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THE IMPORTANCE OF MULTIPLE ANALYTICAL STRUCTURES IN THE EVALUATION OF RISK EXPOSURES OF CONSTRUCTION PROJECTS

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Abstract

Construction projects are complex, multifaceted operations that involve multiple perspectives and different resources and activities. The success of a project depends on its ability to balance the resources and activities that comprise it in a way consistent with all of its stakeholders' needs. Construction projects must be evaluated from different perspectives to assess risk exposures. Each view will render a different financial impact depending on which resources and activities are included in a particular perspective. A separate analysis of a single project mandates a computer-assisted framework to define multiple analytical classes. Multiple analysis of a single project implies comparing various projects by the same analytical structure. This paper discusses a framework that enables an arbitrary number of analytical classes for a particular project.

Keywords: risk exposure, construction project analysis

1. INTRODUCTION

The lifecycle of construction projects involves multiple phases, many stakeholders, and resources and spans multiple years, making it a complex process. It starts with the design, cost estimate, evaluation of acceptability, and final owner's decision to commit. Request for proposals is issued, analysed by contractors, and cost and schedule are estimated. In this phase, the contractor must evaluate the project's different perspectives before deciding to bid. After bid acceptance, the contractor makes a detailed schedule and plan of resources and enters the construction phase. The construction phase is the most sensitive phase of the project and is the focus of numerous research as a large number of activities, a large number of participants, and a large number of resources make this phase prone to errors, misunderstandings, and disputes. In the post-construction stage, mistakes made in the construction become visible, which complicates maintenance and raises the cost and, hence, the total cost of ownership.

The construction project, in general, and large projects, infrastructure projects in particular, constantly underperform and cause delays and cost overruns. Flyvbjerg, Skamris Holm & Buhl (2004) analysed 258 large infrastructure projects in twenty countries, showing that 86% of the projects suffered from cost overruns, and the cost overruns were, on average, 28% over expected values. They further concluded that the cost overruns were not caused by some isolated or a few isolated catastrophic events but by many minor delays and disruptions whose cumulative financial effect was only visible too late. The study revealed another concerning fact: the average underperformance has been constant over the last 70 years, and nothing has changed with the introduction of new technology in construction.

Ahmed, Azhar, Kappagntula, & Gollapudil (2004) reviewed the causes of cost overruns for the Florida Department of Transportation (FDOT) in 102 projects with a total budget of US$ 302.7 million. Cost overruns were 9.5% of the budget, and more than half were recognised as avoidable costs. The responsibility for those costs was shared among FDOT consultants (55%), Third parties (32%), and FDOT staff (13%).

The underperformance of construction projects triggered an avalanche of research into risks associated with every phase of the project to find potential causes of delays and cost overruns, manage them, and either resolve them or acceptably mitigate them.

Risk management is considered of such importance for the enterprise that the American National Standards Institute (ANSI) (2004) devoted a separate chapter in their Program Management Body of Knowledge (PMBOK). They specify six processes necessary to manage the risks of a project. They start with Planning, considering organisational process assets, project scope, risk management plan, and project management plan as inputs and obtaining Risk Register as output. The next step is risk identification, where documentation reviews, information gathering, and checklist and assumption analysis are used to modify the Risk Registry. Qualitative Risk Analysis follows with risk probability and impact assessment and matrix, data quality assessment, risk categorisation, and urgency assessment. The next step is Quantitative Risk Analysis, where data gathering and modelling techniques are used for representation. Risk response planning follows, rendering updates to Risk Register, project management plan, and possible risk-related contractual agreements. Finally, Risk Monitoring and Control techniques are used for risk reassessments, audits, variance and trend analysis, and performance measurement via status meetings.

This paper explores a real-life infrastructure project analysed by a contractor using multiple analytical categories organised into fifteen tree-like analytical structures or classes, which rendered different financial and quantitative views of the project. The author suggests that those structures are analogues to the analysis structures used in risk management methodologies and allow an arbitrary project analysis from the risk management point of view.

2. LITERATURE REVIEW

Hallowell and Gambatese (2010) explore the use of the Delphi methodology in qualitative risk analysis, which optimizes the proper parameters, expert panellists' team composition, feedback type, and consensus measure.

Corominas, van Westen, Frattini, Cascini, Malet, Fotopoulou, and Smith (2014) describe the quantitative analysis that evaluates the probabilities of occurrence of different landslide types with specific characteristics.

Timmermans and Tavory (2012) outline how proper methodological steps enrich abductive analysis through revisiting, defamiliarization, and alternative casing.

The general benefits of qualitative research are discussed by Doz (2011), Hesse-Biber and Leavy (2010), and reflexive methodology by Alvesson and Sköldberg (2017).

Dziadosz, Tomczyk, and Kapliński (2015) tried to verify the relationship between the kind of structure, the size of the contract, and the scope and degree of risk.

Smith, Merna, and Jobling (2014), in their 3rd edition, recognize the reality of multi-project or program management and the risks in this context, especially the problem of risk management in international joint ventures.

Zavadskas, Turskis, and Tamošaitiene (2010) researched risk assessment on multi-attribute decision-making methods. They used TOPSIS grey and COPRAS-G methods to rank the objects and determine their optimality.

Tang, Shen, and Cheng (2010) reviewed Public-Private-Partnership papers from six top journals in the construction field and classified them into two groups empirical and non-empirical. They then compared them and contrasted several elements, including the project risks.

Hubbard (2020) explores some failures of risk management and the reason they failed. The book aims to convince managers to stop using ineffective risk management techniques and focus on methodologies to avoid losses.

In his book Aven (2015) takes a step back and discusses the role of the analyses in risk management and how they should be planned, executed, and used so that they meet professional standards and are useful in practical decision-making contexts.

Zhang, Zhang, Gao, and Ding (2016) researched the problem of improper risk allocation between the owner and the contractor. They collected data from 284 Chinese project professionals and empirically explored whether, how, and when risk allocation influences the contractor's cooperative behaviour. The findings in this paper can help the project owners design better contracts because contractors are not looking favourably when owners' risks are allocated to them.

Nasirzadeh, Khanzadi, and Rezaie (2014) used an integrated fuzzy-system dynamics approach for quantitative risk allocation between owners and contractors. They simulated project costs at different levels of risk allocation and concluded that the optimal allocation is the point of minimal cost.

El-Sayegh and Mansour (2015) explored 33 risks associated with highway construction projects in the United Arab Emirates. The most substantial risks encompass inadequate project planning, unforeseen underground utilities, the quality and reliability of the design, delays in obtaining approvals, and postponements in property expropriations. Interviewed contractors and consultants also agreed that internal project risks were more significant than external ones.

Mills (2001) reviews a systematic management approach to risk and discusses the allocation of risk. He suggests that risks must be identified and managed early in the procurement process.

Wang, Dulaimi, and Aguria (2004) propose a qualitative risk mitigation framework that manages multifaceted risks with international construction projects in developing counties. Twenty-eight critical risks were identified and grouped into three hierarchical levels (country, market, and project), and mitigation measures were proposed.

Rostami, Sommerville, Wong, and Lee (2015) explored the challenges faced by small and medium enterprises in the U.K. in implementing risk management strategies. Of the 153 companies that responded, most identified that the main difficulty experienced is how to scale the Risk management process to meet their requirements

Quantifying the severity and frequency of risk in an activity or project structure has been addressed by numerous authors with different approaches. De Marco and Thaheem (2014) analysed project risk methodologies to help managers choose an appropriate risk analysis technique. They recognised two main categories of project risk analysis techniques qualitative and quantitative. Qualitative methods do not operate on numbers but instead use descriptive terms like high, medium, or low depending on the human perception of participants. It uses brainstorming, checklists, Event Tree Analysis, Risk Breakdown Matrix, and risk data quality assessment. In quantitative analysis methods, the evaluation of risk exposure is linked to the usage of numerical metrics. In this context, the potential impact of consequences is quantified in terms of monetary value, while the probability of a risk occurring is determined based on the frequency of past occurrences, leveraging available historical data.

Risk matrices are commonly used to quantify the severity and frequency of occurrence. However, Risk matrices have mathematical shortcomings like poor resolution, errors, suboptimal resource allocation, and ambiguous inputs and outputs, suggesting they should be used cautiously (Cox, 2008).

3. RESEARCH METHODOLOGY

The model proposed in this paper builds upon post-tender bidding procedures and analyses conducted from 1992 to 2008. The primary aim was to accurately determine the financial implications of various aspects of bid data, enabling a more informed assessment of a project's exposure to potential obstacles. The analysis of tender data was carried out within the estimating department of Croatia's leading construction company, providing a solid empirical foundation for the current research.

This model utilises the findings and methodologies of the author's previous work (Bačun, 2022) as a basis for further refinement and enhancement, broadening its capabilities for assessing potential challenges in construction project bids. This previous research provides an essential backdrop for the current paper, which extends the original model. This expansion sees the model incorporating the evaluation of tender data by applying arbitrary analytical structures. Such an extension allows for a more nuanced and versatile understanding of bid data, adding further depth to project assessment.

The contractor company whose data was used for this paper was, at the time, a distinguished civil engineering firm headquartered in Split, Croatia. They focused on infrastructure construction, specialising in various projects, including roads, bridges, tunnels, dams, and intricate facilities. They had a workforce of roughly 3000 individuals, with a core group of ten expert estimators responsible for executing bidding calculations. Besides local infrastructural projects, they had projects in the rest of Europe, Africa, and the Middle East.

One of the standout features of this contractor was its proprietary set of corporate standards for work units. This standard system represented required resources such as materials, labour, equipment, subcontractors, and work sub-assemblies. They formulated templates outlining the resources needed per unit of time (day/week/month). This approach was beneficial when estimating the overall resource quantities for projects where the chosen technology restricts the pace of work, a scenario commonly encountered in tunnel construction.

In the unit price estimating methodology, a comprehensive calculation of each resource's total quantity and sum was executed at the tender level. A unit price was determined for each item on the Bill of Quantities (BoQ). This was achieved by summing up the amounts of the various resources deployed for that specific item. The calculated unit price indicates the total cost required for producing or completing a single unit of that particular BoQ item.

This methodology allows for detailed cost tracking and resource usage estimation for each BoQ item, group of items level, and the whole project. This method is integral in maintaining cost-effectiveness and ensuring optimal allocation of resources throughout the project, facilitating financial oversight and efficient project management.

4. RESULTS OF THE RESEARCH

The data for the analysis in this paper was obtained from data for a water supply system in Libya that was estimated between 2004 and 2007. The project included a water plant to extract the water from the Nubian aquifer system (Thorweihe, 2017) and two roads: coastal road Sabrata – Ras Jedir and Tobruk – Musaad.

Fifteen classes were created for analysis with a tree-like structure of subclasses. Some had a single level of subclasses, while others had up to five subclass levels that were not all of the same depth. The simplest is the Operating cost of the machinery class which totals the cost of three subclasses across the whole BoQ (fuel, lubricants, and tires). This variant of the operating cost class gave information about the fuel quantity needed for the project's duration (both the quantity and amount), including totals per the same group of machines.

Fixed machinery costs per hour rendered totals per each machine in three variants: machinery used up to one week, up to one month, and over one month.

The machinery rental class gave the full rental cost information, enabling the estimators to conduct a "What-if" scenario analysis. By assigning a machine to the class, the estimator could evaluate which would be more cost-effective: using the company's resources or renting them locally.

The class of preparatory work was used to estimate the cost of labour, materials, and machinery subclassed per type of resource. Those works are not a BoQ item but necessary to achieve site functionality, like auxiliary roads, dwellings, telephone lines installation, Etc.

Dynamic workforce plan class defined work positions and necessary qualifications and the number of employees for seven categories: site administration, site managers, production workforce, auxiliary workforce, manufacturing, construction workforce, and kitchen services.

The dynamic plan of the machinery class contained information about hourly machinery rates and a total of 158 subclasses.

Direct costs of construction class had material, labour, and machinery data per qualification and type, structure per site, objects inside a site, and BoQ item.

Further, two classes rendered analysis per each site, object, and BoQ item: Direct and indirect costs of machinery and equipment class and Indirect cost of administrative personnel class.

One of the more important classes is the Fixed costs of machinery class because those are time-independent costs and increase the project's total cost for any delay in the schedule. İt is subclassed as depreciation, the interest on investment, interest on bank credits, insurance, regular maintenance, current maintenance, registration, and tolls.

Accounting class is the most common form of project analysis as it is base for budgeting. In this particular case, the class had twenty-eight different accounts used to track the costs.

The cost structure class revealed the structure of the leading group of costs. It was subclassed into eight subclasses: material and operating costs, construction wages, administrative wages, fixed cost per worker, machinery costs, leasing costs, preparatory works costs, and indirect costs.

The Selling Price Class was structured into two main subclasses: subcontractors and the company's construction works. The latter were further subclassed into direct costs and two different variants of indirect costs. The direct costs were divided into brutto construction wages, materials embedded into the final product, and fixed machinery costs. The first set of indirect costs are generally called site indirect costs and include Brutto administrative wages, site labour allowance, overhead material costs, transport costs, site operating costs, site fixed machinery costs, and cost of preparatory works. The second variant of indirect costs is those that emerge outside the site, like the reserved funds for the guarantee period, insurance, interest and bank provisions, head office costs, legal obligations, and profit.

In typical construction projects, cost analysis is usually conducted from a mainly accounting standpoint. Specific costs are attributed to accounting codes, which serve as the foundation for budget creation and subsequent tracking of costs according to these designated codes. This traditional approach, however, has its limitations. It falls explicitly short due to the time delay between the actual cost consumption and the point at which it is registered in the accounting records. This delay only allows for retrospective or 'post-mortem' analysis of the charges, limiting the scope for proactive decision-making.

In the project discussed, the approach to cost analysis was significantly expanded to reflect better the multifaceted nature of the project's financial landscape. Fifteen unique analysis classes were established to provide fifteen distinct financial perspectives of the project. This more holistic view allows for a much deeper understanding of the financial implications of the project.

It is recommended that this framework be further expanded to include analysis classes related to risk exposure. Such classes could encompass aspects like environmental considerations, potential delays, the age and condition of machinery used, workforce experience, and other factors that could affect the cost and progress of the project. However, the analysis classes primarily focused on estimating costs in this case.

Expanding the framework this way would provide a more comprehensive and nuanced understanding of the project's financial situation and risk factors. This approach would pave the way for more informed decision-making during infrastructure project estimating, pre-construction, and construction phases.

5. DISCUSSION

The case study presented in this paper emphasises the significance of employing multiple analytical structures for any facet of project analysis to accurately assess the economic importance of diverse project perspectives.

The framework described in this paper allows the user to define an arbitrary number of analytical structures that would be applied to analyse data in a particular project. In the presented example, all the classes are used to enhance the estimate and bid position to optimise the data gathered in the Selling price class.

Some classes straightforwardly gather project values, for example, the Direct cost of construction class, as it deals with three primary resource databases: materials, labour, and machinery. This means that the framework has to be able to assign all the materials into the materials category of the Direct cost of construction class.

The Machinery Operating Costs class is more complicated because it analyses just a few data points in the materials database: fuel, lubricants, and tires. This means those materials must be singled out for the Operating cost of machinery class. Note that there may be various fuels, numerous lubricants, and numerous types of tires. Those would be different materials in the inventory system, as tires would have different dimensions, prices, and characteristics. This implies that it would be advantageous if the materials catalogue had a tree-like structure of variable depth to organise the materials with operating procedures in mind rather than administrative codes.

The plot thickens with the use of Accounting class analysis. Fuel oil and gasoline would be assigned to the Fuels account. However, suppose the contractor has many machinery units and trucks on site. In that case, the site Repair workshop almost certainly exists on the construction site or nearby. There, gasoline and fuel oil are used for cleaning and testing, and in that case, the same materials would be assigned to the Auxiliary materials account code. In other words, the same material would need to be assigned to a different class element depending on the activity in which it was consumed.

Access roads, dormitories, parking lots, fuel pump stations, administrative buildings, telephone lines, electricity cables, and others had to be built with the same bulldozers, trucks, dumpers, and cranes and the same materials and workforce used in the project. Those resources are assigned an element from the Preparatory Works class, while in the Selling Price class, they are assigned to an element in the Site Indirect Costs group.

A simple assignment of a class element to a material is illustrated in Figure 1.

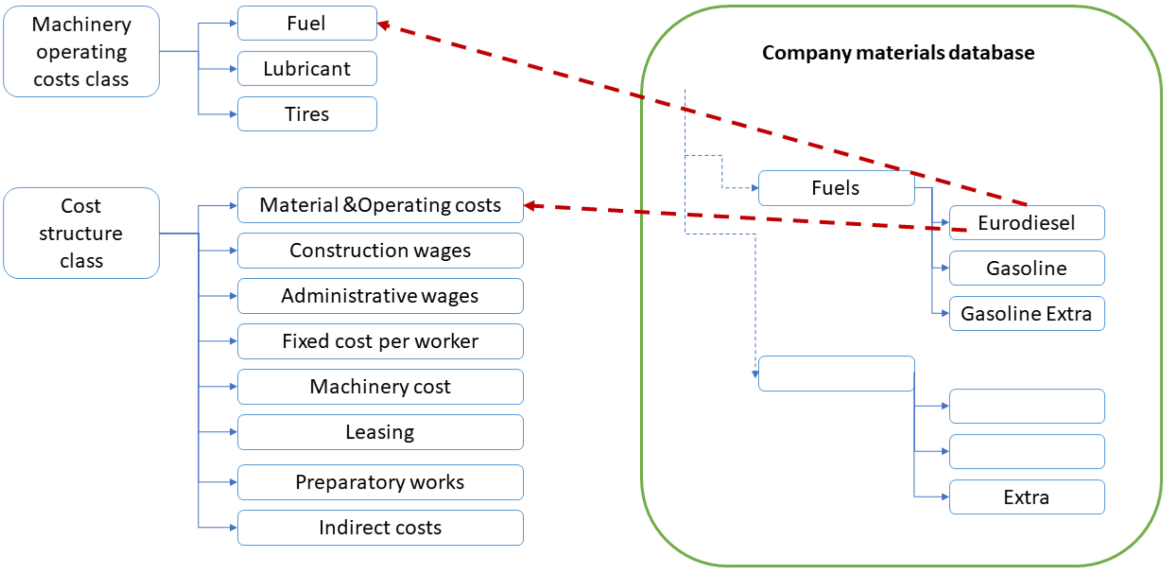

Figure 1 Simple assignment to a class element

Each material or machine, or labour type may be assigned to a single class element in a Class and another class element in another Class. Generally, a single material may be assigned to an arbitrary number of classes but only to a single component inside a class. A group of materials (for example, fuels) may also be assigned to a single class element, which means that any of the materials in the group will automatically be set to the same class element.

The BoQ unit price is calculated as the sum of resources needed to produce one unit of BoQ item. Suppose those resources are assigned to different class elements inside a single class. In that case, the total value of the BoQ item will be distributed into multiple class elements in the class structure. In another class, the same resources might have different class element assignments, so in another class, the same BoQ element's value might be distributed differently, giving a financial perspective from another point of view.

The BoQ element is just a node in the BoQ structure, and as such, it can also be assigned to a class element. In that case, the total value of the BoQ element (unit price * quantity) will be assigned to a single class element, regardless of whether its resources were allocated to different class elements in the same class.

As a BoQ element is a node in a BoQ structure, any group of BoQ elements on any hierarchical level can be assigned to a single class element. This means that the total value of the group or works will be assigned to a single class element, regardless of possible assignments of lower-level nodes.

The project schedule is a sequence of activities explaining the work timeline necessary to complete the project. The activities are often hierarchically structured so parties can better understand the project's progress. The quantities of consumed resources in a period (week, month, year) are the basis of the Dynamic plan of machinery and the Dynamic plan of labour (how many machines and workforce are needed in a particular period). The value of consumed resources in a period renders a Dynamic financial plan and is the basis for the project's budget.

Resources needed to complete a task are the same ones used to calculate the unit price of a BoQ element. Although Schedule activities and BoQ elements are not correlated in a one-to-one relationship, the total quantity of each resource calculated in BoQ, plus resources from indirect cost activities, should equal the total resource consumptions defined in the project's schedule. Often a single Schedule activity production process requires the construction of partial quantities of one or more BoQ elements concurrently. This establishes a tight relationship between the project schedule and BoQ, creates backlinks toward BoQ elements and enables integration of those structures in a single frame from the analysis point of view.

Any node in such a structure (a material, a resource in a unit price calculation, a BoQ element, a group of BoQ elements, a Schedule activity, or a group of Schedule activities) can be assigned to a class element to be analysed. Any such node can also be set to another class element from a different class.

An analytical class is also a tree-like structure of arbitrary shape and depth that depicts the points of interest for quantitative and financial analysis. Its function summarises the quantities and values of all the BoQ elements/schedule activities/elementary resources assigned to a particular class element. If class elements are in a class group, then all the values and quantities in the class elements will be summarised in the class group. The sum of quantities across the project structure makes sense only if homogenous quantities are summed. Summarising work hours across the project regardless of the type of workforce will give important information (total work hours in the project). However, the sum is meaningless if the resources assigned to a class element are different, like tons and hours. The value of the class element, however, is significant because it renders the total cost of all the project structure nodes that were assigned to it.

Hillson (2002) states that structuring is an essential strategy to ensure that the necessary information is generated and understood when a large volume of data is produced, like in construction projects.

Risk Breakdown Structure (RBS) is such a tree-like structure. It is also a class in which elements could be assigned to nodes in the project structure. Each end node in the RBS structure is an identified risk, and the upper nodes are different class groups. Hall and Hulett (2002) suggest three groups at level one: management, external, and technology. At level two, the Management group is divided into Corporate and Customer Stakeholders, specifying each identified risk. Project Risk Class elements would be assigned to multiple activities, BoQ nodes, or elementary resources to render the total value tied to the project's History/experience/culture risk.

This approach allows for numerous exciting possibilities.

One of the most common risks is schedule delay. One of the elements of activity delay is the machinery's correct functionality, which depends on age. If we assign used machines to the Machinery Age class elements with the structure: up to 5 years, 5-10 years. 10-15 years over 15 years, we could quickly analyse what activities are more prone to failure due to equipment malfunction. Additionally, we can get information on how much funds are tied into such activities across the project.

The same might be applied to the Workforce Experience class or any other analytical structure that the project manager finds attractive.

The functional details of such a framework were specified by Bačun (2022).

6. CONCLUSIONS

Construction projects need to be analysed from numerous different perspectives to understand all the facets that might influence the successful bid and construction of the project. Fifteen classes analysed the real-life example project described in this paper and focused on the correct estimate and Selling Price Class.

The structure of the classes used in the example project is analogous to the formats used in risk analysis so that risk analysis would have the same functionality. This means that any risk class could be defined and the project analysed by any or all of them to give multiple risk views of the project.

The shortcoming of such an approach is the need to manually assign a particular node of the project structure to a class element, but if the user of such a framework is to be given the freedom to design any form of a class, a certain amount of manual work will be needed. Advances in modern algorithms should minimise manual assignment work.

Future work should involve the design of run-time triggers to detect the changes to a class element that would force the change of risk status and automatically alert project stakeholders and risk owners of that particular risk.

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