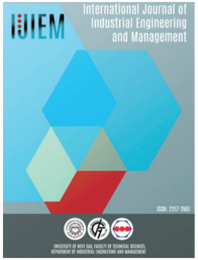
ISSN 2683-345X
journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial Engineering and Management

Volume 13 / No 4 / December 2022 / 250 - 264



Original research article

Time-cost estimation probabilistic model using MCS in quantitative risk analysis in BOT renewable energy projects

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ABSTRACT

The purpose of this study is to investigate the impacts of risks in the construction and operation period of BOT waste-to-energy projects, and the estimation of the final costs. In this study, the cost and impact of identified risks on the activities of the construction and operation phase are estimated, then the time and cost of a waste-to-energy project are calculated. The results of this study indicate that simultaneous and continuous consideration of risk effects such as inflation, sanctions, and maintenance in projects leads to much different time and cost than the forecasted fixed costs; that is, in the case of an error by the private sector in the determination of the operation period, the project might be faced with delays and ultimately failure.

ARTICLE INFO

Article history:
Received March 23, 2022
Revised November 17, 2022
Accepted November 22, 2022
Published online November 28, 2022

Keywords:
Risk quantitative analysis;
BOT project;
Waste to energy;
Monte Carlo simulation;

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1. Introduction

Infrastructure projects require proper risk management throughout their life cycle [1]. Therefore, in time identification of deviations from the project goals is vital to the project's success because they may cause delays or financial losses. while the responsibility for managing such risks rests with the contractor and the project manager, because of the complexity of such projects, each stakeholder in public-private partnerships plays a role in risk management; thus, as the scale and complexity of projects increase, the role of risk management in such projects becomes more challenging. managing risk appropriately is crucial to the success of public-private partnerships (PPPs), where one of the key issues estimates the probability of occurrence and its impact on project objectives [2].

In general, the risk management process commences with risk identification; the identified risks are classified into qualitative risk analysis. appropriate proactive responses are drawn followed by their

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

http://doi.org/10.24867/IJIEM-2022-4-317

implementation and monitoring; considering that, it is evident that quantitative risk analysis would be necessary for risk management [3].

According to Caltrans [4], in complex projects where chances of deviation from the main objectives are high, the implementation of quantitative risk analysis is important, because this process helps in the detection of possible deviations and proper decision makings. So, researchers have implemented different techniques and have introduced various models for quantitative analysis.

Waste-To-Energy (as an important component of renewable energy) plants are widely adopted in many developing countries [5]. In China, the WTE incineration industry has grown rapidly since the time the first WTE plant was built in 1988 [6]. Waste-To-Energy projects, due to their novel and complex nature, face uncertainties that can pose major challenges to project management [7]. Also, as research in this field does not have a long history, rare studies have been done on these projects, their risks, and their quantitative effect on project objectives. Such projects that form a subset of complex infrastructure projects, based on knowledge and realities require further quantitative analysis and investigations; though simple quantitative risk analysis will not suffice.

In developing countries, due to unstable economic conditions and the existence of various uncertainties, as well as the complexity of contractual relations in public-private partnership projects, the private sector generally faces problems in terms of implementation, advancement, and operation of the projects; Therefore, identification and management of risks and uncertainties of such projects could guarantee project success for the private sector. This study aims to calculate the effect of risks on the main project objectives by forming a quantitative risk analysis on waste-to-energy conversion projects (a subset of renewable and new energy projects). Such analyses are implemented as BOT and assist the private sector in making the best managerial decisions and planning prior to the start of the project.

2. Literature review

Since the focus of this research is on quantitative risk analysis and risk management in renewable and new energy BOT projects (especially on waste-to-energy projects), the literature review of this paper has been performed on quantitative risk analysis and public-private partnership projects presented in the following sections.

2.1 Public-Private-Partnership Projects

Public-private partnership waste-to-energy projects are exposed to a wide spectrum of risks during the construction and operation period. These risks might arise from a variety of sources such as the capital budget, construction, and operation of time and cost, government policies and regulations, market conditions, economic environment, etc. Previous studies have identified several public risks in public-private partnership projects. Bing et al. [8] have provided a checklist of 46 risk factors for these projects. In 2010, Ke et al. [9], using a Delphi questionnaire from academics and professionals, Conducted a risk identification study on Chinese public-private partnership projects in the areas of transportation, water, sanitation, etc.; In this study, after a series of telephone interviews and a comprehensive review of past research, they identified 37 key risks. They asked interviewees to identify risks in five categories. At the end of the study, they found that the risk of expropriation was to be transferred to the public sector alone. Also, 12 more risks, including land acquisition and approval, were to be borne by the sector.

In the past two decades, numerous studies have been done on risk management in public-private partnership agreements such as water supply [10], electricity supply [11], public places [12], road construction [13], etc. In spite of previous research, little attention has been paid to public-private partnership projects over waste-to-energy projects. The main factors of threat and also their effects on the project life cycle have not been adequately and appropriately studied for the development of waste-to-energy conversion projects; though, some recent research done in this area has been mentioned here.

In 2013, Song et al. [14] examined and identified the risks of waste-to-energy projects and named municipal solid waste as an important source of converting waste into energy. With the dramatic increase in waste generation in China, power plants that incinerate waste also grow rapidly; as a result, the private sector has entered this field. In their research, they pointed out that owing to the entry of the private sector and the high construction cost of the factories, significant risks could emerge that have led to the failure of some projects in the industry. So, their research was centered on the investigation of key risks of those projects in China as well as the study of the management strategies of such risks using experience and lessons. They first analyzed municipal solid waste management practices, related laws and policies, and the development of incineration projects in China, later they identified the top ten risks through interviews, surveys, and visits to selected projects, and provided a detailed analysis of those risks. Finally, they developed strategies for responding to the risks from the perspective of the public and private sectors.

In a similar study done in 2015, Xu et al. [15] identified the threat factors affecting waste-to-energy projects in public-private partnerships. They mentioned that since 2003, China has developed a model of public-private partnership in waste incineration to reduce waste disposal and improve environmental quality. By analyzing the risks and accidents that occurred in 14 waste incineration plants, they introduced five main risk factors that were affecting the construction and operation of waste incineration projects obtained. The factors include inadequate waste disposal, unauthorized waste disposal, environmental risk, payment risk, and lack of support infrastructure. For their study, a complete waste incineration plant (Shanghai Tianma Project) was examined to gain insights into the effective management of key risk factors. First-hand data and lessons on the Shanghai Tianma Project were then collected with a focus on project negotiation and concession agreement (exploitation). In their research, they provided a detailed study of the contract structure, risk distribution plan, response measures of key risk factors, and the project transfer period. Xu et al. argued that the results of the study, by reducing and effectively managing the risks involved in waste incineration and energy conversion projects, provided the government with enough reasons to provide fair concessions and profitability to private investors.

In 2017, Sun et al. [16], reviewing several different projects, conducted a study on identifying public-private partnership risks. They cited the increase in such partnership projects as one of the main risk factors in this area. Besides, pointed out that despite the increase in such projects, unanticipated factors and uncertainties during the project implementation have led to the failure of some of these projects. Thus, it was stated that the purpose of their research was to identify unforeseen risks in the projects. Based on a review of several case studies, they identified four key risk factors from 10 waste-to-energy conversion projects. Later they analyzed the characteristics and causes of such risks according to the conditions of waste incineration projects in China. Finally, they examined risk response strategies from the perspectives of the public sector, the private sector, and from the perspective of both. In conclusion, they noted that as it is, on one hand, the public sector should improve its decision-making ability, and the private sector, on the other hand, should constantly update its technology and equipment; therefore, both parties must cultivate talents.

In 2018, Liu et al. [17] noted the pivotal role of risk identification, analysis, and response in the successful development of waste-to-energy projects in such partnerships. Based on that, they stated that the purpose of their study was to use several case studies to identify the underlying risk factors in China. They examined 35 power plants which resulted in the identification of 18 main risk factors; The most important of which was the risk of public opposition, environmental pollution, government decision-making, faulty legal and regulatory system, and the risk of supplying municipal solid waste. In their research, they pointed out that previous research was not that reliable because their case studies dated back to 2012, the time when central and local governments had recently introduced a new set of policies and regulations related to the waste-to-energy industry. The results of their study provided a reliable basis for future risk analysis, risk allocation, and risk response of waste incineration projects; besides, they showed the performance improvements of such projects as well as the development of the industry.

Recently, Cui et al. [18] conducted an overview of public-private partnerships in China's waste-to-energy industry. They stated that the public-private partnership market has been currently under a period of rapid expansion. But they noticed that such expansion has been at a level of market concentration that is significantly lower than in mature markets such as the ones in the United States and Japan. Their findings make strong contributions for researchers to conduct more studies in this field (its risks and challenges).

2.2 Quantitative risk analysis approach

Risk management is a scientific approach to the identification, prediction, and minimization of adverse effects on infrastructure projects [19]. Therefore, the stakeholders should continuously improve their risk management knowledge. In 2001, Davis et al. [20] recognized that real project risk management was highly needed for improving project performance. He stated that 37% of the projects in Egypt had cost overruns and 98% of the Egyptian contractors delivered their projects with delays. There are many similar examples to the cited research, all of which point to the importance of risk management in projects, and in particular in large infrastructure projects (please see [21]-[23]). Infrastructure projects have generally high costs and durations and are defined according to the needs of society, so the importance of achieving success in these projects is very important. So in the literature, the use of quantitative risk analysis for the improvement of risk management is recommended; though, the lack of knowledge and the implementation of quantitative risk analysis in infrastructure projects of developing countries is evident.

The researchers have proposed different approaches for quantitative risk analysis. Stochastic methods have been used to investigate time and cost risks. Decision support systems were initially used as risk assessment techniques. These systems had limitations such as difficulty in collecting information, difficulty in quantifying all project data, and failure in system design [22]. Monte Carlo simulation, to achieve the possible distribution of outputs, supports project schedule integration and combines the risks. In 2005, Sato et al. [24] conducted a study to quantitatively analyze the risks of road projects based on empirical data in Japan. From the viewpoint of project management, they considered quantitative risk analysis and implementation of risk management crucial but acknowledged that there was undoubtedly very little information available for those analyses in East Asian countries. They stated that their goal was to research the implementation of quantitative risk analysis based on real information from road projects in Japan and to examine risk management. Based on the obtained data, they analyzed the number and effect of each risk event, and summarized them in the risk rating matrix; furthermore, using an arrow network, they showed the project execution sequence and then simulated the project model by converting the arrow network to the Monte Carlo simulation system. The results of the Monte Carlo simulation have shown the value of several important concepts, such as strategy management according to the possible paths that lead to program bottlenecks.

Two studies are mentioned as the main part of research in quantitative risk analysis in the years 2013 to 2018. In one study ([25]) quantitative risk analysis was performed in a quay construction infrastructure project in Canada. In that project, the implementation cost was estimated at 180 million dollars over 12 years. the project was aimed to increase the capacity of the city's infrastructure, adapt to the effects of climate change, and guarantee the safety and well-being of Canadians. The results of the study showed that the Monte Carlo analysis was quite effective in the decision-making process. Quantitative risk analysis throughout the project also helped the decision-makers and planners to successfully deliver the project in terms of budget and schedule. In this study, the evaluation of the feasibility of other infrastructure projects, as well as transportation using decision-making based on risk analysis was suggested. In another study [26] risk analysis was examined on a runway project at London Gatwick Airport, which is known as a successful example of risk analysis for the overall planning of an infrastructure project. In this research, a decision-making approach is presented that makes predictions based on information from previous projects. In this study, a database, containing information on 200 transport infrastructure projects in Europe, was developed. Based on this database a risk management framework was introduced to evaluate, identify, and quantify project-specific risks; besides, in the current study, a risk management report was prepared to highlight the effects of risk on cost estimation and scheduling. The results of the study showed that owing to the preparation of quantitative risk analysis reports and a good prediction of exposure to various risks in conditions of uncertainty, the performance of project contractors has improved.

In recent years, other research has been conducted in the field of quantitative risk analysis. Platon and Constantinescu [27] conducted a study on the risks of investment projects using Monte Carlo simulation. They stated that the purpose of risk assessment in investment projects was to study the likelihood that the projects would perform well for the threshold value of the internal rate of return or net present value. Besides, according to their statement, the goal of quantitative risk analysis was to estimate project risks using numerical sources. They also and Monte Carlo simulation to calculate the distribution of all possible outputs of an event. Thus, they showed that knowing the effect of risks can greatly help in investment and the financing parameters of the projects. In 2015, Alfalla et al. [28] identified variables that could significantly affect the success of quantitative risk analysis in large projects. These variables include project scope (interdisciplinary, transportation, services), source of funding (private sector, public sector, both), type of contract, implementation technology, and project status (predesign, design, construction, operation). Digiesi et al. [29] proposed a model for minimizing the exposure risk of workers involved in repetitive manual tasks. They developed their model by balancing the human workloads and reducing the ergonomic risk within acceptable limits, for a given production target. Using the RULA method, they evaluated Risk and its acceptability according to a mixed integer programming approach. They indicated the effectiveness of their model to identify the optimal job rotation.

Despite the previously conducted research, the need for further studies in the quantitative risk analysis of infrastructure projects seems evident and might lead to a better understanding of risk management. There are also gaps such as the need to review more diverse case studies for analyzing the effect of newer variables like inflation, quantitative risk analysis in BOT contracts, its effect on the operational period, etc. that should be further studied.

3. Research contribution and objectives

Although there are extensive studies in this field, there are still gaps that would entail further studies. The risk management models have been introduced in various sectors such as water, electricity supply, public housing, roads, etc.; however, comprehensive risk management in the field of waste-to-energy conversion (renewable and new energies) is scant in the previous literature. Quantitative risk analysis models, owing to the complexity that have, are generally less used in research. In spite of the studies done in the field of risk management in public-private partnership projects, quantitative risk analysis of waste-to-energy conversion has been so scarce. in developing countries, due to the novelty of renewable energies and the lack of experience in implementing infrastructure projects, a great need is felt for a full and comprehensive study of risk and quantitative analysis of risk effects on project parameters and their stakeholders; Therefore, this paper aims to quantitatively analyze the identified risks of a waste-to-energy conversion project in a public-private partnership, to calculate their effects on project time and costs during different periods of construction and operation, and to identify the main influencing factors on project parameters; This helps project planners in being proactive through making the necessary arrangements and risk responses.

In this study, the main focus has been on the integration of quantitative information on time and cost from a waste-to-energy conversion project in the construction and operational phase and their integration with the probability and effect of different risks. This issue, which has not been addressed in prior research, is considered as the main contribution of this research. This might be regarded as a prelude to a better understanding of the challenges of such projects, and thus better planning for the realization of other project goals (reducing project time, cost, and increasing project success).

4. Research Methodology

According to the purpose of this research, it would be necessary to draw a roadmap and to introduce the research methodology based on it so as to calculate the quantitative effect of risk on project schedule and cost. Figure 1 shows the general framework for implementing the quantitative risk analysis of the project.

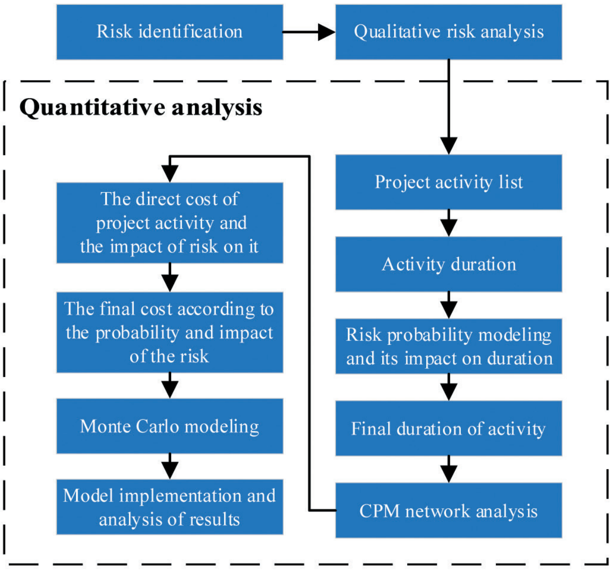

Figure 1. Roadmap for quantitative risk analysis

As shown in Figure 1, first the structure of the schedule and cost information shall be defined for final modelling; then the probability and effect of the risks are defined for each activity. eventually, the last model would be generated. In the following, a more detailed review of the introduced framework is given.

4.1 Monte Carlo simulation

According to the literature review, it is observed that four main techniques are used in most of the research. the Monte Carlo simulations, three-point estimation, and the Earned Value Method are among them. Despite its focus on schedule and cost management, the Monte Carlo is generally viewed as a risk management tool [30]. The Project Management Institute (PMI) recommends using the Monte Carlo method for risk assessments that could adversely affect a project and justify scheduling or budgeting reserves. Some advantages justify the use of Monte Carlo in quantitative risk analysis; its use is mainly related to quantifying the level of risk associated with a budget or competition period in terms of cost and time management [31]. As part of schedule development, the Monte Carlo might be used to quantify the confidence degree at which the target completion date will be met. One of the foundations of quantitative risk analysis is the simulation of project schedules via the Monte Carlo method. Monte Carlo simulations have been proven to be easy to use for analyzing schedule risk in practical examples [32]. To achieve reasonable duration and cost expectations, project managers can use the Monte Carlo method to incorporate uncertainty into their schedules and networks. So based on Monte Carlo's results, contingency decisions could be made on a solid basis.

Monte Carlo simulations can help reveal the likelihood of meeting a planned completion date or point to the expected results in terms of time and cost, with a certain degree of reliability. Examining, the impact of issues and risks, The Monte Carlo simulation predicts the project schedule and the budget that increases the decision-making power based on the possible outputs of various scenarios; Therefore, in this study, the Monte Carlo simulation technique is used to investigate the effect of risk on project activities.

The concept of Monte Carlo simulation, which was first introduced in 1944, has had many interpretations and definitions so far. Thus, it can be said that this method has gone through a long and evolutionary process. Initially, the important application of this method was to generate large series of random numbers [33]. In the first stage, pseudo-random numbers were used, but with the development of computer technology, this barrier was removed. presently, relatively low computational effort, compared to the difficulty of problems that could be solved using this method, has made it a proper choice.

In the Monte Carlo method, the values of a stochastic variable that are between zero and one, along with the cumulative distribution function of that variable, are generated using a uniform random number generator. This method is implemented in the following five steps:

(1) Creating a parametric function.
(2) Creating a random set of input data.
(3) Calculating and storing the obtained results.
(4) Repeating steps 2 and 3 until the end of the repetitions.
(5) Analyzing results using histograms, confidence levels, and other statistical measures resulting from the simulation.

In the following sections, the creation of a project schedule and cost model, along with its risks, will be examined in detail.

4.2 Schedule activity list

Due to the scope of the project, and to avoid modeling complexities, project scheduling consists of two parts: construction and operation. The main construction schedule is available in the appendix of the article; besides, there is a time horizon for the operation period which is reviewed annually. It should be noted that the construction schedule for the waste-to-energy conversion project has been developed using expert opinion and includes four main parts: design, procurement, implementation, and initial commissioning. all the special points in the scheduling of this field have been considered so that the developed program would be similar to reality. Table 1 shows the headings of the items in the activity list, which include the WBS activity level, the WBS activity code, the activity name, and the activity code.

Table 1. Title of available items in the scheduled activity

Activity List			
Outline Level	WBS	Task Name	Activity Code

4.3 Duration of scheduling activities during the construction period

This section includes a probabilistic distribution of the time of activities. As the activities are considered at a high level, their execution time is long. A triangular distribution consisting of three optimistic, expected, and pessimistic numbers are considered for each activity. According to the opinion of the project control unit, optimistic and pessimistic numbers are calculated as a percentage of the expected time. Table 2 shows the titles of these items in the model. “Sim. Value” column is also used to define the distribution hypotheses in the Monte Carlo simulation section of the model.

Table 2. Title of available items in the activity duration

Normal Duration			
Optimistic	Expected	Pessimistic	Sim. Value

4.4 Modeling the probability of risk occurrence and its impact on the schedule

Table 3 shows the titles of the items in the risk modeling section and their effect on the schedule. As it can be seen, “Risk1” item on the left includes the risk rating (obtained after reviewing the risk in qualitative analysis), the assumption of uniform probabilistic distribution, and the probability of risk occurrence, respectively. The “Impact R1” section includes the following items from the left: the optimistic, probable, and pessimistic percentages of the time effect of risk (based on the opinions of experts and project planners), assumptions of the defined triangular distribution, and the formula for investigating the occurrence and effect of risk based on Equation (1). It shall be noted that some items have two different risk probabilities and impacts that are considered independently in this table, and their impact is combined.

$$Conditional_{R1} = if(UniformDist._{R1} > Prob._{R1}\,; Sim.Value_{R1}; 0) \tag{1}$$

Based on the probability of the occurrence of each risk and their effect on the time of each activity, the duration of each activity is obtained from Equation (2).

$$Final\ Duration_{Act_i} = Sim.Value_{Normal\ Duration}(1 + Conditional_{R_1} + Conditional_{R_2}) \tag{2}$$

4.5 CPM network analysis during the construction period

The schedule network analysis is done according to the CPM method. Table 4 shows the titles of the items in this section. These columns are equal to the earliest start time, earliest end time, latest start time, latest end time, total float, and the criticality index of each activity. For more simplicity, all prerequisite relationships are defined as Finish-to-Start with lag values, which can be calculated in Equation (3).

$$EST_j = \max_i(1, EFT_i + Lag_i) \tag{3}$$

In the above equation, EST_j stands for the earliest start time of successor activity, j; EFT_i stands for the earliest finish time of the predecessor activity i, and Lag_i stands for the time interval between the Finish time of the predecessor activity i and the Start time of the successor activity j.

4.6 Modelling the costs of the program and the impact of its risks

The project costs, during the construction period, include direct (related to activity) and indirect (daily overhead) costs. Table 5 shows the heading for direct costs. According to the below picture, these costs have a triangular distribution with pessimistic, probable, and optimistic modes. Though the final cost value is aggregated in the “Sim. Value” column with software. The costs in the “Expected” column are obtained by multiplying the direct cost by the weights of each item. Information about these values, as well as the values of the optimistic and pessimistic columns, has been received from the PMO Cost Control team.

Table 5. Title of available items in direct cost

Normal Cost			
Optimistic	Expected	Pessimistic	Sim. Value

Table 6 shows the daily overhead costs. Indirect costs are generally associated with conditions such as specific project features and headquarters costs. Therefore, with the prolongation of project duration, the impact of indirect costs on the final cost of the project becomes important and thus might lead to losses for the project. It’s needed to mention that the size of the project increases overhead costs.

Table 6. Title of available items in overhead cost

Daily Overhead			
Optimistic	Expected	Pessimistic	Sim. Value

The probability and impact of risks are calculated for both project time and project costs. The only dif-

Table 3. Title of available items in Probability of occurrence of the risk and its time impact

Risk 1			Impact R1				
Risk ID	Uniform Dist. R1	Prob. R1	Optimistic	Expected	Pessimistic	Sim. Value	Conditional

Table 4. Title of available items in CPM analysis

CPM Analysis					
Earliest start time	Earliest finish time	Latest start time	Latest finish time	Total float	Critical index

ference is that all risks that affect project time do not necessarily affect project costs. For example, delays in the delivery of drawings in the design phase do not directly affect costs; besides, increasing the project time increases the overhead costs and subsequently the total project costs. When the effect of risk on direct costs is defined, the correlation of some of them with time shall be considered either; For example, the cost impact of a risk on an activity may have a direct or inverse correlation to its time risk. In the modelling this is considered according to the opinions of the PMO cost control team. Finally, with considering the probability and impact of the associated risks, the final costs of each activity are equal to the direct costs. as shown in Equation (4).

According to Song et al. [34], operating costs include payroll, maintenance, energy, and raw materials. Since the time horizon of the operation phase of such public-private partnership projects is long (at least 10 years), while the effect of existing risks is taken into account for the purpose of being able to accurately estimate the final cost of the period, it would be necessary to calculate the associated periodic costs; Therefore, the impact of risks during the operation period is calculated annually and the base cost of the next year for the four main costs is considered when the risk impact is calculated. the impact of inflation risk is considered separately at the end of each year on all four costs, and its value is calculated via the triangular distribution function in each year.

Given the above, the calculation of the final cost of each of the four main costs is shown in Equation (5). It shall be noted that the main expenses in year zero are obtained according to the opinions of the experts of the PMO cost control team.

4.7 Final outputs of the quantitative risk analysis model

The outputs of this study, as mentioned at the beginning of this paper, are the quantitative analysis of project risks on the final time and cost of the project. These outputs include the completion time of the construction period, the cost of the construction period, the cost of the operation period, and the total cost of the project. The calculation of each output is shown in Equations (6) to (9), respectively.

5. Case study and Monte Carlo simulation modelling

To model the proposed framework, a case study has been introduced in the field of renewable and new energy with an emphasis on the conversion of waste into energy through incineration. The design phase of this project includes the design of structures and buildings, mechanical installations, electrical installations, instrumentation, and landscaping. Similarly, for each of the mentioned cases in the procurement phase some activities are considered; With the difference that some of the mechanical and electrical equipment is procured from abroad. So, this section is considered as a separate activity. Moreover, for each of the items defined in the procurement section, some activity in the construction phase is defined either. Finally, in the initial commissioning phase, the project is started temporarily to check the performance of the items. The approximate initial duration, regardless of the consideration of risks, is planned for three years. There is also a 16-year timeframe for the private sector. According to the mentioned cases, the general view of the Monte Carlo simulation model can be seen in Figure 2 (appendix).

To run the model, "Crystal Ball" software is used as an add-on in Excel software. To sample the probabilistic distributions, the Monte Carlo method is used and the number of simulation iterations is considered to be 100,000 iterations. Achieving a 95% confidence level is also selected as a condition for stopping the simulation.

$$Final\ Cost_{Act_i} = (Sim.Value_{NormalCost_i} \times (1 + Conditional(Cost)_{Impact_{R1}}) \tag{4}$$

$$Final\ Cost_{it} = Sim.Value_{NormalCost} \times (1 + Conditional(Cost)_{Impact_{R1}} + Conditional(Cost)_{Impact_{R2}}) \tag{5}$$

$$Total\ Duration = Max(EFT_i) \tag{6}$$

$$Total\ Cost_{Construction} = \sum_i Final\ Duration_i + (Total\ Duration \times Daily\ Overhead\ Cost) \tag{7}$$

$$Total\ Cost_{Operation} = \sum_{t=1}^{n} \sum_{i=1}^{4} FinalCost_{it} \tag{8}$$

$$Total\ Cost = Total\ Cost_{Construction} + Total\ Cost_{Operation} \tag{9}$$

6. Results

According to the methodology of this study, the obtained results are discussed. Prior to reviewing the results of the quantitative risk analysis, the project risks, their probability of occurrence, and their impact are to be determined. A questionnaire has been prepared and completed by experts and managers to identify the risks of the waste-to-energy conversion project. When the questionnaire review is over, the risks, along with their probability of occurrence and their impact on the main project objectives (time and cost) are obtained. Also, using both optimistic and pessimistic approaches, the risks obtained from the questionnaire are qualitatively analyzed and ranked. Thus, the mentioned risks can be used in quantitative risk analysis; the risks are listed in Table 7, respectively.

The results obtained from the implementation of the Monte Carlo simulation on the main objectives including the duration of the construction period, the cost of the construction period, the cost of the operation period, and the total cost are shown in Figure 3.

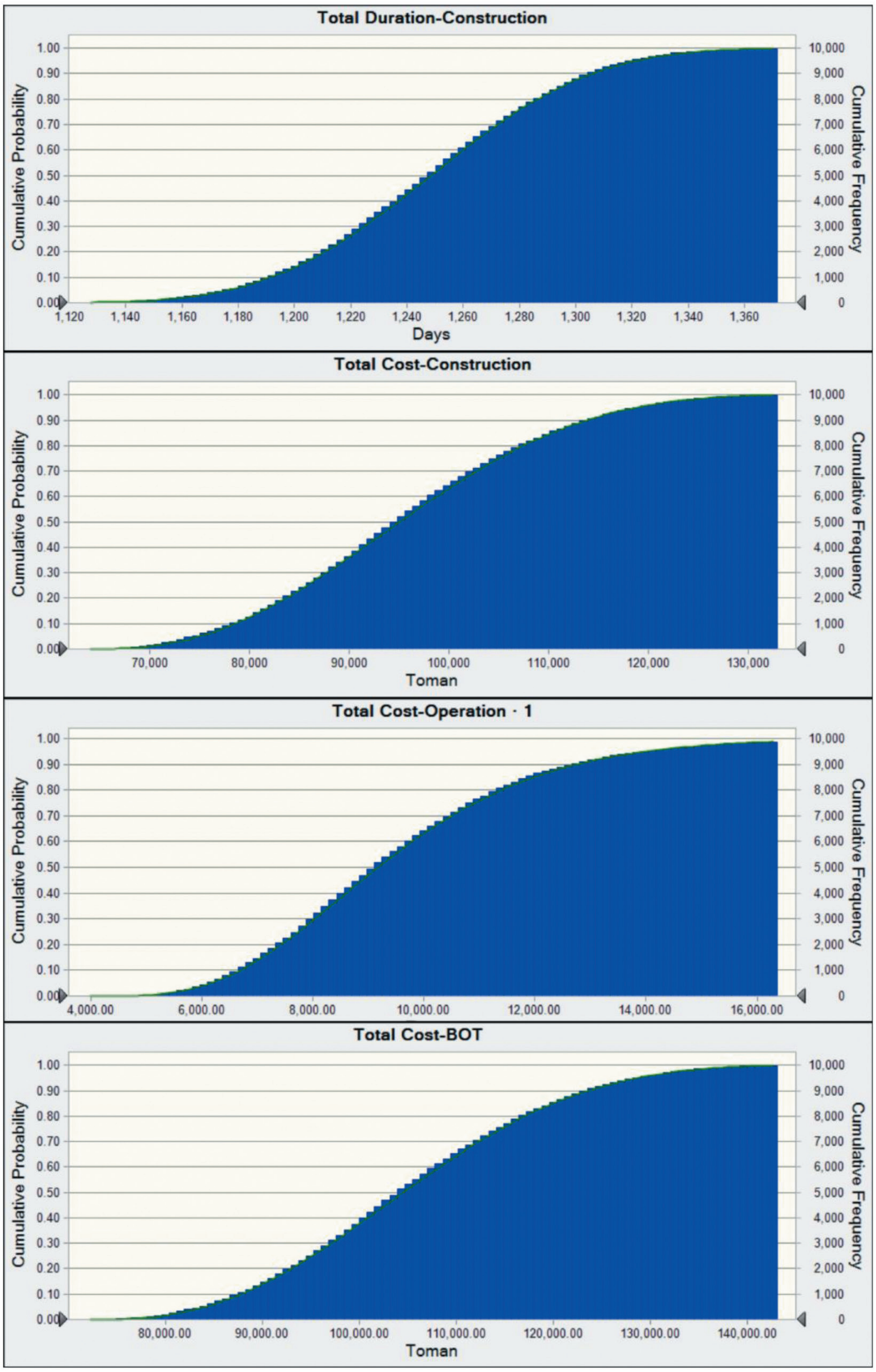

Figure 3. Cumulative distributions of the implementation of simulation on the main objectives

Table 7. Rated risks along with the probability of occurrence and its impact

row	Risk	Probability (P)	Impact (I)	Optimistic approach*		Pessimistic approach**	
				Risk score	Rank	Risk score	Rank
1	The possibility of excessive inflation considered in the contract due to exchange rate fluctuations and ...	74%	83%	0.614	1	0.956	1
2	Probability of claim by subcontractors due to rising material prices during the project	75%	75%	0.563	3	0.938	3
3	Possibility of not completing the project due to financial issues	72%	80%	0.575	2	0.943	2
4	Possibility of non-allocation of the budget by the investor to the project	68%	77%	0.521	4	0.926	4
5	Possibility of problems in providing the currency required for the project	68%	75%	0.513	5	0.921	5
6	Possibility of delay or non-supply of main equipment due to country conditions	63%	74%	0.462	6	0.902	6
7	Possibility of changing the vendor list and changing the technical specifications of the main devices due to sanctions	63%	70%	0.444	7	0.890	7
8	Possibility of non-payment of low-interest loans by the public sector	62%	68%	0.423	10	0.879	11
9	Possibility of changing technical drawings during the construction phase	60%	72%	0.432	8	0.888	8
10	Possibility of not completing the project due to management issues	59%	72%	0.422	11	0.884	10
11	Possibility of delay in issuing customs licenses for imported equipment	60%	72%	0.430	9	0.887	9
12	Possibility of the project's main contractor not being able to get a loan or credit	56%	69%	0.387	12	0.863	12
13	Possibility of public sector inflexibility in issuing licenses to increase energy sales price (mandatory price determination)	61%	60%	0.361	15	0.841	15
14	Lack of supply of raw materials during the operation phase	59%	65%	0.384	13	0.857	14
15	Possibility of public sector inflexibility in issuing licenses to increase the price of waste treatment (mandatory price determination)	59%	58%	0.343	19	0.828	19
16	Possibility of delay in starting the operation period due to non-issuance of necessary permits	58%	66%	0.383	14	0.857	13
17	Possibility of public sector inflexibility in extending the operation period	56%	62%	0.351	16	0.836	17
18	Possibility of non-approval of project insurance and tax start-up exemptions	56%	61%	0.338	20	0.826	20
19	Possibility of non-cooperation of consultant and supplier due to debt early in the project	55%	63%	0.347	18	0.834	18
20	The possibility of failure of the main parts of the main devices and the time it takes to repair or replace them according to the country's conditions	55%	64%	0.350	17	0.837	16
21	Possibility of not guaranteeing the minimum purchase of energy by the public sector	53%	58%	0.304	24	0.800	24
22	Possibility of not appointing a relevant specialist for the main equipment	50%	62%	0.311	23	0.811	23
23	Possibility of non-cooperation of the Environment Organization to prepare the project infrastructure	54%	61%	0.327	21	0.819	21
24	Possibility of delay in the approval of technical specifications of materials by the consultant	50%	62%	0.312	22	0.811	22
25	The possibility of ambiguity in the project vision from the point of view of the public operator	53%	57%	0.301	25	0.797	26
26	Probability of weakness in the execution of the construction phase	47%	62%	0.292	26	0.800	25
27	Possibility of failure in the initial commissioning phase	45%	60%	0.272	27	0.782	27
28	Lack of HSE control over the project	44%	51%	0.222	29	0.723	29
29	Probability of occurrence of coercive conditions such as earthquakes, floods, storms	35%	64%	0.225	28	0.768	28

* $P \times I$; ** $P+I-P\times I$

As can be seen in Figure 3, the cumulative probability distributions obtained from the simulations of all the main objectives are obtained from quantitative risk analysis and investigation of the risk effects. The average cost of the construction period would be 582 billion Tomans, and its standard deviation is 19 billion Tomans, which is 14% more than the final cost of the construction period obtained from the probable case (510 billion Tomans) of triangular distribution. it shows the significant effect of risks in the costs of the construction period. The average time obtained was 1446 days that, compared to the estimated duration of 1095 days (three years), has increased by 32%. The cost of the operating period has increased by 21% from the probable mode of the triangular distribution; this percentage, due to the length of this period and also the effect of inflation and other risks on the four main costs each year, seems more significant. Also, the appropriate distribution fitted to these four main parameters is the beta and gamma distributions.

6.1 Sensitivity analysis

In this section, a sensitivity analysis is performed to determine the intensity of risk effects on the activities of the construction period; besides, it is carefully examined according to the results obtained from the previous section. Figure 4 shows the sensitivity analysis of the costs of the construction period. As it is evident, the greatest effect on the cost during the construction period is related to the cost of supplying the main foreign equipment and related risks, including currency exchange risks, change of foreign vendor list, and sanctions, which can be up to 26% of costs; Therefore, a special attention shall be given to the issue of the supply of foreign products.

Figure 5 shows the results of the sensitivity analysis on the completion time of the construction period. As evident, the implementation of instrumentation is the activity that its time and project time is mostly affected by risks (about 20%). This is important because the instrumentation is the last and most important stage in the completion of construction (landscaping is a minor activity and the identified risks do not have much impact on that). After instrumentation, designing phase 1 (due to the importance of determining the main specifications in this phase), implementation and installation of the main mechanical equipment (due to the complexity of the supply and installation process), and initial commissioning (due to the complexity and novelty of the project) all affect the completion time of the project in a descending order.

According to the performed sensitivity analysis and the simulation results obtained from the previous section, it can be pointed out that due to risks such as inflation, sanctions, currency exchange, and other

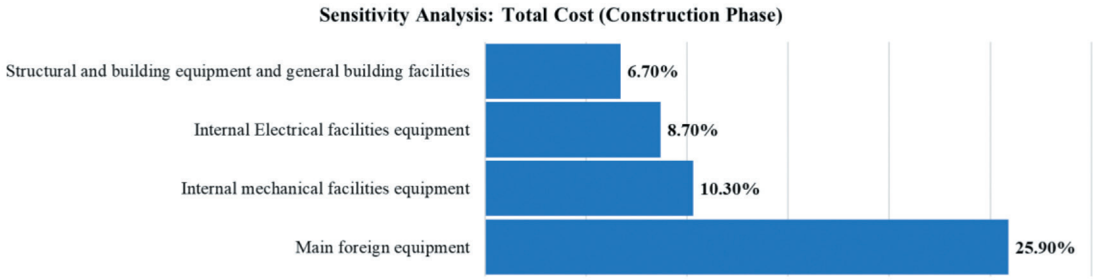

Figure 4. Results of sensitivity analysis on the total cost of the construction period

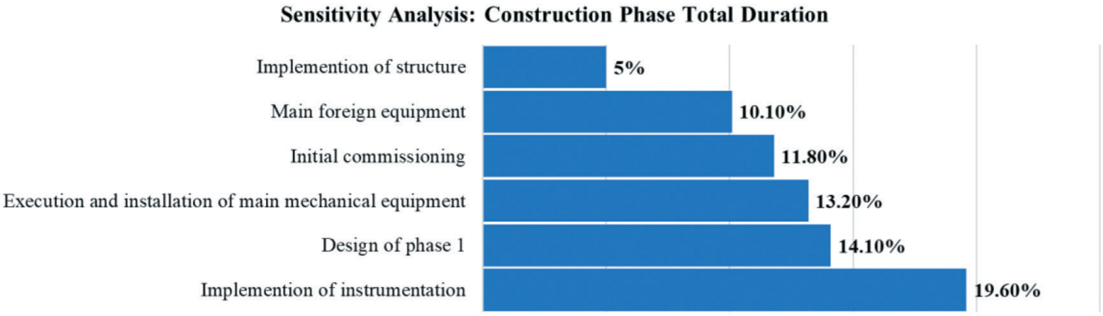

Figure 5. Results of sensitivity analysis on the total project duration of the construction period

identified risks, these risks are expected to cause a significant increase in execution time and costs of the construction and operation phase; Therefore, prior to the implementation of the project, different response plans and alternatives are needed to be considered. The results show that considering the existing risks, their occurrence probability, their severities, an increase of 30% in construction time, and an increase of 17% in construction and operation costs seem to be very likely and executing the project with an estimated initial time and cost wouldn't seem to be possible. This simulation helps project managers and decision-makers to get aware of the increase in costs, and to make appropriate decisions regarding project progress even before the project is stated.

7. Conclusion

In this paper, based on the discussions in the previous sections like the novelty of waste-to-energy conversion projects and other mentioned topics, the application of quantitative risk analysis on a real waste-to-energy project is performed. In this research, after identifying qualitative analysis, and ranking of risks, the probability of risk occurrence, the impact of each risk on construction period activities, and also operating period costs are simulated. The cost of the operation period and the total cost of the project have been calculated. The results of simulation and quantitative analysis of project risks show that by taking into account the effect of risks, the total cost is calculated to be averagely about 17% more than the costs obtained without the consideration of risks. And what is important is that the impacts of risks are required to be considered by planners and project managers. Also, the construction period is estimated to be averagely 32% longer than the initial estimated time, which may change the start of the operation phase and cause a conflict between the public and private sectors. The results of this study can help project managers to resolve potential conflicts prior to the start of the project via considering special conditions and uncertainties in the project. It also helps them prepare an appropriate response plan, so that when the risk occurs the project managers are not faced with any problems or delays. Moreover, according to this study, risks such as currency supply, sanctions, and change of vendor list have a significant effect on delays and increase of project costs; in case these risks are ignored, the success of the project would be jeopardized.

Because of the importance of contractual and financing issues in infrastructure projects, especially renewable and new energy start-up projects, as well as the need to identify and to get prepared for threats and take advantage of opportunities that arise during the project to ensure project success, Contractors will be the main stakeholders in the first place. This is because the results of this research enable contractors to have the power to develop the best plan to advance project goals with a full understanding of the impact of risks. Financiers with a full understanding of the time and cost risks, and their interactions can ensure the success of the project, the investment return, and their profits. Finally, the employer whose role is played by the government can be aware of all the risks in advance of taking the project and taking preventive measures and decisions.

Since the project studied in this research is among infrastructure and public projects, accurate and appropriate planning to avoid any disruptions during implementation, and especially during operation, could be considered as a basic principle. The model presented in this research can be easily configured for other schedules developed in this field. And their implementation will be possible with very minor changes.

7.1 Limitation and suggestions

The conducted research quantitatively analyses the identified risks and their impacts on BOT public-private partnership contracts in new renewable energy projects, and with a focus on waste-to-energy conversion projects; no similar research has been done in the previous studies; Therefore, the present study can be of great help to project stakeholders in terms of the impact of risks that may occur during different periods (construction and operation period) of the project. Also, the project stakeholders, knowing the uncertain conditions of the project at different times, might consider risk response measures at the time of planning, and based on that modify the project schedule, budget, and other contractual factors. This can significantly guarantee the success of the project.

In the present study, despite the quantitative analysis of the introduced project at the time of construction and operation, there are more considerable issues (such as more details about scheduling and budgeting) that are suggested to be considered by researchers in future research. Also, in future studies, the authors use quantitative analysis to optimize the operation time, financing, and cost of the project until the end of the operation period. In addition, further research is underway to create an automated plugin for the quantitative analysis of project risks.

Acknowledgments

The authors would like to thank the contractor of the case study for their support. In addition, the valuable assistance and collaboration of several practitioners involved in the case study are greatly appreciated.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Abbreviations

Abbreviation	Definition
MCS	Monte Carlo Simulation
BOT	Build-Operate-Transfer
PPP	Public Private Partnership
WTE	Waste To Energy
PMI	Project Management Institute
WBS	Work Breakdown Structure
CPM	Critical Path Method
PMO	Project Management Office
$Prob._{R1}$	A sample value drawn from a uniform distribution between 0 and 1 (related to risk R1)
$UniformDist._{R1}$	The probability of occurrence of risk R1
$Sim.Value_{R1}$	The sample value taken from the Triangular distribution of R1 impact
$Sim.Value_{Normal\ Duration_i}$	The sample value taken from the Triangular distribution of duration of activity i
$Final\ Duration_{Act_i}$	The total duration of activity i with consideration of risk occurrence impact
EST_j	The earliest start time of successor activity j
EFT_i	The earliest finish time of the predecessor activity i
Lag_i	The time interval between the Finish time of the predecessor activity i and the Start time of the successor activity j
$Sim.Value_{Normal\ Cost_i}$	The sample value taken from the Triangular distribution of the cost of activity i
$Final\ Cost_{\mathrm{Act}_i}$	The total cost of activity i with consideration of risk occurrence impact
$Final\ Cost_{it}$	The final cost of operation cos i t at time t
$Total\ Cost_i$	The total cost of phase i

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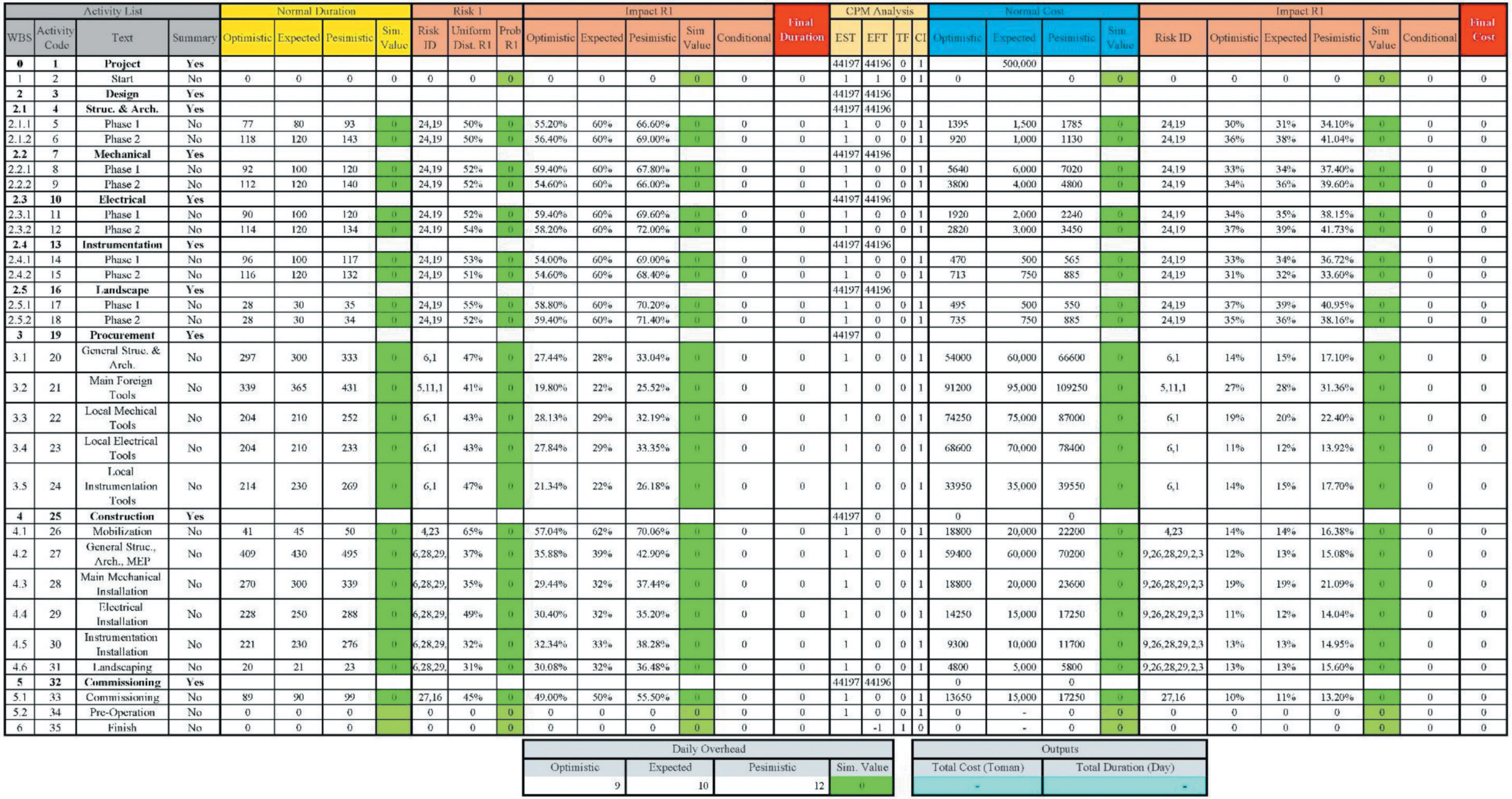
Appendix



Activity List				Normal Duration				Risk 1			Impact R1					Final Duration	CPM Analysis				Normal Cost				Impact R1						Final Cost
WBS	Activity Code	Text	Summary	Optimistic	Expected	Pesimistic	Sim. Value	Risk ID	Uniform Dist. R1	Prob R1	Optimistic	Expected	Pesimistic	Sim Value	Conditional		EST	EFT	TF	CI	Optimistic	Expected	Pesimistic	Sim Value	Risk ID	Optimistic	Expected	Pesimistic	Sim Value	Conditional	
0	**1**	**Project**	**Yes**														44197	44196	0	1		500,000									
1	2	Start	No	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0		0	0	0	0	0	0	0	0	0
2	**3**	**Design**	**Yes**														44197	44196													
2.1	**4**	**Struc. & Arch.**	**Yes**														44197	44196													
2.1.1	5	Phase 1	No	77	80	93	0	24,19	50%	0	55.20%	60%	66.60%	0	0	0	1	0	0	1	1395	1,500	1785	0	24,19	30%	31%	34.10%	0	0	0
2.1.2	6	Phase 2	No	118	120	143	0	24,19	50%	0	56.40%	60%	69.00%	0	0	0	1	0	0	1	920	1,000	1130	0	24,19	36%	38%	41.04%	0	0	0
2.2	**7**	**Mechanical**	**Yes**														44197	44196													
2.2.1	8	Phase 1	No	92	100	120	0	24,19	52%	0	59.40%	60%	67.80%	0	0	0	1	0	0	1	5640	6,000	7020	0	24,19	33%	34%	37.40%	0	0	0
2.2.2	9	Phase 2	No	112	120	140	0	24,19	52%	0	54.60%	60%	66.00%	0	0	0	1	0	0	1	3800	4,000	4800	0	24,19	34%	36%	39.60%	0	0	0
2.3	**10**	**Electrical**	**Yes**														44197	44196													
2.3.1	11	Phase 1	No	90	100	120	0	24,19	52%	0	59.40%	60%	69.60%	0	0	0	1	0	0	1	1920	2,000	2240	0	24,19	34%	35%	38.15%	0	0	0
2.3.2	12	Phase 2	No	114	120	134	0	24,19	54%	0	58.20%	60%	72.00%	0	0	0	1	0	0	1	2820	3,000	3450	0	24,19	37%	39%	41.73%	0	0	0
2.4	**13**	**Instrumentation**	**Yes**														44197	44196													
2.4.1	14	Phase 1	No	96	100	117	0	24,19	53%	0	54.00%	60%	69.00%	0	0	0	1	0	0	1	470	500	565	0	24,19	33%	34%	36.72%	0	0	0
2.4.2	15	Phase 2	No	116	120	132	0	24,19	51%	0	54.60%	60%	68.40%	0	0	0	1	0	0	1	713	750	885	0	24,19	31%	32%	33.60%	0	0	0
2.5	**16**	**Landscape**	**Yes**														44197	44196													
2.5.1	17	Phase 1	No	28	30	35	0	24,19	55%	0	58.80%	60%	70.20%	0	0	0	1	0	0	1	495	500	550	0	24,19	37%	39%	40.95%	0	0	0
2.5.2	18	Phase 2	No	28	30	34	0	24,19	52%	0	59.40%	60%	71.40%	0	0	0	1	0	0	1	735	750	885	0	24,19	35%	36%	38.16%	0	0	0
3	**19**	**Procurement**	**Yes**														44197	0													
3.1	20	General Struc. & Arch.	No	297	300	333	0	6,1	47%	0	27.44%	28%	33.04%	0	0	0	1	0	0	1	54000	60,000	66600	0	6,1	14%	15%	17.10%	0	0	0
3.2	21	Main Foreign Tools	No	339	365	431	0	5,11,1	41%	0	19.80%	22%	25.52%	0	0	0	1	0	0	1	91200	95,000	109250	0	5,11,1	27%	28%	31.36%	0	0	0
3.3	22	Local Mechical Tools	No	204	210	252	0	6,1	43%	0	28.13%	29%	32.19%	0	0	0	1	0	0	1	74250	75,000	87000	0	6,1	19%	20%	22.40%	0	0	0
3.4	23	Local Electrical Tools	No	204	210	233	0	6,1	43%	0	27.84%	29%	33.35%	0	0	0	1	0	0	1	68600	70,000	78400	0	6,1	11%	12%	13.92%	0	0	0
3.5	24	Local Instrumentation Tools	No	214	230	269	0	6,1	47%	0	21.34%	22%	26.18%	0	0	0	1	0	0	1	33950	35,000	39550	0	6,1	14%	15%	17.70%	0	0	0
4	**25**	**Construction**	**Yes**														44197	0			0		0								
4.1	26	Mobilization	No	41	45	50	0	4,23	65%	0	57.04%	62%	70.06%	0	0	0	1	0	0	1	18800	20,000	22200	0	4,23	14%	14%	16.38%	0	0	0
4.2	27	General Struc., Arch., MEP	No	409	430	495	0	6,28,29,	37%	0	35.88%	39%	42.90%	0	0	0	1	0	0	1	59400	60,000	70200	0	9,26,28,29,2,3	12%	13%	15.08%	0	0	0
4.3	28	Main Mechanical Installation	No	270	300	339	0	6,28,29,	35%	0	29.44%	32%	37.44%	0	0	0	1	0	0	1	18800	20,000	23600	0	9,26,28,29,2,3	19%	19%	21.09%	0	0	0
4.4	29	Electrical Installation	No	228	250	288	0	6,28,29,	49%	0	30.40%	32%	35.20%	0	0	0	1	0	0	1	14250	15,000	17250	0	9,26,28,29,2,3	11%	12%	14.04%	0	0	0
4.5	30	Instrumentation Installation	No	221	230	276	0	6,28,29,	32%	0	32.34%	33%	38.28%	0	0	0	1	0	0	1	9300	10,000	11700	0	9,26,28,29,2,3	13%	13%	14.95%	0	0	0
4.6	31	Landscaping	No	20	21	23	0	6,28,29,	31%	0	30.08%	32%	36.48%	0	0	0	1	0	0	1	4800	5,000	5800	0	9,26,28,29,2,3	13%	13%	15.60%	0	0	0
5	**32**	**Commissioning**	**Yes**														44197	44196			0		0								
5.1	33	Commissioning	No	89	90	99	0	27,16	45%	0	49.00%	50%	55.50%	0	0	0	1	0	0	1	13650	15,000	17250	0	27,16	10%	11%	13.20%	0	0	0
5.2	34	Pre-Operation	No	0	0	0		0	0	0	0	0	0	0	0	0	1	0	0	1	0	-	0	0	0	0	0	0	0	0	0
6	35	Finish	No	0	0	0		0	0	0	0	0	0	0	0	0		-1	1	0	0	-	0	0	0	0	0	0	0	0	0

Daily Overhead			
Optimistic	Expected	Pesimistic	Sim. Value
9	10	12	0

Outputs	
Total Cost (Toman)	Total Duration (Day)
-	-

Figure 2. Monte Carlo simulation model