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A MATHEMATICAL FORMULATION OF TIME-COST AND RELIABILITY OPTIMIZATION FOR SUPPLY CHAIN MANAGEMENT IN RESEARCH-DEVELOPMENT PROJECTS

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Abstract. One of the most important strategic decisions in Research-Development projects is network design. It needs to be optimized for the long-term efficient operation. This paper aims at designing the network of Supply Chain for R&D projects. Accordingly, it proposes a Goal programming model for solving a Project-oriented Supply Chain Management problem. The proposed model is developed to determine the optimal combination of the main contractors, executers, and various alternatives for project implementation. The model optimizes time, cost and reliability in the whole lifecycle for the R&D projects. A case study is presented to validate and illustrate the proposed model. The main reason for the high cost and time in the case study was due to the incorrect choice of the network of suppliers and consultants. The model has been tested by the numerical data, revealing that the model could have a significant contribution to the productivity of project-oriented organization. This model could serve as a guideline for managers and decision makers in R&D projects, enabling them to identify the best networks of the SC in their organizations to resolve and improve problems. It also acts as a useful basis for researchers to continue research concerning SCM in R&D projects.

Mathematics Subject Classification. 90C29.

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1. Introduction

The SCM requires the proper selection of the participating members. PSCs are complex in structure and consist of numerous participants. Although there are advantages in applying the SC in projects, project managers and project-based organizations do not know how to use the PSCM in their projects. Mohamed *et al.* states that about 40% of the work in the construction industry includes non-value added activities such as the time spent to get approvals or to receive materials at the project site [13].

SCs in R&D project face many problems in the Iranian industries. In the pull strategy, in response to the market, project-driven organizations have been tackling with significant problems in the integration levels and actions in the acquisition cycle, supply and support in the lifecycle. Specific projects delays can be the result of inappropriate actions regarding the supply of needed materials and resources, both technically and systematically. In the push strategy, in response to technological pressure, R&D projects are faced with the

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rapid technological changes. They cannot be flexible and adaptable to environmental conditions. Projects may not have efficiency and cannot be effective and active in the operating environment consisting of a large number of participants who work together. It should be, therefore, possible to reduce the gap between idea creation and production output (the project lifecycle) in the shortest reasonable time with the optimization and integration of the whole stakeholder's network involved.

SC network design for R&D projects can help to understand the complexity, identify the bottlenecks, prioritize resources, and add values to the projects. R&D projects organizations need to understand the issues and the cognitive abilities of SCs [5]. They need to create interactivity, cooperation, and coordination (integration) between executors, contractors, suppliers, subcontractors and other organizations to resolve the critical problems. In addition, they should design the network to gain the maximum benefit of knowledge and non-knowledge resources, which represent their existing potential capabilities in the national industry across various industries. They should also plan technology development and demonstration to minimize uncertainty [11, 21].

Therefore, the main purpose of this paper has been to design the SC network for R&D projects and to elaborate on a quantitative method for the stakeholders' selection process. In addition, the developed model considers multiple objectives. It is based on the Goal programming approach. The mathematical model will indicate the best basket of stakeholders for collaborating on the R&D projects. The model optimizes time, cost and reliability in the whole lifecycle for the R&D projects. Finally, to illustrate the applications of the model, a hypothetical experiment with the realistic data related to an Iranian organization in a R&D project is used. The model is implemented in the GAMS Optimization software.

This paper proceeds with the theoretical background and literature review on PSCM in R&D in Section 2. Section 3 presents the mathematical model. Section 4 introduces the solution methodology of this model and the numerical results. Finally, conclusions are drawn in Section 5.

2. Theoretical background and literature review

R&D projects are a temporary set of activities with high uncertainties. They are intended to fulfil the scientific discovery and production of new knowledge or to achieve specific system tools. They include any scientific research in science, technology and systems at any organizational level [12, 21].

SCM is a set of approaches used to integrate suppliers manufacturers, warehouses, and stores efficiently [6], [4]. SC defines a management linking the organizations in order to fulfil demands across the whole chain as efficiently as possible. The aim of the SC is to satisfy all customers with more facilities, less costand time, as well as enuring good quality [18]. So, SC is a distribution and facility network implementing the activities of material procurement and its reformation into finished and intermediary products, as well as the finished products distributed to customers [8]. Recently, there has been a growing interest in the performance, design, and the study of the SC as a whole [10].

The use of mathematical models to optimize the SC has recently been increased; this has been mainly because of their lower cost and higher capability. Sarkar *et al.* considers a SC coordination model with backorder for the buyer, an inspection cost for the vendor, and a coordination strategy between them [17]. The use of mathematical modeling is not specific to any particular level; it can be used at any level (strategic, tactical or operational). In a paper, an algebraical procedure was employed to obtain the minimum cost of the entire SCM [19]. Asghari examined the applicability of numerous measures and metrics in a multi objective optimization problem of the SC network design to allocate customers' orders. He determined the important aspects of strategic planning of manufacturing in a SC model [18]. However, considering the effects of all the sustainability enablers may affect decisions of logistics managers during planning their activities in an efficient manner [14, 17]. It is apparent that the modelling approach and solution methods are very closely associated with the complexity of the SC structure. Also, along with developing solution techniques and enhancing the capability of modern computing technologies over the last years, researchers can deal with more complicated PSC structures [4, 7, 21].

PSCM has emerged both from the SC and from the project management domain. In fact, PSCM is the management of a complex and dynamic network of integrated companies, organizations and stakeholders involved in

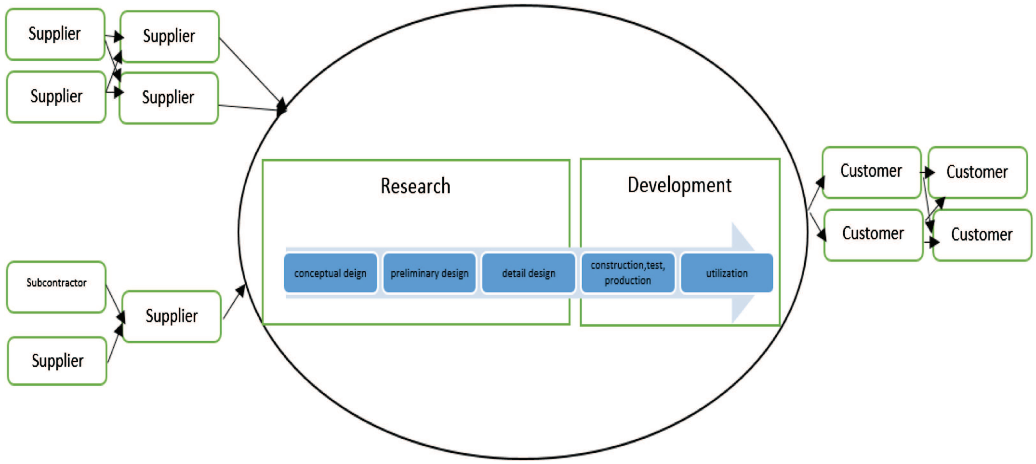


FIGURE 1. The project supply chain [9].

FIGURE 2. R&D project lifecycle (Source: [20]).

different chains for satisfying the project's final customer [1,2,15]. The SC of R&D project involves the selection of the Contractor, the Executor, the Alternative, the Supplier, and the Consultant (Fig. 1).

The lifecycle of the R&D project commences with the statement of need, and it ends with the disposal of the project. There is no universally accepted agreement on how many phases exist in a project lifecycle. According to Blanchard and Fabrycky, as well as MIL-STD 499B, the project lifecycle can be divided into two phases: the acquisition phase and the utilization phase. The acquisition phase comprises six main stages: need assessment, feasibility study, conceptual design, preliminary design, detail design, and construction-test-production. The utilization phase consists of operational use and system support [20]. In this article, the lifecycle of R&D projects is divided into five stages: conceptual design, preliminary design, detail design, production and utilization (Fig. 2).

One of the key criteria in the selection process is the integration and expansion of the model for the whole lifecycle of the projects via the system engineering approach. The most important benefit of system engineering is the scope provided for saving money during all phases of the system life cycle. Experience indicates that the early emphasis on system engineering can result in significant cost savings later in the whole life cycle [3]. System engineering should also assist in reducing the overall schedule associated with bringing the system into service. System engineering ensures that the user requirement is accurately reflected in the design of the system, thereby helping to minimize costly and time-consuming changes that may be required later in the life cycle.

System engineering focuses on the entire system life cycle and considers this life cycle during decision-making processes. A system' life cycle begins during system definition and design, and passes through construction and production, operation, support, and phase-out. The life cycle is concluded only with the disposal of the system. In another paper, authors consider design options only for research projects associated with the acquisition phase for the optimization of time and cost, not paying attention to through-life support issues [9]. Authors typically focus on the acquisition phase of the research project and on the development of a system meeting

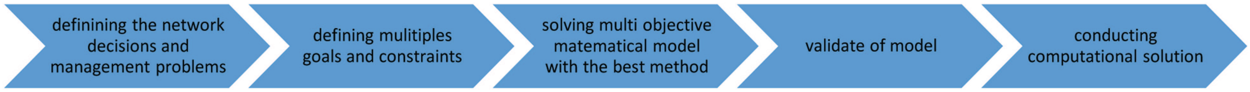


Figure 3. The Proposed methodology.

the design requirement while minimizing cost and time. This has often led to larger than expected costs in the utilization phase that should be provided by budgets insufficient to keep systems in service. A system focus takes into account all constituent elements of the system, including operation, support, and retirement or disposal. In this paper, authors develop a mathematical model considering R&D projects through the system engineering approach.

Therefore, PSCM and its importance in R&D projects have not been considered adequately in the recent research for the whole lifecycle. Network design is costly and complicated for the R&D projects. In fact, choosing the stakeholders and their allocation is a complicated optimization problem. Therefore, the main aim of the present paper has been optimization of time, cost and reliability in the whole life cycle.

3. Research methodology

This study proposes a mathematical model to determine the optimal combination of the main contractors, executors, and various alternatives for the project implementation. It determines how the devolution of activities in each of the five stages of the R&D project is divided among the consultants for monitoring suppliers during the supply of materials, specialized labourand product. The model aims to minimize the cost of the project, maximize reliability, and minimize the time required for the implementation of the project. This model assists the simultaneous optimization of the three goals of cost, reliability and time. The methodology for solving the network problem is developed using a five-step procedure. Figure 3 indicates the steps involved in this methodology.

The assumptions of the model are:

- All the objectives and constraints are considered linear functions.
- The earliest start time of the project is equal to zero.
- A project with N activities is considered. The precedence relations of the activities are zero-lag, finish to start. The node network with no loop shows the activity. Activities 1 and N are dummies representing the project start and project completion, respectively.
- All the R&D projects conducted in five stages include the feasibility study and conceptual design, preliminary design, detail design, construction and production, and utilization.
- The amount required for the material m to become the activity j is independent of the activity duration.
- All the needed amounts of each material for each activity are ordered at the same time.
- To carry out any project, at first, the main contractor must be selected.
- The main contractor works with a project executor. Therefore, the main contractor selection is the decision variable of the model.
- The selected executer should select and execute an option among the available alternatives to implement the project and to achieve the ultimate goals, such as the optimization of the objective functions.
- After the selection of the existing alternatives, the beginning of the project lifecycle includes the conceptual design, the preliminary design, the detailed design, the production, and the utilization. This lifecycle is shown in Figure 2.
- Each of the above steps consists of activities that need a series supplier and a consultant to supervise their implementation. There are so many suppliers and consultants for each activity selected. Decision variables in this model are a fraction of the supply and the monitoring of any activity included in any of the available options.

Table 1. The indices used in the model.

Description	Indices
The index for the selection of the main contractor	$i_1 = 1, \ldots, n_1$
The index for the selection of the project executer	$i_2 = 1, \ldots, n_2$
The index for the selection of alternatives	$i_3 = 1, \ldots, n_3$
The index for activities of conceptual design	$i_4 = 1, \ldots, n_4$
The index for activities of preliminary design	$i_5 = 1, \ldots, n_5$
The index for activities of detail design	$i_6 = 1, \ldots, n_6$
The index for activities of construction and production	$i_7 = 1, \ldots, n_7$
The index for activities of utilization	$i_8 = 1, \ldots, n_8$
The index for the suppliers of conceptual design activities	$j_1 = 1, \ldots, m_1$
The index for the consultant of conceptual design activities	$j_2 = 1, \ldots, m_2$
The index for suppliers of preliminary design activities	$j_3 = 1, \ldots, m_3$
The index for consultant of preliminary design activities	$j_4 = 1, \ldots, m_4$
The index for suppliers of detail design activities	$j_5 = 1, \ldots, m_5$
The index for consultant of detail design activities	$j_6 = 1, \ldots, m_6$
The index for the suppliers of construction and production activities	$j_7 = 1, \ldots, m_7$
The index for consultant of construction& production activities	$j_8 = 1, \ldots, m_8$
The index for the consultant of utilization activities	$j_9 = 1, \ldots, m_9$

The signs and symbols are used to explain the problem, assumptions, and mathematical modeling. In Table 1, the symptoms related to the used indices in the problem modeling are given.

In Table 2, the symptoms related to the used parameters in the modeling are shown.

In Table 3, the symptoms related to decision variables and their dependent variables are shown.

3.1. Mathematical modelling

The purpose of this article is the simultaneous optimization of three objectives including time, cost and reliability of the R&D project. The model of this study is development of authors' model for research projects [9].

3.2. Proposed model

3.2.1. Objective functions and constraints

Firstly, one main contractor should be selected. Then, the main contractor selects an executor and the best alternative for the project implementation. The first constraint implies that only a main contractor will be chosen for the project.

$$\sum_{i_1=1}^{n_1} \mathrm{MC}_{i_1} = 1, \qquad \forall i_1 : \mathrm{MC}_{i_1} = 0 \text{ or } 1 \tag{3.1}$$

– Constraints on the project executor by the selection of only one executor.

$$\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \mathrm{EX}_{i_1,i_2} = 1, \quad \forall i_1, i_2 : \mathrm{EX}_{i_1,i_2} = 0 \text{ or } 1 \tag{3.2}$$

– Constraints on the selected contractor by the executor.

$$\sum_{i_2=1}^{n_2} \mathrm{EX}_{i_1,i_2} - \mathrm{MC}_{i_1} = 0, \quad i_1 = 1, \ldots, n_1 \tag{3.3}$$

TABLE 2. The used parameters in the model.

Description	Parameter
The demand or requirements related to the i_4 activity in the conceptual design	$\text{Demand}_{i_1,i_2,i_3,i_4}$
The response capacity of j_1 supplier to the i_4 activity in the conceptual design phase	$\text{CapSupe}_{i_1,i_2,i_3,i_4,j_1}$
The time distance between the end of the i_4 activity and start of the i'_4 activity in the conceptual design phase	$\text{lag}_{i_1,i_2,i_3,i_4,i'_4}$
The required time for doing the i_4 activity if it is fully transferred to the j_1 supplier in the conceptual design phase	$\text{tesup}_{i_1,i_2,i_3,i_4,i_5,j_3}$
Demand or counseling need or the monitoring of the i_4 activity in the conceptual design phase	$\text{Demandc}_{i_1,i_2,i_3,i_4}$
The response capacity of the j_2 consultant to the i_4 *activity* in the conceptual design phase	$\text{CapConse}_{i_1,i_2,i_3,i_4,j_2}$
The required cost to perform the i_4 activity if it is fully transferred to the j_1 supplier in the conceptual design phase	$\text{csupe}_{i_1,i_2,i_3,i_4,j_1}$
The required cost to perform the i_4 activity if it is fully transferred to the j_2 consultant in the conceptual design phase	$\text{cconse}_{i_1,i_2,i_3,i_4,j_2}$
The reliability to perform the i_4 activity if it is fully transferred to the j_1 supplier in the conceptual design phase	$\text{qsupe}_{i_1,i_2,i_3,i_4,j_1}$
The reliability to perform the i_4 activity if it fully transferred to the j_2 consultant in the conceptual design phase	$\text{qconse}_{i_1,i_2,i_3,i_4,j_2}$
The demand or requirements related to the i_5 activity in the preliminary design	$\text{Demand}_{i_1,i_2,i_3,i_5}$
The response capacity of j_3 suppliers to the i_5 activity in the preliminary design phase	$\text{CapSupc}_{i_1,i_2,i_3,i_5,j_3}$
The Time distance between the end of the i_5 activity and start of the i'_5 activity in the preliminary design phase	$\text{lag}_{i_1,i_2,i_3,i_5,i'_5}$
The required time for doing the i_5 activity if it is fully transferred to the j_3 supplier in the preliminary design phase	$\text{tcsup}_{i_1,i_2,i_3,i_5,j_3}$
Demand or counseling need or the monitoring of the i_5 activity in the preliminary design phase	$\text{Demandc}_{i_1,i_2,i_3,i_5}$
The response capacity of the j_4 consultant to the i_5 *activity* in the preliminary design phase	$\text{CapConsc}_{i_1,i_2,i_3,i_4,j_4}$
The required cost to perform the i_5 activity if it is fully transferred to the j_3 supplier in the preliminary design phase	$\text{csupc}_{i_1,i_2,i_3,i_5,j_3}$
The required cost to perform the i_5 activity if it is fully transferred to the j_4 consultant in the preliminary design phase	$\text{cconsc}_{i_1,i_2,i_3,i_5,j_4}$
The reliability to perform the i_5 activity if it is fully transferred to the j_3 supplier in the preliminary design phase	$\text{qsupc}_{i_1,i_2,i_3,i_5,j_3}$
The reliability to perform the i_5 activity if it is fully transferred to the j_4 consultant in the preliminary design phase	$\text{qconsc}_{i_1,i_2,i_3,i_5,j_4}$
The demand or requirements related to the i_6 activity in the detail design	$\text{Demand}_{i_1,i_2,i_3,i_6}$
The response capacity of j_5 suppliers to the i_6 activity in the detail design phase	$\text{CapSupd}_{i_1,i_2,i_3,i_6,j_5}$
The Time distance between the end of the i_6 activity and start of the i'_6 activity in the detail design phase	$\text{lag}_{i_1,i_2,i_3,i_6,i'_6}$
The required time for doing the i_6 activity if it is fully transferred to the j_5 supplier in the detail design phase	$\text{tdsup}_{i_1,i_2,i_3,i_6,j_5}$
Demand or counseling need or the monitoring of the i_6 activity in the detail design phase	$\text{Demandc}_{i_1,i_2,i_3,i_6}$
The response capacity of the j_6 consultant to the i_6 *activity* in the detail design phase	$\text{CapConsd}_{i_1,i_2,i_3,i_6,j_6}$
The required cost to perform the i_6 activity if it is fully transferred to the j_5 supplier in the detail design phase	$\text{csupd}_{i_1,i_2,i_3,i_6,j_5}$
The required cost to perform the i_6 activity if it is fully transferred to the j_6 consultant in the detail design phase	$\text{cconsd}_{i_1,i_2,i_3,i_6,j_6}$
The reliability to perform the i_6 activity if it is fully transferred to the j_5 supplier in the detail design phase	$\text{qsupd}_{i_1,i_2,i_3,i_6,j_5}$

TABLE 2. (continued.)

Description	Parameter
The reliability to perform the i_6 activity if it is fully transferred to the j_6 consultant in the detail design phase	$\text{qconsd}_{i_1,i_2,i_3,i_6,j_6}$
The demand or requirements related to the i_7 activity in the production phase	$\text{Demand}_{i_1,i_2,i_3,i_7}$
The response capacity of j_7 suppliers to the i_7 activity in the production phase	$\text{CapSupp}_{i_1,i_2,i_3,i_7,j_7}$
The Time distance between the end of the i_7 activity and start of the i'_7 activity in the production phase	$\text{lag}_{i_1,i_2,i_3,i_7,i'_7}$
The required time for doing the i_7 activity if it is fully transferred to the j_7 supplier in the production phase	$\text{tpsup}_{i_1,i_2,i_3,i_7,j_7}$
Demand or counseling need or the monitoring of the i_7 activity in the production phase	$\text{Demandc}_{i_1,i_2,i_3,i_7}$
The response capacity of the j_8 consultant to the i_7 *activity* in the production phase	$\text{CapConsp}_{i_1,i_2,i_3,i_7,j_8}$
The required cost to perform the i_7 activity if it is fully transferred to the j_7 supplier in the production phase	$\text{csupp}_{i_1,i_2,i_3,i_7,j_7}$
The required cost to perform the i_7 activity if it is fully transferred to the j_8 consultant in the production phase	$\text{cconsp}_{i_1,i_2,i_3,i_7,j_8}$
The reliability to perform the i_7 activity if it is fully transferred to the j_7 supplier in the production phase	$\text{qsupp}_{i_1,i_2,i_3,i_7,j_7}$
The reliability to perform the i_7 activity if it is fully transferred to the j_8 consultant in the production phase	$\text{qconsp}_{i_1,i_2,i_3,i_7,j_8}$
Demand or counseling need or the monitoring of the i_8 activity in the utilization phase	$\text{Demandc}_{i_1,i_2,i_3,i_8}$
The response capacity of the j_9 consultant to the i_8 *activity* in the utilization phase	$\text{CapConsi}_{i_1,i_2,i_3,i_8,j_9}$
The required cost to perform the i_8 activity if it is fully transferred to the j_9 consultant in the utilization phase	$\text{cconsi}_{i_1,i_2,i_3,i_8,j_9}$
The reliability to perform the i_8 activity if it is fully transferred to the j_9 consultant in the utilization phase	$\text{qconsi}_{i_1,i_2,i_3,i_8,j_9}$

– Constraints on the sequence needed to choose an alternative. It makes choices on the related alternatives for the main contractor and the selected executor in the previous step.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3} A_{i_1,i_2,i_3} = 1, \quad \forall i_1,i_2,i_3 : A_{i_1,i_2,i_3} = 0 \text{ or } 1 \tag{3.4}$$

$$\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3} A_{i_1,i_2,i_3} - \text{MC}_{i_1} = 0, \quad i_1 = 1,\ldots,n_1 \tag{3.5}$$

$$\sum_{i_3=1}^{n_3} A_{i_1,i_2,i_3} - \text{EX}_{i_1,i_2} = 0, \quad \forall i_1,i_2 \tag{3.6}$$

3.2.1.1. *Conceptual design phase.* After the alternative has been selected, the conceptual design stage starts. This phase consists of several activities. Each activity must supply a fraction of their supply needs through the existing suppliers. The sum of these fractions should be equal to one. The constraint seven also states that the supply fraction for each activity of each supplier has to be a number between zero and one.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_1=1}^{m_1} \text{supe}_{i_1,i_2,i_3,i_4,j_1} = 1, i_4 = 1,\ldots,n_4 \tag{3.7}$$
$$\forall i_1,i_2,i_3,i_4,j_1 : 0 \leq \text{supe}_{i_1,i_2,i_3,i_4,j_1} \leq 1$$

The following constraint indicates that the amount of supply dedicated to each of the suppliers is equal to a fraction of the activity needed while being prepared by the suppliers. It must be less than the capacity of the

TABLE 3. Decision variables in the model.

Variable	Description
MC_{i_1}	Variable related to the selection or not to the selection of the main contractor
EX_{i_1,i_2}	Variable related to the selection or not to the selection of the project executer
A_{i_1,i_2,i_3}	Variable related to the selection or not to the selection of alternatives
$supe_{i_1,i_2,i_3,i_4,j_1}$	Variable related to a fraction of the i_4 activity supply of the j_1 suppliers in the conceptual design phase
tes_{i_1,i_2,i_3,i_4}	Start time of i_4 activity in the conceptual design phase
tef_{i_1,i_2,i_3,i_4}	Completion time of i_4 activity in the conceptual design phase
te_{i_1,i_2,i_3,i_4}	The required time for implementation of i_4 activity in the conceptual design phase
TED	The finish time of the conceptual design phase
$conse_{i_1,i_2,i_3,i_4,j_2}$	Variable related to a fraction of the i_4 activity supply of the i_2 counsellor in the conceptual design phase
CED	The total cost of conceptual design phase
$QSED_{i_4}$	The reliability of the implementation i_4 activities suppliers in the conceptual design phase
$QCED_{i_4}$	The reliability of the implementation i_3 activities counselor in the conceptual design phase
logQED	The log reliability of the conceptual design stage implementation
$supc_{i_1,i_2,i_3,i_5,j_3}$	Variable related to a fraction of i_5 activity supply from j_3 suppliers in the preliminary design phase
tcs_{i_1,i_2,i_3,i_5}	Start time of i_5 activity in the preliminary design phase
tcf_{i_1,i_2,i_3,i_5}	Completion time of i_5 activity in the preliminary design phase
tc_{i_1,i_2,i_3,i_5}	The required time for implementation of i_5 activity in the preliminary design phase
TCD	Finish time of preliminary design phase
$consc_{i_1,i_2,i_3,i_5,j_4}$	variable related to the fraction of the i_5 activities supply of j_4 counselor in the preliminary design phase
CCD	Total cost of preliminary design phase
$QSCD_{i_5}$	Reliability of implementation i_5 activities suppliers in the preliminary design phase
$QCCD_{i_5}$	Reliability of implementation i_5 activities counsellor in the preliminary design phase
logQCD	Log reliability of preliminary design stage implementation
$supd_{i_1,i_2,i_3,i_6,j_5}$	Variable related to a fraction of i_6 activity supply from j_5 suppliers in the detail design phase
tds_{i_1,i_2,i_3,i_6}	Start time of i_6 activity in the detail design phase
tdf_{i_1,i_2,i_3,i_6}	Completion time of i_6 activity in the detail design phase
td_{i_1,i_2,i_3,i_6}	The required time for implementation of i_6 activity in the detail design phase
TDD	Finish time for detail design phase
$consd_{i_1,i_2,i_3,i_6,j_6}$	variable related to the fraction of the i_6 activities supply of j_6 counselor in the detail design phase
CDD	Total cost of detail design phase
$QSDD_{i_6}$	Reliability of implementation i_6 activities suppliers in the detail design phase
$QCDD_{i_6}$	Reliability of implementation i_6 activities counsellor in the detail design phase
logQDD	Log reliability of detail design stage implementation
$supp_{i_1,i_2,i_3,i_7,j_7}$	Variable related to a fraction of i_7 activity supply from j_7 suppliers in the production phase
tps_{i_1,i_2,i_3,i_7}	Start time of i_7 activity in the production phase
tpf_{i_1,i_2,i_3,i_7}	Completion time of i_7 activity in the production phase
tp_{i_1,i_2,i_3,i_7}	The required time for implementation of i_7 activity in the production phase
TP	Finish time of production phase
$consp_{i_1,i_2,i_3,i_7,j_8}$	variable related to the fraction of the i_7 activities supply of j_8 counselor in the production phase
CP	Total cost of production phase
QSP_{i_7}	Reliability of implementation i_7 activities suppliers in the production phase
QCP_{i_7}	Reliability of implementation i_7 activities counsellor in the production phase

TABLE 3. (continued.)

Variable	Description
logQP	Log reliability of production stage implementation
$\text{consi}_{i_1,i_2,i_3,i_8,j_9}$	variable related to the fraction of the i_8 activities supply of j_9 counselor in the utilization phase
CI	Total cost of the utilization phase
QCI_{i_8}	Reliability of implementation i_8 activities counsellor in the utilization phase
logQI	The log reliability of the utilization stage implementation

suppliers.

$$\text{Demand}_{i_1,i_2,i_3,i_4} \times \text{supe}_{i_1,i_2,i_3,i_4,j_1} \leq \text{CapSupe}_{i_1,i_2,i_3,i_4,j_1}, \qquad \forall i_1, i_2, i_3, i_4, j_1 \tag{3.8}$$

The following constraint indicates that the start time of the first activity will be zero in the contractor's selection of all possible scenarios, executors and alternatives; this is because this is the first activity of the first stage of the project.

$$\text{tes}_{i_1,i_2,i_3,1} = 0, \qquad \forall i_1, i_2, i_3 \tag{3.9}$$

The following constraint indicates that the end time of each activity is equal to the time duration of the activity implementation by adding the activity start time.

$$\text{tef}_{i_1,i_2,i_3,i_4} \geq \text{tes}_{i_1,i_2,i_3,i_4} + \text{te}_{i_1,i_2,i_3,i_4}, \qquad \forall i_1, i_2, i_3, i_4 \tag{3.10}$$

The following constraint indicates that the start of any activity can be specified based on the end of its preferred activity and the time duration between the end of the preferred activity and the beginning of the dependent activity.

$$\text{tef}_{i_1,i_2,i_3,i_4} + \text{lag}_{i_1,i_2,i_3,i_4,i'_4} \leq \text{tes}_{i_1,i_2,i_3,i'_4}, \qquad \forall i_1, i_2, i_3, i_4, i'_4 \tag{3.11}$$

Through consideration, any supplier can reach a fraction of the supply. The time duration of implementation will be a fraction of the project implementation that will be entirely implemented by the suppliers. The time duration of the project implementation is the maximum involved time of the suppliers in this project.

$$\text{te}_{i_1,i_2,i_3,i_4} = \max_{j_1} \left(\text{tesup}_{i_1,i_2,i_3,i_4,j_1} \times \text{supe}_{i_1,i_2,i_3,i_4,j_1}\right), \quad \forall i_1, i_2, i_3, i_4 \tag{3.12}$$

Time running out of a stage to reach another stage, such as in the conceptual design stage, is equal to the maximum time for the completion of the activities. It is calculated with the constraint 13.

$$\text{TED} = \max_{i_1,i_2,i_3,i_4} \left(\text{tef}_{i_1,i_2,i_3,i_4}\right) \tag{3.13}$$

– Constraints on monitoring the implementation of the activities by the consultants and the supervisors.

$$\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_2=1}^{m_2} \text{conse}_{i_1,i_2,i_3,i_4,j_2} = 1, i_4 = 1, \ldots, n_4 \tag{3.14}$$

$$\forall i_1, i_2, i_3, i_4, j_2 : 0 \leq \text{conse}_{i_1,i_2,i_3,i_4,j_1} \leq 1$$

$$\text{Demandc}_{i_1,i_2,i_3,i_4} \times \text{conse}_{i_1,i_2,i_3,i_4,j_2} \leq \text{CapConse}_{i_1,i_2,i_3,i_4,j_2}, \quad \forall i_1, i_2, i_3, i_4, j_2 \tag{3.15}$$

– Constraints on implementing the cost of the conceptual design stage.

$$\sum_{i_4=1}^{n_4}\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_1=1}^{m_1}\text{csupe}_{i_1,i_2,i_3,i_4,j_1}\times\text{supe}_{i_1,i_2,i_3,i_4,j_1}+\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_2=1}^{m_2}\text{cconse}_{i_1,i_2,i_3,i_4,j_2}\times\text{conse}_{i_1,i_2,i_3,i_4,j_2}\right)=\text{CED} \tag{3.16}$$

– Constraints on the supply reliability of each activity.

$$\text{QCED}_{i_4}=\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_2=1}^{m_2}\text{qconse}_{i_1,i_2,i_3,i_4,j_2}\times\text{conse}_{i_1,i_2,i_3,i_4,j_2}, i_4=1,\ldots,n_4 \tag{3.17}$$

Owing to the nature of reliability, it is necessary to calculate the total reliability of the stage. So, the logarithm (3.17) is used for the linearization of the related limitation. Owing to this limit, the sum of several variables cannot replace its log independent expression. So, it is used in the Taylor expansion of log $(1+x)$ for the condition in which x is in the interval $(-1,\, 1)$. As mentioned previously, the following constraint is a new form of the constraint (3.17).

$$\begin{aligned}\text{logQCED}_{i_4}&=\log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_2=1}^{m_2}\text{qconse}_{i_1,i_2,i_3,i_4,j_2}\times\text{conse}_{i_1,i_2,i_3,i_4,j_2}\right)-1\right)\right)\\&=\left(\text{QCED}_{i_4}-1\right)-\left(\left(\text{QCED}_{i_4}-1\right)^2/2\right), i_4=1,\ldots,n_4\end{aligned} \tag{3.18}$$

– Constraints on monitoring the reliability of every activity.

$$\text{QSED}_{i_4}=\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_1=1}^{m_1}\text{qsupe}_{i_1,i_2,i_3,i_4,j_1}\times\text{supe}_{i_1,i_2,i_3,i_4,j_1},\qquad i_4=1,\ldots,n_4 \tag{3.19}$$

The reason is the same as those mentioned in the constraints (3.17) and (3.18).

$$\begin{aligned}\text{logQSED}_{i_4}&=\log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_1=1}^{m_1}\text{qsupe}_{i_1,i_2,i_3,i_4,j_1}\times\text{supe}_{i_1,i_2,i_3,i_4,j_1}\right)-1\right)\right)\\&=\left(\text{QSED}_{i_4}-1\right)-\left(\left(\text{QSED}_{i_4}-1\right)^2/2\right), i_4=1,\ldots,n_4\end{aligned} \tag{3.20}$$

– Constraints on the total reliability of the conceptual design phase.

$$\text{logQED}=\sum_{i_4=1}^{n_4}\left(\text{logQCED}_{i_4}+\text{logQSED}_{i_4}\right) \tag{3.21}$$

3.2.1.2. *Preliminary design phase.* For the preliminary design phase, we have the constraint with the same logic regarding the conceptual design phase.

– Constraints on the fraction of each activity allocated to the suppliers.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_3=1}^{m_3}\text{supc}_{i_1,i_2,i_3,i_5,j_3}=1, i_5=1,\ldots,n_5 \tag{3.22}$$

$$\forall i_1,i_2,i_3,i_5,j_3: 0\le\text{supc}_{i_1,i_2,i_3,i_5,j_3}\le 1 \tag{3.23}$$

$$\text{Demand}_{i_1,i_2,i_3,i_5}\times\text{supc}_{i_1,i_2,i_3,i_5,j_3}\le\text{CapSupc}_{i_1,i_2,i_3,i_5,j_3}, \forall i_1,i_2,i_3,i_5,j_3 \tag{3.24}$$

– Constraints on the implementation time of the activities are the same as the the conceptual design constraint. The only difference is that the related constraint at the start time of the first activity is not equal to zero. It is equivalent to the complementation time of the conceptual design phase (3.25).

$$\mathrm{tcs}_{i_1,i_2,i_3,1} = \mathrm{TED}, \quad \forall i_1, i_2, i_3 \tag{3.25}$$

$$\mathrm{tcf}_{i_1,i_2,i_3,i_5} \geq \mathrm{tcs}_{i_1,i_2,i_3,i_5} + \mathrm{tc}_{i_1,i_2,i_3,i_5}, \quad \forall i_1, i_2, i_3, i_5 \tag{3.26}$$

$$\mathrm{tcs}_{i_1,i_2,i_3,i_5} + \mathrm{lag}_{i_1,i_2,i_3,i_5,i'_5} \leq \mathrm{tcs}_{i_1,i_2,i_3,i'_5}, \quad \forall i_1, i_2, i_3, i_5, i'_5 \tag{3.27}$$

$$\mathrm{tc}_{i_1,i_2,i_3,i_5} = \max_{j_3} \left(\mathrm{tcsup}_{i_1,i_2,i_3,i_5,j_3} \times \mathrm{supe}_{i_1,i_2,i_3,i_5,j_3}\right), \quad \forall i_1, i_2, i_3, i_5 \tag{3.28}$$

$$\mathrm{TCD} = \max_{i_1,i_2,i_3,i_5} \left(\mathrm{tcf}_{i_1,i_2,i_3,i_5}\right) \tag{3.29}$$

– Constraints on the fraction of each activity allocated to monitoring the implementation.

$$\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_4=1}^{m_4} \mathrm{consc}_{i_1,i_2,i_3,i_5,j_4} = 1, i_5 = 1, \ldots, n_5 \tag{3.30}$$

$$\forall i_1, i_2, i_3, i_5, j_4 : 0 \leq \mathrm{consc}_{i_1,i_2,i_3,i_5,j_4} \leq 1 \tag{3.31}$$

$$\mathrm{Demandc}_{i_1,i_2,i_3,i_5} \times \mathrm{consc}_{i_1,i_2,i_3,i_5,j_4} \leq \mathrm{CapConsc}_{i_1,i_2,i_3,i_5,j_4}, \forall i_1, i_2, i_3, i_5, j_4 \tag{3.32}$$

– Constraints on the costs related to the implementation, and the monitoring of the preliminary design stage.

$$\sum_{i_5=1}^{n_5} \left(\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_3=1}^{m_3} \mathrm{csupc}_{i_1,i_2,i_3,i_5,j_3} \times \mathrm{supc}_{i_1,i_2,i_3,i_5,j_3} + \sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_4=1}^{m_4} \mathrm{cconsc}_{i_1,i_2,i_3,i_4,i_5,j_4} \times \mathrm{consc}_{i_1,i_2,i_3,i_4,i_5,j_4} \right) = \mathrm{CCD} \tag{3.33}$$

– Constraints on the reliability of the process of the consultant/supervisor for the implementation of each activity.

$$\mathrm{QCCD}_{i_5} = \sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_4=1}^{m_4} \mathrm{qconsc}_{i_1,i_2,i_3,i_5,j_4} \times \mathrm{consc}_{i_1,i_2,i_3,i_5,j_4}, i_5 = 1, \ldots, n_5 \tag{3.34}$$

$$\begin{aligned}\mathrm{logQCCD}_{i_5} &= \log \left(1 + \left(\left(\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_4=1}^{m_4} \mathrm{qconsc}_{i_1,i_2,i_3,i_5,j_4} \times \mathrm{consc}_{i_1,i_2,i_3,i_5,j_4} \right) - 1 \right)\right) \\ &= \left(\mathrm{QCCD}_{i_5} - 1\right) - \left(\left(\mathrm{QCCD}_{i_5} - 1\right)^2/2\right), i_5 = 1, \ldots, n_5\end{aligned} \tag{3.35}$$

– Constraints on the supply process reliability for the needs of each activity of the suppliers.

$$\mathrm{QSCD}_{i_5} = \sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_3=1}^{m_3} \mathrm{qsupc}_{i_1,i_2,i_3,i_5,j_3} \times \mathrm{supc}_{i_1,i_2,i_3,i_5,j_3}, i_5 = 1, \ldots, n_5 \tag{3.36}$$

$$\begin{aligned}\mathrm{logQSCD}_{i_5} &= \log \left(1 + \left(\left(\sum_{i_1=1}^{n_1} \sum_{i_2=1}^{n_2} \sum_{i_3=1}^{n_3} \sum_{j_3=1}^{m_3} \mathrm{qsupc}_{i_1,i_2,i_3,i_5,j_3} \times \mathrm{supc}_{i_1,i_2,i_3,i_5,j_3} \right) - 1 \right)\right) \\ &= \left(\mathrm{QSCD}_{i_5} - 1\right) - \left(\left(\mathrm{QSCD}_{i_5} - 1\right)^2/2\right), i_5 = 1, \ldots, n_5\end{aligned} \tag{3.37}$$

– Constraint on the total reliability of the preliminary design stage.

$$\mathrm{logQCD} = \sum_{i_5=1}^{n_5} \left(\mathrm{logQCCD}_{i_5} + \mathrm{logQSCD}_{i_5}\right) \tag{3.38}$$

3.2.1.3. *Detail design phase.* For the detail design, the constraint is the same as logic mentioned in the previous steps.

– Constraints on the fraction of each activity allocated to the suppliers.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_5=1}^{m_5} \mathrm{supd}_{i_1,i_2,i_3,i_6,j_5} = 1, i_6 = 1,\ldots,n_6 \tag{3.39}$$

$$\forall i_1, i_2, i_3, i_6, j_5 : 0 \le \mathrm{supd}_{i_1,i_2,i_3,i_6,j_5} \le 1$$

$$\mathrm{Demand}_{i_1,i_2,i_3,i_6} \times \mathrm{supd}_{i_1,i_2,i_3,i_6,j_5} \le \mathrm{CapSupd}_{i_1,i_2,i_3,i_6,j_5} \tag{3.40}$$

– Constraints on the implementation time of the activities are the same as those of the previous stage. The start time of the first activities of this stage is equal to the complementation time of the preliminary design phase (3.41).

$$\mathrm{tds}_{i_1,i_2,i_3,1} = \mathrm{TCD}, \quad \forall i_1, i_2, i_3 \tag{3.41}$$

$$\mathrm{tdf}_{i_1,i_2,i_3,i_6} \ge \mathrm{tds}_{i_1,i_2,i_3,i_6} + \mathrm{td}_{i_1,i_2,i_3,i_6}, \quad \forall i_1, i_2, i_3, i_6 \tag{3.42}$$

$$\mathrm{tds}_{i_1,i_2,i_3,i_6} + \mathrm{lag}_{i_1,i_2,i_3,i_6,i'_6} \le \mathrm{tds}_{i_1,i_2,i_3,i'_6}, \quad \forall i_1, i_2, i_3, i_6, i'_6 \tag{3.43}$$

$$\mathrm{td}_{i_1,i_2,i_3,i_6} = \max_{j_5}\left(\mathrm{tdsup}_{i_1,i_2,i_3,i_6,j_5} \times \mathrm{supd}_{i_1,i_2,i_3,i_6,j_5}\right), \quad \forall i_1, i_2, i_3, i_6 \tag{3.44}$$

$$\mathrm{TDD} = \max_{i_1,i_2,i_3,i_6}\left(\mathrm{tdf}_{i_1,i_2,i_3,i_6}\right) \tag{3.45}$$

– Constraints on the fraction of each activity allocated to monitoring the implementation of activity.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_4=1}^{m_4} \mathrm{consd}_{i_1,i_2,i_3,i_6,j_6} = 1, i_6 = 1,\ldots,n_6 \tag{3.46}$$

$$\forall i_1, i_2, i_3, i_6, j_6 : 0 \le \mathrm{consd}_{i_1,i_2,i_3,i_6,j_6} \le 1$$

$$\mathrm{Demandc}_{i_1,i_2,i_3,i_6} \times \mathrm{consd}_{i_1,i_2,i_3,i_6,j_6} \le \mathrm{CapConsd}_{i_1,i_2,i_3,i_6,j_6}, \forall i_1, i_2, i_3, i_6, j_6 \tag{3.47}$$

– Constraints on the costs related to the implementation and monitoring of the detail design stage.

$$\sum_{i_6=1}^{n_6}\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_5=1}^{m_5} \mathrm{csupd}_{i_1,i_2,i_3,i_6,j_5} \times \mathrm{supd}_{i_1,i_2,i_3,i_6,j_5} + \sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_6=1}^{m_6} \mathrm{cconsd}_{i_1,i_2,i_3,i_6,j_6} \times \mathrm{consd}_{i_1,i_2,i_3,i_6,j_6}\right) = \mathrm{CDD} \tag{3.48}$$

– Constraints on the reliability of the process of the consultant/supervisor for the implementation of each activity.

$$\text{QCDD}_{i_6} = \sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_6=1}^{m_6} \text{qconsd}_{i_1,i_2,i_3,i_6,j_6} \times \text{consd}_{i_1,i_2,i_3,i_6,j_6}, i_6 = 1,\ldots,n_6 \tag{3.49}$$

$$\begin{aligned}\text{logQCDD}_{i_6} &= \log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_6=1}^{m_6} \text{qconsd}_{i_1,i_2,i_3,i_6,j_6} \times \text{consd}_{i_1,i_2,i_3,i_6,j_6}\right)-1\right)\right)\\ &= \left(\text{QCDD}_{i_6}-1\right) - \left(\left(\text{QCDD}_{i_6}-1\right)^2/2\right), i_6 = 1,\ldots,n_6\end{aligned} \tag{3.50}$$

– Constraints on the supply process reliability for the needs of each activity of the suppliers.

$$\text{QSDD}_{i_6} = \sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_5=1}^{m_5} \text{qsupd}_{i_1,i_2,i_3,i_6,j_5} \times \text{supd}_{i_1,i_2,i_3,i_6,j_5}, i_6 = 1,\ldots,n_6 \tag{3.51}$$

$$\begin{aligned}\text{logQSDD}_{i_6} &= \log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_5=1}^{m_5} \text{qsupd}_{i_1,i_2,i_3,i_6,j_5} \times \text{supd}_{i_1,i_2,i_3,i_6,j_5}\right)-1\right)\right)\\ &= \left(\text{QSDD}_{i_6}-1\right) - \left(\left(\text{QSDD}_{i_6}-1\right)^2/2\right), i_6 = 1,\ldots,n_6\end{aligned} \tag{3.52}$$

– Constraint on the total reliability of the detail design stage.

$$\text{logQDD} = \sum_{i_6=1}^{n_6}\left(\text{logQCDD}_{i_6} + \text{logQSDD}_{i_6}\right) \tag{3.53}$$

3.2.1.4. *Production phase.*

– Constraints on the fraction of each activity allocated to the suppliers.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_7=1}^{m_7} \text{supp}_{i_1,i_2,i_3,i_7,j_7} = 1, i_7 = 1,\ldots,n_7 \tag{3.54}$$

$$\forall i_1,i_2,i_3,i_7,j_7 : 0 \le \text{supp}_{i_1,i_2,i_3,i_7,j_7} \le 1 \tag{3.55}$$

$$\text{Demand}_{i_1,i_2,i_3,i_7} \times \text{supp}_{i_1,i_2,i_3,i_7,j_7} \le \text{CapSupp}_{i_1,i_2,i_3,i_7,j_7}, \forall i_1,i_2,i_3,i_7,j_7 \tag{3.56}$$

– Constraints on the implementation time of the activities is the same as those of the previous stages. The start time of the first activities of this stage is equal to the complementation time of the detail design phase (3.57).

$$\text{tps}_{i_1,i_2,i_3,1} = \text{TDD}, \quad \forall i_1,i_2,i_3 \tag{3.57}$$

$$\text{tpf}_{i_1,i_2,i_3,i_7} \ge \text{tps}_{i_1,i_2,i_3,i_7} + \text{tp}_{i_1,i_2,i_3,i_7}, \quad \forall i_1,i_2,i_3,i_7 \tag{3.58}$$

$$\text{tps}_{i_1,i_2,i_3,i_7} + \text{lag}_{i_1,i_2,i_3,i_7,i_7'} \le \text{tps}_{i_1,i_2,i_3,i_7'}, \quad \forall i_1,i_2,i_3,i_7,i_7' \tag{3.59}$$

$$\text{tp}_{i_1,i_2,i_3,i_7} = \max_{j_7}\left(\text{tpsup}_{i_1,i_2,i_3,i_7,j_7} \times \text{supp}_{i_1,i_2,i_3,i_7,j_7}\right), \quad \forall i_1,i_2,i_3,i_7,j_7 \tag{3.60}$$

$$\text{TP} = \max_{i_1,i_2,i_3,i_7}\left(\text{tpf}_{i_1,i_2,i_3,i_7}\right) \tag{3.61}$$

– Constraints on the fraction of each activity allocated to monitor the implementation.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_8=1}^{m_8} \text{consp}_{i_1,i_2,i_3,i_7,j_8} = 1, i_7 = 1,\ldots,n_7 \tag{3.62}$$

$$\begin{aligned}&\forall i_1,i_2,i_3,i_7,j_8 : 0 \le \text{consp}_{i_1,i_2,i_3,i_7,j_8} \le 1\\ &\text{Demandc}_{i_1,i_2,i_3,i_7} \times \text{consp}_{i_1,i_2,i_3,i_7,j_8} \le \text{CapConsp}_{i_1,i_2,i_3,i_7,j_8}, \forall i_1,i_2,i_3,i_7,j_8\end{aligned} \tag{3.63}$$

– Constraints on the costs related to the implementation and monitoring of the production stage.

$$\sum_{i_7=1}^{n_7}\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_7=1}^{m_7}\text{csupp}_{i_1,i_2,i_3,i_7,j_7}\times\text{supp}_{i_1},i_2,i_3,i_7,j_7+\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_8=1}^{m_8}\text{cconsp}_{i_1,i_2,i_3,i_7,j_8}\times\text{consp}_{i_1,i_2,i_3,i_7,j_8}\right)=\text{CP} \quad (3.64)$$

– Constraints on the reliability of the process of the consultant/supervisor for the implementation of each activity of the production stage.

$$\text{QCP}_{i_7}=\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_8=1}^{m_8}\text{qconsp}_{i_1,i_2,i_3,i_7,j_8}\times\text{consp}_{i_1,i_2,i_3,i_7,j_8},i_7=1,\ldots,n_7 \quad (3.65)$$

$$\text{logQCP}_{i_7}=\log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_8=1}^{m_8}\text{qconsp}_{i_1,i_2,i_3,i_7,j_8}\times\text{consp}_{i_1,i_2,i_3,i_7,j_8}\right)-1\right)\right)=\left(\text{QCP}_{i_7}-1\right)-\left(\left(\text{QCP}_{i_7}-1\right)^2/2\right),i_7=1,\ldots,n_7 \quad (3.66)$$

– Constraints on the supply process reliability for the needs of each activity of the suppliers.

$$\text{QSP}_{i_7}=\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_7=1}^{m_7}\text{qsupp}_{i_1,i_2,i_3,i_7,j_7}\times\text{supp}_{i_1,i_2,i_3,i_7,j_7},i_7=1,\ldots,n_7 \quad (3.67)$$

$$\text{logQSP}_{i_7}=\log\left(1+\left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_7=1}^{m_7}\text{qsupp}_{i_1,i_2,i_3,i_7,j_7}\times\text{supp}_{i_1,i_2,i_3,i_7,j_7}\right)-1\right)\right)=\left(\text{QSP}_{i_7}-1\right)-\left(\left(\text{QSP}_{i_7}-1\right)^2/2\right),i_7=1,\ldots,n_7 \quad (3.68)$$

– Constraint on the total reliability of the production stage.

$$\text{logQP}=\sum_{i_7=1}^{n_7}\left(\text{logQCP}_{i_7}+\text{logQSP}_{i_7}\right) \quad (3.69)$$

3.2.1.5. *Utilization phase.* At this stage, the only point is using and monitoring for the implementation.

– Constraints on the fraction of each activity allocated.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_9=1}^{m_9}\text{consi}_{i_1,i_2,i_3,i_8,j_9}=1,i_8=1,\ldots,n_8 \quad (3.70)$$

$$\forall i_1,i_2,i_3,i_8,j_9:0\le\text{consi}_{i_1,i_2,i_3,i_8,j_9}\le 1$$

$$\text{Demandc}_{i_1,i_2,i_3,i_8}\times\text{consi}_{i_1,i_2,i_3,i_8,j_9}\le\text{CapConsi}_{i_1,i_2,i_3,i_8,j_9},\forall i_1,i_2,i_3,i_8,j_9 \quad (3.71)$$

– Constraints on the costs related to the implementation and monitoring of the utilization stage.

$$\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_9=1}^{m_9}\text{cconsi}_{i_1,i_2,i_3,i_8,j_9}\times\text{consi}_{i_1,i_2,i_3,i_8,j_9}=\text{CI} \quad (3.72)$$

– Constraints on the reliability of the process of the consultant/supervisor for the implementation of each activity of the utilization stage.

$$\mathrm{QCI}_{i_8} = \sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_9=1}^{m_9} \mathrm{qconsi}_{i_1,i_2,i_3,i_8,j_9} \times \mathrm{consi}_{i_1,i_2,i_3,i_8,j_9}, i_8 = 1,\ldots,n_8 \tag{3.73}$$

$$\begin{aligned}\mathrm{logQCI}_{i_8} &= \log\left(1 + \left(\left(\sum_{i_1=1}^{n_1}\sum_{i_2=1}^{n_2}\sum_{i_3=1}^{n_3}\sum_{j_9=1}^{m_9} \mathrm{qconsi}_{i_1,i_2,i_3,i_8,j_9} \times \mathrm{consi}_{i_1,i_2,i_3,i_8,j_9}\right) - 1\right)\right) \\ &= \left(\mathrm{QCI}_{i_8} - 1\right) - \left(\left(\mathrm{QCI}_{i_8} - 1\right)^2/2\right), i_8 = 1,\ldots,n_8\end{aligned} \tag{3.74}$$

– Constraint on the total reliability of the utilization stage.

$$\mathrm{logQI} = \sum_{i_8=1}^{n_8} \left(\mathrm{logQCI}_{i_8}\right) \tag{3.75}$$

The objective function.

$$\mathrm{TotalCost} = \mathrm{CED} + \mathrm{CCD} + \mathrm{CDD} + \mathrm{CP} + \mathrm{CI} \tag{3.76}$$

$$\mathrm{TotalTime} = \mathrm{TP} \tag{3.77}$$

$$\mathrm{logTotalQ} = \mathrm{logQCD} + \mathrm{logQCD} + \mathrm{logQDD} + \mathrm{logQP} + \mathrm{logQI} \tag{3.78}$$

The ideal amount for the three objectives.

$$\mathrm{TotalCostCED} + \mathrm{SCost}^+ - \mathrm{SCost}^- = \mathrm{CostGoal} \tag{3.79}$$

$$\mathrm{TotalTime} + \mathrm{STime}^+ - \mathrm{STime}^- = \mathrm{TimeGoal} \tag{3.80}$$

$$\mathrm{logTotalQ} + \mathrm{SQ}^+ - \mathrm{SQ}^- = logQGoal \tag{3.81}$$

The ultimate objective function.

$$\min z = \mathrm{SQ}^+ + \mathrm{STime}^- + \mathrm{SCost}^- \tag{3.82}$$

4. Implementation of the model

4.1. Solution procedure

In this study, the SC of R&D projects has been considered with six level structures. It includes an employer, many contractors, many executors, many suppliers, many consultants, a supervisor, and a customer (the end user). At the beginning of the project, one employer should select the best option for many contractors and many executors. Proper executors must examine the alternatives and select the most appropriate choice. Then, the selected executors should implement the project lifecycle sequentially. The best suppliers, consultants, and supervisors should be selected. For the whole lifecycle, the selection of the suppliers and consultants should be done to supply the required material and resources, respectively, and to create the product in the proper time, without stopping an uninterrupted cycle of production. Finally, in the utilization phase, the selection of the consultants and supervisors is done for the better performance of maintenance. The proper selection of these stakeholders in the whole lifecycle leads to the optimized cost, time, and reliability in the running project. Therefore, the project is closed in the best position.

Table 4. Description of the case study.

Main contractor		First alternative	Second alternative
First contractor	First executor	1	1
First contractor	Second executor	1	10 00 000
Second contractor	First executor	1	1
Second contractor	Second executor	1	10 00 000

Table 5. Description of the case study.

Main contractor			First activity	Second activity
First contractor	First executor	First alternative	15	20
First contractor	First executor	Second alternative	10	10
First contractor	Second executor	First alternative	15	15
First contractor	Second executor	Second alternative	0	0
Second contractor	First executor	First alternative	18	20
Second contractor	First executor	Second alternative	16	14
Second contractor	Second executor	First alternative	15	20
Second contractor	Second executor	Second alternative	0	0

4.2. Implementation

The proposed model has been implemented in the GAMS software and tested by a Research project organization using a real data model. The first index shows the main contractor in the input, the second index represents the executor, and the third index displays the alternative. As the second executor of both the contractors has only one implementation alternative and the second alternative is impossible by the GAMS software, it does not actually exist (Tab. 4).

Two activities are considered at each stage of the lifecycle for simplicity. In the solved case study, all the supply requirements and monitoring of all activities of all stages are considered, as shown in Table 5.

In this research, three suppliers are considered. The capacity of each supplier or consultant is defined for monitoring in each stage of the project lifecycle. The supplier's capacity is brought for the supply of the conceptual design activity, as shown in Table 6.

In the conceptual design, to calculate the time consumed for performing the activity, the implemented time is considered when the complete transfer any activity to any supplier takes place. The negative numbers indicate a lack of suppliers for the activities. Also, in the case study, the cost of any activity is considered if any supplier entirely supplies it and all the possible combinations are selected for the contractors, executors and alternatives. The reliability of each activity is calculated as a complete supply from any suppliers in the event of the selection of all the possible combinations of the contractors, executors, and alternatives. Table 6 contains the data related to the suppliers in the conceptual design. Also, in this research, two consultants, two activities, two suppliers and the two consultants/supervisors are considered in the whole lifecycle for each phase. Table 7 shows the consultant or supervisor's capacity for the monitoring of conceptual design activity, implementation time, cost and reliability.

To express the time interval between the activities, the form of the Finish to start is used as Lag parameters. Table 8 shows the values of the time interval between activities at the conceptual design phase. The important point is that the relationship between the two activities is the only positive value. The great negative values indicate a lack of alternatives for the conceptual design stage. In addition, we have the same conditions for all other stages. The related data have been collected and applied for other stages.

TABLE 6. The data related to suppliers in the conceptual design stage.

Main contractor				First supplier				Second supplier				Third supplier			
				Capacity	Time	Cost	Reliability	Capacity	Time	Cost	Reliability	Capacity	Time	Cost	Reliability
First contractor	First executor	First alternative	First activity	50	15	1000	0.95	20	20	2000	0.99	30	20	850	0.98
First contractor	First executor	First alternative	Second activity	30	10	3000	0.95	20	10	200	0.975	20	10	500	0.89
First contractor	First executor	Second alternative	First activity	15	15	1500	0.99	20	15	2000	0.99	20	15	5000	0.98
First contractor	First executor	Second alternative	Second activity	25	12	900	0.88	25	12	1500	0.85	25	12	2500	0.9
First contractor	Second executor	First alternative	First activity	18	18	1800	0.75	20	20	2000	0.9	20	20	2000	0.95
First contractor	Second executor	First alternative	Second activity	20	16	2000	0.85	20	14	2000	0.85	20	14	2000	0.85
First contractor	Second executor	Second alternative	First activity	0	−1	−1	−1	0	−1	−1	−1	0	−1	−1	−1
First contractor	Second executor	Second alternative	Second activity	0	−1	−1	−1	0	−1	−1	−1	0	−1	−1	−1
Second contractor	First executor	First alternative	First activity	20	12	2000	0.99	25	25	2500	0.99	15	15	1500	0.98
Second contractor	First executor	First alternative	Second activity	20	15	1000	0.88	20	20	1000	0.85	10	10	2000	0.9
Second contractor	First executor	Second alternative	First activity	20	10	2000	0.75	20	5	500	0.9	20	20	1800	0.95
Second contractor	First executor	Second alternative	Second activity	15	15	1500	0.95	20	20	1200	0.99	10	10	1000	0.98
Second contractor	Second executor	First alternative	First activity	12	12	1200	0.95	15	4	1500	0.975	10	10	1000	0.89
Second contractor	Second executor	First alternative	Second activity	45	18	700	0.98	30	20	5000	0.95	20	20	2000	0.99
Second contractor	Second executor	Second alternative	First activity	0	−1	−1	−1	0	−1	−1	−1	0	−1	−1	−1
Second contractor	Second executor	Second alternative	Second activity	0	−1	−1	−1	0	−1	−1	−1	0	−1	−1	−1

TABLE 7. The data related to the consultant/supervisor in the conceptual design stage.

Main contractor				First consultant/supervisor				Second consultant/supervisor			
				Capacity	Time	Cost	Reliability	Capacity	Time	Cost	Reliability
First contractor	First executor	First alternative	First activity	50	15	1000	0.95	20	20	2000	0.99
First contractor	First executor	First alternative	Second activity	30	10	3000	0.95	20	10	200	0.975
First contractor	First executor	Second alternative	First activity	15	15	1500	0.99	20	15	2000	0.99
First contractor	First executor	Second alternative	Second activity	25	12	900	0.88	25	12	1500	0.85
First contractor	Second executor	First alternative	First activity	18	18	1800	0.75	20	20	2000	0.9
First contractor	Second executor	First alternative	Second activity	20	16	2000	0.85	20	14	2000	0.85
First contractor	Second executor	Second alternative	First activity	0	−1	−1	−1	0	−1	−1	−1
First contractor	Second executor	Second alternative	Second activity	0	−1	−1	−1	0	−1	−1	−1
Second contractor	First executor	First alternative	First activity	20	12	2000	0.99	25	25	2500	0.99
Second contractor	First executor	First alternative	Second activity	20	15	1000	0.88	20	20	1000	0.85
Second contractor	First executor	Second alternative	First activity	20	10	2000	0.75	20	5	500	0.9
Second contractor	First executor	Second alternative	Second activity	15	15	1500	0.95	20	20	1200	0.99
Second contractor	Second executor	First alternative	First activity	12	12	1200	0.95	15	4	1500	0.975
Second contractor	Second executor	First alternative	Second activity	45	18	700	0.98	30	20	5000	0.95
Second contractor	Second executor	Second alternative	First activity	0	−1	−1	−1	0	−1	−1	−1
Second contractor	Second executor	Second alternative	Second activity	0	−1	−1	−1	0	−1	−1	−1

4.3. Solution to the problem

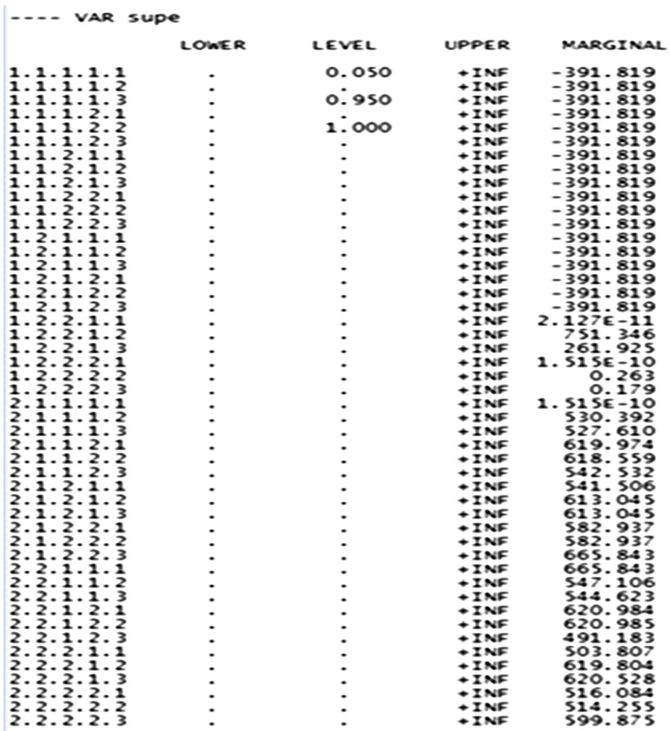
The results of the code implementation are brought in the following entries. GAMS output states that it selects the main Contractor 1, the first main executor of the Contractor 1, and the first alternative. Figure 4 shows the combined selection of the suppliers for the conceptual design phase activities.

The results suggest that the contractor 1, the executor 1, and the alternative 1 of the executor 1, for the activity 1, 5% of the supplier 1 and 95% of the supplier 3 should be provided. The second activity is supplied by all the requirements of the supplier 2. The other variables could be examined in the same way:

- All the monitoring of the activity 1 of the conceptual design was assigned to the consultant 1, and all the supervisors of the activity 2 in that stage were appointed to the consultant 2.
- The cost of the conceptual design stage (CED) was equal to the currency of 2257.
- All supply of the activity 1 in the preliminary design stage was supplied to the s supplier 1, and all the supply of the activity 2 was provided to the supplier 2.

TABLE 8. The data related to the time interval between activities.

Main contractor				First activity	Second activity
First contractor	First executor	First alternative	First activity	0	15
First contractor	First executor	First alternative	Second activity	−15	0
First contractor	First executor	Second alternative	First activity	0	15
First contractor	First executor	Second alternative	Second activity	−15	0
First contractor	Second executor	First alternative	First activity	0	5
First contractor	Second executor	First alternative	Second activity	−5	0
First contractor	Second executor	Second alternative	First activity	−10 000	−10 000
First contractor	Second executor	Second alternative	Second activity	−10 000	−10 000
Second contractor	First executor	First alternative	First activity	0	15
Second contractor	First executor	First alternative	Second activity	−15	0
Second contractor	First executor	Second alternative	First activity	0	5
Second contractor	First executor	Second alternative	Second activity	−5	0
Second contractor	Second executor	First alternative	First activity	0	4
Second contractor	Second executor	First alternative	Second activity	−4	0
Second contractor	Second executor	Second alternative	First activity	−10 000	−10 000
Second contractor	Second executor	Second alternative	Second activity	−10 000	−10 000



---- VAR supe

	LOWER	LEVEL	UPPER	MARGINAL
1.1.1.1.1	.	0.050	+INF	-391.819
1.1.1.1.2	.	.	+INF	-391.819
1.1.1.1.3	.	0.950	+INF	-391.819
1.1.1.2.1	.	.	+INF	-391.819
1.1.1.2.2	.	1.000	+INF	-391.819
1.1.1.2.3	.	.	+INF	-391.819
1.1.2.1.1	.	.	+INF	-391.819
1.1.2.1.2	.	.	+INF	-391.819
1.1.2.1.3	.	.	+INF	-391.819
1.1.2.2.1	.	.	+INF	-391.819
1.1.2.2.2	.	.	+INF	-391.819
1.1.2.2.3	.	.	+INF	-391.819
1.2.1.1.1	.	.	+INF	-391.819
1.2.1.1.2	.	.	+INF	-391.819
1.2.1.1.3	.	.	+INF	-391.819
1.2.1.2.1	.	.	+INF	-391.819
1.2.1.2.2	.	.	+INF	-391.819
1.2.1.2.3	.	.	+INF	-391.819
1.2.2.1.1	.	.	+INF	2.127E-11
1.2.2.1.2	.	.	+INF	751.346
1.2.2.1.3	.	.	+INF	261.925
1.2.2.2.1	.	.	+INF	1.515E-10
1.2.2.2.2	.	.	+INF	0.263
1.2.2.2.3	.	.	+INF	0.179
2.1.1.1.1	.	.	+INF	1.515E-10
2.1.1.1.2	.	.	+INF	530.392
2.1.1.1.3	.	.	+INF	527.610
2.1.1.2.1	.	.	+INF	619.974
2.1.1.2.2	.	.	+INF	618.559
2.1.1.2.3	.	.	+INF	542.532
2.1.2.1.1	.	.	+INF	541.506
2.1.2.1.2	.	.	+INF	613.045
2.1.2.1.3	.	.	+INF	613.045
2.1.2.2.1	.	.	+INF	582.937
2.1.2.2.2	.	.	+INF	582.937
2.1.2.2.3	.	.	+INF	665.843
2.2.1.1.1	.	.	+INF	665.843
2.2.1.1.2	.	.	+INF	547.106
2.2.1.1.3	.	.	+INF	544.623
2.2.1.2.1	.	.	+INF	620.984
2.2.1.2.2	.	.	+INF	620.985
2.2.1.2.3	.	.	+INF	491.183
2.2.2.1.1	.	.	+INF	503.807
2.2.2.1.2	.	.	+INF	619.804
2.2.2.1.3	.	.	+INF	620.528
2.2.2.2.1	.	.	+INF	516.084
2.2.2.2.2	.	.	+INF	514.255
2.2.2.2.3	.	.	+INF	599.875

FIGURE 4. A sample of results.

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR v	-INF	4.609	+INF	.
---- VAR QED	-INF	-0.124	+INF	-7.96E-13
---- VAR QCD	-INF	-0.153	+INF	-7.96E-13
---- VAR QDD	-INF	-0.153	+INF	-1.98E-11
---- VAR QP	-INF	-0.153	+INF	1.591E-12
---- VAR QI	-INF	-0.077	+INF	1.591E-12
---- VAR TotalQ	-INF	-0.660	+INF	1.591E-12
---- VAR spq	.	.	+INF	1.591E-12
---- VAR smq	.	2.298	+INF	1.591E-12
---- VAR spcost	.	.	+INF	1.4416E-9
---- VAR smcost	.	4.609	+INF	-1.452E-9
---- VAR sptime	.	.	+INF	4.798E-11
---- VAR smtime	.	.	+INF	-4.26E-11
---- VAR TotalTime	.	240.000	+INF	-391.819
---- VAR TotalCost	.	10657.500	+INF	-391.819

FIGURE 5. The final answer.

TABLE 9. Optimal solution of the case study.

Goal value of reliability logarithm	−0.2
Goal value of cost logarithm	1900
Goal value of time logarithm	240

– All the surveillance of the activity 1 in the preliminary design stage was transferred to the consultant 1, and all monitoring of the activity 2 was supplied to the consultant 2.
– The cost of the preliminary design stage (CCD) was equal to the currency of 2400.
– All the supply of the activity 1 in the detail design stage was transferred to the supplier 1, and all the supply of the activity 2 was transferred to the supplier 2.
– All the surveillance of the activity 1 in the detail design stage was transferred to the consultant 1, and all monitoring of the activity 2 was transferred to the consultant 2.
– The cost of the detail design stage (CDD) was equal to the currency of 2400.
– All the supply of the activity 1 in the production stage was supplied to the supplier 1, and all the supply of the activity 2 was provided to the supplier 2.
– All the surveillance of the activity 1 in the production stage was transferred to the consultant 1, and all monitoring of the activity 2 was transferred to the consultant 2.
– The Cost of Production (CP) was equal to 2400 monetary units.
– All surveillance of the activity 1 in the utilization stage was transferred to the consultant 1, and all monitoring of the activity 2 was transferred to the consultant 2.
– The Cost of Production (CP) was equal to 1200 currencies.

Although the reliability of each of the activity stages was specific, the overall reliability of each step was the logarithm of the number in the existing results. The detailed answers to the other stages are available in the implementation results. The final answer of the model is mentioned in Figure 5.

The values of the ideal (optimum solution) are, rreview, project management deals with multiple coespectively, placed in the following amounts for the reliability logarithm cost and the implementation time of the entire project (Tab. 9).

This project was closed without the use of models in five years (1800 days) at the cost of $3500 million. The main reason for the high cost and time was due to an incorrect choice of the network of suppliers and consultants. The used model was closed within 240 days, costing $1900 million with the confidence of 98%.

4.4. Validation of the model

Different tests could be used to validate the model, such as model structural analysis, a sensitivity analysis of the models' parameters, the ultimate point test, and the adequacy test. In this article, we will discuss the structural analysis method for validating the model to analyze the structure of the objective function and the constraints. The model has been resolved by the experts in operations research modeling. According to the availability of information, the model has been tested and examined in the available case studies. The proposed model is, therefore, motivated by the real-life experience of the authors and the problem present in dealing with the high technology R&D projects. The authors had the opportunity to work on the system engineering a multi-project environment involving the development of the technologies and systems. The proposed model was validated using data from real life projects from R&D industries in Iran. The values of these projects were gathered from different stakeholders. Some Projects were high technology projects, and others were an operational system developed against the specific requirement of the customer. In addition, it has been confirmed and examined by experts in this field from universities and industries, thereby proving its validity and reliability.

5. Conclusion and future research directions

PSCs are complex in structure and consist of numerous participants. SC network design for R&D projects facilitates the identification of bottlenecks and serves as the basis for re-configuration and re-engineering. It can help to understand the complexity of the structure. R&D project proposals are initiated based on the stated customer requirement. These proposals are selected, executed and developed. One of the important factors that can affect the success of these projects is the network design of them. R&D managers are continually faced with a series of decisions regarding how to select the main contractors, suppliers, executors, most appropriate projects and alternatives. Due to the inherent complexity and uncertainty, R&D Projects are not readily amenable to network design.

This study was conducted to contribute to developing a unique and first multi-objective decision problem by a Goal programming model that could enable decision makers to simultaneously optimise cost, time, and reliability for R&D projects. The model could design the best network model for co-operation through the successful implementation of R&D projects with the system engineering approach. It can be used for the performance monitoring of the SC for R&D projects. Based on the literature review, project management deals with multiple conflicting objectives and uncertain situations during the decision-making process in real-life applications. With the implementation of this model, managers and decision-makers of the research and development projects can compare extant options in the collaboration network and select the network that does not stop the lifecycle in any phase and assures the success of the projects.

This model solves the integrity problem throughout the lifecycle of research and presents the optimal design for decision-makers in the field of R&D projects. In addition, the network design solution may be considered as a guideline for the tactical planning problems. To do so, it needs a more tightly integrated network design, production planning, and material planning. The results showed that any changes in parameters could have an effect on the total cast, time and reliability. The proposed model presented a framework for R&D problems and illustrated how this complicated systems could be modelled.

This study has some limitations in terms of the model and the methodology that could be addressed in the future studies. Although the mathematical model of the study can be altered to consider significant conflicting objectives and decision-making factors in project network problems, the corporative relationships can be added to the model for satisfying the requirements of different stockholders. Also, the model can be expanded with the addition of some constraints to bring a solution to a specific problem. The other limitation of the model can be attributed to the fuzziness involved in the unclear objectives. However, in real life situations, the project managers are confronted with high uncertainty and imprecise information about cost and time. Therefore, the future studies can be conducted with fuzzy parameters to cope with such vagueness.

The authors of the present paper have been working on R&D projects for ten years. The proposed model has been designed based on the review of 50 different projects in various areas such as electronics, physics, maritime engineering, etc. from 2008 to 2018. They have various conditions: current, closed out and stopped. Therefore, this model has been tested for various projects, one of which is presented in the article as a case study. We use the model now. The proposed model is an actual work of the authors' work environment. Industrial managers can use the proposed model to select the best combination of the SC network in research and development projects. Therefore, the data are from industry and the optimal amount is optimal for the entire life cycle.

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