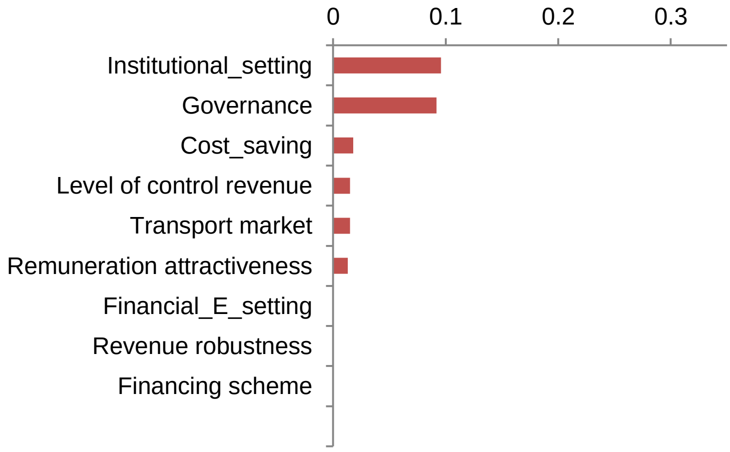
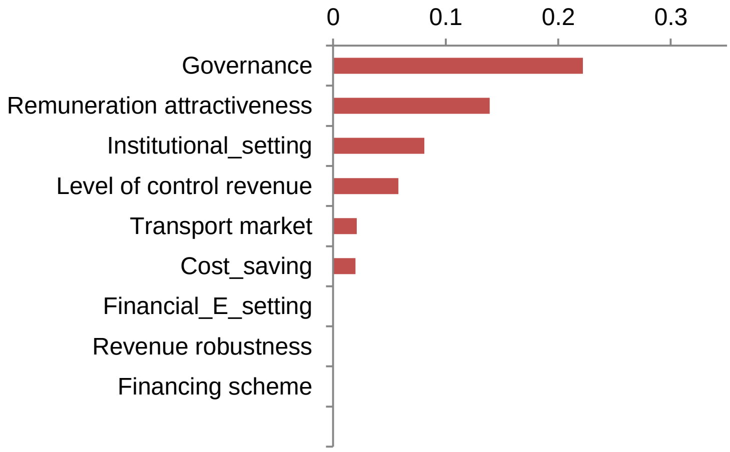
Graph	Sample
	3. Remuneration attractiveness 4. Financing scheme 5. Financial and Economic setting
	**Completed before crisis** <u>Relevant Indicators:</u> 1. Institutional setting 2. Governance 3. Level of control of revenue 4. Cost saving <u>Insignificant indicators (δ <0.05):</u> <u>Independent Indicators:</u> 1. Transport market 2. Revenue robustness 3. Remuneration attractiveness 4. Financing scheme 5. Financial and Economic setting
	**Completed after crisis** <u>Relevant Indicators:</u> 1. Institutional setting 2. Level of control of revenue 3. Governance 4. Cost saving <u>Insignificant indicators (δ <0.05):</u> <u>Independent Indicators:</u> 1. Transport market 2. Revenue robustness 3. Remuneration attractiveness 4. Financing scheme 5. Financial and Economic setting

Table 4. Results obtained with respect to the outcome: TIME

Graph	Sample
	**Awarded before crisis** <u>Relevant Indicators:</u> 1. Governance 2. Institutional setting 3. Remuneration attractiveness 4. Level of control of revenue <u>Insignificant indicators (δ <0.05):</u> 1. Cost saving 2. Transport market <u>Independent Indicators:</u> 1. Financial and Economic setting 2. Revenue robustness 3. Financing scheme
	**Completed before crisis** <u>Relevant Indicators:</u> 1. Institutional setting 2. Governance <u>Insignificant indicators (δ <0.05):</u> 1. Cost saving 2. Level of control of revenue 3. Transport market 4. Remuneration attractiveness <u>Independent Indicators:</u> 1. Financial and Economic setting 2. Revenue robustness 3. Financing scheme
	**Completed after crisis** <u>Relevant Indicators:</u> 1. Governance 2. Remuneration attractiveness 3. Institutional setting 4. Level of control of revenue <u>Insignificant indicators (δ <0.05):</u> 1. Transport market 2. Cost saving <u>Independent Indicators:</u> 1. Financial and Economic setting 2. Revenue robustness 3. Financing scheme

The results report variables, which are independent of particular outcomes (output variables), as well as others that are not relevant. It is noted that the models developed include relationships of variables confirmed by rejection of the hypothesis of independence for each marginal and conditional relationship (using the cut off $p < 0.05$ for different relationships). The relevance of a given variable is given by the sensitivity analysis performed. An importance value threshold δ = 0.05 has been adopted as suggested and used by Plischke, Borgonovo and Smith (2013).

From Table 3, one could observe that the "financial & economic setting", "remuneration attractiveness", "revenue robustness", "transport market efficiency & acceptability", and "financing scheme" variables seem to be independent of "cost" variable across the different datasets analysed. Meanwhile, "level of control of revenue", "institutional setting", "governance", and "cost saving" exhibit high significance. Notably, "cost saving" variable relative ranking does not seem to vary significantly across the different data sets. This variable exhibits stability but has the lowest significance importance level in comparison with the other factors. Note however that, independence tests carried out, within the context of this analysis, shown strong associations between "institutional and financial-economic setting factors", being the latter probably an input variable of "institutional setting" factor.

With respect to the output variable "time" whose results are shown in Table 4, the variables "financial & economic setting", "revenue robustness", and "financing scheme" appeared as independent of the time outcome. Across the samples analysed, the variables "cost saving" and "transport market efficiency & acceptability" are not relevant. Meanwhile, the "governance", "institutional setting", "remuneration attractiveness", and "level of control of revenue" are typical factors relevant to time output variable. Remarkably, "level of control of revenue" variable stably ranks always at the lowest level of significance among the significant factors.

Conversely, according to our analysis which is shown in Table 5, all the input factors analysed resulted to be insignificant to explain changes in the variable "traffic" across cases.

Likewise, when it comes to achieving revenue expectations, Table 6 shows that the "level of control of revenue" variable, in two out of the three datasets analysed, and "remuneration attractiveness" factor, in one instance, are significant factors. The remaining input factors considered here resulted either to be insignificant to or independent of the variable "revenue".

In general, our findings suggest that many of the variables considered in this research are important to "cost", "time", and "revenue" output variables. The outcome "traffic" appears to be no related to any of the factors modelled. This suggests the need for a revision of how this output variable is measured to ultimately conclude on its significance to measure project performance. In addition to this, the variables associated with "revenue robustness", "transport market efficiency & acceptability", and "financing scheme" appeared to be insignificant to the outcome variables analysed here, and probably they do not affect project outcomes as hypothesised earlier in this research.

With respect to the proposed analysis aimed to shed light on how the significant factors identified and discussed in the previous paragraphs can inform responsive actions to face potential economic crisis, some points of interest are discussed below per outcome. The analysis of this issue can be conducted by looking at the ranking changes between the "completed before crisis" and "completed after crisis" datasets analyses in Tables 3 to 6.

Table 5. Results obtained with respect to the outcome: TRAFFIC

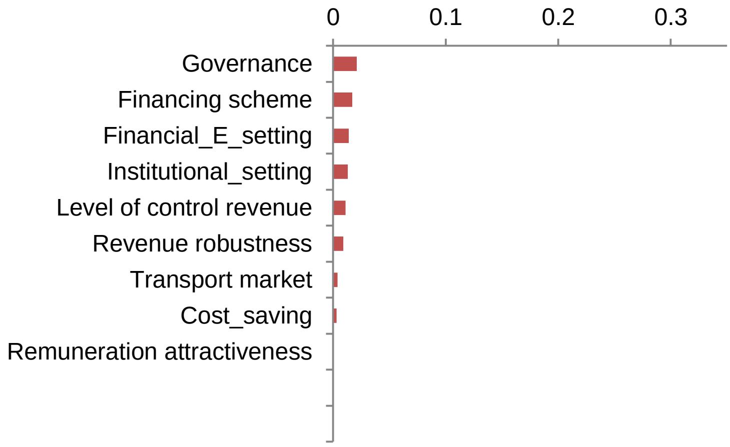
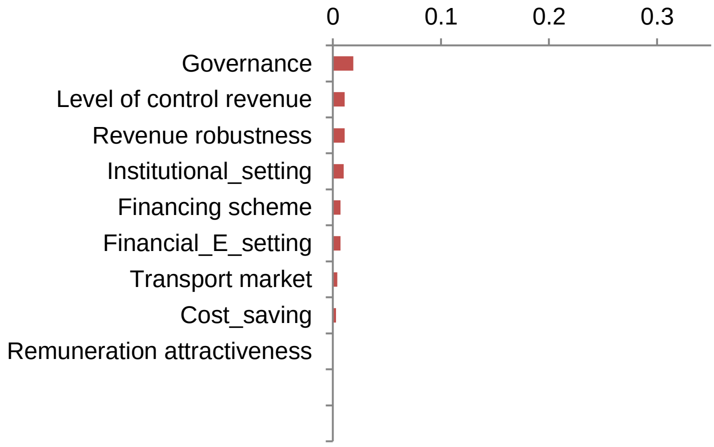
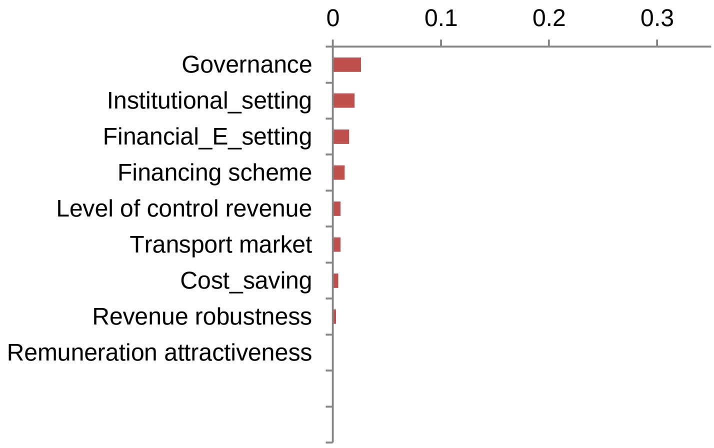
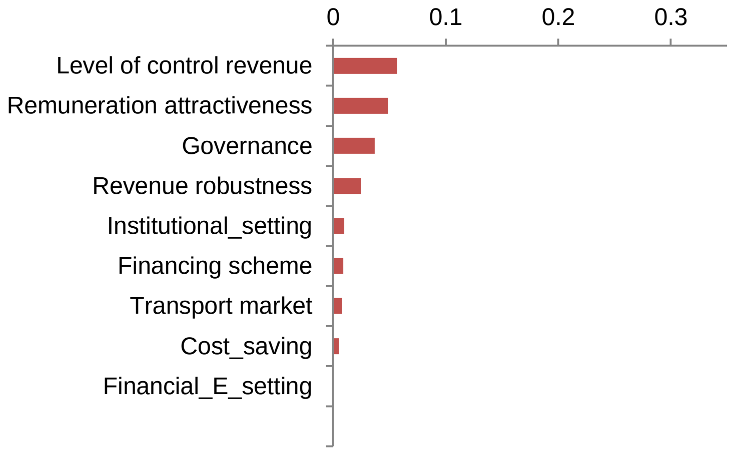
Graph	Sample
	**Awarded before crisis** Relevant Indicators: Insignificant indicators (δ <0.05): 1. Governance 2. Financing scheme 3. Financial and Economic setting 4. Institutional setting 5. Level of control of revenue 6. Revenue robustness 7. Transport market 8. Cost saving Independent Indicators: 1. Remuneration attractiveness
	**Completed before crisis** Relevant Indicators: Insignificant indicators (δ <0.05): 1. Governance 2. Level of control of revenue 3. Revenue robustness 4. Institutional setting 5. Financing scheme 6. Financial and Economic setting 7. Transport market 8. Cost saving Independent Indicators: 1. Remuneration attractiveness
	**Completed after crisis** Relevant Indicators: Insignificant indicators (δ <0.05): 1. Governance 2. Financial and Economic setting 3. Financial and Economic setting 4. Financing scheme 5. Level of control of revenue 6. Transport market 7. Cost saving 8. Revenue robustness Independent Indicators: 1. Remuneration attractiveness

Table 6. Results obtained with respect to the outcome: REVENUE

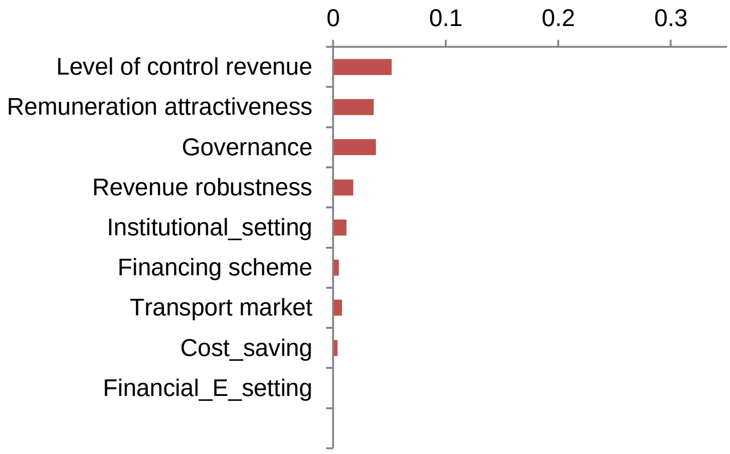
Graph | Sample



Awarded before crisis
<u>Relevant Indicators:</u>
1. Level of control of revenue
2. Remuneration attractiveness

<u>Insignificant indicators (δ <0.05):</u>
1. Governance
2. Revenue robustness
3. Institutional setting
4. Financing scheme
5. Transport market
6. Cost saving

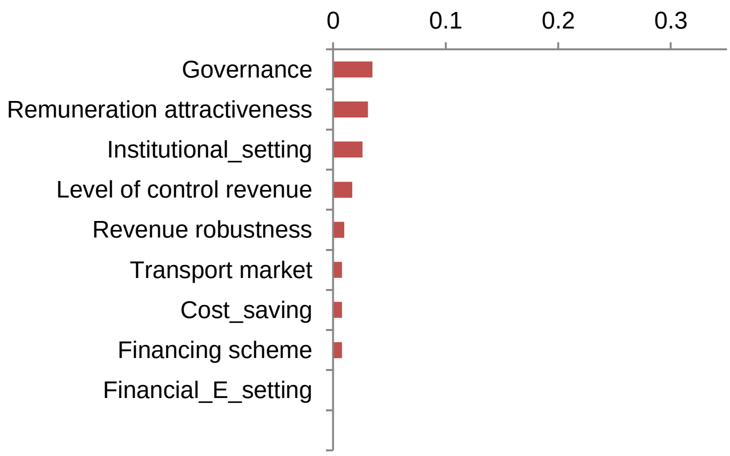
<u>Independent Indicators:</u>
1. Financial and Economic setting



Completed before crisis
<u>Relevant Indicators:</u>
1. Level of control of revenue

<u>Insignificant indicators (δ <0.05):</u>
1. Remuneration attractiveness
2. Governance
3. Revenue robustness
4. Institutional setting
5. Financing scheme
6. Transport market
7. Cost saving

<u>Independent Indicators:</u>
1. Financial and Economic setting



Completed after crisis
<u>Relevant Indicators:</u>

<u>Insignificant indicators (δ <0.05):</u>
1. Governance
2. Remuneration attractiveness
3. Institutional setting
4. Level of control of revenue
5. Revenue robustness
6. Transport market
7. Cost saving
8. Financing scheme

<u>Independent Indicators:</u>
1. Financial and Economic setting

In terms of cost expectations in Table 3, the ranking of the “completed before crisis” and “completed after crisis” datasets analyses did not experience major changes, and this suggests that no other factors were necessary to achieve cost expectations. In other words, one might infer that actions set in place and related to these significant factors resulted to be sufficient to bear the effects of the economic crisis in 2008.

In contrast with the cost output results, additional actions were introduced to or successfully implemented in the project cases analysed during the economic crisis to achieve time goals (Table 6). This is evident from the fact that "remuneration attractiveness" and "level of control of revenue" appear to be significant factors in the "completed after crisis" dataset, whereas these factors resulted to be irrelevant in the "completed before crisis" dataset.

Next, it is possible to infer from the changes in the rankings between the "completed before crisis" and "completed after crisis" datasets (Table 5 and Table 6), that no additional action was deployed or was effective for the project cases completed after the crisis to achieve traffic or revenue expectations.

The results presented here, indicated that some actions were implemented at some instances during the European economic crisis time in the projects analysed. This is the case of actions to meet project time expectations such as those related to "remuneration attractiveness" and "level of control of revenue" variables which appeared to be important in the "projects completed after" crisis' models. On the other hand, actions leading to cost expectations in projects and related to "governance", "level of control of revenue", and "cost saving" seemed to be sufficiently robust to face the economic crisis. This is because no other management action appeared to be significant to achieve project cost expectations during the crisis.

The findings reported here have important implications. We have provided evidence on the relevance, to meet project expectations, of factors beyond project governance and procurement processes in transport infrastructure projects, namely the importance of factors such as the "institutional setting", "level of control of revenue", and "remuneration attractiveness". With this evidence we have advanced the work of Eriksson and Westerberg (2011), Li, Arditi, and Wang (2012), and by Chen and Manley (2014) who focused on factors related to procurement, project governance, and transaction costs. Li, Arditi, and Wang (2012) and Chen and Manley (2014) have developed and extensively tested conceptual models in which relevant project governance instruments and factors were identified and related to the performance and the reduction in transaction costs of construction projects.

Note, however, that "cost saving" related variables have been to a certain extent studied by Li, Arditi, and Wang (2012). Cost saving covers aspects such as the capability to construct, monitor, operate, innovate, and plan of the all parties involved. Their and our research findings coincide in that these aspects of cost saving are important to achieve cost expectations, but they have a moderated effect.

This research encourage the undertaking to consider whether the significant factors identified here should be broken down into sub-factors, and that if, by modelling these, more specific particular interventions would be revealed that would allow one to more optimally resource a project and further enhance project outcomes.

5. Conclusions

Based on the examination of the transactions in 58 case study projects, we have developed probabilistic causation models in which relevant project factors were identified and related to the performance of transport infrastructure projects. These models contain relationships that link a number of significant project variables to project performance. To identify the most significant relationships among those hypothesised in BENEFIT research project, we used the Importance Analysis approach. Such an approach was deployed in combination with Bayesian Networks and Sensitivity Analysis.

This research has advanced knowledge by identifying relevant factors affecting transport project performance, which have not been exhaustively analysed and reported earlier in the specialised literature on the basis of case studies data. According to the advocated analysis, the variables that resulted important to achieve cost, time and revenue expectations in transport infrastructure projects are "institutional setting", "project governance", "cost saving", "level of control of revenue", and "remuneration attractiveness".

The "institutional setting" factor captures aspects such as the political stability and absence of violence, control of corruption, and voice and accountability of a country, and covers the issue of "public sector capacity".
The variables incorporated in the "governance" factor consider aspects as the early involvement of the contractor in the design and estimation of costs, procurement procedures, integration of design and construction, the incentives and disincentives regime, risk allocation, contract flexibility, and actions that allow the contracting party to maintain bargaining power during possible renegotiations.
"Cost saving" factor can be described to be measuring the ability to avoid or reduce cost overruns. It covers aspects such as the capability to construct, monitor, operate, innovate, and plan of the all parties involved.
"Level of control of revenue" measures the capability of the all parties involved to secure revenue for the project when facing traffic demand changes.
"Remuneration attractiveness" reflects the attractiveness of the remuneration scheme for investors and includes costs coverage (income streams) and risk of income measurements.

Additionally, we analysed how projects in our sample responded to the effects of the European economic crisis in 2008. The results indicated that some actions were implemented at some instances during the crisis time. This is the case of actions to meet project time expectations such as those related to "remuneration attractiveness" and "level of control of revenue" variables which were adopted and appeared to be important in a data set that contains projects completed after crisis. On the other hand, actions leading to achieve cost expectations in projects and related to "project governance", "level of control of revenue", and "cost saving" seemed to be sufficiently robust to face the economic crisis. This because from our analysis no other factors appeared to be significant to meet project cost expectations during the crisis.

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References

Anderson, R. D., & Vastag, G. (2004). Causal modeling alternatives in operations research: Overview and application. *European Journal of Operational Research*, 156(1), 92-109.

Anderson, R. D., Mackoy, R. D., Thompson, V. B., & Harrell, G. (2004). A Bayesian Network Estimation of the Service Profit Chain for Transport Service Satisfaction. *Decision Sciences*, 35(4), 665-689.

Andsten, R. S., & Vaurio, J. K. (1992). Sensitivity, uncertainty, and importance analysis of a risk assessment. *Nuclear Technology*, 98(2), 160-170.

Borgonovo, E. (2006). Measuring uncertainty importance: investigation and comparison of alternative approaches. *Risk analysis*, 26(5), 1349-1361.

Borgonovo, E., Castaings, W., & Tarantola, S. (2011). Moment independent importance measures: New results and analytical test cases. *Risk Analysis*, 31(3), 404-428.

Borgonovo, E., & Plischke, E. (2016). Sensitivity analysis: a review of recent advances. *European Journal of Operational Research*, 248(3), 869-887.

BENEFIT database (2017) Available from http://www.benefit4transport.eu/wiki

Cárdenas, I.C., Al-Jibouri, S.H.S., Halman, J.I.M, & Tol, F.A. (2014). Modeling risk-related knowledge in tunneling projects. *Risk Analysis*, 34 (2), 323–339.

Cárdenas, I. C., Voordijk, H., & Dewulf, G. (2017). Beyond theory: Towards a probabilistic causation model to support project governance in infrastructure projects. *International Journal of Project Management*, 35(3), 432-450.

Chen, L., & Manley, K. (2014). Validation of an instrument to measure governance and performance on collaborative infrastructure projects. *Journal of Construction Engineering and Management*, 140(5).

Eriksson, P.E., & Westerberg, M., (2011). Effects of cooperative procurement procedures on construction project performance: a conceptual framework. *International Journal of Project Management*, 29 (2), 197–208.

Lee, M. S., & Moore, A. W. (2014). Efficient algorithms for minimizing cross validation error. In *Machine Learning Proceedings 1994*: Proceedings of the Eighth International Conference (p. 190), 1994.

Li, H., Arditi, D., & Wang, Z. (2012). Factors that affect transaction costs in construction projects. *Journal of Construction Engineering and Management*, 139(1), 60-68.

Onisko, A., Druzdzel, M. J., & Wasyluk, H. (2001). Learning Bayesian network parameters from small data sets: Application of Noisy-OR gates. *International Journal of Approximate Reasoning*, 27(2), 165-182.

Plischke, E., Borgonovo, E., & Smith, C. L. (2013). Global sensitivity measures from given data. *European Journal of Operational Research*, 226(3), 536-550.

Roumboutsos, A., et al. (2015). Methodological Framework for Ex-post Analysis. Business models for enhancing funding and enabling financing for infrastructure in Transport. Version 1.0. Technical Report. *Athenas: Benefit research project. European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 635973.*

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., ... & Tarantola, S. (2008). *Global sensitivity analysis: The Primer.* John Wiley & Sons. Chichester

van der Gaag, L. C. (1996). Bayesian belief networks: odds and ends. *The Computer Journal*, 39(2), 97-113.

Appendix A: Variables and their discretisation

The below table shows how variables in this study were discretised. Note that most of the factors take values from the interval [0, 1].

Type	Variable	Classes
Input variables	Institutional setting	More than 0.73
		Between 0.67 and 0.73
		Less than 0.67
	Financial Economic setting	More than 0.63
		Between 0.50 and 0.63
		Less than 0.50
	Availability/Reliability	More than 0.75
		Between 0.56 and 0.75
		Below 0.56
	Governance	More than 0.69
		Between 0.56 and 0.69
		Less than 0.56
	Cost saving	More than 0.47
		Between 0.18 and 0.47
		Less than 0.18
	Level of control of revenue	More than 0.73
		Between 0.45 and 0.73
		Less than 0.45
	Revenues	More than 0.10
		Between 0.06 and 0.10
		Less than 0.06
	Remuneration attractiveness	More than 0.67
		Between 0.33 and 0.67
		Less than 0.33
	Revenue robustness	More than 0.67
		Between 0.57 and 0.67
		Less than 0.57
	Transport market efficiency & acceptability	More than 0.44
		Between 0.22 and 0.44
		Less than 0.22
	Financing scheme	More than 0.91
		Between 0.70 and 0.91
		Less than 0.70
Output variables	Cost Overrun	Cost underrun
		Cost overrun
	Time Overrun	Time underrun
		Time overrun
	Actual vs Forecasted Traffic	Forecast as expected
		Below forecast
	Revenue vs Forecasted Revenue	Forecast as expected
		Below forecast

Note that, input variables classes are determined using the 33th and 67th percentiles values of each variable data sets.

The "Availability/Reliability" variable was not analysed because of their insignificance to the project outcomes, verified earlier in this research.

The Table , further note that, cost underrun class includes values associated with costs on budget. Likewise, time underrun class includes values associated with situations in which time to completion was achieved as originally planned in a project. The class "Forecast as expected" corresponds to values associated with either exceeding or meeting forecasts made in earlier stages in a project. The class "Below forecast" is related to values either below or far below expectations made in earlier stages in a project.

Appendix B: Case study projects

The following table depicts the basic characteristics of the projects.

	Project	Country	Main mode delivered	Main delivery mode
1	A2 Motorway	Poland	Road	Private Co-Financed
2	A5 Maribor - Pince Motorway	Slovenia	Road	Public funding
3	A19 Dishforth To Tyne Tunnel	UK	Road	Private Co-Financed
4	A22 - Algarve	Portugal	Road	Private Co-Financed
5	A23 - Beira Interior	Portugal	Road	Private Co-Financed
6	Athens International Airport 'Eleftherios Venizelos'	Greece	Airport	Private Co-Financed
7	Athens Tramway	Greece	Tram	Public funding
8	Attiki Odos (Athens Ring Road)	Greece	Road	Private Co-Financed
9	Barcelona Europe South Terminal	Spain	Seaport	Private Co-Financed
10	Belgrade By-Pass Project, Section A: Batajnica-Dobanovci	Serbia	Road	Public funding
11	Berlin Brandenburg Airport (BER)	Germany	Airport	Public funding
12	Blanka Tunnel Complex	Czech	Bridges and Tunnels	Public funding
13	BNRR (M6 Toll)	UK	Road	Private Co-Financed
14	Brabo 1	Belgium	Tram	Private Co-Financed
15	Central Greece (E65) Motorway	Greece	Road	Private Co-Financed
16	Central Public Transport Depot of the City of Pilsen	Czech	Terminals	Private Co-Financed
17	Combiplan Nijverdal	The Netherlands	Road	Public funding
18	The Hague New Central Train Station	The Netherlands	Terminals	Public funding
19	Deurganckdoksluis-Deurganckdock Lock	Belgium	Seaport	Private Co-Financed
20	E4 Helsinki-Lahti	Finland	Road	Private Co-Financed
21	E18 Muurla-Lohja	Finland	Road	Private Co-Financed
22	E39 Orkdalsvegen Public Road	Norway	Road	Private Co-Financed
23	Eje Aeropuerto (M-12). Airport Axis	Spain	Road	Private Co-Financed

	Project	Country	Main mode delivered	Main delivery mode
	Toll Motorway			
24	Elefsina Korinthos Patra Pyrgos Tsakona Motorway	Greece	Road	Private Co-Financed
25	Fertagus Train	Portugal	Rail	Private Co-Financed
26	Herrentunnel Lübeck	Germany	Bridges and Tunnels	Private Co-Financed
27	Ionia Odos Motorway	Greece	Road	Private Co-Financed
28	Koper - Izola Expressway	Slovenia	Road	Public funding
29	Larnaka Port & Marina Re-Development	Cyprus	Airport	Private Co-Financed
30	Larnaca and Paphos (Cyprus) International Airports	Cyprus	Seaport	Private Co-Financed
31	Liefkenshoekspoor-verbinding - Liefkenshoek Rail Link	Belgium	Rail	Private Co-Financed
32	Lusoponte - Vasco Da Gama Bridge	Portugal	Bridge and Tunnels	Private Co-Financed
33	Tram T4 (Line 4 Of Lyon Tramway)	France	Tram	Public funding
34	Velo'V	France	Bicycles	Private Co-Financed
35	Metrolink LRT, Manchester	UK	Tram	Private Co-Financed
36	M-25 Motorway London Orbital	UK	Road	Private Co-Financed
37	M-45	Spain	Road	Private Co-Financed
38	M80 Haggs	UK	Road	Private Co-Financed
39	Metro de Malaga	Spain	Metro	Private Co-Financed
40	Metro do Porto S.A.	Portugal	Metro	Private Co-Financed
41	Modlin Regional Airport	Poland	Airport	Public funding
42	Moreas Motorway	Greece	Road	Private Co-Financed
43	Motorway E-75, Section Donji Neradovac - Srpska Kuca	Serbia	Road	Public funding
44	Horgos - Pozega	Serbia	Road	Private Co-Financed
45	MST - Metro Sul do Tejo	Portugal	Tram	Private Co-Financed
47	Piraeus Container Terminal	Greece	Seaport	Private Co-Financed
48	Port Leixões	Portugal	Seaport	Private Co-Financed
49	Port of Sines Terminal XXI	Portugal	Seaport	Private Co-Financed
50	Port of Agaete (concessioned operation)	Spain	Seaport	Public funding
51	Radial 2 Toll Motorway	Spain	Road	Private Co-Financed
52	Reims Tramway	France	Tram	Private Co-Financed
53	Rion-Antirion Bridge	Greece	Bridge and Tunnels	Private Co-Financed
54	SERVICI	Spain	Bicycles	Private Co-Financed
55	Terminal Muelle Costa at Port of Barcelona	Spain	Seaport	Private Co-Financed
56	Tram-Train 'Kombiloesung' Karlsruhe	Germany	Rail	Public funding
57	Via-Invest Zaventem	Belgium	Road	Private Co-Financed
58	Warsaw's Metro II-2nd Line	Poland	Metro	Public funding

Appendix C: Metrics of the analyses developed in Table 2

The following table depicts metrics of the analyses 1 to 12 conducted as mentioned in Table 2. These metrics provide information on the quality of the modelling.

Analysis # (1)	Marginal log-likelihood (2)	Average diagnostic accuracy (3)	Objective of the analysis "Identification of factors relevant to …" (4)
1	-855	72.77%	Cost
2	-855	83.33%	Time
3	-803	79.06%	Traffic
4	-803	87.21%	Revenue
5	-524	59.24%	Cost
6	-524	62.96%	Time
7	-532	71.18%	Traffic
8	-532	84.75%	Revenue
9	-532	84.75%	Cost
10	-532	93.22%	Time
11	-425	80.00%	Traffic
12	-425	95.55%	Revenue

The minimal percentage of correct diagnoses obtained was 59.24% (Analysis # 5). In terms of goodness of fit, which is measured by each model's marginal log-likelihood (column 2 in Table A-3), we did not obtained significant differences among similar datasets. Thus the models analysed are equivalent in terms of goodness of fit to the data. The most optimal dataset is the one composed by the records associated with projects completed after crisis.