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A systematic review of quantitative risk analysis in construction of mega projects

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ABSTRACT

Mega projects (MP) require efficient management of risks during their construction. Therefore, it is crucial to identify any possible deviations towards meeting their objectives. Such deviation forced MP to be delivered behind schedule and over budget. According references, MP does not require only qualitative analysis but requires an accurate quantitative analysis based on knowledge and practice. Thus, this paper aims to undergo a systematic review of quantitative analysis literature in construction of worldwide MP, with the utmost aim to improve contractors quantitative risk analysis practices in the presence of uncertainty. A time line was produced which shows the process of quantitative risk analysis in this literature including the past six years from 2013 to 2018. This was followed by a critical analysis in order to account for quantitative risk analysis techniques highlighted throughout literature sources. Furthermore, the paper reviews the literature of worldwide mega projects by which quantitative risk analysis process was practiced. It was observed that Monte Carlo analysis technique has succeeded in supporting project managers in allocating deviations in the objectives of MP. The paper adds value to practitioners using the process of quantitative risk analysis as well as contractors working on construction of MP.
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1. Introduction

Construction projects are subjected to different types of uncertainties throughout their life cycle. While managing such risks are nowadays the responsibility of the contractor and the project manager, there is a responsibility for managing risks on each of the projects stakeholders. In consequence with increasing the scale of projects and the increased sophistication of their systems to cope with contemporary users' needs and technological boosts, the role of risk management in such Mega Projects (MP) is quite challenging. While text books in risk management discuss a systematic process for managing risks that starts with identification, goes through classification, qualitative risk analysis, managing risk and finally monitoring and controlling risks, there is a clear evidence that undergoing quantitative risk analysis process in particular is essential for managing risk in MP.

According to Caltrans [1], the process of quantitative risk analysis is important to be practiced in more complex projects. Where this type of projects is categorized as level 3 complex projects due to the importance of recognising possible deviations in project objectives in respect of activities constructed on site. The quantitative risk analysis process has assisted the process of decision making in recognizing possible deviations in MP objectives. In the light of that researchers used quantitative techniques and developed quantitative risk analysis models, frameworks, and systems to improve practitioner's practice in using the process of quantitative risk analysis.

Therefore, this paper aims to undergo a systematic review of quantitative analysis of literature in construction of worldwide MP. The utmost aim of the paper is to help improving contractors quantitative risk analysis practices in the presence of uncertainty. Quantitative researches are highlighted as well as quantitative techniques used in analysing construction risks in mega projects. The practice of the process is then reviewed to account for different techniques used by researchers by which lessons learned are identified and analysed.

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2. Paper methodology

The paper starts by reviewing quantitative risk analysis in construction of mega projects. The review aims at highlighting quantitative analysis importance, techniques, and output recognized from using the process. A time line is developed which included researchers and years of published papers from year 2013 to year 2018. This provides a systematic analysis for practitioners' using the process of quantitative risk analysis. Step 3 is concerned with quantitative risk analysis techniques adopted in the literature. Matrix analysis is then followed which include description for techniques, and to account for the most efficient technique regarding the practice of quantitative risk analysis process in construction of mega projects. Step 5 include a review of worldwide mega projects which practice the process of quantitative risk analysis, Fig. 1.

3. Literature review of worldwide mega projects

Van [2] ensured that there is a lack in knowledge and awareness related to infrastructure project and risk analysis practice in Africa. The author emphasises the importance of interrelating quantitative analysis with a standard procedure. In practice, there is no standard procedure, and the awareness and skills of practitioners vary a lot. Table 1 presents worldwide mega projects explored from the literature. The review is concerned with the knowledge and practice of quantitative analysis during managing risks induced with the construction of mega projects. Several projects were explored including the infrastructure development of water front Toronto, Gatwick Runway and Infrastructure Development, and other case studies. Leo [3] recommended that further research should be carried out to analyse risks during construction of mega projects. The author ensures the importance of using more case studies in order to develop analysis taking into account the control variables and to be able to perform an in-depth analysis regarding to megaproject data. Water front Toronto [4] is classified as large infrastructure projects, as the project progresses project cost and schedule estimates become more certain.

A quantitative analysis model was developed in Water front Toronto MP. Amounts for contingency and escalation were removed. The baseline cost and schedule were entered into the project's risk assessment simulation model. The model employs probabilistic simulation techniques to combine the project flowchart, the base costs with uncertainty, the risk register, and other key inputs and assumptions, to produce probability distributions for project cost and schedule outputs. Rados [5] stay was to quantify construction risks in order to recognise risks of greatest impact towards project objectives. The author concluded that Critical risk include policy and institutional aspects, existing economic policies and development plans, management of services to be provided/developed by the project are the highest risks causing failure of delivery in mega projects.

4. Review of quantitative risk analysis process in construction of mega projects

Based on their projects size, Caltrans [1] classified projects into three categories small, medium, and large. The risk management standard ensures the importance of practicing quantitative risk analysis in mega projects. Leo [3] identified variables which can impact successful practice of quantitative risk analysis in construction of mega projects. These variables include: sector (cross-sectorial, transport, utility), finance source (public, private, both), contract type, technology, situation of the megaproject (Front-end, design, construction, operation). Due to the gap in research, Leo [3] ensured the importance of conducting more researches on quantitative risk analysis. She ensured that this would help in understanding of risk management. Gap in researches include: collecting more case studies in order to develop quantitative risk analysis taking into account different control variables and a research studying in-deeps analysis regarding to megaproject qualitative data.

Venkata [8] used the technique of earned value in quantitative risk analysis. The technique proved its effectiveness in recognising cost variance and schedule variance. It was observed that construction risks related to schedule impact can invariably impact the project cost due to the resources needed to manage mega projects. Rathna [9] integrated the technique of earned value management with risk management to prevent delay and improve mega projects performance. The author used this technique in order to improve the ability of mega projects to analyse risks during construction and to proactively be able to analyse risks in the presence of large amount of resources. Khattab [10] identified forty-six construction risks to be considered as prominent risk factors for mega road con-

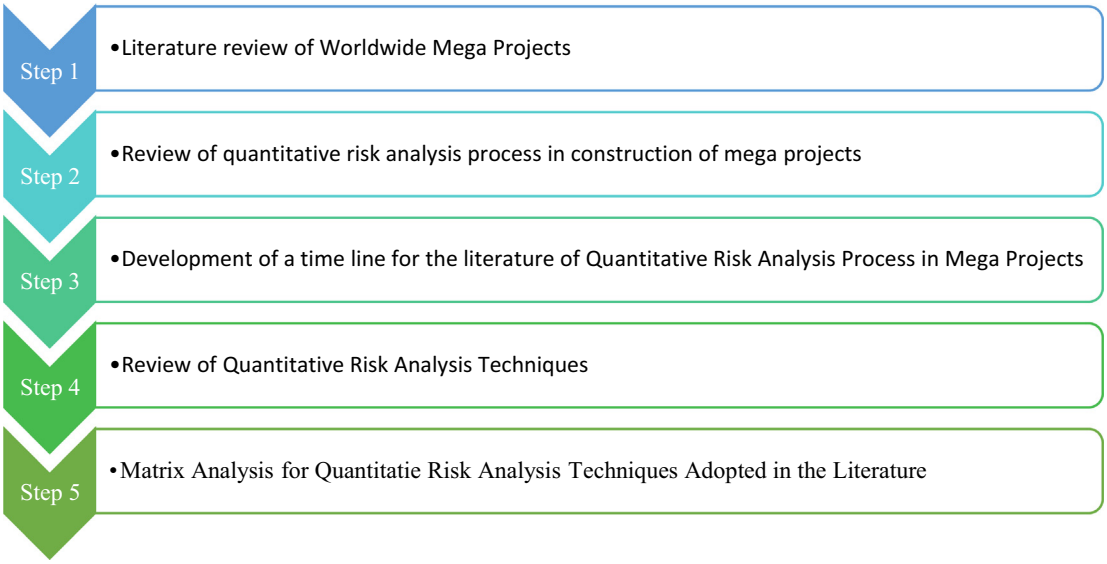

Fig. 1. Paper methodology.

Table 1
Review of quantitative risk analysis in worldwide mega projects.

Author/Year	Mega Project	Objective	Findings
Gatwick Risk Report [6]	Figure 1. London Gatwick Runway and Infrastructure Development https://www.ukconstructionmedia.co.uk/news/3bn-investment-london-gatwick/	To Deliver new runway including development of infrastructure to increase its capacity by 2025	Quantitative model shows that there is a probability of 80% or confidence in meeting schedule and budget
Ivana [7]	Megaproject 1. Offshore Platform EPCI in the Mediterranean Sea. https://www.compelo.com/energy/news/saipem-berri-marjan-fields/	To analyse how the risk has been managed in different megaproject case studies and develop some theoretical framework	Control variables that can affect the risk analysis process includes Sector (transport, utility), Source of financing, Type of contracting, Technology Situation of the megaproject
	Megaproject 2. Sava Zagreb, The River, Croatia Leo [3]		
	Megaproject 3. Danube Bridge 2 –Combined rail/road bridge between Bulgaria and Romania at Vidin-Calafat https://www.railwaypro.com/wp/romania-bulgaria-		

(*continued on next page*)

Table 1 (*continued*)

Author/Year	Mega Project	Objective	Findings
	build-third-bridge-danube/		
	Megaproject 4. FERTAGUS Train Concession – Railway Axis North/South Lisbon, Portugal https://vaaju.com/portugal/news-breaking-news-hundreds-of-personalities-support-the-railroad-announcement-to-fertagus/		
	Megaproject 5. Industrial Zones, Bulgaria https://www.citymetric.com/chart-bulgaria-s-second-city-has-one-europes-biggest-manufacturing-sectors		
	Megaproject 6. Highway A1, Croatia. https://seenews.com/news/croatian-govt-approves-financing-of-south-dalmatia-road-connectivity-project-558428		

Table 1 (*continued*)

Author/Year	Mega Project	Objective	Findings
Water Waterfront Risk Assessment [4]	Development of Waterfront Toronto Mega Infrastructure Project https://www.waterfrontoronto.ca/nbe/portal/waterfront/Home	Analyse Risks Associated with the Development of Waterfront Toronto Infrastructure	Project specific escalation rates were developed and incorporated into a risk assessment tool. Probabilistic cost and schedule estimates were generated accounting possible deviation from the base schedule

struction projects in Erbil. The author used the technique of Monte Carlo analysis as an effective quantitative risk analysis technique in analysing mega projects risks. The results of Monte Carlo simulation proved that technical risks are the most significant risks considering their impact on the total project cost.

A quantitative analysis model developed by Prince [11], was able to improve decision making of project managers in analysing construction risks in worldwide mega projects. The model proved to be a successful tool in quantitative risk analysis practices. The model is broken down into steps which provide a technical competency framework. The quantitative framework provides a robust mechanism for assessing the effect of construction risks on the performance of megaprojects at the construction phases. The quantitative risk analysis framework is developed to benefit megaproject managers to account for the risks behaviour and improve construction performance of mega. The model presents a unique quantitative approach to effectively tackle all risks associated with construction issues affecting megaproject delivery. Prince [11] validated the quantitative risk analysis model by applying it on a comprehensive case study on a mega project. The case study covered the history and profile of the project, lessons learnt from the Edinburgh tram network project delivery. A technical description about a new dynamic systems approach to quantitative risks analysis and simulation for megaproject was used in this model.

Several risk management standards and guidelines including project risk quantitative analysis methods was analysed by Augustin [12], where, the author developed a comparative analysis of the effectiveness of two quantitative risk analysis techniques, Monte Carlo simulation and the Three Scenario Approach. Two experiments were designed to analyse and compare the effectiveness of both methods, based on real mega projects. The tool used produces success probability trend. Probability histogram is found to be used as the best indicator for analysing deviations in time and cost during the execution of mega projects. Despite the importance of performing quantitative analysis in mega projects, Olalekan [13] realised that local contractors and project managers worldwide moderately use qualitative analysis than quantitative analysis. Rados [5] examined the correlation of political risks on successful delivery of mega projects. The author ensured that correlation analysis is taken in consideration during risk analysis. It was observed that political risks are directly correlated to the current status of any country development in which the projects are conducted. His study was focused specifically in countries performing quantitative risk analysis on megaprojects included within the European Union region.

5. A time line for the literature of quantitative risk analysis process in mega projects

A time line for researches developed within the past six years starting from the year 2013 to the year 2018 illustrates the years of publish and corresponding authors is shown in Fig. 2. It provides a detailed preview for researches related to knowledge and practice of the quantitative risk analysis process. Despite that there are researches accomplished within this period, but still the number of researchers related to quantitative risk analysis is considered to be limited specifically before the year 2018. The year 2018 has the greatest number of researches. This ensures the importance recognized by researchers working on the analysis of risks quantitatively. In addition, the results highlight the increased number of quantitative risk analysis researches recognizably increased in the year 2017 and year 2018 due to the increase in number of projects.

According to the global risks report [14] the world is facing a massive increase in population which forced countries into construction and development of infrastructure and mega projects. The lowest rate of published researches where in year 2014 and year 2016. Researches explanation of quantitative analysis knowledge and their guidance from risk standards increased the familiarity of using quantitative tools after the year 2016. It was observed that the ascending rate in developing quantitative researches including new models, frameworks, and systems is strongly interrelated with the increase of mega projects construction. Thus, knowledge of quantitative risk analysis was proposed together with developed quantitative techniques to account for the analysis of any possible escalation in mega projects and infrastructure projects delivery objectives.

6. Review of quantitative risk analysis techniques

Despite the importance of using quantitative risk analysis, Olalekan [13] observed that most contractors perform qualitative risk analysis on infrastructure risks with limited practice of quantita-

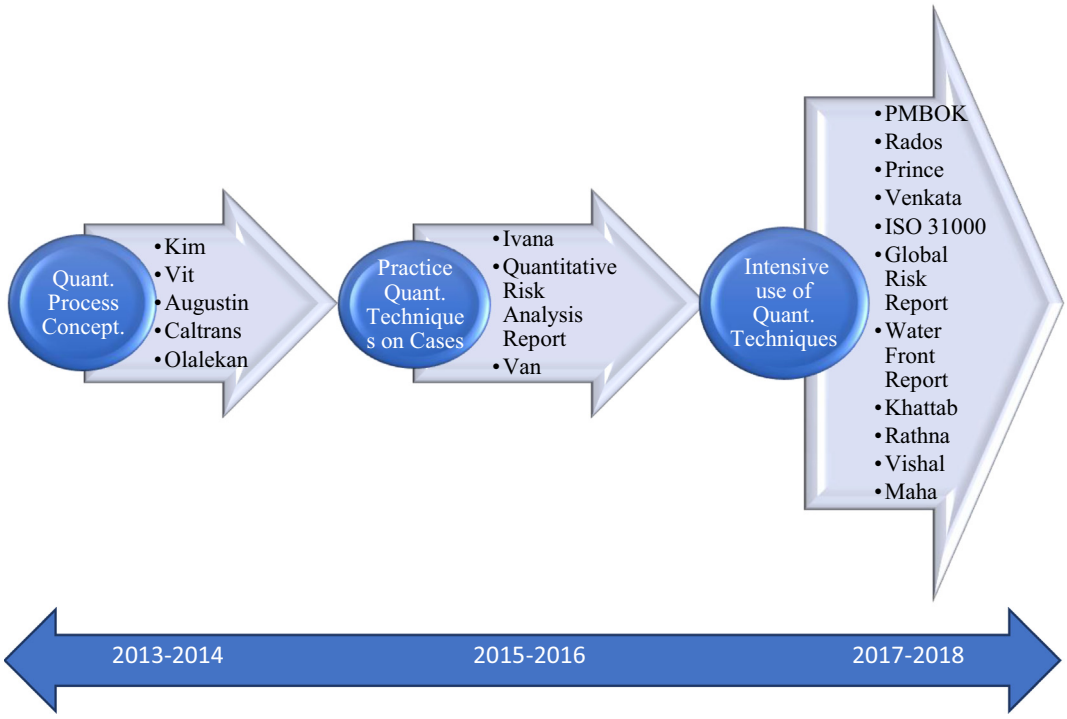

Fig. 2. Time line of quantitative risk analysis researches in construction of mega projects.

tive risk analysis. This was due to lack of knowledge and practice in using different techniques of quantitative risk analysis. Table 2 presents a matrix analysis of quantitative risk analysis techniques. The most effective quantitative technique practiced by researchers was the Monte Carlo analysis. Monte Carlo analysis allows researchers to account for possible deviations in construction time and cost of mega projects and infrastructure projects. The analysis results in obtaining a probability histogram by applying large number of simulations. It is considered a very realistic quantitative analysis technique which directly support project managers during construction. PMBOK [15].

Augustin [16] successfully analysed construction risks effectively using a semi-probabilistic approach. After performing Monte Carlo Analysis, the author ensured that Monte Carlo analysis is more accurate, understandable computations, and can easily be applied in practice. Augustin [16] realized that after the year 2013 worldwide companies which are facing with continuous delays and cost overruns have started using quantitative risk analysis more often. The researcher provided a practical approach of quantitative risk analysis using Monte Carlo analysis technique and highlighted the correlation between time, cost and resources limitations in mega projects. The author analysed risks during the construction stage by integrating the scope, time, cost, resources and risks and providing a better tool in decision making. He practiced Monte Carlo analysis on a case study of a mega project using the software Spider Project. Augustin observed that by determining the contingency amount for the project, it can be realized that with allocating a determined budget, a specific level of risks can be covered. Fahimeh [17] achieved a stochastic quantitative analysis has been performed using Monte Carlo Simulation (MCS) with the aim to obtain the probability distribution of the contingency cost and the related level of risks. The proposed method has been applied on a construction project of a real life company using the software at Risk.

Vishal [18] the research adopts an approach to quantify risks in terms of overall project delays using Monte Carlo Simulation (MCS). Khattab [10] observed that the results of Monte Carlo simulation also show that the technical risks are the most significant risks considering their effect on the total project cost. The author developed a risk analysis model for the road construction projects in Erbil. A survey questionnaire was used for data collection with the participation of 56 respondents to perform qualitative risk analysis. Monte Carlo Simulation was also used as a quantitative risk analysis method. Anastasios [19] performed a quantitative

Table 2
Matrix of quantitative risk analysis techniques (Authors).

Year	Authors	Quantitative Risk Analysis Techniques			
		Monte Carlo Analysis	Three Scenario Approach	Sensitivity Analysis	Earned Value Analysis
2013	Augustin	X	X		
	Kim			X	
2014	Augustin	X			
2015	Anastasios	X		X	
2017	Fahimeh	X			
	Prince	X			
	Venkata				X
2018	Rathna				X
	Vishal	X			
	Khattab	X			

analysis using Monte Carlo simulation. Through the deterministic analysis it was observed to be almost certain that the risks within the tasks of the project would cause delays beyond the 10 days' margin.

Sensitivity analysis and earned value analysis were also effectively studied as quantitative risk methods by researchers. According to Kim [20], the technique of sensitivity analysis captures the total variability especially as concerns the costs and demands estimated. Different risk management standards have highlighted the benefit of using sensitivity analysis ISO 31000 [21]. This technique guides risk analyst into accurate allocation of actual drivers to failure in delivery of mega projects objectives. Anastasios [19] ensures that the sensitivity analysis presented earlier revealed the most influential input parameters for the variations. The author used the technique in order to identify the most driving activities to failure. A repair project was used as a case study, were as it was concluded that the contradictory fact that became apparent through this analysis is that the "Repairs" of Heater task. It has the greatest impact on the projects' duration and the least impact on the projects' cost, while exactly the opposite occurs in the "Catalyst removal" task in the Reactor. According to Rathna [9], the technique of earned value analysis can be used to predict the cost at completion and percentage of completion with reference to the baseline budget and schedule. When the difference between planned and actual value is observed the risks can be identified using work break down structure. The author concluded that earned value management and risk management can be integrated to prevent delay and improve performance of the project.

7. Conclusion

The paper was able to fulfil its aim by reviewing the literature of quantitative analysis process in construction of worldwide MP. However, regarding its utmost aim of this paper, the Contractors' related one, the authors believe that their quantitative practices is improved by guiding them to use a suitable quantitative technique during their MP analysis.

In the light of that, the paper conducted a critical analysis to account for quantitative techniques including Monte Carlo analysis, Sensitivity Analysis, and Earned Value Analysis. Based on this analysis, it became clear that the most efficient and widely used quantitative technique for detecting deviations in schedule and budget is the Monte Carlo analysis technique. However, Sensitivity analysis is also an efficient quantitative technique when the management priority is to identify activities and risk drivers that lead to failure in construction delivery of MP.

By this, the paper added has succeeded to add value to practitioners using the process of quantitative risk analysis as well as contractors working on construction of MP. Thus, practice of quantitative risk analysis proved to improve decision making in risk management process. However, the validation of the paper results shall require further work on the application of Monte Carlo Analysis on real life case studies on MP, in order to come up with a prototype to follow or a framework that could fit within the process of risk management in Mega Projects.

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