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Project characteristics and performance in Europe: an empirical analysis for large transport infrastructure projects

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Abstract

Infrastructure megaprojects are historically associated with poor delivery, both in terms of cost and schedule performance. Large Transport Infrastructure Projects (TIPs) are amongst the most controversial and are often delivered late, over budget, and providing less benefits than expected. While there is a growing theoretical body of literature addressing TIPs, empirical research is still required to determine which TIPs characteristics affect TIPs schedule & cost performance. This paper addresses this issue, applying an empirically-based methodology to a dataset of 30 European TIPs. The results highlight the importance of financial support from the government and the strong influence of both external and internal stakeholders, mainly in relation to their early engagement and to their nationality. Technological characteristics and the presence of Special Purpose Entities are also correlated with the TIPs performance. These key findings both support and contradict the literature, and are relevant for both policy makers and project managers during the decision-making process, planning and delivery of TIPs.

Keywords: Planning; Budget; Schedule; large Transport Infrastructure Project; Megaprojects; Statistical Analysis;

Highlights:

- Transport Infrastructure Projects (TIPs) are often over budget and late
- This study investigates the correlation between project characteristics and performance
- The identification of correlations allow a focused investigation on the causations
- The paper is based on 30 European large Transport Infrastructure Projects.
- External and Internal stakeholders account for most of the correlations

1 Introduction

Megaprojects are endeavours characterized by vast organizational complexity, long-lasting impact on the economy, environment & society and a large investment commitment (Locatelli, Mancini, et al. 2014). Gellert and Lynch (2003, p.16) show that *"Mega-projects can be divided analytically into four types: (i) infrastructure (e.g., ports, railroads, urban water and sewer systems); (ii) extraction (e.g. minerals, oil, and gas); (iii) production (e.g. industrial tree plantations, export processing zones, and manufacturing parks); and (iv) consumption (e.g. massive tourist installations, malls, theme parks, and real estate developments)"*.

There is not a single accepted definition of megaproject in the literature and different criteria can be adopted. For instance, from the investment point of view, megaprojects have budgets above $1 billion with an high level of innovation and complexity (Flyvbjerg et al. 2003; Locatelli et al. 2014a; Merrow 2011; Van Wee 2007). Looking at the operations phase, megaprojects are projects having long-term and far-reaching effects on their environment (Orueta and Fainstein 2008; Ren and Weinstein 2013, Warrack 1993). With respect to the economic dimension, Warrack (1985) argues that $1 billion is not a constraint in defining megaprojects, as sometimes a relative approach is needed because in some contexts, a much smaller project (such as one with a $100 million budget), could constitute a megaproject. Van Marrewijk et al. (2008, p.591) define megaproject as *"multibillion-dollar mega-infrastructure projects, usually commissioned by governments and delivered by private enterprise; and characterised as uncertain, complex, politically-sensitive and involving a large number of partners".* This latter definition emphasizes the organizational complexity that comes with the presence of multiple private firms in connection to the political stakeholders (frequently, some form of national or local government).

Large Transport Infrastructure Projects (TIPs) are megaprojects in the transportation sector such as high speed railways, airports and long bridges are often late, costly, and fail to provide the promised benefits to the society (Cantarelli et al. 2010; Flyvbjerg et al. 2004). Since large TIPs have these characteristics and often exceed the threshold of 1 billion USD (Flyvbjerg 2014; Zidane et al. 2013), they can be addressed as megaprojects.

TIPs are a key determinant of performance in the transport sector (OECD 2015), and over the next ten years, a significant level of investment in TIPs is expected. For instance, research by Oxford Economics predicts a global increase of 5% of the transport infrastructure investments, with investments in the Asia Pacific region expected to grow from $557bn per year to nearly $900bn per year in 2025, and more modest investment levels in Western Europe (PWC 2015).

Budget constraints always play a pivotal role, so decision-makers need information regarding the spending and benefits promoted by infrastructure development to prioritize investment (OECD 2015). However, there is a "*lack of common definitions and practices to measure transport infrastructure spending hinders comparisons between countries and spending options*" (ITF 2013) that hinders comparison between countries and across options. In particular, it is unclear which TIP characteristics are correlated with the TIP performance.

Considering the prominent role that TIPs will play in the future, their planning and construction will be fundamental in securing their effective and efficient performance during their lifecycle, and a more effective design and delivery of TIPs is becoming increasingly important.

Following the research methodology proposed in (Brookes & Locatelli 2015) and inspired by (Eisenhardt 1989) this paper presents the method and the results of a rigorous and systematic investigation to identify the characteristics that contribute to the effective design and delivery of new TIPs, based on data collected of 30TIPs across Europe. It identifies the correlation and discusses possible causation linking TIPs characteristics to TIPs performance. This is worthwhile to provide guidance for decision-makers about future projects.

2 Literature review

2.1 Relevance of transportation megaprojects

Transportation plays a critical role in promoting the competitiveness of the economies, as high quality services and infrastructure improve economic performance and facilitate regional competitiveness. The OMEGA Centre (2015) investigates what delineates a successful mega infrastructure project, programme and/or plan. Dimitriou et al. (2013) examines the "agent of change" of mega transport project against their cost, time and quality performance, exposing the different understanding of what are the project boundaries of such investments.

Other authors that focus on the transportation sector broaden their analysis to project under 1 billion USD of budget. Knowles & Ferbrache (2015) examine the economic impacts of modern light rail systems in the UK and globally. They highlight the benefits of tram and light metro in relation with geographic constraints (e.g. the extension of labour market catchment areas, reorganisation of production and the enhancement of employment,) concluding that light rail encourages inward investment by widening labour catchment areas and boosting property prices. Mullen & Marsden (2015) explore the role of TIPs in economic development and city competitiveness, and state that the key to promoting an effective transport scheme is "*a high benefit-to-cost ratio which will typically be dominated by large volumes of relatively small scale time savings*". Melo et al. (2013) conduct an empirical analysis based on the output elasticity of transport infrastructure: they analyse a sample of 563 estimates obtained from 33 studies, drawing the conclusions that the existing estimates of the productivity effect of transport infrastructure can be very different. They show that productivity is higher for the US economy than for European countries, and are higher for roads than other modes of transport. Cantarelli et al. (2012) focuses on the Netherlands and show that cost overruns in this country appear to be smaller than the rest of the world. Graham (2007) investigates the relationships between agglomeration, productivity, transport investment and provides an empirical quantification of the links between urban density and productivity.

Given the importance of TIPs as described by the aforementioned research, the authors present an empirically-based methodology to identify the characteristics of TIPs associated to cost and schedule performance.

2.2 Project performance

TIPs performance is a debated topic: on the one hand, the OECD (2015) highlights the relevance of TIPs for the economic development, since TIPs can create employment and promote labour mobility;

on the other hand, TIPs can fail to support the expected growth in the regional and national competitiveness (Vickerman 2010). Even if there has been a long term desire to investigate project performance, according to different stakeholders perspectives over different timescales (Turner & Zolin 2012; Cooke-Davies 2002; Atkinson 1999), this paper focuses on cost and schedule performances.

Indeed, TIPs are often characterized by schedule spanning over decades and budget in the region of millions or billions of dollars and are affected by significant uncertainties and risks (Bruzelius et al. 2002). Therefore, time and cost forecasts are difficult to estimate, and often prove to be wrong. Anas (2012) analyses the complexity concerning the optimal allocation of the pricing, financing and supply of urban transportation. Berechman & Chen (2011) emphasize that the risk of cost overrun should be incorporated in the project evaluation and decision-making. In fact, particularly in the transportation infrastructure sector, substantial cost escalation seems to be the rule, rather than the exception (Flyvbjerg, Skamris holm, et al. 2003). Mishra et al. (2011) point out that TIPs are irreversible investments and require long-time commitment maintenance and operation. These authors also criticize traditional economic analysis techniques based upon the assumption of deterministic future cash flows and they propose a framework for addressing uncertainty and risk for TIPs investments involving public and private entities.

Other relevant publications also show how large TIPs are historically associated with poor delivery, both in terms of cost and schedule performance. For instance, Cantarelli et al. (2010), investigate the explanations of costs overrun in the literature, distinguishing four categories: technical, economic, psychological, and political; Flyvbjerg & Holm (2005) assess 210 TIPs in 14 nations, showing that estimates often prove to be inaccurate, and that forecasts have not improved over the last 30 years: and Flyvbjerg et al. (Flyvbjerg et al. 2002; Flyvbjerg et al. 2004) analyse project performance regarding costs and cost-related risks, and found that 9 out of 10 projects present significant cost overrun.

Flyvbjerg (2008) also investigates the causes of TIPs poor performance, analysing 252 TIPs, and proposing that the reasons why megaprojects performed poorly were strategic misrepresentation or optimism bias. Optimism bias was already thoroughly investigated by Flyvbjerg in 2004 (Flyvbjerg & COWI 2004). Makovsek (2014) adds a new perspective to the hypothesis of Flyvbjerg showing that is the mechanism of the bidders itself during the tendering process that implies that some systematic cost over-run will likely occur. Odeck (2014) analyses a data base of 1045 projects, demonstrating that the impact of reforms has not been equal and describing the differences in the outcomes, and highlighting that: (1) the reform that led to full competition (encompassing the separation and privatization of construction work) brought to a significant improvement in the cost estimates and

construction time but this does not occur when planning and construction are separated into two different departments; (2) the reduction in overruns after the implementation of full competition mainly affected the larger projects.

This research was pivotal to define the list of independent variables needed to describe the selected case studies and to critically gauge the results obtained through the statistical analysis.

2.3 Investment appraisal and opportunities for improvements

The authors agree with Cascetta et al. (2015) regarding the fact that the quality of the decision-making process is a key factor for the successful planning and delivery of TIPs: this process should be structured involving "political, technical and communication abilities" to design technically consistent solutions that also maximizes stakeholders consensus. Also, Giezen et al. (2015) scrutinize the decision-making process, grouping three institutional elements (strategic ambiguity, redundancy and resilience) under the notion of strategic capacity. Hensher et al. (2015) review the role of local population and how the emotional bias toward certain type of project can shape the decision process and ultimately the project performance.

In summary, the poor performance of TIPs suggests opportunities for improvement, both in the assessment of schedule and costs estimates and in the method employed for their previous appraisal. Taking into account all the aforementioned research studies, the authors propose a statistical analysis based on the Fisher Exacts Test (FET) and apply it on our database composed of 30 TIPs. The results would be the starting point to develop guidelines to contribute to the improvement of the decision-making process.

3 Methodology

3.1 Cross-case analysis

The research methodology proposed in this work is a further development of the work presented in (Brookes & Locatelli 2015). The methodology consists of an inductive cross-case analysis, a technique that takes similarly constructed cases and uses a structured process to review the cases to arrive at "cross-case" patterns. These "patterns" are used to generate theoretical propositions.

The approach adopted is inspired by the work of Eisenhardt (1989), who derived a process where theoretical generalizations could be generated from reviewing a set of cases of a particular phenomenon. Eisenhardt (1989, p.545) discusses "reaching closure," i.e., *"when to stop adding cases, and when to stop iterating between theory and data"*. She advises researchers to stop adding cases upon reaching theoretical saturation and/or when the incremental improvement to quality is minimal.

This research is enclosed within a broader research stream initiated and supported by the Megaproject COST Action that focuses on Europe. The main objective of this action is to understand how megaprojects can be designed and delivered to ensure their effective commissioning within Europe. As a further development of (Cantarelli, Van Wee, et al. 2012), statistical analyses can be used to reveal relationship between TIPs characteristics (independent variables) and TIPs performance (dependent variables)[1].

However, there are inherent problems in trying to understand these relationships. Firstly, the absolute number of TIPs is small for statistical purposes, as most statistical techniques associated with establishing relationships require a greater sample size. Secondly, it is not possible to test parametric distributions. Indeed, parametric distributions assume that the data come from a certain probability distribution and hence infers about its parameters (Leach 1979), which does not suit the dataset of this study. Thirdly, data associated with PPMs characteristics is rich and qualitative and hence needs to be converted into a quantitative form to enable statistical analysis. This process is notoriously difficult (Easterby-Smith et al. 2012). Lastly, the evaluation of "performance" for projects in general and TIPs in particular can be controversial (Ika 2009) and it depends on the stakeholders perspective and the timeframe (Turner et al. 2012).

[1] *Please, see the Appendix B for the descriptions of dependent variables and Appendix A for independent variables.*

3.2 Fisher Exact Test

In order to overcome the research challenges previously presented, this methodology adopts the Fisher Exact Test (FET). The main advantage of this test relates to the ability to identify correlations within small data sets (Leach 1979). However, the FET has two main limitations. Firstly, it limits the typology of variables (both independent and dependent variables) to be considered: these must be binary/Boolean variables (i.e. Yes/No, On/Off, True/False). Hence, the test is less informative than other approaches because it considers black and white and not the grey spectrum between these two extremes. While binary data are commensurate with the use of the FET, it can detect a relationship between an independent and dependent variable and cannot describe the nature of the relationship. Secondly, the test considers the correlations between one independent variable and one dependent variables (i.e. one vs. one). Therefore, the test does not consider the mutual (or compound) correlations between variables. Finally, the investigators chose to evaluate the TIPs performance in terms of its planning and construction (both lead-time and cost). This enabled an unambiguous characterization of performance but had the drawback that the trade-off between construction costs and lead-time and operational efficacy cannot be investigated. We chose to adopt a higher significance level than that traditionally associated with this type of research (i.e. p-value <0.15 rather than a more typical value of p-value <0.05). This means that statistically significant findings must be dealt in a circumspect fashion with regard to suggested causation.

3.3 TIPs characterisation: dependent and independent variables

In order to investigate relationships, a purposive sample of 30 TIPs was selected from the wider portfolio that had been created by the Megaproject COST Action (Brookes 2015) and the Omega Centre (OMEGA Centre 2015). These TIPs are distributed across Europe (see Appendix A). The qualitative cases describing the TIPs were coded according to the presence (or absence) of 42 binary characteristics (i.e. the independent variable of the FET, detailed in Appendix C). The independent variables were collected and selected after a deep analysis of the single case studies. Then, the independent variables were listed and grouped into macro categories and operationalized in as clearly defined way as possible, in an iterative process of brainstorming and consultations with experts that lasted two years, and each TIP was "coded" according to its performance. In particular, the following performance (dependent) variables were considered: delays during the planning phase; delays during the construction phase, and costs over budget. Precise definitions are given in Appendix C (Table 3). Once the TIP had been coded, the dataset was used to identify which of the 126 potential relationships

(c.f. 42 binary independent characteristic and 3 binary dependent performance items) demonstrated statistical significance using the FET.

Given the vast variety and limited cohesiveness among existing theoretical explanations for TIPs performance, the authors chose to combine the existing theoretical understanding of megaproject performance with a portfolio of practical findings from the Megaproject COST Action (Brookes 2013). This led to the formulation of five categories of TIPs characteristics that were reviewed with respect to their impact on performance. These categories were:

- Project Stakeholders
    - Internal Stakeholders
    - External Stakeholders
- Project Environment
    - Legal Environment
    - Socio-Economic Environment
    - Political Environment
- Project Management (PM)
- Technological aspects & Other characteristics

The Appendix C provides a description of these broad categories into individual megaproject characteristics (independent variables) and the operationalization of these characteristics into binary representations.

4 Results

The first finding is that only a few of the TIPs characteristics demonstrate a statistically significant relationship with performance (Table 1). Of the 126 potential relationships, only 16 proved to be statistically significant. The following paragraphs detail the most important aspects.

Independent variable that showed a correlation		Planning	Construction	
			Budget	Schedule
External and Internal Stakeholders	The project is mono cultural - Client, EPC and all the important first tier contractors have different nationality (strong definition)		Respected (0.12)	
	More than 50% share of the client is under government control			Delays (0.08)
	The project has national public acceptability			Respected (0.12)
	The project has local public acceptability			Respected (0.11)
	Environmental groups have been engaged ex-ante, not ex post		Respected (0.04)	
Project Environment	The project has a strong regulation system as evidenced by action from the authority postponed the final completion of the project	Delays (0.01)		
	Financial Support from national government	Delays (0.03)		
	The compensation of local community above 0.1% of the total budget			Delays (0.02)
	The density of the population of the province is below the national average			Respected (0.13)
PM	There was a formal litigation procedure (e.g. international chamber of commerce) during the contract between Client and EPC			Delays (0.14)
Technological aspects & others	First Of A Kind (FOAK) weak – country level	Delays (0.07)		
	The project has a Special Purpose Entity (SPE)			Respected (0.04)
	Within the project scope, there is the construction of one or more tunnels	Delays (0.08)		
	Within the project scope, there is the construction of one or more bridges			Respected (0.13)
	Within the project scope there is the construction of one or more underground structure (e.g. an underground station)		Overbudget (0.04)	
	The project is a railway			Delays (0.12)

Table 1 Summary of the results P-values are shown in brackets.

4.1 External and internal stakeholders

Stakeholders can be classified into two macro categories, i.e. external and internal stakeholders: internal stakeholders include in the supply-side the clients and financiers, and in the demand side the principal contractors and other tier contractors; external stakeholders include regulatory agencies, the local & national government and environmentalists (PMI 2013). External stakeholders are sometimes defined in direct opposition to internal ones, as the "people outside the project team or organization" (Maylor 2010).

The results of the FET regarding internal stakeholders highlight the correlation between client, EPC and the first tier contractor having the same nationality and the conclusion of a project within the budget. This may be because stakeholders form the same country understand and trust each other, and are generally more confident in their initial estimates. This hypothesis is further sustained by the fact that no correlation is found between the fact that the client and the EPC (and eventually the first tier contractor) have the same nationality and the occurring of delays. Indeed, delays are often one of the most relevant driver for the costs increase, and this research analyses both the factors. In this situation, it can be assumed that delays both in the planning and in the construction phase are avoided by the network of stakeholders that are from the same country, which enables easier communication and collaboration, and facilitate the proceeding of the work without interruption. Moreover, benchmarking across countries might be limited by cultural barriers and the difficulty of entering new markets. Nevertheless, this does not appear to hinder the process of finding the most cost-effective solution to deliver the TIP, since the project characteristic of being "mono-cultural" is correlated with delivery within the budget[2].

Regarding external stakeholders, the dominant argument in the literature is that improving acceptance of a project will increase the chance of the project being successful (Aaltonen et al. 2008). In fact, in this research, the engagement of environmental activists and regulators ex-ante, is not correlated to neither delays in the planning phase nor in the construction phase, and is correlated with the completion of projects within the budget. This shows that, when environmental activists and the regulatory body are involved in time and the regulatory constraints are overcome, the project is likely to be finalized successfully. Similarly, there is a correlation between project acceptance (both at local level and at national level) and the delivery of project on time during the construction phase. This result is intuitive and the implementation of the FET permits to highlight it empirically: when actions

[2] With the term "mono-cultural" the authors refer to either (1) situation in which client and EPC have different nationality, (main headquarters in different countries – weak definition); or (2) client, EPC and all the important first tier contractors have different nationality (main headquarters in different countries – strong definition), as explained in Table 4.

(public talks, dissemination events…) to avoid public dissatisfaction and unacceptance are undertaken, the project is likely to avoid further issues and to be delivered on time. Conversely, no correlation is found between public acceptability and over budget.

Another key finding of the analysis is the correlation between having more than 50% share of the client under the government control and delays in the construction. This is not a completely unexpected outcome, since optimism bias and strategic misinterpretation can explain the optimistic forecast (Flyvbjerg 2006). However, the FET shows the presence of a correlation between the presence of financial support from the government and the delivery of the project within the budget.

4.2 The project environment

The legal, socio-economic and political environment plays a key role in the delivery of a project, and the FET highlights several interesting correlations between the environment and the TIPSs' performance.

First of all, the implementation of the FET has revealed a strong correlation between both the presence of a strong regulation system (evidenced by action from the authority postponed the final completion of the project) and financial support from the Government and the delays of the project in the planning phase, with a p-value of 0.01 and 0.03 respectively. Secondly, the FET has highlighted a strong correlation (p-value=0.02) between the compensation of the local community and delays in the construction.

Lastly, the FET underlines that, when the density of the population is below the national average, the TIP will not incur in delays during the construction phase. This empirical result is significant as it is strictly related with the relevance of the impact of stakeholders: if the density of the population is low, the probability that episodes of public unacceptance occur are lower.

4.3 Project Management

The PM characteristics assessed during this research have not shown a strong correlation with the project performances. The FET highlighted only the correlation between the fact that there was a formal litigation procedure (e.g. international chamber of commerce) during the contract between Client and EPC and delays in the construction phase.

4.4 Technological aspects of the TIP & others

The technological characteristics and the degree on innovation of the different TIPs are also taken account in this research, in order to investigate the possible correlation between their design & scope and their project performance in terms of cost and time. Scope management is fundamental to produce reliable cost estimate and schedule that facilitate programming decision making and accountability (NCHRP 2016).

First-of-a-kind technologies (FOAK), for instance, have frequently been associated with poor performances in planning and construction (Merrow 2011). In this study, the FET shows a significant correlation between FOAK technologies (at least in the country) and delays in the planning phase. Indeed, FOAK technologies require a great deal of Front End Loading and Front End Engineering Design (FEED) that might postpone the beginning of the construction. Moreover, the approval might also be jeopardised by delays, considering that the stakeholders might be unfamiliar with the technology.

In addition, the FET shows that, if the project is a railway, it is likely to be late in the construction phase. In particular: (1) the presence of one or more tunnel in the TIP is correlated with delays in the planning phase, (2) the presence of underground structures, such as underground stations, is correlated with over budget.

This results have several practical applications (e.g. in the design of the infrastructure), as it depicts which technological characteristics should be taken into account with proper care in order to avoid unexpected delays or cost overrun. This is the empirical confirmation of the “keep it simple” design philosophy advocated by Giezen (2012).

Lastly the FET shows that the presence of a Special Purpose Entity (SPE) is correlated with no delays in the construction phase. SPEs are *“fenced organization having limited pre-defined purposes and a legal personality”* (Sainati et al. 2015). SPEs are also known as Special Purpose Vehicles or Project Companies, and are typically involved in megaprojects for project partnering and project financing. Usually, public private partnerships and incorporated project joint venture are based on these organisational vehicles, and their exploitation lies on their ability to insulate the assets and the risks underlying to the project activities. In particular, the SPEs can be set up to design, deliver or operate with TIPs.

5 Discussion and conclusions

Decision-making supporting the initiation and design of TIPs is an extremely lengthy process involving multifarious stakeholders and is very difficult to discern. This lack of clarity does not make a readily identifiable and contained stakeholder audience to which the findings of this project can be directed. This makes the dissemination of the results of this investigation more difficult. However, similar guidance has been encapsulated and disseminated particularly initiated by the stakeholders financing the project (e.g. (Jaspers 2015)) and a similar approach is suitable for this investigation. To this end, the outputs from these investigations can be converted to a set of guidelines to be aimed at a general audience of policy-makers and other stakeholders. Key to the approach in the creation of these guidelines is the clear (albeit high level) identification of drivers of TIPs performance be that for good or bad.

This paper presents the relationships between TIPs characteristics and performance in terms of cost and time during their planning and construction phases, bearing in mind that the success of a project should be assessed according to a number of success criteria, according to different stakeholders and in different timescales (Müller & Turner 2007; Turner et al. 2012). The final goal of this research is to use the understanding that stemmed from empirical analysis to design and deliver more successful TIPs.

The first point to note is that this investigation has identified very few characteristics that have a statistically significant relationship between TIPs independent variables (TIPs characteristics) and dependent ones (TIPs performances). Indeed, the relationships uncovered by this investigation both support and contradict some of the existing understanding of the factors that influence TIPs performance, and this investigation has discovered relationships between characteristics and performance that had not been previously widely identified in the literature (e.g. the specific stakeholder characteristics, the compensation to the local community, the presence of SPEs, etc.).

This research highlights that the Government needs to promote local supply-chain companies and enhance their awareness in the importance of working collaboratively, ideally coming together and sharing the risk through SPEs. Also, the Government should increase its effort in increasing public acceptability, both nationally and locally, and focusing on the environmental aspects. Moreover, it has to be considered that FOAK TIPs are likely to incur into delays in the planning phase, and that (1) tunnels and railways risk delays in the construction phase and (2) the construction of underground structures can cause overbudget in the construction phase.

This investigation has three limitations: firstly, the dataset is geographically constrained: the limited European context of the TIPs studied here increases the confidence during the comparison, but it would be of interest to extend these findings to other comparable environments (such as the USA). Secondly, increasing the sample would enable a multivariate analysis or more advanced techniques of data mining. Thirdly, the statistical analysis technique employed, which is appropriate for small sample sizes, requires that dependent and independent variables are expressed in a binary "categorical nature". This limits what can be ascertained about relationships, and could be improved and overcame by the implementation of other statistical analysis such as the Qualitative Comparative Analysis (Schneider & Wagemann 2012). Lastly, by concentrating only on planning and construction, the whole life-cycle performance is not captured.

Nevertheless, this study provides a novel and systematic approach to understanding the characteristics associated with good and poor TIPs performance. These findings offer guidance for practitioners to ensure that TIPs can perform as intended. Additionally, the cross-project comparison using the FET provides a useful mechanism for individual policy-makers to 'benchmark' their TIP against a portfolio of projects that they themselves have initiated or of similar projects that have been initiated in similar context. Further research in this area, particularly in terms of multivariate analysis, will yield a better understanding of how the billions of dollars needed for transport infrastructure can be invested in the most effective manner. Ultimately, the results of this research need to be translated into guidance for policy-makers making critical and expensive decisions surrounding the design and delivery of large TIPs.

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Appendix A – Project Portfolio

Project Name	Type	Country	Planned Completion date	Actual Completion date	Planned Budget	Actual Budget
HSR Nuremberg- Inglostadt	Rail (HSR[3])	Germany	2006	2006	1.9bn	3.57bn
Norra Lanken, Stockholm	Road	Sweden	2025	N/A	1.84bn	N/A
A2 motorway, Nowy Tomysi	Road	Poland	2006/2012	2012	0.64bn	1.01bn
HSR Vigo-Oporto-Lisbon-Madrid	Rail (HSR)	Portugal	suspended	N/A	1.3bn	1.35bn
HSR Madrid-Seville	Rail (HSR)	Spain	1989	1992	1.58bn	2.69bn
HSR Barcelona-Figueres	Rail (HSR)	Spain	2009	2012	7.8bn	N/A
Big City Road Circuit, Brno	Road	Czech Republic	2030	N/A	1.77bn	N/A
Athens Ring Rd	Road	Greece	2004	2004	N/A	1.6bn
Edinburgh Tram Network, Scotland	Tram	UK	2011	2013	0.6bn	>0.6bn
The Channel Tunnel Rail Link, London-Kent	Tunnel	UK	2003	2007	6.4bn	9.63bn
Oresund Link (Öresundbron)	Rail and highway	Denmark - Sweden	2000	2000	2.96bn	4.10bn
Bundesautobahn 20, Baltic Sea Coast	Rail (Light Rail)	Germany	2005	2005	3.1bn	2.74bn
Tgv Med, Valence-Marseille	HSR	France	2000	2001	6.84bn	6.61bn
Beneluxlijn (Metro Line), Rotterdam-Schiedam-Spijkenisse	Rail (Light Rail)	The Netherlands	2002	2002	1.27bn	0.97bn
HSL-Zuid: The Netherlands/Belgium	HSR	Belgium	2005	2009	6.87bn	9.79bn
Attiko Metro (Athens Metro Base Project), Attiki	Rail (Light Rail)	Greece	1997	2003	3.10bn	4.61bn
Hsr Neubaustrecke (Nbs) Köln-Rhein/Main, Cologne-Frankfurt	Rail (HSR)	Germany	1997	2004	8.21bn	8.57bn
Tiergarten Tunnel, (Road And Rail), Berlin	Rail and road	Germany	2002	2006	9.73bn	9.04bn
Thameslink, (Railway)	Rail	UK	2015	N/A	6.5bn	N/A
High Speed 1, (Railway)	Rail (HSR)	UK	N/A	2007	N/A	7.149bn
High Speed 2, (Railway)	Rail (HSR)	UK	2026/2032	N/A	19.31bn to 21.69bn	N/A
Hsr West Coast Main Line,	Rail (HSR)	UK	2008	2008	10.799bn	N/A
Crossrail	Rail (HSR)	UK	2019	N/A	26.338bn	N/A
Arlanda Rail Link, Stockholm	Rail	Sweden	2000	1999	0.81	0.79
Rion-Antirion Bridge (Harilaos Trikoupis Bridge), Gulf Of Corinth	Bridge	Greece	2004	2004	1.10bn	0.96 bn
Millau Viaduct, (Bridge, Road) Millau	Bridge	France	2004	2004	0.5 bn	0.37 bn
M6 Toll, West Midlands	Road	UK	2003	2003	1.06 bn	1.23 bn
Météor, Paris	Rail (Light Rail)	France	2005	2007	1.22 bn	1.31 bn
Jubilee Line Extension, London,	Rail (Light Rail)	UK	1997	1999	3.52 bn	4.99 bn
Larnaca And Paphos International Airports	Airports	Cyprus	2009	2009	0.64 bn	0.64 bn

Table 2 TIPs considered in the analysis

[3] High Speed Rail

Appendix B – Assessment of Project Performance

Dependent variable construct	Operationalization
The project was delayed in the planning phase	The project was judged to be delayed in the planning if the actual commencement of physical construction was more than 12 months later than the planned date for the commencement of construction. The planned date for the commencement of construction was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the point at which the first formal activity (such as the first stage in the acquisition of any land rights required for the project) was entered into. The actual date for the commencement of construction was taken at the point at which any physical construction activity related directly to key functionality of the project was undertaken as reported through direct interview with the project client or through public review
The project was delayed in the construction phase	The project was judged to be delayed in the construction phase if it exceeded the planned date for entry into service by 12 months set at the point of entry into construction. The planned date for the entry into service was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the commencement of construction work. The actual date for the entry into service was taken at the point at which output from the project was first provided to its intended beneficiaries as reported through direct interview with the project client or through public review
The project was over-budget	The project was judged to be over budget if the final cost of the project was greater than the 110% of the original estimate (adjusted for the inflation). The estimated cost was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the time as close as possible to the point at which the first formal activity (such as the first stage in the acquisition of any land rights required for the project) was entered into. The final cost was taken to be a publically available figure obtained either through direct interview with the project client or through public review at the point at which the project entered operation. The final cost and initial estimate were assumed to have been made on the same basis.

Table 3 Dependent variable operationalization

Appendix C – Project Characteristics and their correlations with Project Performance

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
Project has a foreign Engineering Procurement and Construction (EPC) / main contractor company	The EPC has his main headquarter in the county hosting the project	The EPC has his main headquarter in a foreign country	Foreign EPC / main contractors could be unfamiliar with the project environment (Poddar 2010)	No correlation is highlighted
The Client is also the EPC or main contractor	The EPC is delivering the infrastructure for a certain customer	The EPC will own the infrastructure	In some projects (e.g. Flamanville 3) the EPC will also be the owner of the infrastructure (Locatelli & Mancini 2012)	No correlation is highlighted
The EPC has a clear goal	There are not documents to backup this characteristic	There are documents to backup this characteristic	It is a key factor in (Pinto & Slevin 1987; Pinto & Mantel 1990)	No correlation is highlighted
The project is mono cultural (weak definition)	Client and EPC have different nationality (main headquarters in different countries)	Client and EPC have the same nationality (main headquarters in the same country)	The impact of multiculturalism in project is stressed in the literature as a key aspect of project governance (Mäkilouko 2004; Rees-Caldwell & Pinnington 2013; Swart & Harvey 2011; Ofori & Toor 2009)	No correlation is highlighted
The project is mono cultural (strong definition)	Client, EPC and all the important first tier contractors have different nationality (main headquarters in different countries)	Client and EPC and all the important first tier contractors have different nationality (main headquarters in the same country)		The presence of the independent variable is correlated with the **absence of over budge**t, i.e. the project is likely to be delivered within the budget.
More than 50% share of the client is under government control	The national state owns directly or indirectly less than 50% of the share in the project	The national state owns directly or indirectly more than 50% of the share in the project	When the customer is the government, the project is managed differently and the risk pattern changes (Aritua et al. 2011)	The presence of the independent variable is correlated with the **presence of delays in the construction phase**

Table 4 Project stakeholders – Internal

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
International environmental groups have been raised concern against the project	No evidence of actions from environmental groups	The project has been openly censured by international environmental groups such as Greenpeace	Concerns from environmental groups can trigger scopes change or even stop the project (Ross & Staw 1993). The real effectiveness is assessed with this variable.	No correlation is highlighted
The project has national public acceptability	There are relevant protests or referendums against the project at national level.	The population living in that nation was supportive (or not objected) about the project	Public acceptability is often advocated as a precondition for project success (Brunsting et al. 2013; Kaldellis et al. 2013)	The presence of the independent variable is correlated with the **absence of delays in the construction phase**
The project has local public acceptability	There are relevant protests or referendums against the project at local level	The local population was supportive (or not objected) about the project		The presence of the independent variable is correlated with the **absence of delays in the construction phase**
Environmental groups have been engaged ex-ante, not ex post	External stakeholders have been involved after the construction started	External stakeholders have been involved before the construction started, particularly in the planning process	In large construction projects, the early involvement of external stakeholders such as "environmental groups" has been suggested as a best practice to avoid later issues such as the NIMBY syndrome (Alexander & Robertson 2004)	The presence of the independent variable is correlated with the **absence of over budget,** i.e. the project is likely to be delivered within the budget
Local level protests occurred during construction or commissioning, not during planning	The definition does not apply to the project	The definition applies to the project	Public participation is a key fact and the support toward a certain infrastructure can evolve over time (Drazkiewicz et al. 2015)	No correlation is highlighted

Table 5 Project Stakeholders – External

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
The project has a strong regulation system as evidenced by a) The safety authority stopped the project or very similar projects in the same country	The definition does not apply to the project	The definition applies to the project	A strong regulatory system, in case of not compliance, can foster the EPC and its contractor to expensive scope changes (Ross & Staw 1993)	No correlation is highlighted
b) The authority gave fine to the EPC or one of the internal stakeholders in the project				No correlation is highlighted
c) Action from the authority postponed the final completion of the project				The presence of the independent variable is correlated with **delays in the planning phase**
The project fits in the long term plan of the country's government	There are no evidences to support how the project fit in the long term plan of the country's government	There is at least an official document presenting how this project fits in the long term strategy of the country	Long term view is often advocated as a key aspect of project delivery. (Ahola et al. 2008; Park 2009)	No correlation is highlighted

Table 6 Project Environment – Legal

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
There is planned a long term stability in usage and value	There is no evidence of long term value/stability planned	There is evidence of instruments like a price floor for electricity to support the long term stability of the project	Long term view is often advocated as a key aspect of project delivery. (Ahola et al. 2008; Park 2009)	No correlation is highlighted
Financial support from the European Union (EU)	The definition does not apply to the project	The definition applies to the project	Infrastructural projects partially financed by the European Union are supposed to go through an independent cost-benefit analysis and third-part appraisal. (Kelly et al. 2015; CBA Guide Team 2008)	No correlation is highlighted
Financial support from national government				The presence of the independent variable is correlated with the presence **of delays during the planning phase**
Unemployment in the area is above national average	Unemployment in the area is below national average	Unemployment in the area is above national average	The deployment of megaprojects in area with high unemployment creates job positions useful to reduce the NIMBY problem (Martinát et al. 2014)	No correlation is highlighted
The majority of the national population trusts the national authority	There are documents (e.g. pools) showing the trust of the national population toward the national authority	There are documents (e.g. pools) showing that the national population do not trust the national authority	The trust on the national authority is linked to public acceptability is positive (He et al. 2013; Locatelli et al. 2016). However, a "trustful national authority" might impose very restricting measures to the project increasing the risks	No correlation is highlighted
The compensation of local community above 0.1% of the total budget	The definition does not apply to the project	The definition applies to the project	Compensation to local community is a way to increase the local public acceptability of the project (NEI 2003; Meacham 2012)	The presence of the independent variable is correlated with the **presence of delays in the construction phase**
The density of the population of the province is below the national average	The definition does not apply to the project	The definition applies to the project	Some projects, particularly the controversial ones, might be delivered in areas scarcely populated to reduce the risk of local protest (Barrett & Lawlor 1997; Lindén et al. 2015)	The presence of the independent variable is correlated with the **absence of delays in the construction phase**

Table 7 Project Environment – Socio-Economics

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
Support of the national government (no local)	The national government has not supported the project through direct financial subsidies, loan guarantee and tax exception.	The national government has supported the project. This includes direct financial subsidies, loan guarantee and tax exception.	The government is a key player in the megaprojects. It can have several roles and influences directly and indirectly the performances. For instance, several megaprojects are delivered as Public-Private Partnerships (Liu et al. 2016; Evers & de Vries 2013)	No correlation is highlighted
Support of the local government (no national)	There are no official documents or incentives or subsides from the local government to support the project	There are official documents or incentives or subsides from the local government to support the project		
Support of both national and local government	The definition does not apply to the project	The definition applies to the project		
Not supported by either national and local government				

Table 8 Project Environment - Political

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
Project uses planning by milestones	There is no evidence that the Project Manager (PM) used a "planning by milestone" approach	There is evidence that the PM used a "planning by milestone" approach	These three variables test the impact of well know PM tools and practices. (Golini et al. 2015; Mir & Pinnington 2014)	No correlation is highlighted
Project uses of formal project management tool and technique	There is no evidence that the PM heavily used formal project management tools and techniques. At least: Gantt chart, PERT (or simulation), Risk analysis, Earned Value, Cost schedule control System.	There is evidence that the PM heavily used formal project management tools and techniques. At least: Gantt chart, PERT (or simulation), Risk analysis, Earned Value, Cost schedule control System.		
Usage of performance metrics	There is no evidence that the PM used performance metrics	There is evidence that the PM used performance metrics		
Turnkey contract between Client and EPC/main contractor	The definition does not apply to the project	The definition applies to the project	The type of contract influences project performance (Suprapto et al. 2016) and turnkey are blamed for poor risk allocation and therefore performance (Ruuska et al. 2009)	
There was a formal litigation procedure (e.g. international chamber of commerce) during the contract between Client and EPC			The alignment of goals between the stakeholders is key for the project delivery.	The presence of the independent variable is correlated with the **presence of delays in the construction phase.**
Project has a well-developed FEED (Front End Engineering Design)	Frequent design amendments and elaborations	There are not change of the FEED during the construction & The FEED was finished before the construction started	A well-developed FEED is often considered a key success factor for the delivery of the project (Merrow 2011)	No correlation is highlighted
An experienced project director is present	The definition does not apply to the project	The definition applies to the project	Key factor suggested in (Pinto & Slevin 1987)	No correlation is highlighted

Table 9 Project Management

Independent Variable	Operationalization		Justification	Highlights
	NO (0)	YES (1)		
The megaproject is composed of more than 1 identical independent unit	The definition does not apply to the project	The definition applies to the project	Modularisation is often advocated as a strategy to make project more manageable and delivery them on time and on budget (Locatelli, Bingham, et al. 2014). Modularisation can be intended in two ways: 1 – as the decomposition of a large structure in dependent prefabricated modules or 2 – as the construction of several small units with a total capacity comparable to a large plant	No correlation is highlighted
a) The project is modular - dependent modules				
b) The project is modular - independent modules				
FOAK weak – country level	At least a similar project was delivered somewhere in the country	The plant is the absolutely the first in the country or the design has radical modification respect to existing ones	FOAK project (in particular megaproject) have several unknown unknowns (Ramasesh & Browning 2014) jeopardizing the planning and delivery. Often FOAK projects are late and over budget (Merrow 2011)	The presence of the independent variable is correlated with the **presence of delays in** the planning phase
FOAK strong – global level	At least a similar project was delivered somewhere in the world	The plant is the absolutely the first in the world or the design has radical modification respect to existing ones		No correlation is highlighted
The project has a Special Purpose Entity (SPE)	No SPE is involved in the delivery of the project	One or more SPE is involved in the delivery of the project as Client and/or EPC	Special Purpose Entities are temporary organisation often involved in the project planning and delivery. They might reconciles the interest of several stakeholder toward the common goals of the project (Sainati et al. 2015)	The presence of the independent variable is correlated with the **absence of delays in the construction phase**
Within the project scope, there is the construction of one or more tunnels	The definition does not apply to the project	The definition applies to the project	The authors assume that the technological characteristics of the TIPs themselves affect the performance of the TIPs.	The presence of the independent variable is correlated with **the presence of delays in the planning phase**
Within the project scope, there is the construction of one or more bridges				The presence of the independent variable is correlated with **the absence of delays in the construction phase**
Within the project scope there is the construction of one or more underground structure (e.g. and underground station)				The presence of the independent variable is correlated with the **presence of over budget**
The project is a railway				The presence of the independent variable is correlated with the **presence of delays in the construction phase**

Table 10 Technological aspects & other

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