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RESEARCH ARTICLE

Resource-constrained time–cost-quality-energy-environment tradeoff problem by considering blockchain technology, risk and robustness: a case study of healthcare project

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Abstract

Blockchain Technology (BCT) is expanding day by day and is used in all pillars of life and projects. In this research, we survey applicable BCT in project management for the first time. We presented a Resource-Constrained Time–Cost-Quality-Energy-Environment Tradeoff Problem by considering BCT, Risk and Robustness (RCTCQEETPBCTRR) in project scheduling. We utilize hybrid robust stochastic programming, worst case, and Conditional Value at Risk (CVaR) to cope with uncertainty and risks. This type of robustification and risk-averse is presented in this research. A real case study is presented in a healthcare project. We utilize GAMS-CPLEX to solve the model. Finally, we analyze finish time, conservative coefficient, the confidence level of CVaR, and the number of scenarios. The most important research result is that applying BCT decreases cost, energy, and pollution and increases quality. Moreover, the total gap between RCTCQEETPBCTRR and without BCT is approximately 2.6%. When compacting finish time happens or if the conservative coefficient increases to 100%, costs, energy, and pollution environment increase, but quality decreases. If the confidence level of CVaR increases, the cost, energy, and environment function functions grow up, and quality is approximately not changed.

Keywords Time–cost-quality-energy-environment · Tradeoff · Blockchain · Healthcare · Project scheduling

Introduction

Nowadays, Blockchain Technology (BCT) is one of the novel technologies that can change the world and move to decentralize and remove inefficiencies of centralized systems. BCT is a decentralized, Distributed Ledger Technology (DLT) that records data as a digital asset. This data cannot be modified and is applicable for payments, cybersecurity, and healthcare industries. A blockchain contains information about the sender, receiver, and the number of cryptocurrencies to be transferred. A set of rules—called a smart contract—is stored on the blockchain and executed automatically to speed transactions. A smart contract can define conditions for corporate bond transfers, including terms for travel insurance to be paid and much more (Almutairi et al. 2022; Tagde et al. 2021).

Researchers recently suggested using BCT in Project Management Offices (PMOs) (Hewavitharana et al. 2019). Applying this technology improves and does activities well and on time. For example, defining suppliers' delay when they do activities with disruption by embedding BCT is concise. Moreover, the smart contract can help pay the vendor and subcontractor automatically and remove the delay in payment (Akhavan et al. 2021). This issue decreases activities' cost, execution time, and project pollution and improves quality and energy consumption (Kim et al. 2020).

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Of course, there is not much research on the applicability of BCT in project management. We need to show how to improve scheduling, quality, energy, and pollution by considering BCT in the mathematical model. However, increasing resiliency, agility and sustainability are advantages of BCT in the project management area (Ivanov 2020). Resiliency and flexibility in facing costs by doing activities shortly and increasing transparency in transactions and exchange with vendors and suppliers with agility (Kamble et al. 2021). Using BCT makes it smooth and decreases the sharpness of costs, quality, energy, and environment in a compact situation (cf. Figure 1).

Adding BCT to RCTCQEETP is one of the subjects showing how BCT helps schedule well and improves sustainability and resource constraints. Therefore, we must go to novel technologies to amplify resiliency in complex situations like COVID-19, natural disasters and disruptions in project management. The leading organization in the project industry worldwide tries to minimize the time of projects and do more tasks.

Eventually, the innovation of this research and the main objective is as follows:

1. Applying BCT and resource-constrained in TCQEETP (RCTCQEETP),
2. Considering risk and robustness in RCTCQEETP,
3. Sustainability, resiliency, and agility improvement in project scheduling by RCTCQEETP.

The paper is organized as follows. In the "Survey on related work" section, we survey related work on the tradeoff problems. The "Problem description" section is stated the novel TCQEETP by considering resource-constrained, BCT, risk, and robustness. In the "Results and discussion" section, the results of research and sensitivity analysis are presented.

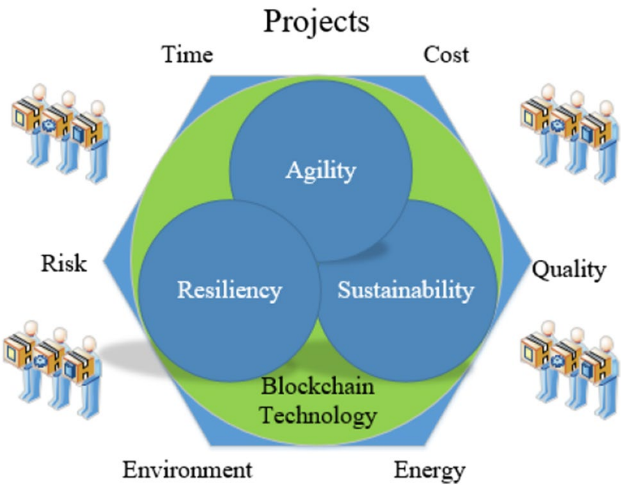


Fig. 1 Effects of BCT on project management

In the "Managerial insights and practical implications" section, the managerial insights and practical implications are discussed. In the "Conclusions and outlook" section, the conclusion is summarized.

Survey on related work

One of the problems that show a good relation of pillars of project management in the present is the time–cost tradeoff problem. However, many researchers have contributed to this problem in the recent decade.

Time–cost tradeoff problem (TCTP)

Toğan and Eirgash (2018) studied the TCTP. A contribution of this research was using non-dominating sorting multi-objective teaching learning-based optimization (NS-MTLBO) algorithm with a new initial population approach. Toğan and Eirgash (2019) surveyed a TC tradeoff optimization for construction projects. They suggested teaching learning-based optimization (TLBO) with Modified Adaptive Weight Approach (MAWA) for solving the model. They found that MAWA-TLBO has better performance than other algorithms. Ballesteros-Pérez et al. (2019) developed a nonlinear TCTP with activity crashing and collaborative or non-collaborative resources. They utilized a Genetic Algorithm (GA) to solve the model.

Time–cost-quality tradeoff problem (TCQTP)

Wood (2017) surveyed the TCQTP for gas and oil projects. They applied stochastic and fuzzy multi-objective for optimization. They solve the model by using a memetic multi-objective algorithm. Kosztyán and Szalkai (2018) expressed a hybrid TCQTP. They suggested a matrix-based method with task dependencies and undecided, supplementary task completion. Wang et al. (2021) considered a TCQTP for planning construction projects. They used multi-objective optimization of Non-Dominated Sorting Genetic Algorithms (NSGA-II). Mrad et al. (2019) suggested a Mixed Integer Linear Programming (MILP) for TCQTP. They considered the project budget as a constraint. They utilized Monte-Carlo Simulation for getting results.

Banihashemi et al. (2021) presented the TCQTP with environmental impacts for construction projects. They utilized GAMS software to gain results and obtain different scenarios for ecological consequences. Luong et al. (2021) optimized a multi-mode TCQTP for a construction project. They utilized opposition multiple objective difference evolution (OMODE) for optimizing the model. Moreover, they compared OMODE with NSGA-II, Multiple Objective Particle Swarm Optimization (MOPSO), and Multiple

Objective Differential Evolution (MODE). They found that the proposed algorithm has better performance than other algorithms. Sharma and Trivedi (2022) modeled a TCQTP for construction projects. They applied the Analytical Hierarchy Process (AHP) to gain weight between activity and quality. Finally, they used NSGA-II to obtain Pareto front for time, cost, and quality.

Time–cost-quality/risk tradeoff problem (TCQRTP)

Tran and Long (2018) presented the TCRTP. They applied adaptive multiple objective differential evolution (AMODE) for solving the model. They suggested considering risks in their model to enhance schedule flexibility. Long et al. (2019) optimized the multi-mode TCRTP. To solve the model, they considered a hybrid multiple objective evolutionary algorithms for optimizing by Artificial Bee Colony (ABC) and differential evolution (DE). They found that MOABCDE has more efficiency to show Pareto front in the model.

Nwaneri and Anyaeche (2018) proposed the TCQRTP in a magnetic resonance imaging installation project. Moreover, they added a fuzzy number to tackle uncertainty. They solved the model by Multi-Objective Genetic Algorithm (MOGA) and applied the Technique for the Order of Preferences by Similarity to Ideal Solution (TOPSIS). The results indicate a tradeoff relationship exists between time, cost, quality, and risks. Mahdiraji et al. (2021) considered a TCRTP with a knowledge-based approach.

Moreover, they added hesitant fuzzy information to tackle uncertainty. They tried to reduce the project's time by 20% compared with the deterministic approach. An R&D project application was the real case study.

Time–cost-quality-energy-environment tradeoff problem (TCQEETP)

Lotfi et al. (2022c) suggested a complete form of tradeoff. They surveyed a TCQEETP with resource-constrained (RCTCQEETP). The real case study was bridge construction. They applied robust convex optimization to cope with uncertainty. They embedded Augmented Epsilon Constraint (AUGEPS) to get results for multi-objective.

Research gap

The classification of the literature is addressed in Table 1. It can be seen that researchers do not survey the RCTCQEETPBCTRR. This study investigates the RCTCQEETPBCTRR and uses mathematical problems to optimize the best time, cost, energy, and environment for projects by considering BCT.

The main innovation of this research is as follows:

1. Applying BCT in the RCTCQEETP,
2. Considering risk and robustness in the RCTCQEETP,
3. Improving sustainability, resiliency, and agility in project scheduling.

Problem description

In this research, we want to show the effect of BCT in project scheduling until sustainability, resiliency, and agility of projects improve. Therefore, we develop a new model of the RCTCQEETP by considering BCT, risk, sustainability, resiliency, and agility. When we add BCT in this model, all parameters cost, quality, energy, and environment improve, but we have fixed cost and variable (maintenance) costs for establishing BCT. Finally, we want to show how the model selects to run with BCT or without BCT by considering the fixed cost and maintenance cost of BCT.

Moreover, we have resource constraints and want to cope with the risk of activity disruption and improve projects' resiliency, robustness, and sustainability. We add risk criteria and robust stochastic optimization to tackle with robustness. Using BCT makes it smooth and decreases the sharpness of costs, quality, energy, and environment in a compact situation.

To describe the mathematical model, consider a project based on an Activity on Node (AON) network. This network has $i \in \{1, \ldots, |I|\} \subset I$ nodes that show the activities. The activity i has a normal time (t_{is}), normal cost, quality, energy, and environment (pollution) (θ_{kis}) under the scenario s, while the compacted time (t'_{is}) and compact cost, quality, energy, and environment (pollution) (θ'_{kis}) under scenario s are denoted.

Assumptions

The main assumptions of the proposed model are as follows:

1. No activity is done before providing the prerequisites (Nunez et al. 2016).
2. Every activity has uncertain time, cost, quality, energy, and pollution (environment).
3. It should be noted that $t_{is} \geq t'_{is}$, $\theta_{kis} \leq \theta'_{kis}\ |k \in \{\text{Cost, Energy}\}$, and $\theta_{kis} \geq \theta'_{kis}\ |k \in \{\text{Quality, Environment}\}$.
4. After considering BCT, because the effects of BCT on cost, quality, energy, and environment, θ'_{kis} change to $\theta b_{kis} \leq \theta'_{kis}$.
5. By reducing time, cost and energy consumption increase, quality and pollution decrease.
6. It should be noted that the energy consumption of each activity is estimated based on the consumption amount of energy-based resources.

Table 1 Survey of related work

Reference	Model type	Platform	Tradeoff/ Objective					Risk	Uncertainty	Solution approach	Case Study
			Time	Cost	Quality	Energy	Environment				
(Nudtasomboon & Randhawa 1997)	RCTCTP	-	✓	✓	-	-	-	-	-	MILP	Numerical Example (NE)
(Wood 2017)	TCQTP	-	✓	✓	✓	-	-	-	Stochastic, fuzzy	MILP	Gas and oil
(Tran & Long 2018)	TCRTP	-	✓	✓	-	-	-	✓	-	MILP + AMODE	NE
(Toğan & Eirgash 2018)	TCTP	-	✓	✓	-	-	-	-	-	MILP + NS-MTLBO	NE
(Nwaneri & Anyaeche 2018)	TCQRTP	-	✓	✓	✓	-	-	✓	Fuzzy	MILP + MOGA	MRI machine installation
(Kosztyán & Szalkai 2018)	TCQTP	-	✓	✓	✓	-	-	-	-	MILP + Matrix-based	NE
(Wang et al. 2021)	TCQTP	-	✓	✓	✓	-	-	-	-	MILP + NSGA-II	Construction
(Toğan & Eirgash 2019)	TCTP	-	✓	✓	-	-	-	-	-	MILP + MAWA-TLBO	Construction
(Mrad et al. 2019)	TCQTP	-	✓	✓	✓	-	-	-	Stochastic	MILP + MOGA	NE
(Ballesteros-Pérez et al. 2019)	TCTP	-	✓	✓	-	-	-	-	Probably	MILP + GA	Construction
(Long et al. 2019)	TCRTP	-	✓	✓	-	-	-	✓		MILP + ABC + DE	Construction
(Lotfi et al. 2022c)	RCTCQEETP	-	✓	✓	✓	✓	✓	-	Robust convex	MILP + AUGEPS	Bridge
(Ghasemi et al. 2020)	RCTCQTP	-	✓	✓	✓	-	-	-	Fuzzy	MILP	NE
(Banihashemi et al. 2021)	TCQETP	-	✓	✓	✓	-	✓	-	-	MILP	Construction
(Mahdiraji et al. 2021)	TCQRTP	-	✓	✓	✓	-	-	✓	Fuzzy	MILP	Construction
(Luong et al. 2021)	TCQTP	-	✓	✓	✓	-	-	-	-	MILP + OMODE	Construction
(Sharma & Trivedi 2022)	TCQTP	-	✓	✓	✓	-	-	-	-	MILP + NSGA-II	Construction
This research	RCTCQEETPBCTRR	BCT	✓	✓	✓	✓	✓	✓	Robust Stochastic + Risk	MILP	Health care

7. Activities have a daily demand for their required resources.
8. Multiple renewable and non-renewable resources are defined. The supply capacity of resources is restricted and is known at the beginning of the project (Bowman 1994).

In the following, the mathematical model of the time–cost-quality-energy-environment tradeoff is introduced. In Fig. 2, we show that duration (x_{is}) is between normal time (t_{is}) and compact time (t'_{is}).

Notation list

Sets (Indices):

i	Set of activity $i,j \in I = \{1,..,n\}$,
I_1	Set of activities with a start to start the relationship $I_1 \subset I$,
I_2	Set of activities with a start to finish the relationship $I_2 \subset I$,
I_3	Set of activities with a finish to start the relationship $I_3 \subset I$,
I_4	Set of activities with a finish to finish the relationship $I_4 \subset I$,
j	Set of resources $j \in J = \{1,..,J\}$,
s	Set of scenario $s \in S = \{1,..,S\}$,
k	Set of objective $k \in K = \{1\text{:Cost}, 2 : \text{Quality}, 3 : \text{Energy}, 4 : \text{Environment}\}$,

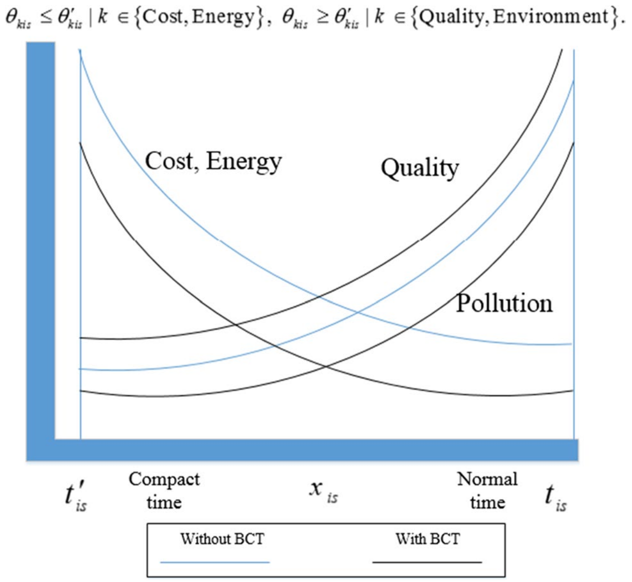


Fig. 2 Effect of BCT on compact of cost, quality, energy, environment

Parameters:

t_{is}	Normal time of activity i under scenario s,
t'_{is}	Compact time of activity i under scenario s,
θ_{kis}	Normal factor for objective k for activity i under scenario s,
θ'_{kis}	Compact factor for objective k for activity i under scenario $s, \theta_{kis} \le \theta'_{kis} \mid k \in \{\text{Cost}, \text{Energy}\}$, $\theta_{kis} \ge \theta'_{kis} \mid k \in \{\text{Quality}, \text{Environment}\}$.
β	Coefficient of conservative,
αb_k	Impact BCT on objective k,
φ_{ks}	Indirect factor on objective k under scenario s,
T	Maximum time of project,
λ_j	Maximum needs of resources j,
pr_s	Probably of scenario s,
r_{ijs}	Amount of resource j for activity i under scenario s,
M	Huge number,
α	The confidence level of CVaR.
fbt_k	Fix coefficient by establishing BCT on the objective function k,

Decision variables:

Binary variables:

xbt	Activation BCT is equal to 1, otherwise 0;

Continuous variables:

st_{is}	Start time of activity i under scenario s,
f_{is}	Finish time of activity i under scenario s,
x_{is}	Duration time of activity i under scenario s,

Auxiliary variables:

z_k	Objective function k,
θb_{kis}	Compact factor of activity i under scenario s by considering BCT, $\theta b_{kis} = \theta'_{kis}(1 - \alpha b_k xbt), \theta b_{kis} \le \theta'_{kis}$.
Γ_{kis}	Direct events for objective function k and activity i under scenario s,
$\Gamma\Gamma_{ks}$	Summation of direct for objective function k under scenario s,
Γt_{ks}	Summation of direct and indirect for objective function k under scenario s by considering establishing BCT,
kk_k	Summation of fixed cost for establishing BCT,
Δ_k	Auxiliary variable for linearization of max function,

$CVaR_{(1-\alpha)}$	CVaR with a confidence level α,
v_{ks}	Auxiliary variable for linearization of max function in CVaR,
VaR_k	VaR for CVaR,
ww_{is}	Auxiliary variable for linearization.

RCTCQEETPBCTRR mathematical model

Sustainable objectives:

$$\text{minimize } z_k = (1-\beta)\sum_s pr_s \Gamma t_{ks} + \beta\left(\frac{\max(\Gamma t_{ks}) + \mathrm{CVaR}_{(1-\alpha)}(\Gamma t_{ks})}{2}\right),\ \forall k \tag{1}$$

subject to:

Resilience constraints (BCT technology):

$$\Gamma t_{ks} = \Gamma\Gamma_{ks} + \varphi_{ks} f_{ns} + kk_k,\ \forall s, k \tag{2}$$

$$\Gamma\Gamma_{ks} = \sum_i \Gamma_{kis},\ \forall s, k \tag{3}$$

$$\Gamma_{kis} = \theta b_{kis} + \frac{\theta_{kis} - \theta b_{kis}}{t_{is} - t'_{is}}\left(x_{is} - t'_{is}\right),\ \forall i, s, k \tag{4}$$

$$\theta b_{kis} = \theta'_{kis}\left(1 - \alpha b_k xbt\right),\ \forall i, s, k \tag{5}$$

$$kk_k = fbt_k \cdot xbt,\ \forall k \tag{6}$$

Agile, predecessor, successor, and resource constraints:

$$st_{1s} = 0,\ \forall s \tag{7}$$

$$f_{ns} \le T,\ \forall s \tag{8}$$

$$\frac{\sum_i r_{ijs} x_{is}}{f_{ns}} \le \lambda_j,\ \forall j, s \tag{9}$$

$$t'_{is} \le x_{is} \le t_{is},\ \forall i, s \tag{10}$$

$$st_{is} + x_{is} \le f_{is},\ \forall i, s \tag{11}$$

$$st_{is} + ss_{is} \le st_{js},\ \forall i, j \in I_1 \tag{12}$$

$$s_{is} + sf_{is} \le f_{js},\ \forall i, j \in I_2 \tag{13}$$

$$f_{is} + fs_{is} \le st_{js},\ \forall i, j \in I_3 \tag{14}$$

$$f_{is} + ff_{is} \le f_{js},\ \forall i, j \in I_4 \tag{15}$$

Decision variables:

$$xbt \in \{0, 1\}, \tag{16}$$

$$st_{is}, x_{is}, f_{is} \ge 0,\ \forall i, s. \tag{17}$$

The objective function (1) considered minimizing the weighted expected value, minimax, and CVaR for the objective function k, including cost, quality, energy, and environment (pollution). This form of the objective function is proposed for robustness and risk-averse against disruption in the worst condition (Lotfi et al. 2021b).

Constraints (2) are the summation of direct and indirect parameters for objective functions k under scenario s by considering establishing BCT. Constraints (3) are the summation of direct for objective function k under scenario s. Constraints (4) are direct events for the objective function k and activity i under scenario s. Constraints (5) are a compact factor of activity i under scenario s by considering BCT. Constraints (6) are the summation of fixed costs for establishing BCT. Constraints (7) guarantee that start time equals zero for each scenario. Constraints (8) consider that finish time is less than the maximum defining time for each scenario. Constraints (9) indicate resource constraints for the proposed model. Constraints (10) express the duration of activity i between compact and normal time for each scenario. Constraints (11) -(15) are predecessor and successor constraints for activities. Constraints (16), (17) are decision variables. Constraint (16) is a binary variable for running BCT in the project network. Constraints (17) are positive variables for activities' start, duration, and finish time.

Preliminaries for linearization

The objective functions (1) are nonlinear and make the model mixed-integer nonlinear programming (MINLP). We transform them into mixed-integer programming (MIP) by mathematical method to improve time solution and solve smoothly (Gondal & Sahir 2013; Sherali & Adams 2013).

Linearizing max function:

Suppose: If $\beta = \max(\Omega_s)$, then we can change $\beta \ge \Omega_s,\ \forall s$.

Linearizing product binary with non-negative variable:

We can change and linearize a binary and a non-negative variable that is produced:

Suppose $z = Ax$, if A be a non-negative and positive variable and x be binary variable. Therefore we can replace these constraints with the model (Glover 1975):

$$z \ge 0, \tag{18}$$

$$z \le Mx, \tag{19}$$

$$z \leq A, \tag{20}$$

$$z \geq A - (1 - x)M. \tag{21}$$

It means that if x be zero, z is zero-based on Eq. (18), (19). If x is 1, z is A based on Eqs. (20), (21).

Linearizing CVaR function:

We used CVaR as a coherent risk measure. Rockafellar and Uryasev (2000) designed the CVaR criterion for a novel embedded risk measure. CVaR (also known as the expected shortfall) is considered a measure for assessing the risk. CVaR is embedded in portfolio optimization to better risk management (Kara et al. 2019; Lotfi et al. 2021a). This measure is the average of losses and is beyond the VaR point in confidence level. CVaR has a higher consistency, coherence, and conservation than other risk-related criteria.

$$\min \quad CVaR_{(1-\alpha)}(\Gamma\Gamma_s) = VaR + \frac{1}{1-\alpha}\sum_s pr_s v_s, \tag{22}$$

Subject to:

$$v_s \geq \Gamma\Gamma_s - VaR, \ \forall s \tag{23}$$

$$v_s \geq 0, \tag{24}$$

Linearization of RCTCQEETPBCTRR

We used linearization by the operational research method. Solving the model by MIP is more straightforward than MINLP in the solver in Eqs. (25) to (36), and these methods decrease the time solution and the complexity of the model. We can write it as follows:

Linearization of RCTCQEETPBCTRR-Step1

$$\text{minimize } z_k = (1-\beta)\sum_s pr_s \Gamma t_{ks} + 0.5\beta(\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks})), \ \forall k \tag{25}$$

Subject to:

$$\Delta_k \geq \Gamma t_{ks}, \ \forall s, k \tag{26}$$

$$\text{CVaR}_{(1-\alpha)}(\Gamma t_{ks}) = VaR_k + \frac{1}{1-\alpha}\sum_s pr_s v_{ks}, \ \forall k \tag{27}$$

$$v_{ks} \geq \Gamma t_{ks} - VaR_k, \ \forall s, k \tag{28}$$

$$v_{ks} \geq 0, \ \forall s, k \tag{29}$$

$$\Gamma_{kis} = \theta'_{kis}(1 - \alpha b_k xbt) + \frac{\theta_{kis} - \theta'_{kis}(1 - \alpha b_k xbt)}{t_{is} - t'_{is}}(x_{is} - t'_{is}), \ \forall i, s, k \tag{30}$$

Constraints (2)-(3), (6)-(17).

Linearization of RCTCQEETPBCTRR-Step2

$$\text{minimize } z_k = (1-\beta)\sum_s pr_s \Gamma t_{ks} + 0.5\beta(\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks})), \ \forall k$$

$$\Gamma_{kis} = \theta'_{kis}(1 - \alpha b_k xbt) + \frac{\theta_{kis} - \theta'_{kis}}{t_{is} - t'_{is}}(x_{is} - t'_{is}) + \frac{\theta'_{kis}\alpha b_k xbt}{t_{is} - t'_{is}}(x_{is} - t'_{is}), \ \forall i, s, k \tag{31}$$

Constraints (2)-(3), (6)-(17), (26)-(29).

Linearization of RCTCQEETPBCTRR-Step3

$$\text{minimize } z_k = (1-\beta)\sum_s pr_s \Gamma t_{ks} + 0.5\beta(\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks})), \ \forall k$$

subject to:

$$\Gamma_{kis} = \theta'_{kis}(1 - \alpha b_k xbt) + \frac{\theta_{kis} - \theta'_{kis}}{t_{is} - t'_{is}}(x_{is} - t'_{is}) + \frac{\theta'_{kis}\alpha b_k ww_{is}}{t_{is} - t'_{is}}, \ \forall i, s, k \tag{32}$$

$$ww_{is} \geq 0, \ \forall i, s \tag{33}$$

$$ww_{is} \leq M \cdot xbt, \ \forall i, s \tag{34}$$

$$ww_{is} \leq x_{is} - tp_{is}, \ \forall i, s \tag{35}$$

$$ww_{is} \geq x_{is} - tp_{is} - (1 - xbt)M, \ \forall i, s \tag{36}$$

Constraints (2)-(3), (6)-(18), (26)-(29).

The complexity of linearization of RCTCQEETPBCTRR includes numbers of binary, positive, free variables, and constraints indicated in Eqs. (37) to (40). As can be seen, one of the essential factors for constraints, positive and free variables, is scenario sets. The relation between scenario and constraints, positive and free variables is linear.

$$\text{Binary variables} = 1, \tag{37}$$

$$\text{Positive variables} = |S|(4|I| + |K|) + 1, \tag{38}$$

$$\text{Free variables} = 2|S||K|(|I| + 1) + 5|K| + 1, \tag{39}$$

$$\text{Constraints} = |S|(4|K| + 6|I| + 2|K||I| + |J| + 3) + |I|^2 + 3|K| + 1. \tag{40}$$

We suggested scenario reduction and new algorithms for removing constraints and binary variables. This subject can help solve minimum time.

Results and discussion

This section surveys a healthcare project establishing a hospital with 500 beds (c.f. Figure 3). Data and information received from managers of healthcare projects. In this complex situation of COVID-19, we should run these hospitals as soon as possible in Iran.

Patients need beds for remedy. Therefore, we should establish a hospital with minimum cost, energy, environment, and maximum quality to provide patients with good quality. We show the network, predecessor, and activities' successor in Fig. 4. The number of indices, constraints, variables, and parameters is defined for the case study in Tables 2 and 3.

We applied a computer with this configuration: CPU 3.2 GHz, Processor Core i3-3210, 6.00 GB RAM, 64-bit operating system. Finally, we solve the mathematical models with GAMS-CPLEX solver. The results show that applying BCT decreases cost, energy, and pollution and increases quality, as shown in Tables 4 and 5, and Fig. 5. The total Gap between P1-RCTCQEETPBCTRR and without BCT is approximately 2.6%. Therefore, we suggest using and activating BCT to improve costs, quality, energy, and pollution. This subject increases resiliency and sustainability in project management and increases responsibility and agility between pillars of projects.

Fig. 3 Healthcare project (hospital 500 beds)

Variation in the Finish time

As can be seen, we surveyed and changed the finish time (T). When compacting finish time happens, costs, energy, and pollution increase, but quality decreases. It is entirely natural because by decreasing time, pushing project is occurred, therefore costs, energy, pollution (environment) increase, and finally we see the declining quality (cf. Figure 6 and Table 6).

Variation on the conservative coefficient

In this section, we do a variation on the conservative coefficient for decision-makers with risk-averse behavior until surveying the performance of the mathematical model. If the conservative coefficient increases to 100%, the cost, energy, and environment function functions grow, and quality decreases (cf. Table 7 and Fig. 7).

Variation on a confidence level of CVaR

In this section, we do a variation on the confidence level of CVaR for decision-makers with risk-averse behavior until

Table 2 Number of indices, constraints, and variables for the case study

Problem	$\|I\|\|J\|\|S\|$	Binary variable	Positive variable	Free variable	Constraint
P1	5.5.3	1	73	165	320

Fig. 4 Network activity of hospital with 500 beds

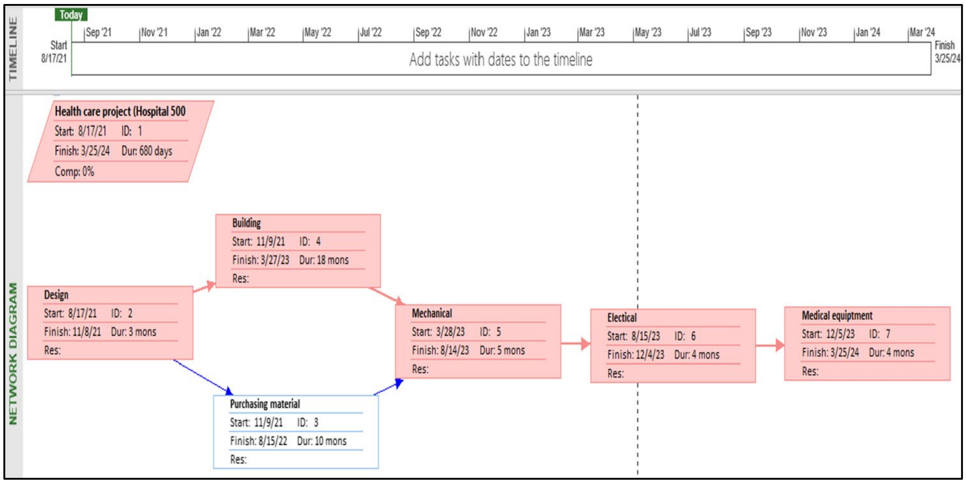


Table 3 Parameters of the case study

Parameters	Value	Unit
t_{is}	$t_{1s}=3\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $t_{2s}=10\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $t_{3s}=18\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $t_{4s}=5\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $t_{5s}=4\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $t_{6s}=4\ \cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$;	Month
t'_{is}	$[\ (t_{is}*0.9)]$	Month
θ_{kis}	$\theta_{11s}=0.1\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{12s}=0.2\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{13s}=0.3\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{14s}=0.15\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{15s}=0.15\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{16s}=0.1\cdot 7500000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$	Dollar
	$\theta_{2is}=\text{-}[\ (U(0.8,0.98).10]/10$;	%
	$\theta_{31s}=0.01\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{32s}=0.01\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{33s}=0.65\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{34s}=0.2\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{35s}=0.08\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{36s}=0.05\cdot U(25,30)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$;	KWh
	$\theta_{41s}=0.05\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{42s}=0.05\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{43s}=0.5\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{44s}=0.20\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{45s}=0.15\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$; $\theta_{46s}=0.05\cdot U(115,120)\cdot 60000\cdot((s\text{-}1)/(\vert S\vert\text{-}1)\cdot 0.1+0.95)$;	Ton
θ'_{kis}	$\theta'_{1is}=[(\theta_{1is}\cdot 1.2)]$;	Dollar
	$\theta'_{2is}=\theta_{2is}\cdot 0.9$;	%
	$\theta'_{3is}=[(\theta_{3is}\cdot 1.2)]$;	KWh
	$\theta'_{4is}=\theta_{4is}\cdot 0.95$;	Ton
β	50	%
αb_k	$\alpha b_1=0.1$	-
	$\alpha b_2=\text{-}0.1$	-
	$\alpha b_3=0.1$	-
	$\alpha b_4=0.1$	-
φ_{ks}	$\varphi_{1s}=500000/T$	Dollar/Mon
	$\varphi_{2s}=0.02/T$	%/Mon
	$\varphi_{3s}=\text{-}100000/T$	KWh/Mon
	$\varphi_{4s}=1000000/T$	Ton/Mon
T	34	Month
λ_j	0.5	-
pr_s	$1/\vert S\vert$	%
α	5	%
r_{ijs}	0.5	-
M	10^{100}	-
fbt_k	$fbt_1=40000$	Dollar
	$fbt_2=\text{-}0.03$	%
	$fbt_3=\text{-}10000$	KWh
	$fbt_4=\text{-}60000$	Ton

surveying the performance of the mathematical model. If the confidence level of CVaR changes between 1 and 5%, the cost, energy, and environment function functions grow up, and quality is approximately not changed (cf. Table 8, Fig. 8).

Variation in the number of scenarios

In this section, we do a variation on the number of scenarios for surveying the performance of the mathematical model. If the number of scenarios changes between 3 and 9, the cost function

Table 4 Results of RCTCQEETPBCTRR

Problem	Objective function	Cost (Dollar)	Quality (%)	Energy (KWh)	Environment Co_2 (Ton)	Activeting BCT
P1- RCTCQEEBCT	Cost	8178245.6	75.7%	1781493.9	8077062.3	Needed
	Quality	8340236.8	84.1%	1794838.5	7859241.5	Needed
	Energy	8299549.0	83.4%	1763188.4	8050137.5	Needed
	Environment	8761617.6	82.7%	1898758.6	6849198.2	Needed

Table 5 Comparing P1- RCTCQEETPBCTRR and without BCT

Problem	Objective function	Cost (Dollar)	Quality (%)	Energy (KWh)	Environment Co_2 (Ton)	Average GAP	Total Gap
P1-TCQEE without BCT	Cost	8206633.8	81.8%	1793305.2	8170535.2	2.6%	2.6%
	Quality	8469342.1	83.0%	1881500.2	8086856.2	2.0%	
	Energy	8336458.3	81.8%	1775985.6	8170145.1	0.2%	
	Environment	9644117.6	74.8%	2111692.6	7584523.6	5.6%	

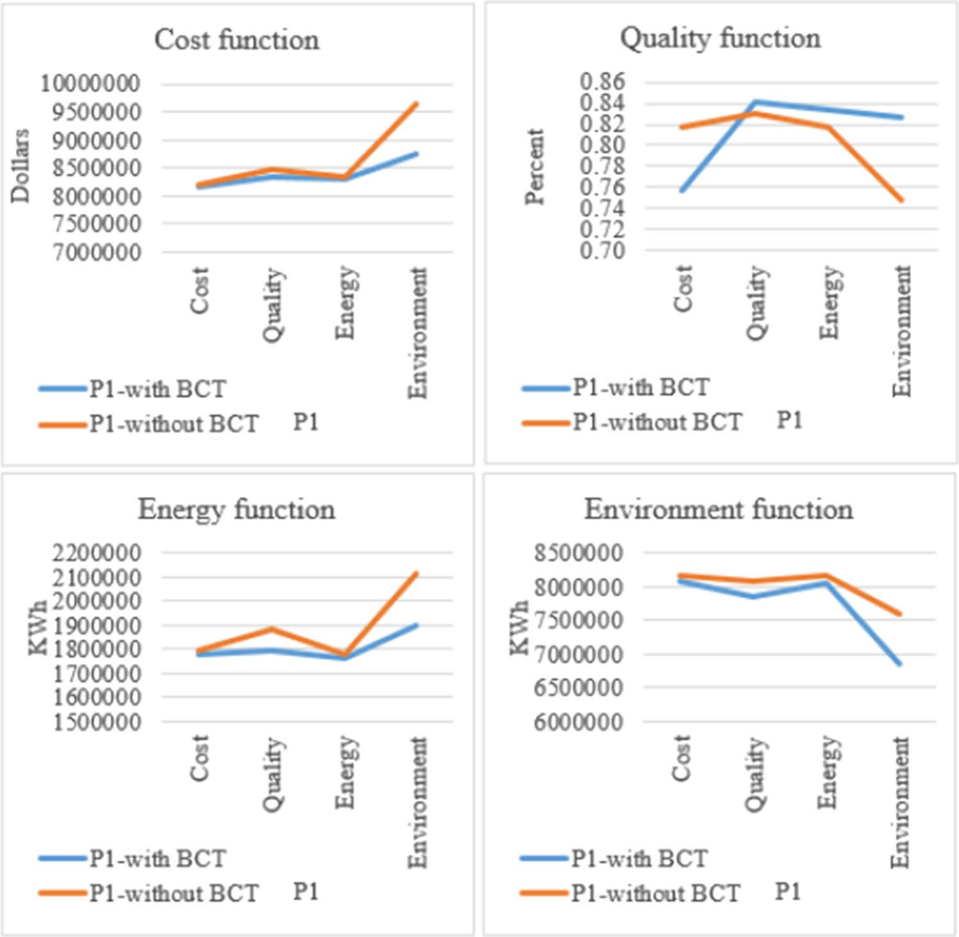


Fig. 5 Comparing P1- RCTCQEETPBCTRR and without BCT

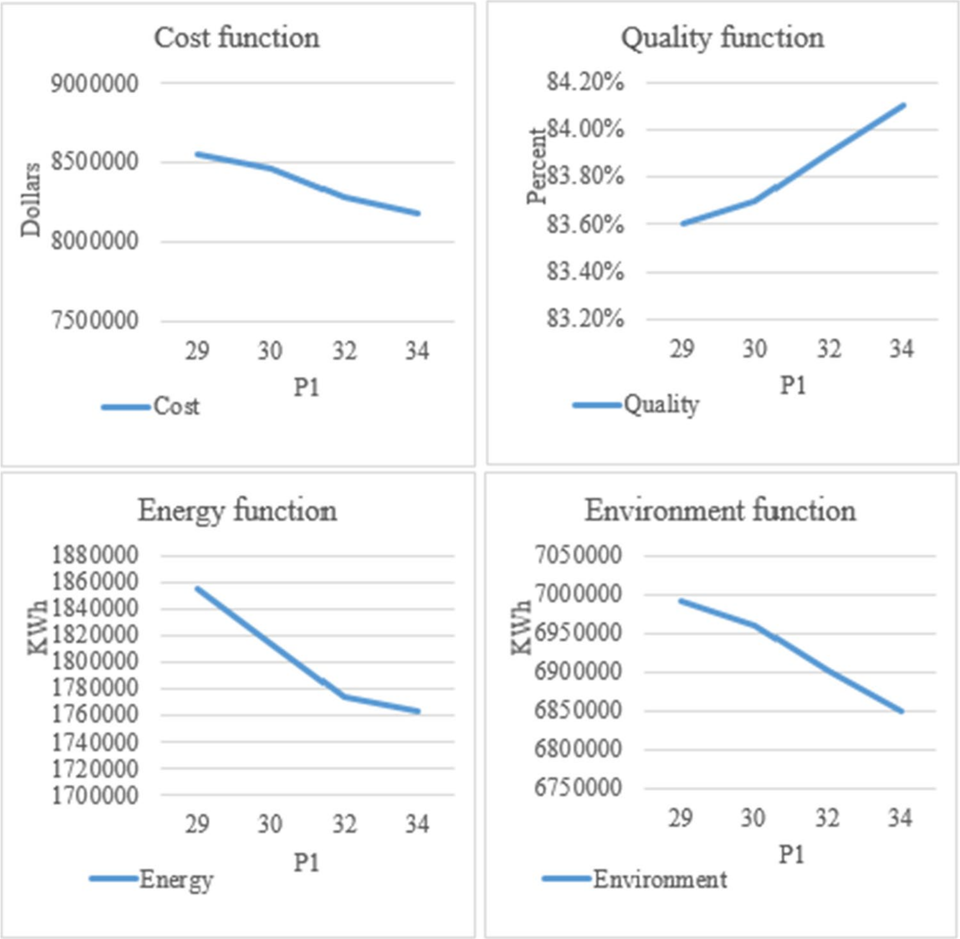


Fig. 6 Variation on the Finish time

Table 6 Variation on the Finish time

Objective function	Finish Time (*T*)	Cost (Dollar)	Quality %	Energy (KW)	Environment Co_2 (Ton)
Cost	29	8552016.0	83.0%	1887865.4	7252741.4
Cost	30	8459305.3	83.1%	1866733.2	7503325.8
Cost	32	8289252.6	83.3%	1792210.9	7892539.1
Cost	34	8178245.6	75.7%	1781493.9	8077062.3
Quality	29	8673150.0	83.6%	1891717.3	7228815.5
Quality	30	8598835.3	83.7%	1885109.7	7373318.5
Quality	32	8461071.4	83.9%	1859988.7	7596657.2
Quality	34	8340236.8	84.1%	1794838.5	7859241.5
Energy	29	8677357.1	83.0%	1855125.9	7262996.8
Energy	30	8577762.3	83.0%	1813109.3	7532145.2
Energy	32	8410127.7	83.3%	1773633.0	7911617.7
Energy	34	8299549.0	83.4%	1763188.4	8050137.5
Environment	29	8833879.3	82.8%	1912957.4	6992520.5
Environment	30	8817500.0	82.8%	1909739.0	6960034.1
Environment	32	8787812.5	82.7%	1903905.7	6901152.5
Environment	34	8761617.6	82.7%	1898758.6	6849198.2

Table 7 Variation on the conservative coefficient

Objective function	Conservative coefficient (β)	Cost (Dollar)	Quality %	Energy (KW)	Environment Co_2 (Ton)
Cost	25	8120021.4	80.2%	1764085.3	7993358.4
Cost	50	8178245.6	75.7%	1781493.9	8077062.3
Cost	75	8236469.9	82.9%	1798901.7	8160765.8
Cost	100	8294694.1	82.3%	1816310.1	8244469.6
Quality	25	8218302.6	84.4%	1783160.1	7826072.4
Quality	50	8340236.8	84.1%	1794838.5	7859241.5
Quality	75	8462171.1	83.8%	1806516.8	7892410.6
Quality	100	8584105.3	83.5%	1818195.2	7925579.7
Energy	25	8195886.0	84.0%	1753984.4	7953819.9
Energy	50	8299549.0	83.4%	1763188.4	8050137.5
Energy	75	8403212.0	82.9%	1772392.4	8146455.1
Energy	100	8506875.0	82.3%	1781596.4	8242772.7
Environment	25	8656691.2	83.3%	1879755.4	6803936.7
Environment	50	8761617.6	82.7%	1898758.6	6849198.2
Environment	75	8866544.1	82.2%	1917761.8	6894459.7
Environment	100	8971470.6	81.6%	1936765.0	6939721.2

Fig. 7 Variation on the conservative coefficient

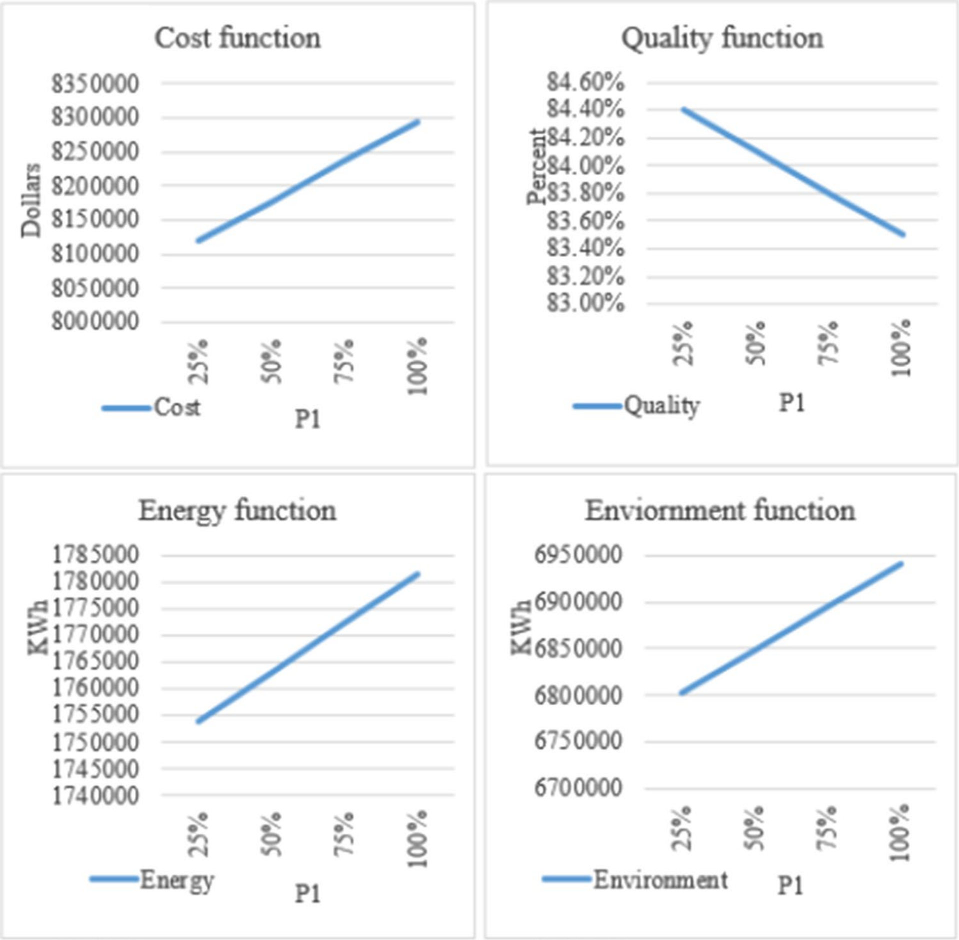


Table 8 Variation on the confidence level of CVaR

Objective function	Confidence level (α)	Cost (Dollar)	Quality (%)	Energy (KW)	Environment Co_2 (Ton)
Cost	1%	8173760.8	75.7%	1781493.9	8077062.3
Cost	2%	8174847.7	75.7%	1781493.9	8077062.3
Cost	3%	8175957.0	75.7%	1781493.9	8077062.3
Cost	5%	8178245.6	75.7%	1781493.9	8077062.3
Quality	1%	8340236.8	84.1%	1794838.5	7859241.5
Quality	2%	8340236.8	84.1%	1794838.5	7859241.5
Quality	3%	8340236.8	84.1%	1794838.5	7859241.5
Quality	5%	8340236.8	84.1%	1794838.5	7859241.5
Energy	1%	8299549.0	83.4%	1762433.0	8050137.5
Energy	2%	8299549.0	83.4%	1762616.0	8050137.5
Energy	3%	8299549.0	83.4%	1762802.9	8050137.5
Energy	5%	8299549.0	83.4%	1763188.4	8050137.5
Environment	1%	8761617.6	82.7%	1898758.6	6845767.7
Environment	2%	8761617.6	82.7%	1898758.6	6846599.1
Environment	3%	8761617.6	82.7%	1898758.6	6847447.6
Environment	5%	8761617.6	82.7%	1898758.6	6849198.2

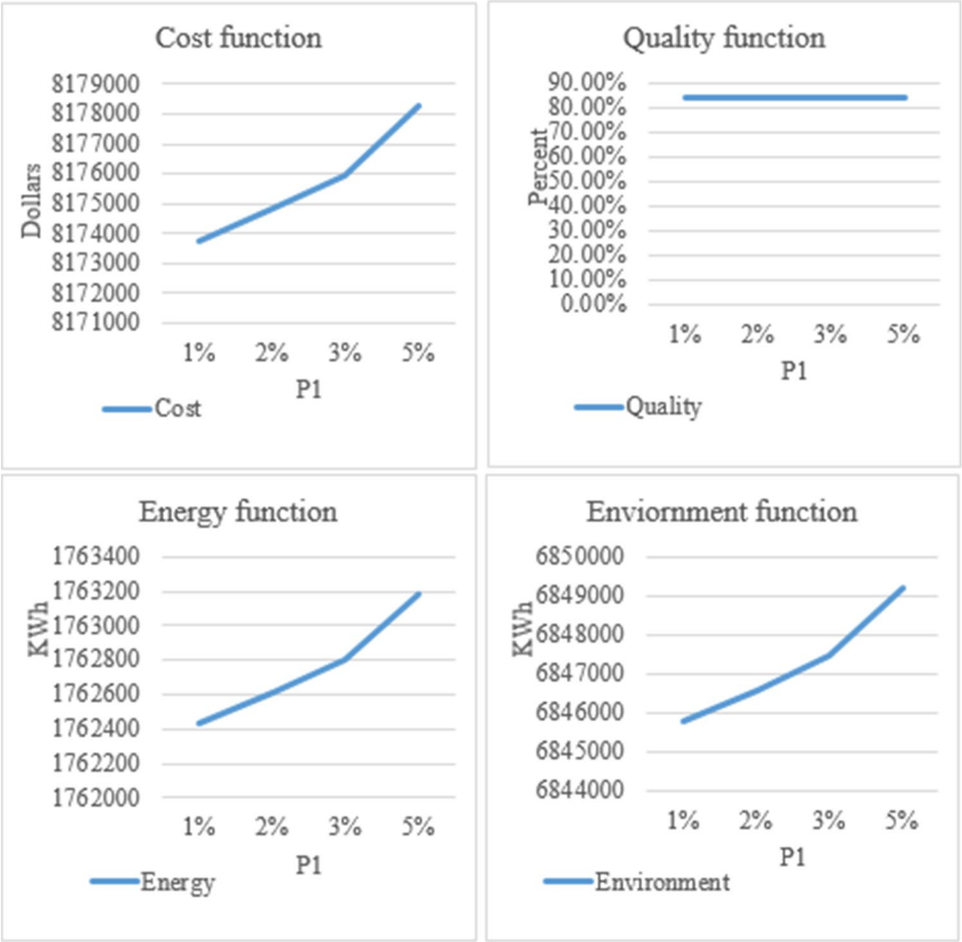


Fig. 8 Variation on the confidence level of CVaR

decreases. Also, overall, quality and energy are declining, and environment function is increasing (cf. Table 9, Fig. 9).

Discussion

We cannot see RCTCQEETPBCTRR in the literature review when surveying related work. This mathematical model is the first time considered. In this section, we explore the RCTCQEETPBCTRR in healthcare projects. We try to show the application of BCT in projects and show how it can help projects. We did sensitivity analysis on important parameters to show the model's performance. Because the difference between this research and the literature review is hard compared with other related work. This research is the development of Lotfi et al. (2022c).

Eventually, we calculate RCTCQEETPBCTRR. We analyze the finish time, the conservative coefficient, the confidence level of CVaR, and the number of scenarios. After solving the model, we receive these findings. The total gap between RCTCQEETPBCTRR and without BCT (Lotfi et al. 2022c) is approximately 2.6%. Therefore, using BCT is completely useful in project management. When compacting finish time happens or if the conservative coefficient increases to 100%, costs, energy, and pollution environment increase, but quality decreases. If the confidence level of CVaR changes, the cost, energy, and environment function functions grow up, and quality is approximately not changed. Although, because of the difference between this research and the literature review, we cannot compare this research and try to compare only with Lotfi et al. (2022c).

Therefore, the results show that BCT increases project network performance and resiliency. As a result, project managers should go fast to this novel technology and run projects as soon as possible. This technology increases resiliency and sustainability in project management and increases responsibility and agility between pillars of the project.

Managerial insights and practical implications

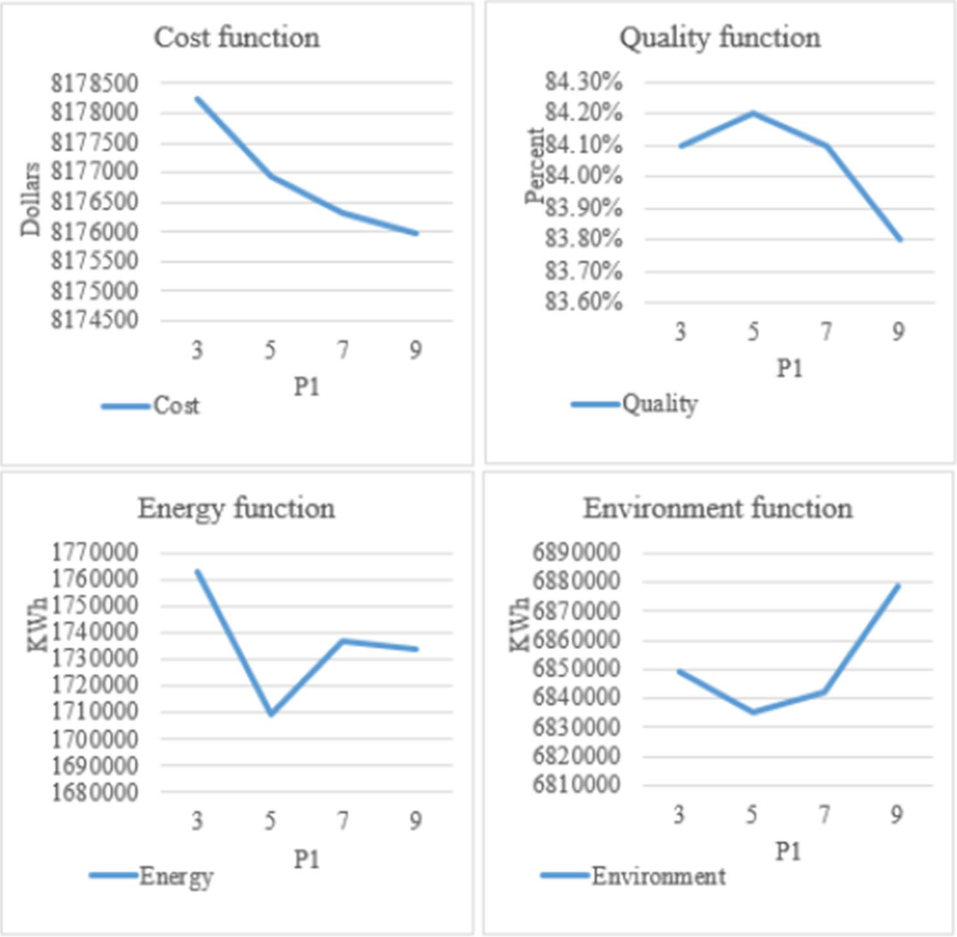
This research focuses on the applicability of BCT in project scheduling. We proposed a time–cost-quality-energy-environment tradeoff by considering BCT. Applying BCT decreases cost, energy, and environmental (pollution) and increases quality. By using BCT, we can improve all objectives by 2.6%. We suggest that all project managers embed novel technology like BCT into their projects to improve the performance of activities.

This research applies BCT as resiliency tools and considers resource constraints related to network pillars as agility tools. Moreover, utilizing BCT increases resiliency, agility, and sustainability in the project management area. Resiliency and flexibility in facing costs by doing activities short and increasing transparency in transactions and exchange with vendors and suppliers with agility. BCT can help project management on digital record storage, digital asset exchange, acceptable conduct assurance, reputation building, and intelligent contract execution. BCT changes the environment of projects from passive to active and can implement strategic projects in organizations.

Table 9 Variation on the number of scenarios

Objective function	Number of scenarios	Cost (Dollar)	Quality %	Energy (KW)	Environment Co_2 (Ton)
Cost	3	8178245.6	75.7%	1781493.9	8077062.3
Cost	5	8176937.2	75.7%	1733430.9	8059719.8
Cost	7	8176306.9	75.6%	1765528.9	8082290.3
Cost	9	8175962.3	75.8%	1759858.0	8124934.2
Quality	3	8340236.8	84.1%	1794838.5	7859241.5
Quality	5	8334097.6	84.2%	1778489.7	7939402.5
Quality	7	8333143.3	84.1%	1811512.5	7902471.8
Quality	9	8331882.5	83.8%	1789442.6	7952332.0
Energy	3	8299549.0	83.4%	1763188.4	8050137.5
Energy	5	8298163.1	83.5%	1709604.8	8032065.5
Energy	7	8297664.5	83.4%	1736952.8	8056416.4
Energy	9	8297595.1	82.7%	1733996.7	8099405.6
Environment	3	8761617.6	82.7%	1898758.6	6849198.2
Environment	5	8760146.8	82.8%	1843622.9	6835339.5
Environment	7	8759516.4	82.7%	1878322.2	6842348.7
Environment	9	8759166.1	82.0%	1872062.9	6878632.9

Fig. 9 Variation on the number of scenarios



Therefore, as managers of projects, we should move and apply novel technology in projects until resiliency, sustainability, and agility increase day by day. Applying and embedding BCT make to increase resiliency and sustainability in project management and increase responsibility and agility between pillars of the project.

Conclusions and outlook

The BCT is growing up day by day and entering the life of humans and projects. Researchers and investors need to use it in their work. Therefore, we proposed to utilize BCT in project management to witness the efficiency as much as possible. In this research, we suggested using BCT and showed a mathematical model. We employed BCT as resiliency tools and considered resource constraints related to network pillars as agility constraints.

We used a robust hybrid optimization by considering a risk-averse approach for modeling RCTCQEETP. We applied weighted expected value, minimax, and CVaR for all objective functions for robustness and risk-averse against disruption with the worst condition.

The findings of this research are as follows:

1. The results show that applying BCT decreases cost, energy, and pollution and increases quality, as shown in Tables 4 and 5, and Fig. 5. The total gap between RCTCQEETPBCTRR and without BCT is approximately 2.6%. Therefore, we suggest using and activating BCT to improve cost, quality, energy, and environment.
2. When compacting finish time happens, costs, energy, and pollution increase, but quality decreases. It is entirely natural because by decreasing time, pushing project is occurred, therefore costs, energy, pollution environment increase, and finally we see the declining quality (cf. Figure 6 and Table 6).
3. We analyze variation on the conservative coefficient for decision-makers with risk-averse behavior. If the conservative coefficient increases to 100%, the cost, energy, and environment function grow, and quality decreases (cf. Table 7 and Fig. 7).

4. We do a variation on the confidence level of CVaR for decision-makers with risk-averse behavior. If the confidence level of CVaR increases, the cost, energy, and environment function functions grow up, and quality is approximately not changed (cf. Table 8, Fig. 8).
5. Finally, we presented a variation on the number of scenarios for surveying the performance of the mathematical model. If the number of scenarios changes from 3 to 9, the cost function decreases. Also, overall, quality and energy are declining, and environment function is increasing (cf. Table 9, Fig. 9).

One of the research constraints is solving the model on a large scale. Because of the existence of MILP, we suggest using a new exact algorithm like Benders decomposition, Lagrange relaxation, and column generation (Lotfi et al. 2021c). Moreover, using heuristic and metaheuristic algorithms (Peng et al. 2022) is advantageous for solving minimum time and gaining near-optimal solutions.

Embedding other methods to cope with uncertainty like fuzzy (Kropat & Weber 2018), robust convex (Lotfi et al. 2022b), and hybrid data-driven robust optimization (Lotfi et al. 2022a) is an exciting approach for researchers. Using risk coherent risk criteria like Entropic VaR (EVaR), Robust CVaR (RCVaR) (Dixit & Tiwari 2020; Li et al. 2021) is a very excitable contribution. Therefore, we proposed to utilize novel technology in project management like the Internet of Things (IoT), 3D printing, and BCT to increase performance, resiliency, sustainability, and agility.

Author contribution Reza Lotfi: conceptualization, supervision, software, methodology; software; formal analysis; data curation; writing original draft; visualization;

Bahareh Kargar: methodology; software; formal analysis; data curation; writing original draft; writing review and edit; visualization;

Alireza Gharehbaghi: methodology, validation;

Hanif Hazrati: validation, writing review and edit;

Sima Nazari: validation, writing review and edit;

Mohsen Amra: validation, writing review and edit;

Data availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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