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Identification and evaluation of social risks in industrial-civil megaprojects with the help of multi-criteria decision-making techniques and system dynamics

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Abstract

Megaprojects play an important role in economics, society, and the environment and during recent years have fast developed. However, due to frequent social involvement induced by the social impact, social risk control has become a big challenge. So, this study is based on the systematic analysis of social risks and behavioural models in megaprojects. This study proposed a model composed of multi-criteria decision-making techniques and system dynamics to analyze the social risks for megaprojects. After choosing the desired risks in the social dimension and obtaining the causal relationships through the DEMATEL-ANP (DANP) method, as seen in the chart, the relationships between the extant variables can be investigated and concluded. The results show that some risks including timely completion of the project and related issues regarding increasing time based on social problems, the extreme internal and external dissatisfaction of megaprojects, and the decreasing risk due to increasing cost are ranked the first, second, and third one, respectively. Also, the extreme internal and external dissatisfaction of the megaproject has the most impact. In this proposed model, the factors affecting the risk related to the timely completion of the project and associated issues regarding the increasing time can be investigated in such a way that the values of this parameter have increased because of an increase in the internal variables, and vice versa. The mutual impact of the variable, the extreme internal and external dissatisfaction of the megaproject, the decreasing risk of the project quality due to excessive increasing cost in terms of social and unpredicted issues, and social interventions of beneficiaries on the timely completion risk of the project and issues of increasing time can be observed. Also, in the below charts, the behaviour of this model has been investigated during 10 coming years by different scenarios. This study can facilitate the perception of social risk in terms of the risk evolution and provide the decision-making support to overcome the social risk with megaproject operation.

Keywords: Project, Megaproject, Risk, Social risk, DEMATEL-ANP, DANP, system dynamics
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1 Introduction

During recent years, the promotion of the political-economic world performance of a country depends on megaprojects [11]. The megaprojects include bridges and projects for transferring water and dams, transportation infrastructures, power supply, oil and gas extraction, and urban development [9]. The megaprojects are complicated and unstable compared to the public projects and have a string of social features [26]. Megaprojects are associated with social issues such as immigration, land dispossession, and destruction, and environmental pollution [20]. Some social conflicts have often occurred between the project implementation units and residents. Projects such as nuclear plants and transformer posts are usually negatively influenced by society [16, 17]. The residents who are affected by these projects follow their interests through the objection and manifestation that in some cases it can lead to unrest and violence [25].

Investigating the social risk factors and their impact on megaprojects and adopting measures are very essential to controlling them and protecting social coordination and stability. To predict and reduce the social risk in megaprojects, governments have developed social risk evaluation as a basic way to control the social risks of megaprojects. These kinds of evaluations aim to identify, measure the social risk factors, and predict the social intervention possibility [21]. Multi-criteria decision-making techniques are useful methods to detect risks in every kind of project [20]. These methods can identify and evaluate [31]; however, these static evaluation methods cannot reflect the real situation of social risk, because the social risks are so dynamic. The occurrence and development of social risk is an evolutionary process [12]. So, traditional methods are not useful for the dynamic management of social risks [21]. To investigate the dynamic nature of social risks, the analysis model of their social risk in megaprojects is vital. It seems that the current research has focused on the social risks of megaprojects and mainly static analysis and does not have dynamic research in terms of the literature. Currently, in the social risk analysis models, the lack of attention to the dynamic nature of social risks leads to the following questions: How can we reflect the dynamic nature of social risks?

How can the social risk analysis model be analyzed based on the dynamic nature and complicated relationship between the social risk factors and dynamic social risks?

To reflect the dynamic nature of social risks, this study suggests an evolutionary path for social risk in megaprojects. This path describes the social risk evolution of how such risks occur and develop; it shows the complicated relationship between the social risks in a qualitative form. Thus, first of all, the social risks were identified by the literature review and screened by the Delphi method. Then, they were determined by the DANP method and cause and effect relationships between the social risks in megaprojects; the state-flow is determined based on the experts' view and obtained cause-effect relationships, and the model of social risk relationships in the megaprojects, completed based on the relationships between the variables. In the end, the behavioural chart is predicted for 10 coming years and formulated based on variations in a suitable scenario model.

2 Literature review

The risk is usually defined as an event or unknown conditions; when happening, it has a negative or positive effect on the project target [22]. Different fields in natural and social sciences have formed their specific concepts. However, all the social risk concepts have this common principle that the causes and consequences of dangers are mediated by social processes [23].

The common definition in the social field is lack of certainty and the intensity of events and consequences of an activity according to what is evaluated by a human [3]. Also, "social risk" is a term from interdisciplinary and transdisciplinary research including sociology, anthropology, economics, political science, etc. It is also mediated through social interpretation and associated with group values and interests [10]. In some ways, social risks are broad, like the accepted "social work" in terms of what they seem, but the risk conception only shows the unknown social consequences of an activity or an event, while the social impact refers to certain cases as well. The social risk especially refers to unexpected consequences of planned interventions, that is policies, plans, programs, and projects) and the potential harmful impact on social stability and mandatory rules. Managing social risk is defined as an institutional and social process that allows the policies, actors, strategies, and actions to be converged; it enhances the conditions or factors that create vulnerabilities in communities due to the impact of potentially destructive events [28]. Indeed, the management processes that use the evaluation of social risk have a role in overcoming social conflicts. Social risk management focuses more on the analysis, monitoring, and management of the social impacts as well as the social consequences of the development. Managing the social risk process can truly help the potential conflicting trends of local communities to lead while reducing dependence on short-term projects.

So, to manage the social risk of the project, it must identify the coming unintended outcomes of its current or suggested action related to people, organizations and social systems and manage them sufficiently. The development projects have embedded in their effects on the local communities; they have the "ripple effect" and these are exposed to social risks with specific external features such as unstable social disorder and widespread public opposition. The social risk, compared to other kinds of risk in project construction (i.e. physical risks, technological risks, risks related to the contractors etc.), is (in)directly stimulated by a lack of immediate benefits and some destructive reactions that may prevent the project implementation [15, 27]. According to the project management, not only does the social risk have a close relationship with contractors and staff, but also with people and community [1, 8, 34]. Since the identification of beneficiaries partially depends on the ideology, investigating the intercultural distinctions clarifies how to identify and address the parts of a project to its main beneficiaries [2]. Moreover, Bredillet [5] proposed that the assessment of social risk is one of the components of project management. Acceptance of the social risk evaluation as its process was completing the parallel changes in the beneficiaries' relationships; this one of the specific performances of the risk evaluation is responsible for perceiving the local communities and their concerns due to having a capability of social fields. Based on the definition, the social risk evaluation in project management is actually a system which aims to identify and determine the quantity of all the possible conflicting factors, exposing the project, to be able to make an informed decision about how to manage the risks. Based on Renn and Sellke in [24], the major task of the risk evaluation is to identify and detect the kinds, intensity, and possibilities of consequences related to the project risk. When the organization or management department identifies the project risk, it must prevent and reduce the consequences using proper actions. According to the risk evaluation approach, it is suggested that we pay more attention to its following monitoring and assessment regardless of focusing on previous evaluations in the literature of the main flow of risk management [4]. To discover the unintended impacts, including unforeseen consequences and accumulated impacts, the following evaluation can be applied. Normally, social risk management aims to implement a comprehensive approach; in this way, its output not only explores a unified social impact but also deals with reactions and reductions of such impacts.

Social risk is defined as a possible social conflict [14] that is mostly in the form of public accidents [33]. Most of the time, social risks refer to unintended consequences of unplanned interventions and their potentially disruptive impact on social stability [18]. Social risk is usually induced by (in)direct damage due to social impact [29]. In the field of construction, the social impact is embedded into project management, considering the risk factors such as the environment, public opinions, and stable development [35]. Some studies have been dedicated to social risk analysis and control in this field. Jia et al. [11] investigated the relationship between social conflicts and large projects theoretically. Chen et al. [6] examined a survey and deep interviews with residents affecting a disruptive project in Guangzhou to acquire info about the potential social risk. Liu et al. [18] showed how the local government dealt with social risk through the case analysis of Jixian Industrial Park in China, including effective ads, proper transparency, and a rapid reaction system. These analysis studies have focused on megaprojects or qualitative analysis of social risk or based on statistical data for a specific project. Some studies begin to quantify the social risk level of specific cases related to a construction project, considering the relationship between the social risk factors and social risk. Miao et al. [20] uses a unified fuzzy approach to quantify the overall level of social risk of construction projects, that is, it is equal to the sum of the levels of 6 social risk groups. Wu et al. [31] created a model to evaluate social risk by combining the analysis of both sets and the main component based on the system index of social stability for large projects of water protection. However, these methods are linear with a lack of discovery and complicated dependence on social risks. Some researchers tried to understand the dependencies of different opinions. For example, Wang et al. [30] investigated the mutual relationship between the public reaction and social impact of construction projects using a structural equation model. Yuan et al. [36] created a social risk analysis model considering the mutual relationship between beneficiaries and social risk to identify the most important social risk of construction projects in high-density urban crises. Furthermore, some studies have been dedicated to specific methods to overcome social risks. Xiao-Zheng and Xiang-Ming [32] created a "behavioral-cognitive" model to combine the risk perception of surrounding residents in social risk analysis; they explored ways to prevent mental crises caused by large projects. Wang et al. [30] generated a framework for social media analysis to analyze the online public perception thoughts in megaprojects; this aimed to develop useful public involvement strategies. Li et al. [13] proposed a social risk evolution for infrastructure projects; it combines the social risk analysis of modelling based on beneficiaries and factors to simulate public behaviours in the US.

Based on the literature review, some social risk analysis methods were for qualitative building projects or based on statistical data or Liner. Some studies have focused on the effect of perception, behaviour, and public opinion on the social risk of construction projects from the beneficiaries' view. There is little research that has systematically investigated the relationship between social risk factors and social risk in terms of the overall process.

3 Research method

In this research, first, the researcher obtained the indicators identified before using valid papers and Persian/Latin books. The current study is applicable in terms of the research goal and description and library in terms of information gathering. The tool for gathering data is a valid databank and articles related to the research, which is collected by a systematic review approach; in this regard, it can be said that the systematic review has been used by surfing the database to determine the dimensions and risk components in the social dimensions. First of all, this systematic review was done by surfing the database, including Science Direct, ELSVIER, EMERALD, Springer, IRANDOC, SID, Noor Mags, and Magiran to find the articles and research related to social risk keywords in industrial-civil megaprojects from 2012 to 2022; it was investigated several times with the help of experts, and eventually, summarized. After gathering and exploring the risks by the researchers and experts, 11 risks were defined as follows:

- Pressure for changing the domain of the project from regulatory and social institutions;
- Threatening the privacy and security of assets associated with the megaproject beneficiaries;
- Social conflicts;
- Cost related to settlement of disputes before and after the megaproject implementation;
- Extreme internal and external dissatisfaction with the megaproject;
- Failure in design and implementation steps;
- Unforeseen increasing cost of the project;
- Unforeseen increasing time of the project;
- The risk of completing the project on time and issues related to increasing time;
- Unforeseen issues and social interventions of beneficiaries;
- The problems related to the on-site coordination.

After obtaining the indicator through studying the literature and interviews with experts, 11 indicators were obtained; they were selected to prioritize and choose the finished indicators through the 7-point Likert scale and provide data and analysis with experts through the Delphi technique.

4 Analysis method

In this section, the research data is analyzed. This study aims to identify the important risks in the social dimensions of megaprojects and analyze their behaviours. To access this target, the DANP method has been used. The ANP method requires the internal relationships between the factors to calculate the weight and is identified by the DEMATEL method, the effectiveness and influence of factors; then, ANP supermatrices are made up by the DEMATEL communication matrix, and next, after reaching the causal relationships between the factors, the model will be analyzed and simulated in the Vensim software.

4.1 DANP technique

In the traditional ANP, it is assumed that every cluster has the same weight although it is clear that the effect of each on others may be different. So, the assumption of traditional ANP based on the same cluster weight is not rational for creating a balanced supermatrix. Subsequently, an effective balanced DANP can eliminate this weakness. In this method, the results are obtained from the completed relationship between T_C and T_D computed by DEMATEL based on the basic conception of ANP. Therefore, the DEMATEL technique is used to build a network structure model for each criterion and dimension as well as to improve the normalization trend of traditional ANP [7]. This technique is very suitable for real-world problems compared to the traditional methods and considers the dependence between the criteria, and eventually, it is combined with an ANP method to create DANP and determine the effective weights of each dimension and criterion [19]. In the following, the steps for the creation of the network relationship structure are described by the DEMATEL technique (steps 1-4) and the determination of effective DANP weights based on the complete communication matrix [7].

4.1.1 DEMATEL technique for creating the network communication map

First step- Calculating the direct communication matrix

The evaluation of criteria (the effect of one criterion on the other) is performed based on the experts' opinions of the study using a rating scale of 0-4 in which 0 is the lack of effectiveness, 1 is a little impact, 2 medium impact, 3 high impact, and 4 very high impact. The experts are asked to determine the effect of one criterion on another, that is, if they believe that the measure i affects the j, then, it is shown by d_c^{ij}. So, the matrix $D = [d_c^{ij}]$ is obtained from the direct relationship:

$$D = \begin{bmatrix} d_c^{11} & \cdots & d_c^{1j} & \cdots & d_c^{1n} \\ \vdots & & \vdots & & \vdots \\ d_c^{i1} & \cdots & d_c^{ij} & \cdots & d_c^{in} \\ \vdots & & \vdots & & \vdots \\ d_c^{n1} & \cdots & d_c^{nj} & \cdots & d_c^{nn} \end{bmatrix} \tag{4.1}$$

Second step- normalizing the direct communication matrix

The direct communication matrix D is normalized by the following equation and the matrix N is obtained:

$$N = VD; \quad V = \min\left\{1/\max_i \sum_{j=1}^{n} d_{ij}, 1/\max_j \sum_{i=1}^{n} d_{ij}\right\}, \quad i, j \in \{1, 2, ..., n\} \tag{4.2}$$

Third step- calculating the complete communication matrix

When the matrix D is normalized and the matrix N obtained, the complete communication matrix is obtained through the following equation. In this equation, I is the unit matrix:

$$T = N + N^2 + ... + N^h = N(1 - N)^{-1}, \quad \text{when} \quad h \to \infty \tag{4.3}$$

The complete communication matrix can be counted by the criteria and is given by T_C:

$$\boldsymbol{T}_c = \begin{array}{cc} & \begin{array}{ccccc} \boldsymbol{D}_1 & & \boldsymbol{D}_j & & \boldsymbol{D}_n \\ c_{11}...c_{1m_1} & \cdots & c_{j1}...c_{jm_j} & \cdots & c_{n1}...c_{nm_n} \end{array} \\ \begin{array}{c} \boldsymbol{D}_1 \; c_{11}, c_{12}, \ldots, c_{1m_1} \\ \vdots \\ \boldsymbol{D}_i \; c_{i1}, c_{i2}, \ldots, c_{im_i} \\ \vdots \\ \boldsymbol{D}_n \; c_{n1}, c_{n2}, \ldots, c_{nm_n} \end{array} & \begin{bmatrix} \boldsymbol{T}_c^{11} & \cdots & \boldsymbol{T}_c^{1j} & \cdots & \boldsymbol{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{i1} & \cdots & \boldsymbol{T}_c^{ij} & \cdots & \boldsymbol{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{n1} & \cdots & \boldsymbol{T}_c^{nj} & \cdots & \boldsymbol{T}_c^{nn} \end{bmatrix} \end{array} \tag{4.4}$$

Fourth step- result analysis

In this step, the sum of rows and columns of the complete communication matrix is calculated separately based on the following equation:

$$\begin{aligned} T &= [t_{ij}], \quad i, j \in \{1, 2, ..., n\} \\ r &= [r_i]_{n\times 1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \\ c &= [c_j]_{1\times n} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \end{aligned} \tag{4.5}$$

The r_i indicator is the sum of the ith row and c_j that of the jth column. The indicator $r_i + c_j$ is obtained from the sum of row i and column j (i=j). This indicator indicates the amount of importance of the ith criterion. Similarly, the indicator $r_i - c_j$ is equal to the difference between the ith row and jth column and shows the effectiveness and influence of the i measure. In total, if $r_i - c_j$ is positive (i=j), the ith measure is from the class of causal criteria or effective. If $r_i - c_j$ is positive (i=j), the ith measure is from the class of influence criteria. The causal graph can be plotted by two mentioned indicators called the network communication map. Based on this map, it is possible to decide how to improve the dimensions and criteria.

4.1.2 DANP technique for finding effective weights for each measure

Fifth step- normalizing the complete communication matrix of criteria ($T_C^{\propto}$) and creating an unbalanced supermatrix

Normalization of T_C with the sum of effectiveness and influence degrees of criteria and dimensions for obtaining $T_C^{\propto}$ is as follows:

$$W = (T_c^{\alpha})' = \begin{bmatrix} W^{11} & \cdots & W^{i1} & \cdots & W^{n1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \cdots & W^{ij} & \cdots & W^{nj} \\ \vdots & & \vdots & & \vdots \\ W^{1n} & \cdots & W^{in} & \cdots & W^{nn} \end{bmatrix} \quad (4.6)$$

(rows: D_1: $c_{11}, c_{12}, \ldots, c_{1m_1}$; D_j: $c_{j1}, c_{j2}, \ldots, c_{jm_j}$; D_n: $c_{n1}, c_{n2}, \ldots, c_{nm_n}$; columns: D_1: $c_{11} \ldots c_{1m_1}$; D_i: $c_{i1} \ldots c_{im_i}$; D_n: $c_{n1} \ldots c_{nm_n}$)

In the following, an example for normalizing the $T_C^{\propto 11}$ has the same calculation as above:

$$d_{ci}^{11} = \sum_{j=1}^{m_1} t_{cij}^{11}, \quad i = 1, 2, ..., m_1 \quad (4.7)$$

$$T_C^{\propto 11} = \begin{bmatrix} t_{c11}^{11}/d_{c1}^{11} & \cdots & t_{c1j}^{11}/d_{c1}^{11} & \cdots & t_{c1m1}^{11}/d_{c1}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{11}/d_{ci}^{11} & \cdots & t_{cij}^{11}/d_{ci}^{11} & \cdots & t_{cim1}^{11}/d_{ci}^{11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{11}/d_{cm1}^{11} & \cdots & t_{cm1j}^{11}/d_{cm1}^{11} & \cdots & t_{cm1m1}^{11}/d_{cm1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c11}^{\propto 11} & \cdots & t_{c1j}^{\propto 11} & \cdots & t_{c1m1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{ci1}^{\propto 11} & \cdots & t_{cij}^{\propto 11} & \cdots & t_{cim1}^{\propto 11} \\ \vdots & & \vdots & & \vdots \\ t_{cm11}^{\propto 11} & \cdots & t_{cm1j}^{\propto 11} & \cdots & t_{cm1m1}^{\propto 11} \end{bmatrix} \quad (4.8)$$

Sixth step- creating the balanced supermatrix

In this step, the transpose of the complete communication matrix was normalized, $T_C^{\propto 11}$ calculated, and the balanced supermatrix obtained:

$$W = (T_c^{\alpha})' = \begin{bmatrix} W^{11} & \cdots & W^{i1} & \cdots & W^{n1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \cdots & W^{ij} & \cdots & W^{nj} \\ \vdots & & \vdots & & \vdots \\ W^{1n} & \cdots & W^{in} & \cdots & W^{nn} \end{bmatrix} \quad (4.9)$$

(rows: D_1: $c_{11}, c_{12}, \ldots, c_{1m_1}$; D_j: $c_{j1}, c_{j2}, \ldots, c_{jm_j}$; D_n: $c_{n1}, c_{n2}, \ldots, c_{nm_n}$; columns: D_1: $c_{11} \ldots c_{1m_1}$; D_i: $c_{i1} \ldots c_{im_i}$; D_n: $c_{n1} \ldots c_{nm_n}$)

Seventh step- restricting the balanced supermatrix

The balanced supermatrix is restricted by exponents to a large number Z until the supermatrix is converged and stabilized. The output of this step is the effective weights of DANP:

$$\lim_{Z \to \infty} (W^{\propto})^Z \quad (4.10)$$

4.2 Introducing the research factors

In this section, the Delphi method is used to identify and screen the indicators; the steps of this method are given as follows.

The first round of the Delphi method

Table 1: The results of the first round of Delphi

Social risks in the projects	**The lowest score**	**The highest score**	**Mean**	**Std.**
The pressure for changing the project domain from the social and regulatory institutions	1	6	2.88	1.763
Threatening the privacy and security of assets related to megaproject beneficiaries	1	6	3.50	1.658
Social conflicts	1	6	3.63	1.728
The cost related to settlement of disputes before, while, and after implementing the megaproject of social dimension	1	6	3.25	1.984
Extreme internal and external dissatisfactions with the megaproject	3	6	4.75	0.968
Unforeseen increasing cost in terms of social issues	2	7	3.88	1.691
Unforeseen increasing time	1	7	3.88	1.763
The risk related to decrease in the project quality due to increasing costs more than expected in terms of social issues	3	7	4.63	1.317
The risk of completing the project on-time and issues related to increasing time	2	7	5.00	1.732
Unforeseen issues and social interventions of beneficiaries	4	5	4.75	0.433
The problems related to the on-site coordination	1	5	2.88	1.452

In the first step, firstly, the questionnaire is designed to screen the risks in social dimensions; it includes 11 indicators which are given to 8 experts to score each of them based on a 7-point Likert scale. In the next Delphi round, does this coefficient make considerable progress or not? The results of the first round are given in Table 1.

The results of the second round of Delphi

In the second round of Delphi, the factors with a mean less than 4 are removed from the first round. In the second round, confirmed factors related to the first round are given by the questionnaire to the experts again to score each indicator the same as the first step. Also, in this round, the mean scores of the first round are also given to them to decide based on the total average. In this round, many experts confirmed their opinions in the first step. The results of the second round are given in Table 2.

Table 2: The results related to the second round of Delphi

Social risks in the projects	**The lowest score**	**The highest score**	**Mean**	**Std.**
Extreme internal and external dissatisfaction with the megaproject	4	6	5.00	0.707
The risk of reducing the quality of the project due to the excessive cost increase from the perspective of social issues	3	7	4.88	1.166
The risk of completing the project on-time and issues related to increasing time	4	7	5.71	1.030
Unforeseen issues and social interventions of beneficiaries	4	5	4.88	0.331

The confirmed indicators of the study are given in the table below as codes

Table 3: The confirmed social risks.

Criteria	**Sub-criteria**	**Sub-criteria code**
Social risk	Extreme internal and external dissatisfaction with the megaproject;	C1
	The risk of reducing the quality of the project due to the excessive cost increase from the perspective of social issues	C2
	The risk of completing the project on-time and issues related to increasing time	C3
	Unforeseen issues and social interventions of beneficiaries	C4

4.3 DANP method

First of all, the influence and effectiveness of the research factors are explored using the DANP method; then, the importance and weight of factors are identified.

4.3.1 The results of the DANP method for social sub-criteria

Creating the direct communication matrix

The direct communication matrix is given in Table 4. This matrix has been completed based on the score of 0-4.

Table 4: The direct communication matrix of criteria.

	C1	C2	C3	C4
C1	0	2	4	2
C2	3	0	3	2
C3	4	3	0	3
C4	2	2	3	0

Normalizing the direct communication matrix

To normalize the obtained matrix, first, the sum of rows and columns of the direct communication matrix must be obtained; then, the highest value should be calculated among the total values, which is given in Table 5.

Table 5: The sum of the row and column of the direct communication matrix

	Sum of rows	sum of columns
C1	8	9
C2	8	7
C3	10	10
C4	7	7
Maximum value = 10		

Next, all the indices of this matrix are divided by 10 to be normalized that the normalized matrix is given in Table 6.

Table 6: The normalized matrix of the DEMATEL method

	C1	C2	C3	C4
C1	0	0.2	0.4	0.2
C2	0.3	0	0.3	0.2
C3	0.4	0.3	0	0.3
C4	0.2	0.2	0.3	0

Calculating the complete communication matrix (T)

To calculate the complete communication matrix, first the identity matrix ($I_{4\times4}$) is created. Then, this identity matrix is subtracted from the normal matrix and the result inverted. Finally, the normal matrix is multiplied by the inverse matrix. The complete communication matrix is given in Table 7.

Table 7: The complete communication matrix of DEMATEL criteria

	C1	C2	C3	C4
C1	1.183	1.127	1.549	1.127
C2	1.394	0.942	1.473	0.109
C3	1.655	1.338	1.465	0.338
C4	1.212	1.015	1.344	0.849

Creating the causal graph

To create the causal graph, the sum of rows (D), that of columns (R) of the complete communication matrix is obtained; then, $D + R$ and $D–R$ are calculated.

Table 8: The importance and influence of criteria

	D	R	D+R	D-R
C1	4.986	5.444	10.430	−0.458
C2	4.918	4.423	9.341	0.496
C3	5.796	5.831	11.627	−0.035
C4	4.420	4.423	8.842	−0.003

According to table 8, the indicator D shows the influence of criteria. The more the number D of a measure is, the more influence it has on a system. Based on this, the extreme increasing internal and external dissatisfaction has the most influence. The indicator R shows the effectiveness of the criteria. The more the number R of the measure is, the more acceptance that measure has in a system. In this way, the timely finished risk and the issues related to increasing time have a high effectiveness based on the social problems. Based on the $D+R$ and $D-R$ values in Table 8, the causal graph can be plotted as is shown in Figure 1. So, the criteria that are at the top of the X axis have a positive $D–R$. These criteria have a causal aspect and their effectiveness is more than their influence; the criteria that are at the bottom have the negative $D - R$. These criteria have a causal effect on the research, that is, they have a higher influence.

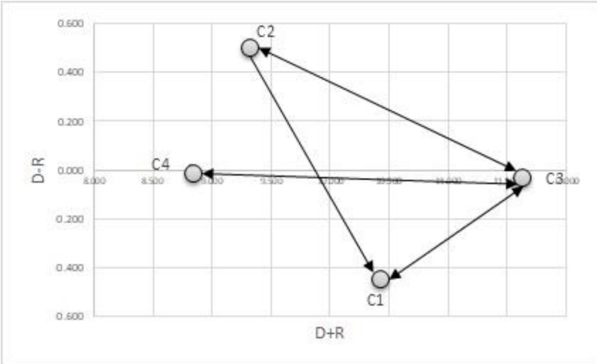

Figure 1: The causal graph of factors.

The internal relationship between the criteria

In this step, to plot the significant relationships, we specify the complete communication matrix from the threshold (arithmetic mean of indices) and each is less than it has a zero number; otherwise, if it is 1, the threshold of criteria is 1.257. These relationships are given in Table 9.

Table 9: The significant relationships between the factors

	C1	C2	C3	C4
C1	0	0	1	0
C2	1	0	1	0
C3	1	1	0	1
C4	0	0	1	0

Normalizing the complete communication matrix (T_c) and creating an unbalanced supermatrix

In this step, the complete communication matrix of Table 9 is normalized and creates an unbalanced supermatrix. The results are given in Table 10.

Table 10: Unbalanced supermatrix

	C1	C2	C3	C4
C1	0.237	0.226	0.311	0.226
C2	0.283	0.192	0.299	0.226
C3	0.286	0.231	0.253	0.231
C4	0.274	0.230	0.304	0.192

Creating an unbalanced supermatrix

In this step, the normal complete communication matrix (T_c) calculated from the previous step, is transposed to generate a balanced supermatrix. The results are given in Table 11.

Table 11: Balanced supermatrix

	C1	C2	C3	C4
C1	0.237	0.283	0.286	0.274
C2	0.226	0.192	0.231	0.230
C3	0.311	0.299	0.253	0.304
C4	0.226	0.226	0.231	0.192

Creating a limit supermatrix

In this step, a balanced supermatrix can be exponentiated to be converged. In this research, this matrix is converged by an exponent to 5. The results are given in Table 12.

The finished weights of factors

Table 12: The limit supermatrix

	C1	C2	C3	C4
C1	0.2696	0.2696	0.2696	0.2696
C2	0.2206	0.2206	0.2206	0.2206
C3	0.2900	0.2900	0.2900	0.2900
C4	0.2198	0.2198	0.2198	0.2198

The finished weight of criteria is the same number obtained from the limit supermatrix and given in Table 13. In this way, the risk of completing the project on-time is in first rank based on social problems, with a weight of 0.29 regarding the increasing time.

Table 13: The finished weights of factors

Criteria name	Criteria code	Criteria weight	Rank
Extreme internal and external dissatisfaction with the megaproject;	C1	0.2696	2
The risk of reducing the quality of the project due to the excessive cost increase from the perspective of social issues	C2	0.2206	3
The risk of completing the project on-time and issues related to increasing time	C3	0.2900	1
Unforeseen issues and social interventions of beneficiaries	C4	0.2198	4

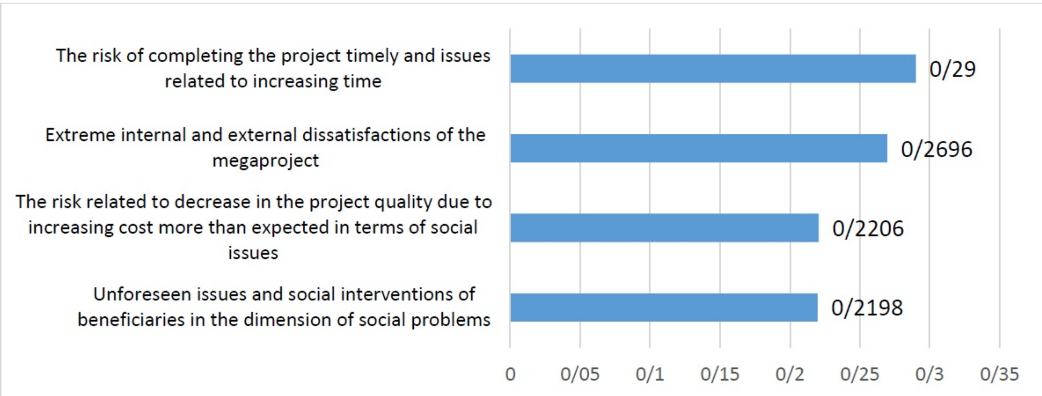

Figure 2: The finished weight of criteria.

After choosing the targeted risks in the social dimension and acquiring the causal relationships, the state-flow relationships between the extant variables are examined and the results are obtained.

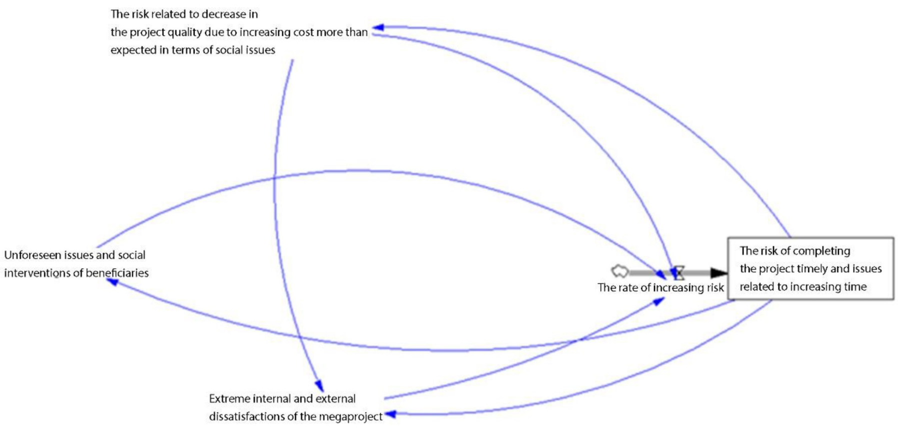

Figure 3: The model related to the risk of completing the project.

In this model, the factors affecting the risk of completing the project on-time and associated problems regarding the increasing time can be investigated in such a way that increasing the internal variables increases the value of this parameter and vice versa.

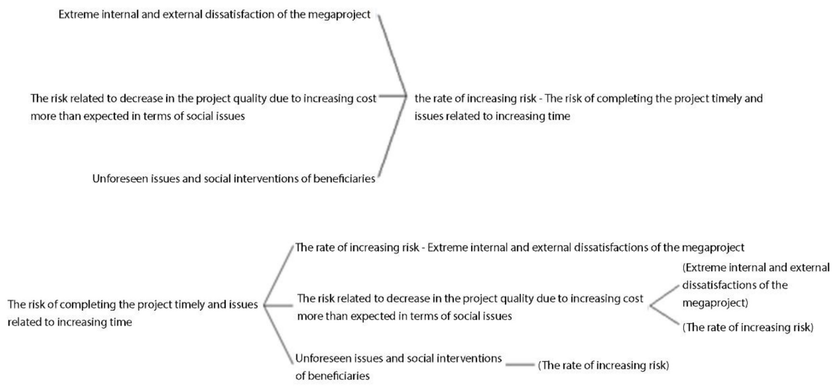

Figure 4: Relationships related to the risk parameter of completing the project timely and the issues related to increasing time.

From the existing relationships, the mutual effect of the variables, extreme internal and external dissatisfactions of the megaproject, the risk related to decrease in the project quality due to increasing cost more than expected in terms of social issues, and unforeseen issues and social interventions of beneficiaries on the risk of completing the project timely and issues related to its increasing time can be observed. In the following graphs, the behavior of this model during the coming 10 years and different scenarios have been investigated.

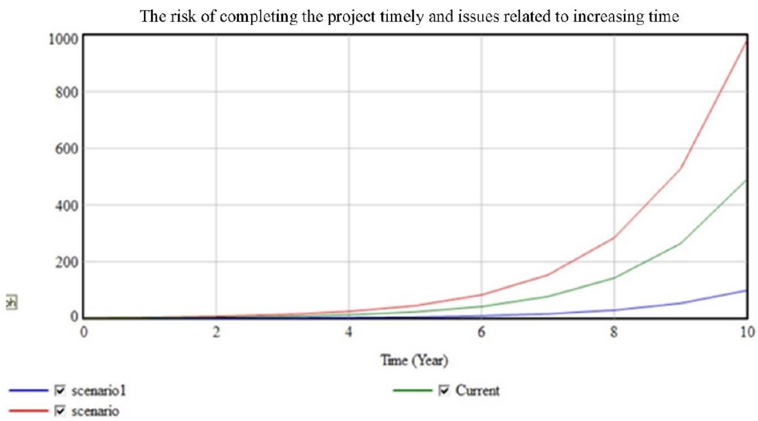

Figure 5: The risk of completing the project timely and issues related to increasing time

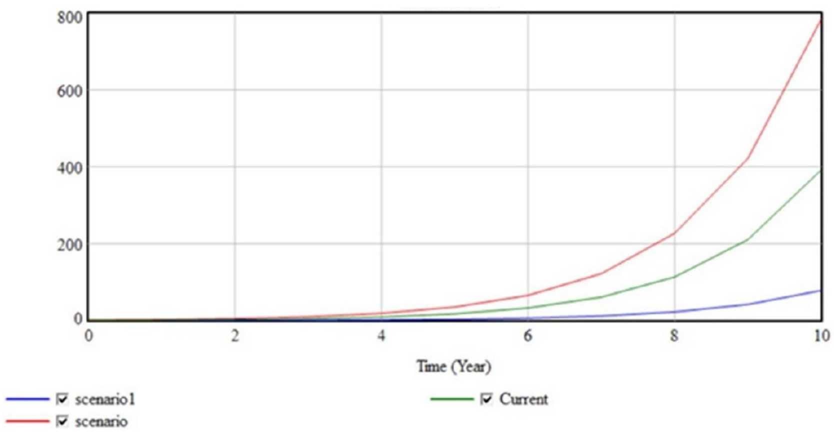

Figure 6: The risk related to decrease in the project quality due to increasing cost more than expected in terms of social issues

As seen in the above figures, the risk of completing the project has 3 risks of extreme internal and external dissatisfactions with the megaproject, unforeseen issues and social interventions of beneficiaries, and the risk related to decrease in the project quality due to increasing cost, more than expected in terms of social issues. Also, this risk

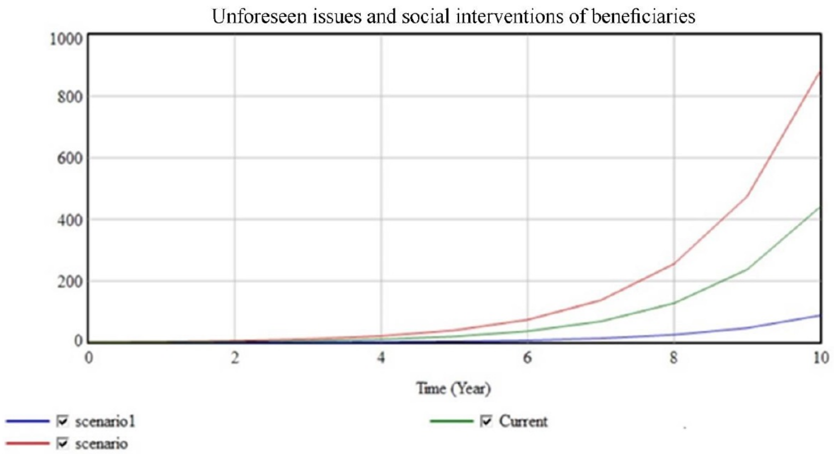

Figure 7: Unforeseen issues and social interventions of beneficiaries

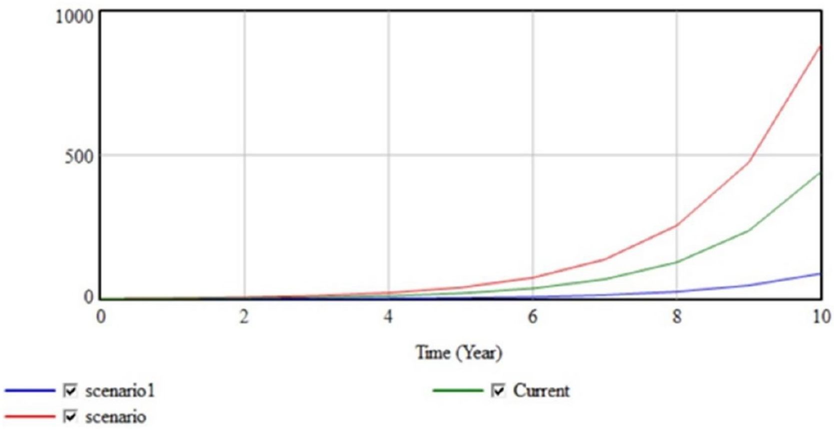

Figure 8: Extreme internal and external dissatisfactions of the megaproject

is progressing dramatically with a low slope over 6 years, and at the end of the 5th year, it reaches 41 units; however, from the beginning of the 6th year, it ascends higher and at the end of 10th year it reaches 490 because of timely completion of the project. The risk of completing the project timely and issues related to its increasing time can be reduced by decreasing the extreme internal and external dissatisfactions of the megaproject, increasing the risk of decrease in the project quality due to increasing costs more than expected in terms of social issues, and unforeseen issues and social interventions of beneficiaries.

4.4 Model validation

To prove the correctness of the modeling and its results, one of the public validation methods that has a great deal of attention is the limit condition test (LCT), which has been used in this research.

4.4.1 LCT

In this test, the variations outside the normal range are created in the variables, and the behavior of the model is investigated on these points. To perform this test, the risk of completing the project timely and issues related to its increasing time is varied to 100 units and based on this figure, these variations are visible and tangible in other variables. So, it can be concluded that the model is valid.

Calculations

$$\text{The risk of completing the project on-time and issues related to its increasing time} = INTEG(\text{the rate of increasing risk} + 1) \tag{4.11}$$

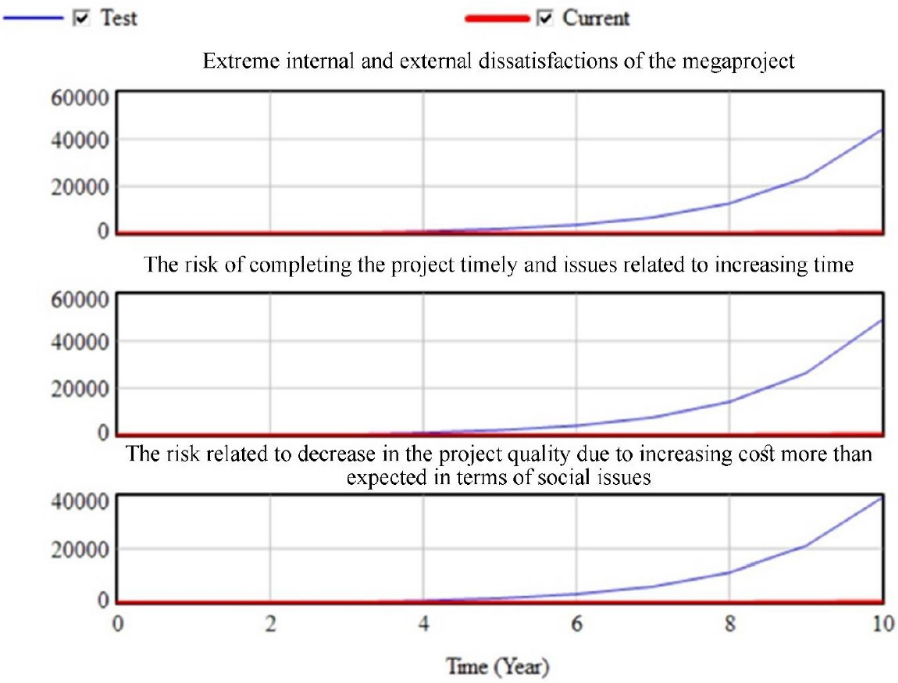

Figure 9: Extreme internal and external dissatisfactions of the megaproject; The risk of completing the project timely and issues related to increasing time; The risk related to decrease in the project quality due to increasing cost more than expected in terms of social issues

$$\text{The rate of increasing risk} = \\ \text{unforeseen issues and social interventions of beneficiaries} \times 0.33 + \text{extreme internal and external dissatisfactions} \times 0.33 + \\ \text{The risk related to a decrease in the project quality due to increasing costs more than expected in terms of social issues} \times 0.33 \tag{4.12}$$

$$\text{The risk related to a decrease in the project quality due to increasing costs more than expected in terms of social issues} = \\ \text{The risk of completing the project timely and issues related to its increasing time} \times 0.8 \tag{4.13}$$

$$\text{unforeseen issues and social interventions of beneficiaries} = \\ \text{The risk of completing the project timely and issues related to its increasing time} \times 0.9 \tag{4.14}$$

$$\text{The extreme internal and external dissatisfactions of the megaproject} = \\ \text{The risk of completing the project timely and issues related to its increasing time} \times 0.5 \tag{4.15}$$

$$\text{The risk related to a decrease in the project quality due to increasing costs more than expected in terms of social issues} \times 0.5 \tag{4.16}$$

5 Discussion and conclusion

To analyze systematically the social risks in megaprojects, this study proposed a behavioural model based on multi-criteria decision-making techniques and system dynamics. Then, for the first time, the compound method of multi-criteria decision-making techniques and system dynamics is used for social risks and quantitative analysis of megaprojects in this study. The compound model is composed of two parts: causal relationships and social risk analysis. The social risk analysis was performed through the sensitivity analysis and scenario analysis of the behavioural model.

The contribution of this study is to complete the social risk identification of the megaprojects to present a creative path for social risk evolution to describe a dynamic interaction of social risk. Moreover, combining the benefits of multi-criteria decision-making techniques with system dynamics, this study develops a quantitative analysis model of the social risk which is suitable for any kind of megaproject. We expect that the results of this study facilitate the perception of analysis and management of social risk of megaprojects. Future studies should investigate the social risk of any kind of megaprojects and test the validity of the proposed model to find the similarities and differences between the various projects. Moreover, this model of social risk can be merged by the shareholders' management to improve decision-making.

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