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Research Article

Keywords: Time-cost-quality-energy-environment, tradeoff, blockchain, healthcare, project scheduling

Posted Date: December 2nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-1088054/v1

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Resource-constrained time-cost-quality-energy-environment tradeoff in project scheduling by considering blockchain technology: 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 of BCT in project management for the first time. We presented a Resource-Constrained Time-Cost-Quality-Energy-Environment tradeoff problem in project scheduling by considering BCT (RCTCQEEBCT). 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 RCTCQEEBCT 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 increase, 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.

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1. Introduction

Nowadays, Blockchain Technology (BCT) is one of the novel technology can change the world and move to decentralize and remove inefficiencies of centralized systems. Recently, Using BCT in Project Management Offices (PMOs) is suggested by researchers (Hewavitharana, Nanayakkara, & Perera, 2019). Applying this technology makes to improve and to do activities well and on time. For example, defining suppliers' delay when they act actions 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, Ravanshadnia, & Shahrayini). This issue decreases cost, improves the quality of activity, energy consumption, and reduces executing time and project pollution (Kim, Lee, & Kim, 2020).

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 short and increasing transparency in transactions and exchange with vendors and suppliers with agility (Kamble et al., 2021). Using BCT makes to smooth and decreases the sharpness of costs, quality, energy, and environment in a compact situation (cf. Figure 1).

Figure 1. Effects of Blockchain technology on project management
Time-cost-quality-energy-environment tradeoff (TCQEE) is one of the subjects that shows how BCT helps schedule well and improve sustainability and resource constraints. In the future, we have to go to novel technology to amplify resiliency in a complex situation like COVID-19 and 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 in project scheduling in TCQEE problem,
2. Considering risk and robustness in TCQEE model,
3. Sustainability, resiliency, and agility improvement in project scheduling by RCTCQEEBCT model.

The paper is organized as follows. In Section 2, we survey related work on time-cost tradeoff. In Section 3, the novel TCQEE by considering BCT is stated. In Section 4, the results of research and sensitivity analysis are presented. In Section 5, the managerial insights and practical implications is discussed. In Section 6, the conclusion is summarized.

2. 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.

2.1. Time-cost tradeoff

Toğan and Eirgash (2018) studied a TC trade-off. 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, Elamrousy, and González-Cruz (2019) developed a non-linear TC tradeoff with activity crashing and collaborative or non-collaborative resources. They utilized a Genetic Algorithm (GA) to solve the model.
2.2. Time-cost-quality tradeoff


Banihashemi, Khalilzadeh, Shahraki, Malkhalifeh, and Ahmadizadeh (2021) presented a TCQ tradeoff with environmental impacts for construction projects. They utilized GAMS software to gain results and obtain different scenarios for ecological impacts. Luong, Tran, and Nguyen (2021) optimized a multi-mode TCQ tradeoff 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), Multiple Objective Differential Evolution (MODE). They found that the proposed algorithm has better performance than other algorithms. Sharma and Trivedi (2022) modeled a TCQ tradeoff 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, quality.

2.3. Time-cost-quality/risk trade-off

Tran and Long (2018) presented a time-cost-risk (TCR) tradeoff. They applied adaptive multiple objective differential evolution (AMODE) for solving the model. They suggested considering risks in their model to enhance schedule flexibility. Long, Tran, and Nguyen (2019) optimized the multi-mode TCR tradeoff problem. To solve the model, They considered Hybrid multiple objective evolutionary algorithms for optimizing by Artificial Bee Colony (ABC) and differential evolution (DE). They found that MOABCDEx has more efficiency to show Pareto front of the model.

Nwaneri and Anyaeche (2018) proposed a Time-Cost-Quality-Risk (TCQR) Tradeoff Model in Magnetic Resonance Imaging Installation Project. Moreover, They added a fuzzy number to tackle
with uncertainty. They solved the model by Multi-objective Genetic Algorithm (MOGA) and applied Technique for the Order of Preferences by Similarity to Ideal Solution (TOPSIS). The results indicate a tradeoff relationship exists among time, cost, quality and risks. Mahdiraji et al. (2021) considered a TCQR tradeoff model with a knowledge-based approach. Moreover, They added hesitant fuzzy information to tackle uncertainty. An R&D project application was the real case study. They found that they reduced the project's time by 20% compared with the deterministic approach.

2.4. Time-cost-quality-energy-environment tradeoff
Lotfi et al. (2020) suggested a complete form of tradeoff. They surveyed a time-cost-quality-energy-environment tradeoff with resource-constrained (RCTCQEE). 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.

Table 1. Survey of related work.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model type</th>
<th>Platform</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Tradeoff</th>
<th>Uncertainty</th>
<th>Solution approach</th>
<th>Case Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Wood, 2017)</td>
<td>TCQ</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Stochastic, fuzzy</td>
<td>*MILP</td>
<td>Gas and oil</td>
</tr>
<tr>
<td>(Tran &amp; Long, 2018)</td>
<td>TCR</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>MILP + AMODE</td>
<td>MILP</td>
<td>Numerical Example (NE)</td>
</tr>
<tr>
<td>(Toğan &amp; Eirgash, 2018)</td>
<td>TC</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MILP + NS-MTLBO</td>
<td>MILP + NS-MTLBO</td>
<td>NE</td>
</tr>
<tr>
<td>(Nwaneri &amp; Anyaeeche, 2018)</td>
<td>TCQR</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>Fuzzy</td>
<td>MILP + MOGA</td>
<td>MRI machine installation</td>
</tr>
<tr>
<td>(Kosztyán &amp; Szalkai, 2018)</td>
<td>TCQ</td>
<td>-</td>
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<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MILP + matrix-based</td>
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<td>Construction</td>
</tr>
<tr>
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<td>TCQ</td>
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<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MILP + NSGA-II</td>
<td>MILP + NSGA-II</td>
<td>Construction</td>
</tr>
<tr>
<td>(Toğan &amp; Eirgash, 2019)</td>
<td>TC</td>
<td>-</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MILP + MAWA-TLBO</td>
<td>MILP + MAWA-TLBO</td>
<td>Construction</td>
</tr>
<tr>
<td>(Mrad et al., 2019)</td>
<td>TCQ</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>Stochastic</td>
<td>MILP+MOGA</td>
<td>NE</td>
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<td>-</td>
<td>-</td>
<td>Probably</td>
<td>MILP+GA</td>
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<td></td>
</tr>
<tr>
<td>(Long et al., 2019)</td>
<td>TCR</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>MILP+GA</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Lotfi et al., 2020)</td>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>Robust convex</td>
<td>MILP + AUGEPS</td>
<td>Bridge</td>
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<tr>
<td>(Banihashemi et al., 2021)</td>
<td>TCQE</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>✓</td>
<td>-</td>
<td>MILP</td>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mahdiraji et al., 2021)</td>
<td>TCQR</td>
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<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>✓</td>
<td>Fuzzy</td>
<td>MILP</td>
<td>Construction</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(Luong et al., 2021)</td>
<td>TCQ</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>MILP+OMODE</td>
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<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
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<td>-</td>
<td>MILP+NSGA-II</td>
<td>Construction</td>
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</table>

<table>
<thead>
<tr>
<th>This research</th>
<th>RCTCQEEBCT</th>
<th>Blockchain</th>
<th>✓</th>
<th>✓</th>
<th>✓</th>
<th>✓</th>
<th>✓</th>
<th>Robust Stochastic+Risk</th>
<th>MILP</th>
<th>Health care</th>
</tr>
</thead>
</table>

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

The main innovation of this research is as follows:

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

3. 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 TCQEE model by considering BCT. When we add BCT in this model, all parameters cost, quality, energy, environment improve, but we have fix cost and variable (maintenance) cost 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 to 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) ($\theta_{kis}$) under scenario $s$, while the compacted time ($t'_{is}$) and compact cost, quality, energy, and environment (pollution) ($\theta'_{kis}$) under scenario $s$ are denoted.

![Diagram of BCT effect on compact of cost, quality, energy, environment.](image)

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

### 3.1. Assumptions

The main assumptions of the proposed model are as follows:

1. No activity is done before providing the prerequisites (Nunez, Kuo, & Chiang, 2016).
2. Time, cost, quality, energy, and environment (pollution) are uncertain for every activity.
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 of effects of BCT on cost, quality, energy, and environment, $\theta'_{kis}$ change to $\theta'_{kis}$.

5. Cost and energy consumption increase as time diminishes, and quality and pollution decrease as time reduce.

6. It should be noted that the energy consumption of each activity is estimated based on the consumption amount of energy-based resources.

7. Activities have a daily demand for their required resources.

8. Multiple 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 Figure 2, we show that duration ($x_i$) is between normal time ($t_{is}$) and compact time ($t'_{is}$).

### 3.2. Notation list

**Indices:**

- $i$: Set of activity $i$, $i \in I = \{1, ..., n\}$,
- $I_1$: 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 $k \in K = \{1: \text{Cost}, 2: \text{Quality}, 3: \text{Energy}, 4: \text{Environment}\}$,

**Parameters:**

- $t_{is}$: Normal time of activity $i$ under scenario $s$,
\( t'_{is} \) Compact time of activity \( i \) under scenario \( s \),

\( \theta_{kis} \) Normal factor for objective \( k \) for activity \( i \) under scenario \( s \),

\( \theta'_{kis} \) Compact factor for objective \( k \) for activity \( i \) under scenario \( s \),

\[ \theta_{kis} \leq \theta'_{kis} \mid k \in \{\text{Cost, Energy}\}, \theta_{kis} \geq \theta'_{kis} \mid k \in \{\text{Quality, Environment}\}. \]

\( \beta \) Coefficient of conservative,

\( \alpha b_k \) Impact BCT on objective \( k \),

\( \varphi_{ks} \) Indirect factor on objective \( k \) under scenario \( s \),

\( T \) Maximum time of project,

\( \lambda_j \) Maximum needs of resources \( j \),

\( pr_s \) Probably of scenario \( s \),

\( r_{is} \) Amount of resource \( j \) for activity \( i \) under scenario \( s \),

\( M \) Huge number,

\( \alpha \) The confidence level of CVaR.

\( fbt_k \) Fix coefficient by establishing BCT on objective function \( k \),

**Decision variables:**

**Binary variables:**

\( x_{bt} \) Activation blockchain technology is equal 1, otherwise 0;

**Continues 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 \( k \),

\( \theta b_{kis} \) Compact factor of activity \( i \) under scenario \( s \) by considering BCT,

\[ \theta b_{kis} = \theta'_{kis} (1 - \alpha b_k x_{bt}), \theta b_{kis} \leq \theta'_{kis}. \]
\( \Gamma_{kis} \) Direct events for objective function \( k \) and activity \( i \) under scenario \( s \),

\( \Gamma_\Gamma_{ks} \) Summation of direct for objective function \( k \) under scenario \( s \),

\( \Gamma t_{ks} \) Summation of direct and indirect for objective function \( k \) under scenario \( s \) by considering establishing BCT,

\( kk_k \) Summation of fix cost for establishing BCT,

\( \Delta_k \) Auxiliary variable for linearization of max function,

\( CVaR_{(1-\alpha)} \) Conditional Value at Risk (CVaR) with a confidence level \( \alpha \),

\( v_{kr} \) Auxiliary variable for linearization of max function in CVaR,

\( VaR_k \) Value at Risk (VaR) for CVaR,

\( \omega_{is} \) Auxiliary variable for linearization of producing binary and positive variable.

3.3. RCTCQEEBCT mathematical model

Sustainable objectives:

\[
\text{minimize } z_k = (1 - \beta) \sum_s p_s \Gamma t_{ks} + \beta \left( \frac{\max(\Gamma t_{ks}) + CVaR_{(1-\alpha)}(\Gamma t_{ks})}{2} \right), \quad \forall k
\]

subject to:

Resilience constraints (BCT technology):

\[
\Gamma t_{ks} = \Gamma \Gamma_{ks} + \varphi_{ks} f_{ns} + kk_k, \quad \forall s, k
\]

\[
\Gamma_\Gamma\Gamma_{ks} = \sum_i \Gamma_{kis}, \quad \forall s, k
\]

\[
\Gamma_{kis} = \theta b_{kis} + \frac{\theta_{kis} - \theta b_{kis}}{t_{is} - t'_{is}} (x_{is} - t'_{is}), \quad \forall i, s, k
\]

\[
\theta b_{kis} = \theta'_{kis} (1 - \alpha b_k xbt), \quad \forall i, s, k
\]

\[
kk_k = fbt_k \cdot xbt, \quad \forall k
\]

Agile, predecessor, successor, and resource constraints:

\[
st_{1s} = 0, \quad \forall s
\]

\[
f_{ns} \leq T, \quad \forall s
\]
\[
\sum_{i} r_{js} x_{is} \left/ f_{ns} \right\} \leq \lambda_{js}, \quad \forall j, s 
\] (9)

\[
t_{is}' \leq x_{is} \leq t_{is}, \quad \forall i, s 
\] (10)

\[
st_{is} + x_{is} \leq f_{is}, \quad \forall i, s 
\] (11)

\[
st_{is} + ss_{is} \leq st_{js}, \quad \forall i, j \in I_1 
\] (12)

\[
s_{is} + sf_{is} \leq f_{ij}, \quad \forall i, j \in I_2 
\] (13)

\[
f_{is} + fs_{is} \leq st_{js}, \quad \forall i, j \in I_3 
\] (14)

\[
f_{is} + ff_{is} \leq f_{js}, \quad \forall i, j \in I_4 
\] (15)

Decision variables:

\[
x_{bt} \in \{0,1\}, \quad \forall i, s 
\] (16)

\[
st_{is}, x_{is}, f_{is} \geq 0. \quad \forall i, s 
\] (17)

The objective function (1) considered minimizing the weighted expected value, minimax and Conditional Value at Risk (CVaR) for objective function \( k \) include cost, quality, energy, environment (pollution). This form of the objective function is proposed for robustness and risk-averse against disruption with the worst condition.

Constraints (2) are the summation of direct and indirect for objective function \( k \) 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 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 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 start, duration and finish time of activities.
3.4. Preliminaries for Linearization

The objective functions (1) are non-linear and make the model mixed-integer non-linear programming (MINLP). We transform them to 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 \( \beta = \max(\Omega) \), then we can change \( \beta \geq \Omega, \forall s \).

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 to the model (Glover, 1975):

\[
\begin{align*}
z & \geq 0, \\
z & \leq Mx, \\
z & \leq A, \\
z & \geq A - (1 - x)M.
\end{align*}
\]

It means that if \( x \) be zero, \( z \) is zero based on equation (18), (19). If \( x \) is 1, \( z \) is \( A \) based on equations (20), (21).

Linearizing CVaR function:

We used Conditional Value at Risk (CVaR), which is a coherent risk measure. Uryasev and Rockfeller designed the CVaR criterion for a novel embed risk measure (Lotfi, Kargar, Gharehbaghi, & Weber, 2021). CVaR (also known as the expected shortfall) is considered as a measure for assessing the risk. CVaR is embedded in portfolio optimization to better risk management (Kara, Özmen, & Weber, 2019; Lotfi, Mehrjerdi, Pishvae, Sadeghieh, & Weber, 2021). This measure is the average of losses are beyond the VaR point in confidence level. CVaR has a higher consistency, coherence, and conservation than other risk-related criteria.

\[
\min \left( \text{CVaR}_{(1-\alpha)}(\Gamma_s) = \text{VaR} + \frac{1}{1-\alpha} \sum_s p r_i y_s \right),
\]

(22)
\[ v_s \geq \Gamma_t - \text{VaR}, \quad \forall s \] (23)
\[ v_s \geq 0, \] (24)

### 3.5. Linearization of RCTCQEEBCT

We used linearization by the operational research method. Solving the model by MIP is more straightforward than MINLP in the solver in equations (26) to (36), and these methods decrease time solution and the complexity of the model.

We can write it as follows:

**Linearization of RCTCQEEBCT-Step1**

**minimize**  
\[ z_k = (1 - \beta) \sum_s p_r \Gamma t_{ks} + 0.5 \beta (\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks})), \]  
\[ \forall k \] (25)

**Subject to:**
\[ \Delta_k \geq \Gamma t_{ks}, \quad \forall s, k \] (26)
\[ \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks}) = \text{VaR}_k + \frac{1}{1 - \alpha} \sum_s p_r v_{ks}, \] \[ \forall k \] (27)
\[ v_{ks} \geq \Gamma t_{ks} - \text{VaR}_k, \quad \forall s, k \] (28)
\[ v_{ks} \geq 0, \quad \forall s, k \] (29)
\[ \Gamma_{kis} = \theta'_{kis}(1 - \alpha b_k x_{bt}) + \frac{\theta_{kis} - \theta'_{kis}(1 - \alpha b_k x_{bt})}{t_{is} - t'_{is}} (x_{is} - t'_{is}), \] \[ \forall i, s, k \] (30)

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

**Linearization of RCTCQEEBCT-Step2**

**minimize**  
\[ z_k = (1 - \beta) \sum_s p_r \Gamma t_{ks} + 0.5 \beta (\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma t_{ks})), \]  
\[ \forall k \]
\[ \Gamma_{kis} = \theta''_{kis}(1 - \alpha b_k x_{bt}) + \frac{\theta'_{kis} - \theta''_{kis}(1 - \alpha b_k x_{bt})}{t_{is} - t'_{is}} (x_{is} - t'_{is}) + \frac{\theta''_{kis} \alpha b_k x_{bt}}{t_{is} - t'_{is}} (x_{is} - t'_{is}), \] \[ \forall i, s, k \] (31)

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

**Linearization of RCTCQEEBCT-Step3**
minimize \( z_k = (1 - \beta) \sum \alpha_j r_j \Gamma_{k, s} + 0.5 \beta (\Delta_k + \text{CVaR}_{(1-\alpha)}(\Gamma_{k, s})) \), \quad \forall k

subject to:

\[
\Gamma_{k, s} = \theta'_k (1 - \alpha_0 b_k x_{b, t}) + \frac{\theta'_s - \theta'_k}{t_{s, t} - t'_{s, t}} (x_{s, t} - t'_{s, t}) + \frac{\theta'_s \alpha_0 b_k w_{s, s}}{t_{s, t} - t'_{s, t}},
\]

\( \forall i, s, k \) (32)

\( w_{s, s} \geq 0, \quad \forall i, s \) (33)

\( w_{s, s} \leq M \cdot x_{b, t}, \quad \forall i, s \) (34)

\( w_{s, s} \leq x_{s, t} - t_{b, t}, \quad \forall i, s \) (35)

\( w_{s, s} \geq x_{s, t} - t_{b, t} - (1 - x_{b, t})M, \quad \forall i, s \) (36)

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

215 The complexity of linearization of RCTCQEEBCT includes numbers of binary, positive, free variables and constraints are indicated in equations (37) to (40). As can be seen, one of the essential factors for constraints, positive and free variables, is scenario sets. Relation between scenario and constraints, positive and free variables is entirely linear.

Binary variables = 1, \hspace{1cm} (37)

Positive variables = \(4|I||S| + |K||S| + 1\), \hspace{1cm} (38)

Free variables = \(5|K| + 2|I||S| + 2|K||S|\), \hspace{1cm} (39)

Constraints = \(1 + 3|K| + 4|K||S| + 6|I||S| + 2|K||I||S| + |I||S| + 3|S| + |I||I|\). \hspace{1cm} (40)

219 We suggested scenario reduction and new algorithms to remove constraints and binary variables.

220 This subject can help solve minimum time.

4. Results and discussion

221 This section surveys a healthcare project that establishes 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, and environment, and maximum quality to provide patients with good quality.
We show network and predecessor and successor of activities in Figure 4. The number of indices, constraints, variables and parameters is defined for the case study in Table 2, Table 3.
Table 2. Number of indices, constraints, and variables for case study.

| Problem | $|I||J||S|$ | Binary variable | Positive variable | Free variable | Constraint |
|---------|-----------------|-----------------|------------------|---------------|------------|
| P1      | 5*5*3           | 1               | 73               | 165           | 320        |

Table 3. Parameters of case study.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{is}$</td>
<td>$t_{is} = 3 \cdot ((s - 1)/</td>
<td>S</td>
</tr>
<tr>
<td>$t'_{is}$</td>
<td>$t'<em>{is} = [t</em>{is} \times 0.9]$</td>
<td>Month</td>
</tr>
<tr>
<td>$\theta_{kis}$</td>
<td>$\theta_{kis} = 0.1 \cdot 7500000 \cdot ((s - 1)/</td>
<td>S</td>
</tr>
<tr>
<td>$\theta'_{kis}$</td>
<td>$\theta'<em>{kis} = [t</em>{is} \times 1.2]$</td>
<td>Dollar</td>
</tr>
</tbody>
</table>
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 by GAMS-CPLEX solver.

The results show that applying BCT decreases cost, energy, and pollution and increases quality, as shown in Table 4, Table 5 and Figure 5. The total gap between P1- RCTQEEBCT and without BCT is approximately 2.6%. Therefore, we suggest using and activating BCT to improve costs, quality, energy, and environment. This subject increases resiliency and sustainability in project management and increases responsibility and agility between pillars of projects.
Table 4. Results of RCTCQEBCT.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Objective function</th>
<th>Cost (Dollar)</th>
<th>Quality (%)</th>
<th>Energy (KWh)</th>
<th>Environment Co₂ (Ton)</th>
<th>Activeting BCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1- RCTCQEBCT</td>
<td>Cost</td>
<td>8178245.6</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
<td>Needed</td>
</tr>
<tr>
<td></td>
<td>Quality</td>
<td>8340236.8</td>
<td>84.1%</td>
<td>1794838.5</td>
<td>7859241.5</td>
<td>Needed</td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>8299549.0</td>
<td>83.4%</td>
<td>1763188.4</td>
<td>8050137.5</td>
<td>Needed</td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td>8761617.6</td>
<td>82.7%</td>
<td>1898758.6</td>
<td>6849198.2</td>
<td>Needed</td>
</tr>
</tbody>
</table>

Figure 5. Comparing P1- RCTCQEBCT with BCT and without BCT

Table 5. Comparing P1- TCQEE with BCT and without BCT

<table>
<thead>
<tr>
<th>Problem</th>
<th>Objective function</th>
<th>Cost (Dollar)</th>
<th>Quality (%)</th>
<th>Energy (KWh)</th>
<th>Environment Co₂ (Ton)</th>
<th>Average Gap</th>
<th>Total Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1- TCQEE without BCT</td>
<td>Cost</td>
<td>8206633.8</td>
<td>81.8%</td>
<td>1793305.2</td>
<td>8170535.2</td>
<td>2.6%</td>
<td>2.6%</td>
</tr>
<tr>
<td></td>
<td>Quality</td>
<td>8469342.1</td>
<td>83.0%</td>
<td>1881500.2</td>
<td>8086856.2</td>
<td>2.0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy</td>
<td>8336458.3</td>
<td>81.8%</td>
<td>1775985.6</td>
<td>8170145.1</td>
<td>0.2%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environment</td>
<td>9644117.6</td>
<td>74.8%</td>
<td>2111692.6</td>
<td>7584523.6</td>
<td>5.6%</td>
<td></td>
</tr>
</tbody>
</table>
4.1. Variation on the Finish time

As can be seen, we surveyed and changed finish time \((T)\). When compacting finish time happens, costs, energy, and pollution environment 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 decreasing quality (cf. Figure 6 and Table 6).

![Figure 6. Variation on the Finish time.](image)

<table>
<thead>
<tr>
<th>Objective function</th>
<th>Finish Time ((T))</th>
<th>Cost (Dollar)</th>
<th>Quality %</th>
<th>Energy (KW)</th>
<th>Environment (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>29</td>
<td>8552016.0</td>
<td>83.0%</td>
<td>1887865.4</td>
<td>7252741.4</td>
</tr>
<tr>
<td>Cost</td>
<td>30</td>
<td>8459305.3</td>
<td>83.1%</td>
<td>1866733.2</td>
<td>7503325.8</td>
</tr>
<tr>
<td>Cost</td>
<td>32</td>
<td>8289252.6</td>
<td>83.3%</td>
<td>1792210.9</td>
<td>7892539.1</td>
</tr>
<tr>
<td>Cost</td>
<td>34</td>
<td>8178245.6</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
</tr>
<tr>
<td>Quality</td>
<td>29</td>
<td>8673150.0</td>
<td>83.6%</td>
<td>1891717.3</td>
<td>7228815.5</td>
</tr>
</tbody>
</table>
### 4.2. 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 mathematical model. If the conservative coefficient increases to 100%, the cost, energy and environment function functions grow and quality decrease (cf. Table 7 and Figure 7).

![Variation on the conservative coefficient](image)

**Figure 7.** Variation on the conservative coefficient.
Table 7. Variation on the conservative coefficient.

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

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

Table 8. Variation on the confidence level of CVaR.

<table>
<thead>
<tr>
<th>Objective function</th>
<th>Confidence level (α)</th>
<th>Cost (Dollar)</th>
<th>Quality (%)</th>
<th>Energy (KW)</th>
<th>Environment (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1%</td>
<td>8173760.8</td>
<td>75.7%</td>
<td>1753984.4</td>
<td>7953819.9</td>
</tr>
<tr>
<td>Cost</td>
<td>2%</td>
<td>8174847.7</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
</tr>
<tr>
<td>Cost</td>
<td>3%</td>
<td>8175957.0</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
</tr>
<tr>
<td>Cost</td>
<td>5%</td>
<td>8178245.6</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
</tr>
<tr>
<td>Quality</td>
<td>1%</td>
<td>8340236.8</td>
<td>84.1%</td>
<td>1794838.5</td>
<td>7859241.5</td>
</tr>
<tr>
<td>Quality</td>
<td>2%</td>
<td>8340236.8</td>
<td>84.1%</td>
<td>1794838.5</td>
<td>7859241.5</td>
</tr>
</tbody>
</table>
4.4. Variation on number of scenarios

In this section, we do a variation on the number of scenarios for surveying the performance of mathematical model. If the number of scenarios, change between 3 to 9, the cost function decrease.
Also, overall, quality and energy are declining and environment function is increasing (cf. Table 9, Figure 9).

![Figure 9](image)

**Figure 9.** Variation on the number of scenarios.

<table>
<thead>
<tr>
<th>Objective function</th>
<th>Number of scenarios</th>
<th>Cost (Dollar)</th>
<th>Quality (%)</th>
<th>Energy (KW)</th>
<th>Environment (Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>3</td>
<td>8178245.6</td>
<td>75.7%</td>
<td>1781493.9</td>
<td>8077062.3</td>
</tr>
<tr>
<td>Cost</td>
<td>5</td>
<td>8176937.2</td>
<td>75.7%</td>
<td>1733430.9</td>
<td>8059719.8</td>
</tr>
<tr>
<td>Cost</td>
<td>7</td>
<td>8176306.9</td>
<td>75.6%</td>
<td>1765528.9</td>
<td>8082290.3</td>
</tr>
<tr>
<td>Cost</td>
<td>9</td>
<td>8175962.3</td>
<td>75.8%</td>
<td>1759858.0</td>
<td>8124934.2</td>
</tr>
<tr>
<td>Quality</td>
<td>3</td>
<td>8340236.8</td>
<td>84.1%</td>
<td>1794838.5</td>
<td>7859241.5</td>
</tr>
<tr>
<td>Quality</td>
<td>5</td>
<td>8334097.6</td>
<td>84.2%</td>
<td>1778489.7</td>
<td>7939402.5</td>
</tr>
<tr>
<td>Quality</td>
<td>7</td>
<td>8333143.3</td>
<td>84.1%</td>
<td>1811512.5</td>
<td>7902471.8</td>
</tr>
<tr>
<td>Quality</td>
<td>9</td>
<td>8331882.5</td>
<td>83.8%</td>
<td>1789442.6</td>
<td>7952332.0</td>
</tr>
<tr>
<td>Energy</td>
<td>3</td>
<td>8299549.0</td>
<td>83.4%</td>
<td>1763188.4</td>
<td>8050137.5</td>
</tr>
</tbody>
</table>
4.5. Discussion

When we survey related work, we cannot see RCTCQEEBCT in the literature review. This mathematical model is the first time considered. In this section, we explore the RCTCQEEBCT 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 performance of the model. Because of the difference between this research and the literature review, comparing with other related work is hard. This research is the development of Lotfi et al. (2020).

Eventually, we calculate RCTCQEEBCT. 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 RCTCQEEBCT and without BCT (Lotfi et al. (2020)) is approximately 2.6%. Therefore, using BCT in project management is completely useful. 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 change, 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. (2020).

5. 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 make to decreases cost, energy, environmental (pollution) and increase quality. By using BCT, we can improve all objectives by 2.6%. We suggest that all project managers embed novel technology like BCT to their projects to improve the performance of activities.
In this research, we apply BCT as resiliency tools and consider resource constraints, relation of network pillar as agility tools. Moreover, utilizing BCT make to increasing resiliency, agility and sustainability in the project management area. Resiliency and flexibility in facing costs by doing activities short and increasing transparency in transaction 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.

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

6. Conclusions and Outlook

The BCT is growing up day by day, and entrance in 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, relation of network pillar as agility constraints.

We used a hybrid robust optimization with considering a risk-averse approach for modeling TCQEE tradeoff. 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 Table 4, Table 5 and Figure 5. Total Gap P1- RCTQEEBCT and without BCT is approximately 2.6%. Therefore, we suggest using and activating BCT to improve costs, quality, energy and environment.

2. When compacting finish time happens, costs, energy, and pollution environment 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
decreasing 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 functions grow and quality decrease (cf. Table 7 and Figure 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 increase, the cost, energy and environment
function functions grow up and quality is approximately not changed (cf. Table 8, Figure
8).

5. Finally, we presented a variation on number of scenarios for surveying performance of the
mathematical model. If the number of scenarios, change between 3 to 9, the cost function
decrease. Also, overall, quality and energy are declining and environment function is
increasing (cf. Table 9, Figure 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. Moreover, using heuristic and metaheuristic algorithms (Peng, Zhang, &
Chen, 2021) is advantageous for solving in minimum time and gaining near-optimal solutions.

Embedding another method to cope with uncertainty like fuzzy, robust convex, and data-driven
robust optimization is an exciting approach for the researcher. Using risk coherent risk criteria like
Entropic Value at Risk (EVar), Robust Conditional Value at Risk (RCVaR) (Dixit & Tiwari, 2020;
Li, Xin, Pardalos, & Chen, 2021) is a very excitable contribution.

Therefore, we proposed to utilize novel technology in project management like Internet of Thing
(IoT), 3D printing and BCT to increase performance, resiliency, sustainability, and agility.

7. Ethical Approval
Not applicable

8. Consent to Participate
Not applicable

9. Consent to Publish
Not applicable

10. Authors Contributions
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;

11. Funding
There is not funding.

12. Competing Interests
The authors declare no competing interests.

13. Availability of data and materials
Not applicable

References


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