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Implementation of 3D Integration Model for Project Delivery Success: A Case Study

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Abstract

The means for assessing what constitutes successful project delivery is a controversial topic in the literature, with many approaches and frameworks in play. This paper extends Langston's existing 3D Integration Model to include an assessment of triple bottom line (TBL) performance and applies it, for the first time, to a real-life case study. A subway station mega-project in Tehran, one of the busiest cities in the world, is retrospectively tested to evaluate its success. The new subway system is an important infrastructure project in Iran, and no research to date has evaluated its delivery from a project management perspective. This paper provides governmental and private sector agencies with a procedure to calculate the project delivery success (PDS) score for the construction of this subway or similar infrastructure projects, enabling a unique means to compare performance with other developments in Iran or elsewhere. From field data, it is shown by the researchers and verified by both the site project manager and client's representative that the subway's construction is an unsuccessful project. The findings quantify what could have been done, based on advice generated from the model, to deliver a successful outcome. The benefit of Langston's 3D Integration Model is its applicability to any project type or context, enabling them to be effectively compared and ranked by the percentage change between planned and actual PDS score. Given the introduction of TBL as a fifth core project constraint, an optimum solution can be found via the application of several heuristics (or rules) that define the boundaries within which a successful solution lies. The extended

model contributes to knowledge through its ability to quantify success and optimize performance, ideally during the delivery of the project rather than as a post-mortem exercise.

Keywords: *project delivery success, PMBOK® Guide, project integration, construction, Iran*

Introduction

An increasing number of organizations are implementing their business operations through projects (Kerzner, 2001). Delivering project outcomes on time and within budget has been a main concern of project managers for many years (Ika, 2009). But by its very nature, the construction industry involves an overwhelming number of risks in delivering successful outcomes. Current construction project management practices, in the public sector specifically, do not always lead to favorable outcomes (Alias et al., 2014).

Dr. Martin Barnes (1969) is credited with the notion of core constraints that underpin successful delivery. He promoted cost, time and output as the iron triangle (or triple constraint) of project management. He argued that making a change to one constraint affects the other two. Many variations ensued, including output sometimes being renamed as quality, scope or performance. Others preferred the terms of ‘budget, schedule and scope’, or simplified it further as ‘cheap, fast and good’. Jha and Iyer (2007) found that the commitment, coordination and competence of project players were key factors that underpin the iron triangle. These were argued as bearing on time, cost and scope respectively, and when nurtured, successful performance outcomes were more likely to occur (Todorovic et al., 2015). But the basic ‘law’ of project management can be broken, and it can be argued there is a need for a more complete paradigm representing the many facets of delivery success (Langston, 2013).

There have been calls for a new paradigm (e.g. Weaver, 2012) and yet plenty of support for the old one. There is confusion between terms such as ‘project success’ and ‘project management success’, and between ‘success factors’ and ‘success criteria’ (de Wit, 1988; Rockart, 1982; Gibson and Hamilton, 1994; Munns and Bjeirmi, 1996; Fortune and White, 2006). As articulated by the Project

Management Institute (PMI, 2013), projects are temporary in nature, and project management success should be measured in terms of criteria related to completing the project within scope, time, cost and risk baselines as approved between the project manager and the client's representatives. Successful delivery is a key outcome on any project, but measuring success remains controversial. International standards such as the *PMBOK® Guide* appear to increasingly avoid the issue and focus more on practice and procedure for the discipline (Langston, 2013).

This study aims to contribute to measuring successful performance of a mega construction project in Iran using a new 3D Integration Model (introduced in Langston, 2013) in order to understand the relationship between specific key performance indicators (KPIs) based on all core knowledge areas contained in the PMI's *PMBOK® Guide* (PMI, 2013), integration of environmental concerns (as an emerging area of professional responsibility) and the objective measurement of overall project delivery success.

The specific contribution to knowledge presented in this paper is threefold, namely:

1. to further develop Langston's 3D Integration Model by extending it to incorporate triple bottom line (TBL) reporting and verifying the application of the model to an actual mega project,
2. to retrospectively compare the planned and actual performance of the project using this model and recommend possible corrective actions that might improve its success, and
3. to authenticate the model that has, until now, never been tested in practice.

This paper is divided into five further sections. The underpinning theory for measuring project success is dealt with next. Then Langston's 3D Integration Model is summarized and extended to incorporate TBL considerations. The methodological approach of the research is presented, followed by an analysis and discussion of the case study. The final section reflects on the model's application to the case study and makes some recommendations for future practice.

Context

Mega Infrastructure Projects

Mega infrastructure projects are worthy of research and investigation not only because of their exceptional physical scale, cost, impact and the specific institutional arrangements involved to develop them, but also their comparison with the more regular practices of local actors often reveals insights into the wielding of power and influence (Altshuler and Luberoff 2003; Kennedy et al., 2011, Robbins, 2015). The US Federal Highway Administration defines mega projects as major infrastructure that costs more than US$1 billion, or projects of a significant cost that attract a high level of public attention or political interest because of substantial direct and indirect impacts on the community, environment, and budgets (Flyvbjerg, 2003).

Subway projects in Tehran have significant impact on all aspects of social life in the world's seventeenth largest city with the largest annual growth in Asia (World Gazetteer, 2012), and hence can be deemed as a mega project. They have the characteristics of large scale, diverse goals, long implementation cycles, uncertainties, multi-technology integration, strong innovation, complex industry association and enormous economic and social environment impact, which makes them significantly different from other construction (Zhang and Xue, 2014). Flyvbjerg (2003) stated that numerous mega infrastructure projects have suffered from surprisingly poor performance records and cost overruns. Researchers and practitioners have long searched for ways of improving delivery success in these mega projects and argued that the prevalence of project failures may be due to the problems associated with traditional project management theory (Chang et al., 2012).

Project Success

Project success has been discussed for years in project management literature (de Carvalho and Rabechini Jr, 2015), revealing the socio-political criteria that govern project performance (Sage et al., 2014). The traditional view of project success is associated with fulfilling time, cost and scope objectives. Financial criteria have been used to measure project performance, including economic return, cost-benefit analyses and profit (de Carvalho et al., 2015), but it is now acknowledged that social and environmental criteria are also important.

Project success may be measured by its efficiency in the short term and its effectiveness in achieving medium and long-term benefits (Jugdev et al., 2001; Müller and Jugdev, 2012). There seems to be no simple definition for this construct – it can be measured differently for various types of projects, from a range of perspectives, at numerous points in time, and in absolute or relative terms (Samset, 1998). It is a multidimensional construct (de Carvalho and Rabechini Jr, 2015; Samset, 1998; Shenhar and Dvir, 2007). Therefore, different stakeholder groups have their own perceptions of project success (Chou and Yang, 2012; de Vries, 2009; Davis, 2014; Toor and Ogunlana, 2010). Every project could be different.

To help define the characteristics of project success, Lim and Mohamed (1999) argued that there are two possible viewpoints: macro-level success and micro-level success. The macro-level viewpoint involves the question of whether the project delivers the intended (designed) performance and therefore meets or surpasses original expectations. Usually the end users and project beneficiaries (perhaps society in general) are the ones looking at project success from this perspective. The micro viewpoint deals with the construction/delivery parties such as consultants and contractors. Cooke-Davies (2002) offers a difference between project success, which is measured against the overall project objective, and project management success, which is measured against the traditional measures of cost, time, and scope. Alarcón et al. (2001) have argued that the triple constraint is not adequate for continuous improvement since it is ineffective in identifying the causes of productivity and quality risks. These parameters do not provide an adequate vision of the potential for improvement and the information obtained usually arrives too late for corrective action to be taken.

Limitations of the traditional way of measuring success are clearly known (Alarcón et al., 2001; Shenhar et al., 1997; Shenhar, 2004; Al-Tmeemy et al., 2011), and researchers have started to talk about introducing new success measures, such as participant satisfaction (Al-Tmeemy et al., 2011; Pocock et al., 1996). Shenhar et al. (2001) offered the four criteria of project efficiency, customer's benefit, organizational success and future potential to the organization. Bryde and Robinson (2005) have used five sets of success criteria, including cost, time, meeting the technical specifications, and customer and stakeholder satisfaction. Crawford and Pollack (2004) grouped construction project success criteria into objective measures (e.g. time, cost, safety and environment) and subjective measures (e.g. quality, functionality and satisfaction of different project participants). Frödell et al. (2008) offered an empirical approach that defined success measures like keeping the project on time, within budget, maintenance costs and project goals as well as ensuring overall profitability. Even a trilogy perspective framework for construction projects was suggested by Elattar (2009), where the client's perspective (e.g. time, cost, functionality, end result, quality, aesthetic value, profitability, marketability, less aggravation), the designer's perspective (e.g. satisfied client, quality, cost and profit, professional related issues like staff fulfillment, marketable product, less construction problems, no liability, socially accepted, client pays and well defined scope of work) and the contractor's perspective (e.g. time, cost, quality, free from claims, clearly defined expectation from all parties, client satisfaction, as well as less surprises during delivery) are all considered criteria for project success. So a confusing array of competing frameworks for analysis of project success currently exists.

Some researchers have merged the strategic impact of projects with other dimensions of project success (Al-Tmeemy et al., 2011). Baccarini (1999), for example, has split project success into two components. The first one is project management success, which consists of the basic criteria, project management process and stakeholder satisfaction. The other component is product success, which comprises owner strategy, user satisfaction, profitability and market share. Similarly, Chan and Chan (2004) proposed two groups of KPIs for construction project success. The first group was objective indicators (time, cost, safety, and environment) and the second group was subjective indicators (quality, functionality and satisfaction of diverse project stakeholders).

Blindenbach-Driessen and van den Ende (2006) conducted research to evaluate the performance of development projects and came to a similar position. They proposed a project success model that included two constructs. The first construct was project success, which related to the development process of new products and services. The second one was market success, which covered the commercial outcome of a development project. In the latter case, Takim and Adnan (2008) also defined five groups: learning and exploitation, client satisfaction, stakeholder objectives, operational assurance and user satisfaction. Qureshi et al. (2009) presented a model called project management performance assessment (PMPA) for construction projects that introduced KPIs as a prerequisite for measuring achieved project performances. Ngacho and Das (2014) developed a multi-dimensional performance evaluation framework comprising time, cost and scope to capture economic dimensions while safety and site disputes accounted for societal risks and site impact accounted for environmental risks. Todorovic et al. (2015) offered a framework based on critical success factors, project performances, KPIs and project environment methods and models developed so far. Finally, Ofori-Kuragu et al. (2016) offered a suite of nine KPIs including quality, client satisfaction, cost, time, business performance, health and safety, environment, productivity and people, developed for Ghanaian contractors that can be used for performance measurement.

Langston (2013) argued that it is vital to ensure the criteria upon which success is judged is clear from the outset. Businesses use KPIs for this purpose. Bryde (2005, p.119) argued that the general absence of KPIs in project management should be redressed. He concluded that this is "*seen to contribute to a failure by organizations to manage necessary increases in their project management capability and to be acting as a possible barrier to long-term, sustainable improvements in performance*". A detailed search of the *PMBOK® Guide* shows that discussion of KPIs is virtually absent.

An important consideration, however, is to develop an approach that is generic and hence able to be applied to any type of project in any industry. It should focus on successful delivery (i.e. the role of the project manager) and not be confused with other perspectives of success such as design innovation, aesthetics and comfort, and matters that relate to functional performance, such as long life (durability), loose fit (adaptability) and low energy (sustainability). It should also enable the delivery success of different projects to be compared objectively at any chosen level of clusterization.

From a typical project manager's perspective, it is often contended that successful delivery is characterized by the following criteria:

1. within budget
2. on time
3. as specified
4. no surprises

This can be alternatively described in the context of cost, time, scope and risk respectively. These criteria (or core project constraints) form the foundations of the 3D Integration Model (Langston, 2013).

3D Integration Model

Langston's model (shown in Fig. 1) for describing project integration takes the form of a tetrahedron containing all knowledge areas existing in the *PMBOK® Guide* (Fifth Edition), plus a new area of project environmental management to recognize the emerging importance of sustainability in modern projects. He contends this model can be used to assess the performance of project teams in delivering successful outcomes at various stages in the project life cycle through the identification of core project constraints (occupying the four vertices of the model) and six KPIs (represented by the edges of the model). KPIs express the relationships between constraints, are relevant to any type of project, and are capable of objective measurement (Langston, 2013).

Insert Fig. 1 here

This 3D project integration model includes six generic KPIs that are related to project delivery success (PDS), and comprise:

1. *Value*. Defined as the ratio of scope over cost (objective: maximize). Value is a function of Project Stakeholder Management, namely meeting expectations and fostering engagement. Scope is treated as an output and cost is treated as an input, so the more utility per unit of cost the greater is the value for money.

2. *Efficiency*. Defined as the ratio of cost over time (objective: maximize). Efficiency is a function of Project Human Resource Management, namely team performance and leadership. Cost in this case is treated as an output (value of work completed) and time as an input, so the more money spent per unit of time the more efficient is the delivery process.

3. *Speed*. Defined as the ratio of scope over time (objective: maximize). Speed is a function of Project Procurement Management, namely outsourcing strategies and parallel supply chains. Scope is treated as an output and time as an input, so the more utility provided per unit of time the faster is the delivery process.

4. *Innovation*. Defined as the ratio of risk over cost (objective: maximize). Innovation is a function of Project Communications Management, namely knowledge management and research-informed learning. Risk is treated as an output (innovation leads to development risks) and cost as an input, so a higher level of risk per unit of cost reflects the search for better ways of doing things.

5. *Complication*. Defined as the ratio of risk over time (objective: minimize). Complication (originally ‘complexity’) is a function of Project Quality Management, namely excessive quality assurance paperwork and engineering over design. Risk is treated as an output and time as an input, so a higher level of risk per unit of time is a sign of project difficulty that should be avoided.

6. *Impact*. Defined as the ratio of risk over scope (objective: minimize). Impact is a function of Project Environmental Management, namely adverse sustainability outcomes and unnecessary resource consumption. Risk is treated as an output and scope as an input, so a higher risk level per unit of utility reflects unwanted environmental disruption.

The relationships among the core project constraints of cost, time, scope and risk and the KPIs of value, efficiency, speed, innovation, complication and impact are illustrated in Fig. 2. A 2D version of the model is presented here for ease of comprehension, but it turns into a 3D tetrahedron by 'folding' along the dotted lines. Core project constraints, which are equally weighted, are shown in upper case. Clearly it is impossible to optimize all KPIs given that most constraints act as outputs in some cases and inputs in other cases (Langston, 2013).

Insert Fig. 2 here

Overall success (computed as the change in PDS between planned and actual performance) is given by the following formula (Langston, 2013):

$$Project\ Delivery\ Success\ (PDS) = \frac{s^3}{ctr}$$

where s = scope baseline, c = cost baseline, t = time baseline and r = risk baseline

In recent years, the importance of environmental sustainability has emerged and captured the attention of project management teams (e.g. Fernández-Sánchez and Rodríguez-López, 2010; Ebbesen and Hope, 2013; Hwang and Ng, 2013). The construction industry has a significant influence on the environment and society, and is a major sector involved in achieving sustainability (Shi et al., 2012), but environmental impact applies to all activities regardless of industry sector. Not only are environmental controls likely to impact on project outcomes and choices, but the wider moral imperative of a sustainable future has led to concern that the balance between economic, social and environmental criteria (i.e. TBL thinking) is not well served by the current *PMBOK® Guide*. In much the same way that stakeholder management was separated from communications management and elevated to higher importance in Edition 5 of the guide, so too will environmental management need to be extracted from scope, quality, procurement and risk management and given more prominence and coherence. Sustainability considerations are paramount to our collective future (Langston, 2013).

Langston (2013) uses the four vertices of the tetrahedron to represent core project constraints of scope, cost, time and risk and the six edges to represent KPIs of value, efficiency, speed, innovation, complication and impact. The four faces of the tetrahedron were not ascribed meaning. In this paper, Langston's 3D Integration Model is extended to add TBL as an integral part of the measurement of project delivery success, effectively forming a fifth core project constraint.

Each face of the tetrahedron can reflect an aspect of sustainable development. Beech (2013) proposed the '4Ps' approach to measuring sustainability: profit, people, planet and progress. When applied to the model, the three KPIs bounding each face simplify to respective performance indices (as shown in Fig. 3). For example, the face called 'profit' is bounded by the KPIs of value, innovation and impact. Value (scope over cost) and innovation (risk over cost) need to be maximized, while impact (risk over scope) needs to be minimized. When multiplied together, this reduces to s^2/c^2. Projects should be progressive, not regressive, and this can be assessed by the average of profit, people and planet indicators being positive. Balancing TBL forms a fifth constraint to measuring success by embedding ethical behavior into procurement decisions. Indeed, 'doing the right project' is arguable more important that 'doing the project right'.

Insert Fig. 3 here

As explained, 'profit' is a function of both scope and cost (i.e. s^2/c^2), and hence has similarities with the measurement of the value KPI, which seems perfectly reasonable given a context of economic performance. Likewise, 'people' is a function of scope and time (i.e. s^2/t^2) with connections to the speed KPI, and contributes to social performance by ensuring that projects are procured in a timely fashion so that their benefits to society are realized sooner. From an environmental perspective, ‘planet’ combines scope and risk (i.e. s^2/r^2) and hence displays similarities to the impact KPI. In all three cases, if scope increases and either cost, time or risk decrease, then TBL performance is enhanced.

Ethical behavior by project managers is modeled by the computed value of ‘progress’. Progress is a combination of efficiency (i.e. c/t), innovation (i.e. r/c) and complication (i.e. r/t), where the latter is minimized while the others are maximized. Progress has no unit, as is seen by multiplying c/t with r/c and dividing by r/t. For this reason, the average of profit, people and planet is used to measure progress. The answer must be positive.

Furthermore, not only should profit, people and planet be equally weighted, but an even balance between them would be ideal. This may not always be possible or even desirable. For some projects, profit may be a low priority. Where it is appropriate, however, balance might be judged by ensuring the percentage change between planned and actual performance for the highest scoring criteria is not more than double the lowest scoring criteria, assuming both are positive numbers.

The inclusion of TBL into the 3D Integration Model completes it conceptually, and enables projects to be assessed not only in terms of their PDS score (higher the better) but also on their TBL score (positive and balanced). This is a new contribution to the existing work described in Langston (2013) introduced here for the first time.

Project Integration Management, a key knowledge area in the *PMBOK® Guide*, is intended to ensure that the right balance between all other parts of a project is achieved. It essence, it assesses scope, time, cost, quality, human resource, communications, risk, procurement, stakeholder (and now environment) holistically. The 3D nature of the model itself reflects how such integration is handled. By incorporating all *PMBOK® Guide* knowledge areas together, all aspects of project delivery and sustainability are embedded, so the argument to include further issues is diminished.

The key point here is that the four core project constraints (scope, cost, time and risk) and six KPIs (value, efficiency, speed, innovation, complication and impact) in the 3D Integration Model are generic and apply to every project type. While the PDS score is based on the generic set of KPIs, there is no reason why secondary KPIs cannot be used to also measure success. These can be treated separately. For example, if the level of disputes on site is important (perhaps due to industrial relations or design change), then a new KPI can be employed based on the number of disputes per month. Obviously minimizing this KPI would be of benefit, and a target of one dispute per month might be a goal of the project manager. However, the six KPIs described early should be considered as mandatory and form a mechanism to enable projects to be compared and ranked for project success within an organizational portfolio, or ultimately at a regional, national or international level. This is a benefit no previous success model or paradigm can claim. The addition of TBL makes the model even more powerful.

The literature, however, does frequently note that project satisfaction is an important criterion for success. Obviously, satisfaction is a generic concept and can apply to all project types. It is undoubtedly relevant. Logically stakeholder satisfaction will be realized when the PDS score is better than forecast. Yet it is conceivable that even if all KPIs are delivered, one or more stakeholder groups may remain dissatisfied. Perhaps specific stakeholders had objectives that conflicted with the way the project manager made decisions based on the recognized power and influence of most stakeholders. Therefore, the question arises as to whether stakeholder satisfaction is a success criterion or a phenomenon. The latter is suspected. Given that satisfaction of the project's designed performance can be difficult to untangle from satisfaction with the delivery process, attempting to embed satisfaction formally in the 3D Integration Model is considered unwise.

Finally, it is worth pointing out that changes occur during project delivery. Planned performance will seldom equal actual performance. Changes are normally agreed and approved and lead to revised baselines for scope, cost time and risk. Overall success, as represented by comparing planned and actual PDS scores, is presented as a percentage change and may be positive, negative or zero. A question arises whether the model is measuring the success of the project manager or the effect of decisions largely influenced by external factors. This question requires further analysis.

Research Method

Case Study

To explore this question, Langston's 3D Integration Model is applied to a mega subway construction project in Iran that involved significant change to the original plan. Computed planned and actual performance is used to determine whether project delivery success is achieved, and the result is compared to participant judgment and reflection.

The case study lies in the heart of Tehran's metropolitan area. This capital city of 8 million people is one of the most populated urban centers in the Middle East and forms the backbone of socio-economic development in Iran. The authors have worked on this construction project for several years. Site visit, analytical observations and data collection were carried out during the execution phase. Basic project data such as contract value and size of construction, and essential data such as detailed technical specifications, construction techniques and other onsite control practices were collected and recorded. Some interview sessions with key personnel such as the site manager and the head of the technical office were also performed.

A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not evident (Yin, 1994). Moreover, Benbasat et al. (1987) emphasized that a case study is a strong methodology that allows researchers as well as practitioners to study information systems in natural settings, learn about the state of the art, and generate theories from actual performance. A case study allows the researchers to explain the nature and complexity of the process that is taking place and gain an in-depth understanding of the phenomenon under investigation. In this regard, a case study is used for exploring new phenomena where quantitative research methodologies are not possible or appropriate (Benbasat et al., 1987; Yin, 1994). Typically, a case study research approach is flexible, and may include multiple data collection methods such as documentation, interviews, questionnaires and field observations. In this case, the data collection methods included gathering archival material, analyzing project outcomes and conducting face-to-face interviews. Therefore, the use of a case study approach is appropriate to answer the question about what the 3D Integration Model is in fact measuring, as it is a conceptual framework that to date has never been adopted or used on a real project. The selected case study was chosen on the basis that it involved significant change external to the project team, potentially leading to an outcome that the project team could do little about.

Tehran Subway Development

Subways are constructed in major cities like Tehran to overcome the transportation problems associated with urbanization. The Tehran Urban and Suburban Railway Operation Company (TUSROC) believe that the Tehran subway development will result in savings of up to USD 18 billion per annum in terms of time and energy. The economic benefits of subway construction are clear considering the cost of constructing 20 km of subway tunnels and stations is around USD 650 million (Darvish, Head of TUSROC, 2015). Subway construction projects are essential in Tehran in view of the city's traffic congestion. The success of such projects is vital for sustaining economic growth and social wellbeing (Ghanbaripour et al., 2015). The ability to travel efficiently inside the city and connect to suburbs in a safe environment whilst reducing environmental pollution and creating a calm and relaxed social atmosphere for travelers are some of the attractions of this type of infrastructure. It facilitates the optimum deployment of urban transportation, decreases commuter travel times and reduces accidents (Yousefi and Ghanbaripour, 2015).

This research focuses on the construction of one of many underground stations. The case project is located beneath some of the most crowded streets in Tehran. The construction method is a general procedure that has been used in Tehran subway projects for many years. The main ribs comprising 21-meter spans (see Fig. 4) are to bear the weight of the soil above the station, and this weight is transferred through piles into the foundation material. The main structure of the station is shown in Fig. 5, while Fig. 6 provides insight into the design including a cross-section of the subway station and the construction sequence adopted from the first stage (denoted as step 1) to the final structure (denoted as step 8).

Insert Fig. 4, 5 and 6 here

Subway construction projects like any other social project involve public funds, follow set procedures and almost always require multiple entities such as contractors, subcontractors, engineers, architects, project management firms and government agencies who work together to deliver the required outcomes. Achieving success in public projects is difficult because it requires economy, efficiency, quality, fairness and transparency (Tabish and Jha, 2011).

Langston's 3D Integration Model is implemented and tested on one of the new subway station contracts that was initially estimated to cost USD 25 million and take 24 months to complete. The authors interviewed the site manager, technical office manager, and seven engineers from the site who have been involved in core management, engineering and contractual processes. Since information on many aspects of the project including scope, time, cost and risk was required, several meetings were held with the project and site managers, client's consultant, technical office director, and many of the contractor's engineers working in diverse sections of the site. This enabled the researchers to extract the necessary data to measure planned and actual performance for the project. All people interviewed had more than 10 years of professional experience in this field.

Data Collection

Scope Baseline

Constructing a subway station includes a wide range of technologies, equipment and expertise in a range of specialist fields, and usually takes a long time from design to completion. The most important work in this project was the construction of the base plate, top arches, side beams and piles that comprise the main structure of the station. In this study, total volume of the concrete is adopted as the scope of the project for the following reasons:

1. Concrete work is the main element of the underground subway station. All structures are made of concrete and it also includes embedded reinforcement and shuttering.
2. Concrete work is the largest factor affecting the project's expected construction cost and time to complete.
3. It is easily measured as the volume (m^3) delivered to site and cast in place.

So, by using concrete volume as the defining element of the project's scope, an effective way to describe the project's scale is captured. It is considered a better method for measuring scope than plan area or footprint. The design team documented a volume of 40,000 m3 of concrete necessary to complete the project.

Actual scope was increased during the construction of the project, culminating in about 43,000 m^3 of concrete being placed. This was beyond the control of the project team and was due primarily to economic impacts, design amendments, stakeholder conflict and latent ground conditions. An increase in project scope usually means that pressure is exerted on cost, time and risk baselines unless the delivery team can find offsets through smarter procurement or implementation solutions. In this case study, such offsets did not appear to have eventuated.

Cost Baseline

The contract sum for the case study project was USD 25 million. The price comprised the contractor's cost, margin and contingency. Based on the data obtained, the final cost was nearly USD 27 million ignoring inflation.

Time Baseline

The project's timeframe was September 2008 to September 2010 inclusive (24 months). Since subway projects aim to improve public transportation, timely completion that minimizes disruption to the local community is critical. A detailed Gantt chart was prepared in the planning phase with several milestones that had to be achieved. Based on the data collected, the actual time from commencement on site to project completion was 36 months and many of the milestones were not delivered on time. This led to an overrun of 12 months or 50%.

Risk Baseline

To extract the planned risks of the project, the researchers reviewed the risk register that was prepared during the initiation phase. Although this document was a preliminary one, it provided some useful data. In order to obtain the list of actual risks, face-to-face interviews with the director and members of technical office were conducted. The interviews were audio-recorded and hand-written notes were also taken. A list of actual risks and impacts was then produced. In this case, actual risk was calculated by assuming each identified risk had a probability score of 5 (i.e. probability was now 'certain'). Any unforeseen risks would have been added to the calculation, although there were none in this case. If a risk event had little or no impact on the project, then it was scored 1, while at the other end of the scale a score of 5 indicated that a significant impact had happened. The risk register is summarized in Table 1.

Insert Table 1 here

Risk level was computed as the multiplication of probability and impact, and hence may be a value between 1 and 25 inclusive. A 5x5 assessment matrix was applied in this process, although this is irrelevant to the method. The planned and actual risk baselines were computed as the mean of individual risk levels. Based on the data collected, the expected mean risk score was 7.32 and the actual mean risk score was 9.03. The increase in actual risk suggests that cost and time pressure were also likely to occur.

Analysis and Discussion

Planned versus Actual

Table 2 shows the calculation method for each KPI in the 3D Integrated Model, and computes the percent increase or decrease between planned and actual performance. The change in PDS score (combining all six KPIs) is negative, and therefore indicates the delivery of the project was not successful. TBL scores are also shown, suggesting that profit, people and planet criteria were all adversely impacted, and hence the case study might be interpreted as regressive. Innovation and complication show positive outcomes (+14.22% and +21.59%), while value, efficiency, speed and impact are negative (-0.46%, -28.00%, -28.33% and -12.86%).

Insert Table 2 here

Value for money was considered the most important objective for this case study, and therefore the value KPI should display the highest positive % change of any KPI. In an ideal scenario, the number of negative KPIs should be minimized (normally no more than two should be negative). Furthermore, it would be ideal if profit, people and planet scores are both positive and balanced (i.e. highest score no more than double lowest score). Projects must be progressive (i.e. have a positive ‘progress’ score), not regressive. Most importantly the change in PDS scores between planned and actual should be positive and as high as possible. These heuristics collectively help to define optimum performance.

Change in PDS can be used to compare the success of this case study against sections of the subway project, other government projects of different types and scales, and across industries or even countries, regardless of time. The higher the percent change in PDS the better. Individual KPIs and TBL scores add further insight into actual project performance.

Stakeholder Perceptions

To obtain a practical point of view, the authors conducted face-to-face semi-structured interviews to recognize whether, from the perception of the main stakeholders, the project was considered successful or not. Following is the opinion of the project manager as collected during the interview process:

> *There are both social and economic expectations out of subway projects like any other public project. Such projects are initiated based on the demand of general public end-users and most of the time involve multiple stakeholders and are also accountable to external financial audit and careful governmental agencies. Hence, late and over budget completion would harm the expected results, excessive loss of money and efforts and scratch the credibility of project itself.*
>
> *This subway construction project suffered from several unexpected surprises that had a huge effect on actual cost and time of the project. Diverse conflicts among main stakeholders, such as client, consultant, contractor, and nearby residents took place, and an overwhelming number of changes to scope were made accordingly. Overall, although this subway station is serving as a public facility and the perception of success or failure is sometimes time-dependent, from the view of project delivery, this project must be considered unsuccessful.*

Moreover, the result of interviews with the client's representative showed that:

> *From the project management point of view, indeed, this project was unsuccessful. There were two kinds of factors that affected the project. Firstly, the factors that could not be controlled by the contractor like inflation. It made serious changes to the prices of resources, and this could be seen in initiating and planning phases. Moreover, due to lack of adequate information from the soil recognition, many obstacles, aqueducts and holes were found during the excavation process that led to scope creep and cost*

overruns. Secondly, numerous conflicts among the project's stakeholders led to many time-consuming meetings, and these conflicts led to some added risk on the project.

Alternative Actions

So what would a successful outcome for this case study actually look like? To explore options that were available to the project team, the 3D Integration Model is used to find the cost, time and risk values that would have led to a successful outcome. Actual scope was assumed to be 43,000 m^3 of concrete work to reflect changes to the design of the project as demanded by circumstances and which, in this case, were largely beyond the control of the project manager.

This case study highlights that factors largely external to the project led to pressure on scope, cost, time and risk baselines and ultimately to an unsatisfactory outcome. The change in PDS score and the negative value for many KPIs indicates that the project's delivery should be considered as unsuccessful. The progress score also suggests actual performance on site is regressive and fails to contribute to profit, people or planet objectives.

However, this does not mean that the project is unsuccessful from other perspectives. Perhaps the people of Tehran are grateful for the provision of new infrastructure. Perhaps the subway solves numerous social problems, such as safety and loss of time due to traffic congestion. Perhaps air pollution is lowered and the new underground structures can provide shelter in time of military conflict or natural disaster. These issues highlight the distinction between project success and project *delivery* success, which in turn demonstrates why some potential success criteria (such as functionality) are not relevant to the assessment of delivery. Further, criteria that relate specifically to construction (such as worker safety) should be evaluated separately to the generic attributes of project delivery success to enable comparison of performance not just on different sections of this project, or on other projects by the same contractor, but across projects of quite different typologies.

Assuming the value KPI was still the main objective here, Table 3 summarizes an example of an optimal performance outcome. Cost would need to be restricted to USD 26 million, extensions of time would need to be no more than one extra month, and risk would need to be restricted to a mean score of 7.62. In this case the change in PDS is computed at +10.16%. It should be noted that profit, people and planet are quite balanced and the project is now considered progressive. This perspective would inform the project manager of what would be needed to deliver the project successfully given the increase in scope, and could form the basis of a plan to get the project back on track before it was too late.

Insert Table 3 here

This is an optimal solution, but not the optimum solution. A higher PDS score can be obtained by reducing cost and/or risk while ensuring that the defined heuristics are observed. Sensitivity testing determines the best combination of constraints that delivers the highest PDS score while complying with the rules described earlier. The highest PDS score found is +16.50%. This arises when scope equals 43,000 m^3 (given), cost equals USD 25,281,315, time equals 25 months and risk equals 7.41.

It must be remembered that the scope (i.e. volume of concrete) has increased 7.5% over its baseline while cost has increased only 1.1% over its baseline, plus risk needs to be reduced from 9.03 to 7.41 and probably can be achieved only by spending more on mitigation. In both cases, therefore, further cost savings must be found. It is recommended that a value engineering process would have been necessary to identify where those savings might lie.

The level of scrutiny and quantification afforded by the model distinguishes it from other forms of analysis that are less integrated or overly time consuming to implement. It is hence argued that normal post-project review may have shown that the project was unsuccessful and highlighted the cause(s), but not facilitated a proactive adjustment during project delivery to arrive at a successful outcome (albeit different from the original plan). While the retrospective study undertaken in this paper cannot influence what occurred on site, in normal circumstances application of the model would occur in real time and be able to adapt the project’s trajectory towards a superior result.

This case study has shown that the 3D Integration Model is capable of not just describing the outcome of external factors, which may or may not be welcome, but how the project team deals with these matters to ensure that success remains a clear objective. Despite the change in scope, other actions could have been pursued to minimize the impact on cost, time and risk and still deliver a successful outcome. Agreed variations to scope, therefore, are not directly responsible for success or failure. Scope, cost, time and risk are related together and dictate what successful project delivery might look like.

So the key point here is that projects change over their delivery period, and this may be for good reason and with mutual consent. It is the ratio of scope, cost, time and risk constraints that determines if the change was well handled or if it resulted in poor performance overall or in specific areas. Unforeseen events that lead to different outcomes can be explored, with outcomes assessed in terms of delivery success or failure. Ultimately the 3D Integration Model measures the performance of the project manager and team despite changes that may arise from external sources, enabling a 'progressive' (not regressive) delivery outcome to be secured.

Conclusion

Performance measurement is one of the most important aspects of project management, especially for public sector projects. In recent years, there has been much effort applied to measuring success. These developments show that no consensus view has emerged to date. In a world of intense competition, projects are no longer seen as routine tasks or business-as-usual. Instead, projects are increasingly seen as powerful strategic weapons that organizations can use to enhance their competitive advantage, increase market share, compete in a dynamic and highly commercial environment, be good corporate citizens and create value for their clients and other stakeholders. The mindset of project performance management must transform from an operational/functional nature to more of a strategic focus. As there are different needs and different goals for any given project, performance measurement should also be capable of generic application.

Theoretically, implementing the 3D Integration Model and the insights accrued from the subway project case study provide empirical support to the view that measures for project success need to be broadened beyond the traditional iron triangle.

New empirical knowledge to the relatively recent research on project success is added by applying a practical evaluation model to a real project. Such knowledge can provide guidance for project managers to measure their projects' performance objectively. This paper makes a practical contribution through the analysis of a mega infrastructure project's performance illustrating a range of optimal PDS scores and what actions are necessary to achieve them. The findings of this study suggest that the management of future mega projects should focus more on KPIs, and actively engage with stakeholders throughout the project construction period to ensure a successful outcome.

While the modeling might highlight strategies that are obvious or even common sense, one must ask the question why action was not taken to correct the trajectory of the project before it was too late. Perhaps use of the model might have helped the team to assert more control or provided them with insight into how various success factors interact with each other. But more importantly, the model can establish a measure of success to judge relative performance against other projects regardless of size, type, location and sector.

This paper presents the results of implementing Langston's 3D Integration Model, extended to include TBL objectives, as a framework for assessing project success. It is based on a comparison of planned and actual performance using numeric values for scope, cost, time and risk constraints. This model is presented in the form of a tetrahedron containing all existing knowledge areas in the *PMBOK® Guide* plus project environmental management. The six mandatory KPIs express the relationships between constraints, are relevant to any type of project and are capable of objective measurement. From the case study explored in this paper, Langston's 3D Integration Model matched the opinion of the project manager and confirmed that the subway station project was unsuccessful. But significantly, the model produced an optimum profile that may have been useful in trying to get the project back on track before it was too late. If this advice had been applied during construction of the project, a better outcome may have still been possible, notwithstanding the increase in scope that was beyond the team's control. A set of heuristics is established and tested to help guide the identification of optimum performance based on the well accepted constraints of scope, cost, time and risk, and the new constraint of progress in delivering TBL objectives.

The model can be used to measure the success of what happened, or the success of various possible scenarios. In determining the optimum solution for the subway station, heuristics were developed and applied that led to a focus on value as the priority KPI, a need to minimize the number of negative KPIs (no more than two), pursuit of a positive percent change in PDS score (higher the better) and a positive progress score (ideally with profit, people and planet all positive and well balanced). Table 3 provided a blueprint for how a change in scope from 40,000 to 43,000 m^3 of concrete, with its implied pressure on cost, time and risk, can lead to an improvement in success over the original plan. If used dynamically during project delivery, the model can show how to reclaim lost stakeholder satisfaction, in much the same way that delays in time led to actions to recover and meet agreed deadlines.

It is a key point that the PDS score can be compared across different projects regardless of type or size or industry to measure project management performance. The percent change in PDS between planned and actual outcomes is the ranking index for success across a portfolio of projects. One could compare a garden shed with an opera house, or a software project with a government policy initiative. Hence this model enables people to assess project management performance over time. This paper makes a contribution to knowledge by testing Langston's approach, for the first time, on a real-life case study.

For further studies, it would be interesting to implement this model in non-construction projects (e.g. software development or service delivery) to compare the results and measure the performance of the project team. This will help in the use of practical decision-making and measurement systems that will enable contractors and managers make better decisions that more consistently lead to successful projects.

References

Altshuler, A.A. and Luberoff, D.E. (2004). “Mega-projects: the changing politics of urban public investment.” *Brookings Institution Press.*

Al-Tmeemy, S.M.H.M., Abdul-Rahman, H. and Harun, Z. (2011). “Future criteria for success of building projects in Malaysia.” *Int. J. Project Manage.,* 29(3), 337-348.

Alarcón, L.F., Grillo, A., Freire, J. and Diethelm, S. (2001). “Learning from collaborative benchmarking in the construction industry.” *Ninth Annual Conference of the International Group for Lean Construction (IGLC-9),* Singapore.

Alias, Z., Zawawi, E.M.A., Yusof, K. and Aris, N.M., (2014). “Determining critical success factors of project management practice: a conceptual framework.” *Procedia-Social and Behavioral Sciences*, 153, 61-69.

Baccarini, D. (1999). “The logical framework method for defining project success.” *Project Manage. J.*, 30(4), 25-32.

Beech, D. (2013). “Quadruple bottom line for sustainable prosperity. Cambridge Leadership Development.”(http://cambridgeleadershipdevelopment/quadruple-bottom-line-for-sustainable-prosperity/.)

Benbasat, I., Goldstein, D.K. and Mead, M. (1987). “The case research strategy in studies of information systems.” *MIS quarterly*, 369-386.

Blindenbach-Driessen, F. and van den Ende, J. (2006). “Innovation in project-based firms: the context dependency of success factors. *Research Policy*, 35(4), 545-561.

Bryde, D.J. and Robinson, L. (2005). “Client versus contractor perspectives on project success criteria.” *Int. J. Project Manage.*, 23(8), 622-629.

Bryde, D.J. (2005). “Methods for managing different perspectives of project success.” *Brit. J. Manage.*, 16(2), 119-131.

Chan, A.P. and Chan, A.P. (2004). “Key performance indicators for measuring construction success.” *Benchmarking: An Int. J.*, 11(2), 203-221.

Chang, A., Chih, Y.Y., Chew, E. and Pisarski, A. (2013). “Reconceptualizing mega project success in Australian Defence: Recognizing the importance of value co-creation.” *Int. J. Project Manage.*, 31(8), 1139-1153.

Chou, J.S. and Yang, J.G. (2012). “Project management knowledge and effects on construction project outcomes: an empirical study.” *Project Manage. J.*, 43(5), 47-67.

Cooke-Davies, T. (2002). “The “real” success factors on projects.” *Int. J. Project Manage.*, 20(3), 185-190.

Crawford, L. and Pollack, J. (2004). “Hard and soft projects: a framework for analysis.” *Int. J. Project Manage.*, 22(8), 645-653.

Davis, K. (2014). “Different stakeholder groups and their perceptions of project success.” *Int. J. Project Manage.*, 32(2), 189-201.

de Carvalho, M.M. and Rabechini Jr, R. (2015). “Impact of risk management on project performance: the importance of soft skills.” *Int. J. Prod. Res.*, 53(2), 321-340.

de Carvalho, M.M., Patah, L.A. and de Souza B. (2015). “Project management and its effects on project success: cross-country and cross-industry comparisons.” *Int. J. Project Manage.*, 33(7), 1509-1522.

de Vries, J. (2009). “Assessing inventory projects from a stakeholder perspective: results of an empirical study.” *Int. J. Prod. Econ.*, 118(1), 136-145.

de Wit, A. (1988). “Measurement of project success.” *Int. J. Project Manage.*, 6(3), 164-170.

Ebbesen, J.B. and Hope, A. (2013). “Re-imagining the iron triangle: embedding sustainability into project constraints.” *PM World J.*, 2(III).

Elattar, S.M.S. (2009). “Towards developing an improved methodology for evaluating performance and achieving success in construction projects.” *Sci. Res. and Essays*, 4(6), 549-554.

Fernández-Sánchez, G. and Rodríguez-López, F. (2010). “A methodology to identify sustainability indicators in construction project management: application to infrastructure projects in Spain.” *Ecol. Indic.*, 10(6), 1193-1201.

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003). “Megaprojects and risk: an anatomy of ambition.” Cambridge University Press.

Fortune, J. and White, D. (2006). “Framing of project critical success factors by a systems model.” *Int. J. Project Manage.*, 24(1), 53-65.

Frödell, M., Josephson, P.E. and Lindahl, G. (2008). “Swedish construction clients' views on project success and measuring performance.” *J. Eng. Des. Tech.*, 6(1), 21-32.

Ghanbaripour, A.N., Ghoddousi, P. and Yousefi, A. (2015). “A framework for evaluating project managers' performance-identification and analysis of KPIs in subway construction projects in Tehran.” *Indian J. Sci. Tech.*, 8(35), 1-7.

Gibson, G.E. and Hamilton, M.R. (1994). “Analysis of pre-project planning effort and success variables for capital facility projects.” Rep. Prepared for Construction Industry Institute, University of Texas at Austin, Austin, Texas.

Hwang, B.G. and Ng, W.J. (2013). “Project management knowledge and skills for green construction: Overcoming challenges.” *Int. J. Project Manage.*, 31(2), 272-284.

Ika, L.A. (2009). “Project success as a topic in project management journals.” *Project Manage. J.*, 40(4), 6-19.

Jha, K.N. and Iyer, K.C. (2007). "Commitment, coordination, competence and the iron triangle." *Int. J. Project Manage.*, 25(5), 527-540.

Jugdev, K., Thomas, J. and Delisle, C. (2001). "Rethinking project management: old truths and new insights." *Int. J. Project Manage.*, 7(1), 36-43.

Kennedy, L., Robbins, G., Scott, D., Sutherland, C., Denis, E., Andrade, J. and Bon, B. (2011)." The politics of large-scale economic and infrastructure projects in fast-growing cities of the south." Literature Review, Chance2Sustain, EADI.

Kerzner, H. (2001). *Project management: a systems approach to planning, scheduling and controlling*, Wiley, Hoboken, NJ.

Langston, C. (2013). "Development of generic key performance indicators for PMBOK using a 3D project integration model." *Australasian Journal of Construction Economics and Building*, 13(4), 78-91.

Lim, C.S. and Mohamed, M.Z. (1999). "Criteria of project success: an exploratory re-examination." *Int. J. Project Manage.*, 17(4), 243-248.

Müller, R. and Jugdev, K. (2012). "Critical success factors in projects: Pinto, Slevin, and Prescott-The elucidation of project success." *Int. J. Managing Projects Bus.*, *5*(4), 757-775.

Munns, A.K. and Bjeirmi, B.F. (1996). "The role of project management in achieving project success." *Int. J. Project Manage.*, 14(2), 81-87.

Ngacho, C. and Das, D. (2014). "A performance evaluation framework of development projects: an empirical study of Constituency Development Fund (CDF) construction projects in Kenya." *Int. J. Project Manage.*, 32(3), 492-507.

Ofori-Kuragu, J.K., Baiden, B.K. and Badu, E. (2016). "Key performance indicators for project success in Ghanaian contractors." *Int. J. Constr. Eng. Manage.*, 5(1), 1-10.

PMI. (2013). *A guide to the project management body of knowledge (PMBOK® Guide)*, Fifth Edition. Pennsylvania: Project Management Institute.

Pocock, J., Hyun, C., Liu, L., and Kim, M. (1996). "Relationship between Project Interaction and Performance Indicators." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)0733-9364(1996)122:2(165), 165-176.

Qureshi, T.M., Warraich, A.S. and Hijazi, S.T. (2009). “Significance of project management performance assessment (PMPA) model.” *Int. J. Project Manage.*, 27(4), 378-388.

Robbins, G. (2015). “The Dube TradePort-King Shaka International Airport mega-project: exploring impacts in the context of multi-scalar governance processes.” *Hab. Int.*, 45, 196-204.

Rockart, J.F. (1982). *The changing role of the information systems executive: a critical success factors perspective*. Boston: Massachusetts Institute of Technology.

Sage, D., Dainty, A. and Brookes, N. (2014). “A critical argument in favor of theoretical pluralism: project failure and the many and varied limitations of project management.” *Int. J. Project Manage.*, 32(4), 544-555.

Samset, K. (1998). *Project management in a high uncertainty situations*. Norwegian University of Science and Technology.

Shenhar, A.J. (2004). “Strategic Project Leadership®: toward a strategic approach to project management.” *R&D Manage.*, 34(5), 569-578.

Shenhar, A.J. and Dvir, D. (2007). *Reinventing project management: the diamond approach to successful growth and innovation*. Harvard Business Review Press.

Shenhar, A.J., Dvir, D., Levy, O. and Maltz, A.C. (2001). “Project success: a multidimensional strategic concept.” *Long Range Plann.*, 34(6), 699-725.

Shenhar, A.J., Levy, O. and Dvir, D. (1997). “Mapping the dimensions of project success.” *Project Manage. J.*, 28(2), 5-13.

Shi, Q., Zuo, J. and Zillante, G. (2012). “Exploring the management of sustainable construction at the programme level: a Chinese case study.” *Constr. Manage. Econ.*, 30(6), 425-440.

Tabish, S.Z.S. and Jha, K.N. (2011). “Identification and evaluation of success factors for public construction projects.” *Constr. Manage. Econ.*, 29(8), 809-823.

Takim, R. and Adnan, H. (2008). “Analysis of effectiveness measures of construction project success in Malaysia.” *Asian Social Sci.*, 4, 74-91.

Todorović, M.L., Petrović, D.Č., Mihić, M.M., Obradović, V.L. and Bushuyev, S.D. (2015). “Project success analysis framework: a knowledge-based approach in project management.” *Int. J. Project Manage.*, 33(4), 772-783.

Toor, S. and Ogunlana, S. (2010). “Beyond the ‘iron triangle’: stakeholder perception of key performance indicators (KPIs) for large-scale public sector development projects.” *Int. J. Project Manage.*, 28(3), 228-236.

Weaver, P. (2012). “The demise of the iron triangle.” (http://network.projectmanagers.net/profiles/blogs/the-demise-of-the-iron-triangle)

World Gazetteer. (2012). (http://www.world-gazetteer.com)

Yin, R.K. (1994). *Case study research: design and methods*. Thousand Oaks: Sage Publications.

Yousefi, A. and Ghanbaripour, A.N., 2015. “Safety status of stations and tunnels of Tehran Line 4 Urban and Suburb Railways (Subway) against fire risks.” *In 17th International Conference on Engineering, Project and Production Management*, Venice, Italy

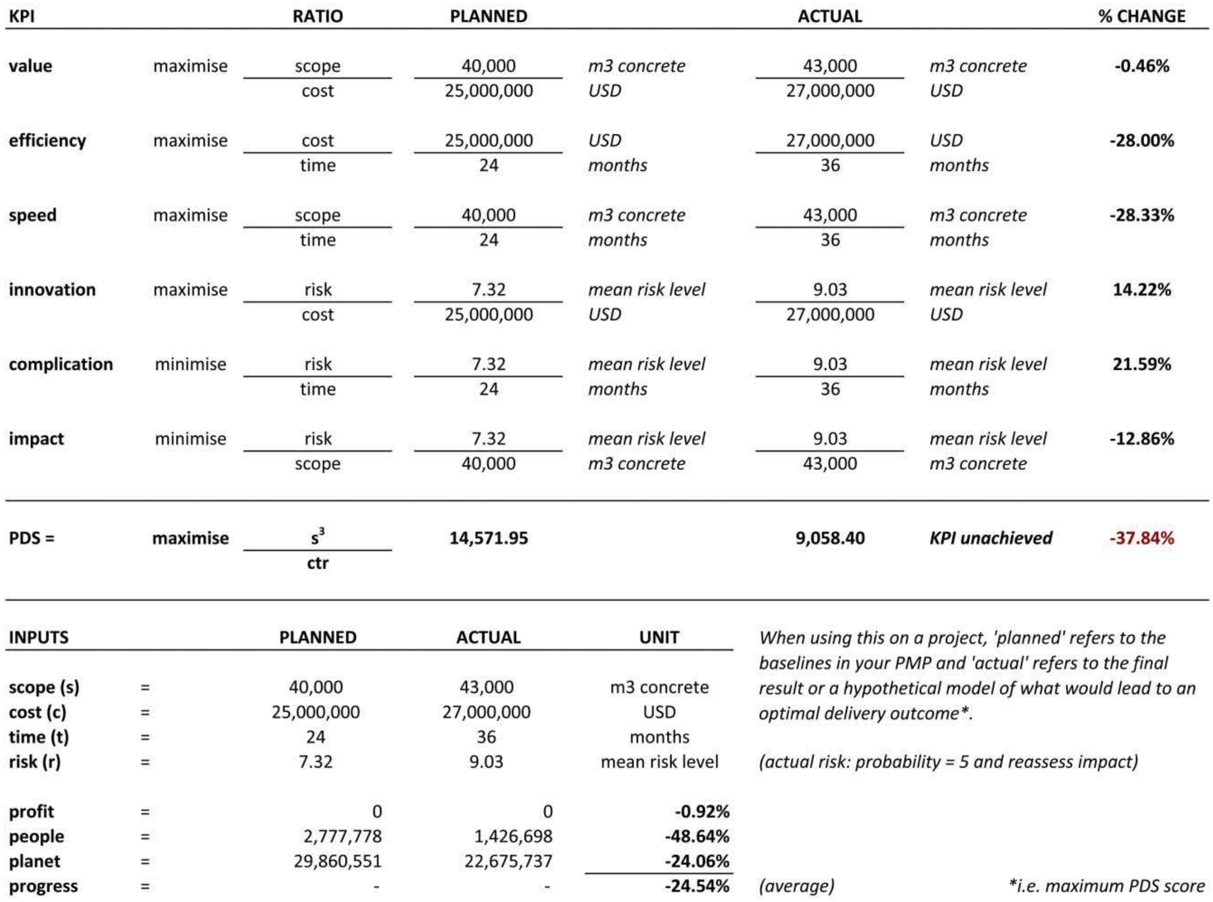
Zhang, L. and Xue, X. (2014). “Dynamic mechanisms of technology innovation across multi-stakeholders in mega infrastructure projects.” *In ICCREM 2014: Smart construction and management in the context of new technology*, ASCE, 166-175.

Table 1. Risk register for subway station construction

ID	**Major risk events**	**Planned**			**Actual**		
		P	*I*	***Risk Level***	*P*	*I*	***Risk Level***
1	Economic crisis	3	2	**6**	5	4	**20**
2	Inflation volatility	4	3	**12**	5	4	**20**
3	Unavailability of client funding	4	4	**16**	5	5	**25**
4	Land problems (i.e. permissions)	2	3	**6**	5	1	**5**
5	Conflict with governmental departments	3	2	**6**	5	1	**5**
6	Conflict with public stakeholders	2	2	**4**	5	1	**5**
7	Wrong site selections	1	2	**2**	5	1	**5**
8	Major contractual issues	3	3	**9**	5	1	**5**
9	Delay in solving disputes and conflict resolution	4	2	**8**	5	3	**15**
10	Change orders from diverse stakeholders	5	3	**15**	5	3	**15**
11	Conflict between project consultants	5	1	**5**	5	3	**15**
12	Inappropriate national standards	2	1	**2**	5	1	**5**
13	Inaccurate data	3	1	**3**	5	3	**15**
14	Problems with detailed design	4	2	**8**	5	1	**5**
15	Major mistakes in design	2	2	**4**	5	1	**5**
16	Major variations in construction phase	3	2	**6**	5	1	**5**
17	Time overruns in design phase	3	2	**6**	5	1	**5**
18	Delay in obtaining governmental permissions	3	3	**9**	5	1	**5**
19	Major accidents and injuries	2	5	**10**	5	1	**5**
20	Delay in approving drawings by government	3	3	**9**	5	1	**5**
21	Delay in procurements	3	3	**9**	5	1	**5**
22	Complex geological and hydrological conditions	3	5	**15**	5	3	**15**
23	Unclear subsurface utility layouts	4	2	**8**	5	3	**15**
24	Conflict with subcontractors	2	2	**4**	5	1	**5**
25	Subsurface obstacles (rocks, holes, etc.)	2	2	**4**	5	1	**5**
26	Underground water	4	4	**16**	5	3	**15**
27	Damage to adjacent buildings	2	4	**8**	5	1	**5**
28	Incompetency of team	1	3	**3**	5	1	**5**
29	Rough construction plan	2	2	**4**	5	1	**5**
30	Untrained human resources	1	4	**4**	5	1	**5**
31	Poor materials	1	5	**5**	5	2	**10**
32	Undesirable sample testing results	2	3	**6**	5	2	**10**
33	Inappropriate construction methods	1	4	**4**	5	1	**5**
34	Scope creep	3	4	**12**	5	2	**10**
35	Poor construction programming	2	2	**4**	5	1	**5**
36	Lack of sufficient rules	3	2	**6**	5	1	**5**
37	Major conflicts with neighbors	3	3	**9**	5	3	**15**
38	Lack of competent consultants	4	3	**12**	5	3	**15**
39	Lack of effective communication	2	2	**4**	5	3	**15**
40	Change of key personnel	4	2	**8**	5	1	**5**
41	Worker strike	3	3	**9**	5	1	**5**
	Mean risk score:			**7.32**			**9.03**

P = probability; I = impact; Risk level = P × I

Table 2. Calculated performance of case study as built



KPI		RATIO	PLANNED		ACTUAL		% CHANGE
value	maximise	scope	40,000	*m3 concrete*	43,000	*m3 concrete*	**-0.46%**
		cost	25,000,000	*USD*	27,000,000	*USD*	
efficiency	maximise	cost	25,000,000	*USD*	27,000,000	*USD*	**-28.00%**
		time	24	*months*	36	*months*	
speed	maximise	scope	40,000	*m3 concrete*	43,000	*m3 concrete*	**-28.33%**
		time	24	*months*	36	*months*	
innovation	maximise	risk	7.32	*mean risk level*	9.03	*mean risk level*	**14.22%**
		cost	25,000,000	*USD*	27,000,000	*USD*	
complication	minimise	risk	7.32	*mean risk level*	9.03	*mean risk level*	**21.59%**
		time	24	*months*	36	*months*	
impact	minimise	risk	7.32	*mean risk level*	9.03	*mean risk level*	**-12.86%**
		scope	40,000	*m3 concrete*	43,000	*m3 concrete*	
PDS =	**maximise**	**s^3**	**14,571.95**		**9,058.40**	***KPI unachieved***	**-37.84%**
		ctr					

INPUTS		PLANNED	ACTUAL	UNIT
scope (s)	=	40,000	43,000	m3 concrete
cost (c)	=	25,000,000	27,000,000	USD
time (t)	=	24	36	months
risk (r)	=	7.32	9.03	mean risk level
profit	=	0	0	**-0.92%**
people	=	2,777,778	1,426,698	**-48.64%**
planet	=	29,860,551	22,675,737	**-24.06%**
progress	=	-	-	**-24.54%**

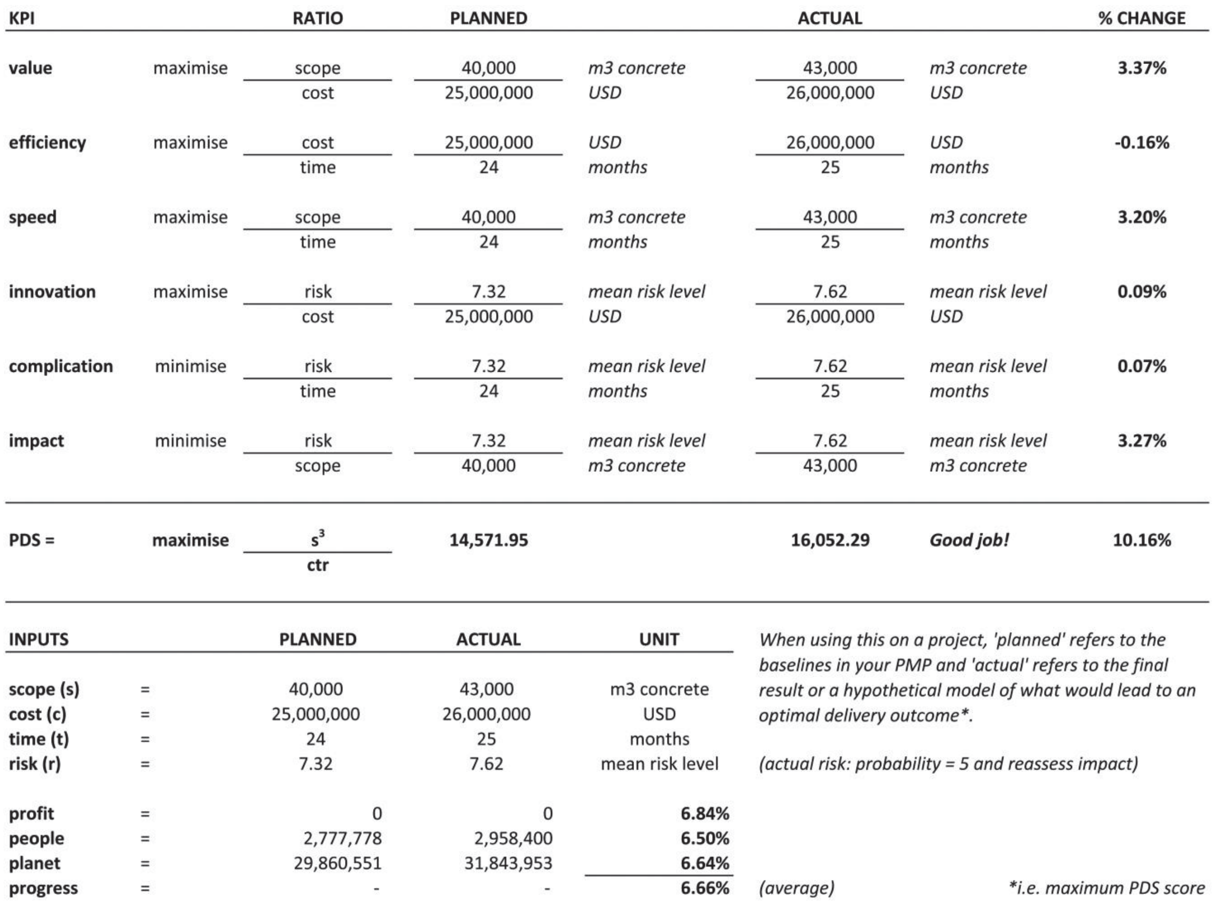
When using this on a project, 'planned' refers to the baselines in your PMP and 'actual' refers to the final result or a hypothetical model of what would lead to an optimal delivery outcome.*

(actual risk: probability = 5 and reassess impact)

(average)

**i.e. maximum PDS score*

Table 3. Calculated performance of case study to be considered successful



KPI		RATIO	PLANNED		ACTUAL		% CHANGE
value	maximise	scope	40,000	*m3 concrete*	43,000	*m3 concrete*	**3.37%**
		cost	25,000,000	*USD*	26,000,000	*USD*	
efficiency	maximise	cost	25,000,000	*USD*	26,000,000	*USD*	**-0.16%**
		time	24	*months*	25	*months*	
speed	maximise	scope	40,000	*m3 concrete*	43,000	*m3 concrete*	**3.20%**
		time	24	*months*	25	*months*	
innovation	maximise	risk	7.32	*mean risk level*	7.62	*mean risk level*	**0.09%**
		cost	25,000,000	*USD*	26,000,000	*USD*	
complication	minimise	risk	7.32	*mean risk level*	7.62	*mean risk level*	**0.07%**
		time	24	*months*	25	*months*	
impact	minimise	risk	7.32	*mean risk level*	7.62	*mean risk level*	**3.27%**
		scope	40,000	*m3 concrete*	43,000	*m3 concrete*	
PDS =	**maximise**	s^3	**14,571.95**		**16,052.29**	***Good job!***	**10.16%**
		ctr					

INPUTS		PLANNED	ACTUAL	UNIT
scope (s)	=	40,000	43,000	m3 concrete
cost (c)	=	25,000,000	26,000,000	USD
time (t)	=	24	25	months
risk (r)	=	7.32	7.62	mean risk level
profit	=	0	0	**6.84%**
people	=	2,777,778	2,958,400	**6.50%**
planet	=	29,860,551	31,843,953	**6.64%**
progress	=	-	-	**6.66%**

When using this on a project, 'planned' refers to the baselines in your PMP and 'actual' refers to the final result or a hypothetical model of what would lead to an optimal delivery outcome.*

(actual risk: probability = 5 and reassess impact)

(average)

**i.e. maximum PDS score*

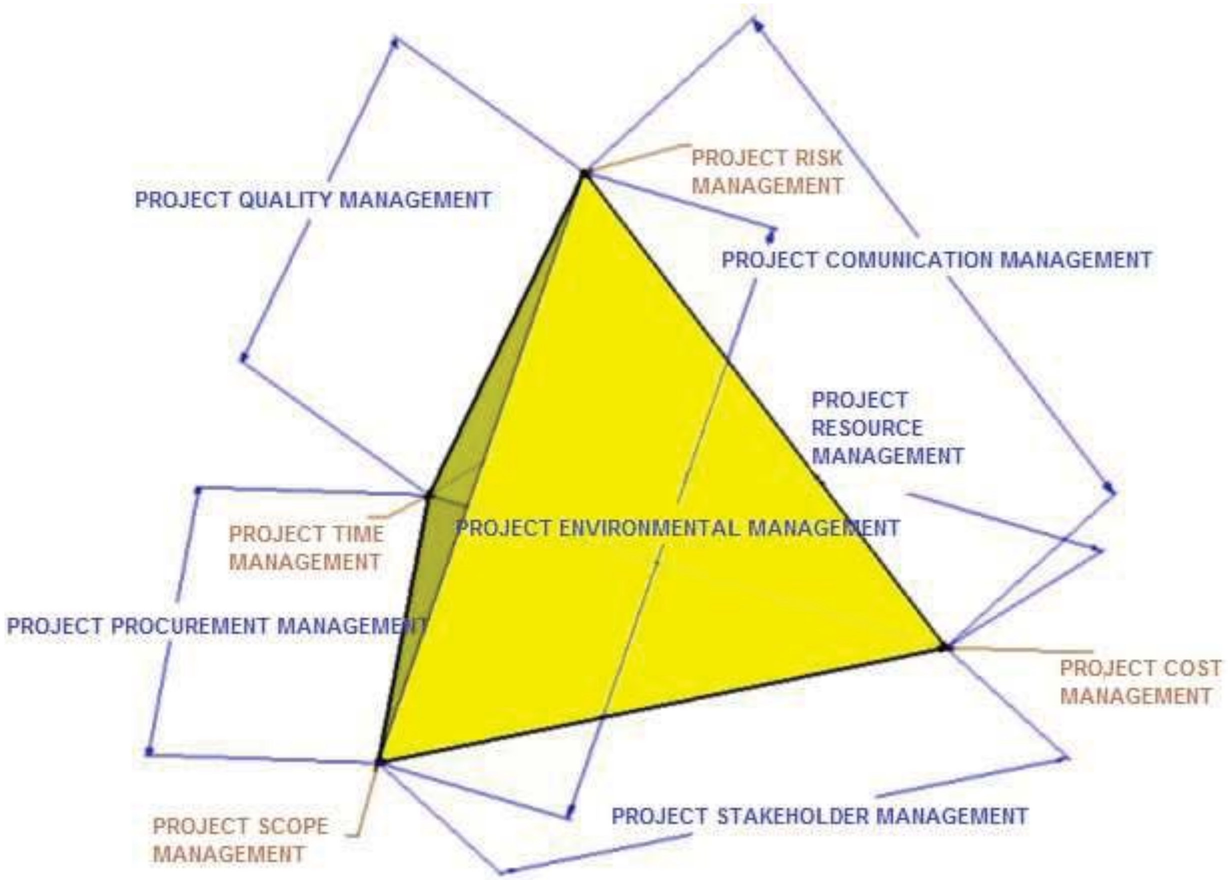


Fig 1. 3D Project integration model (Langston, 2013)

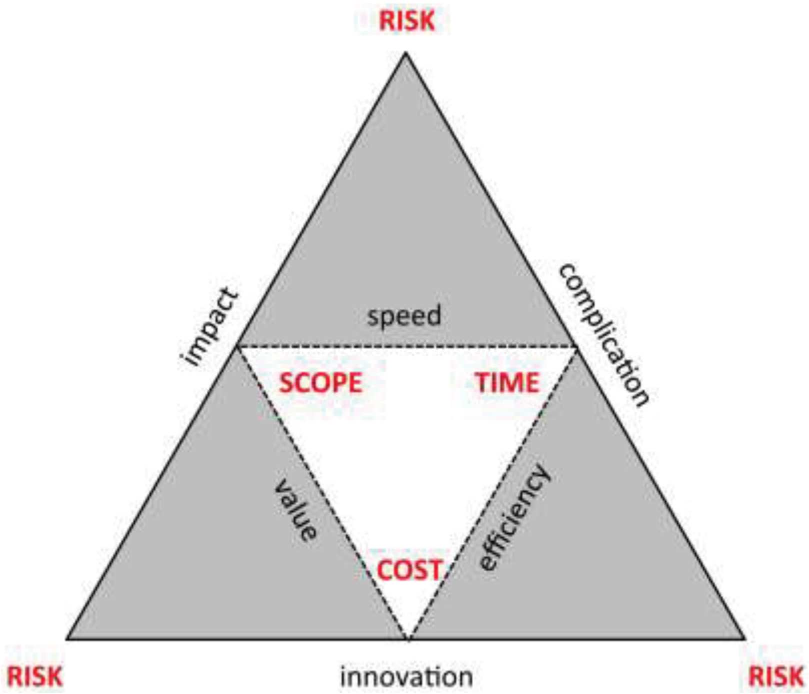


Fig 2. Project constraints and key performance indicators (Langston, 2013)

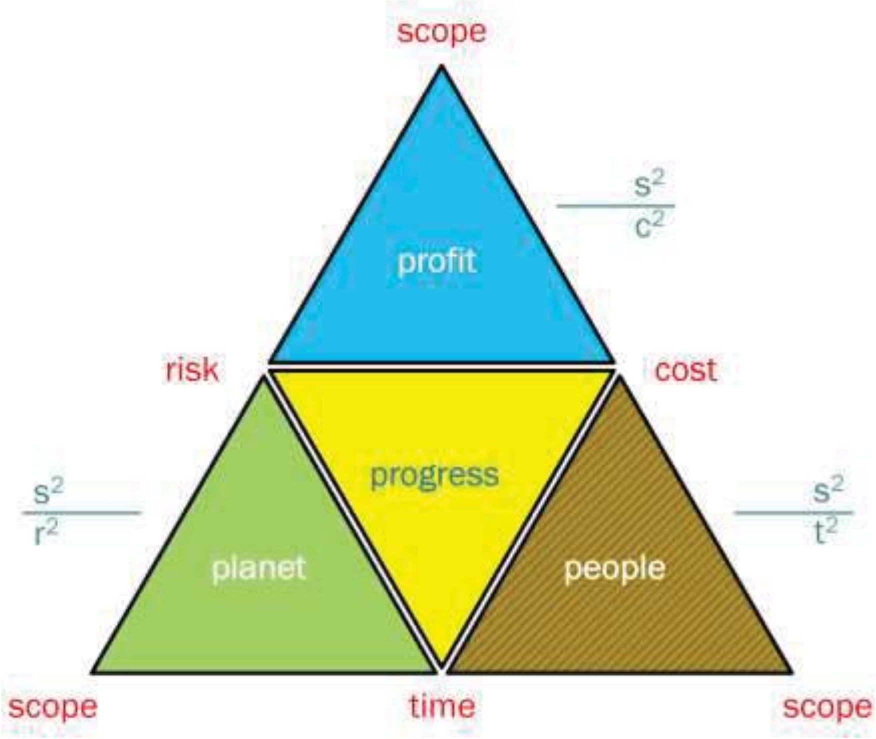


Fig 3. TBL reporting applied to 3D Integration Model

Fig 4. Construction of concrete ribs

Fig 5. Main structure of the underground station

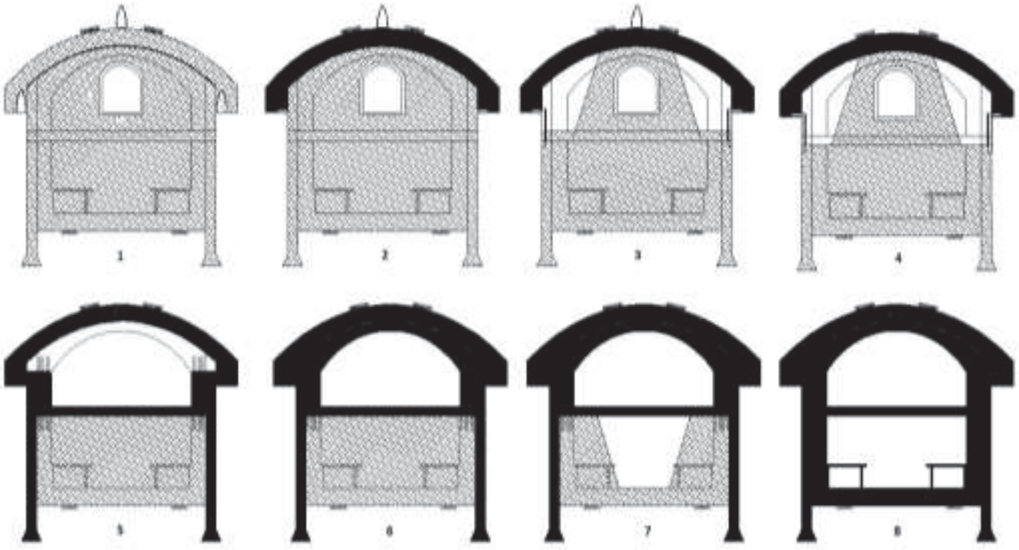


Fig 6. Construction phases and method

Figure Caption List