Chapter

Fuzzy Approach Model to Portfolio Risk Response Strategies

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Abstract

Risk management and control of project risks have been the intrinsic characteristics of high-rise building projects in a changing built environment. In this research, a novel bi-objective model for the best mixture of projects is proposed. The first objective focuses on maximizing profits and efficiency of risk responses, and the second objective aims at minimizing project direct cost including machinery, human, and material costs to implement proper risk responses over a planning horizon under uncertainty. In this model, risks of the projects are controlled by time, quality, and cost constraints, and the most optimum risk response strategies (RRSs) are selected to eliminate or reduce the impacts of the risks. Thus, the combination of optimum projects with the best RRSs can be selected for an organizational portfolio model. Finally, to assess the solution method and the proposed model, the empirical result and sensitivity analysis are carried out. Ten large-scale high-rise building projects and their associated risks are evaluated as cases in this study.

Keywords: building engineering, fuzzy system, portfolio selection, project risk management

1. Introduction

The purpose of the risk management framework is to assist the organization in integrating risk management into significant activities and functions. The effectiveness of risk management will depend on its integration into the governance of the organization, including decision-making. This requires support from stakeholders, particularly top management. Framework development encompasses integrating, designing, implementing, evaluating and improving risk management across the organization.

Managing risks at all levels is an active process involving continuous planning, analysis, response, and monitoring and control. The execution of response strategies should be anticipatory and implemented by trigger events that launch response actions before the risk materializes so that opportunities (positive risks) may be enhanced or threats (negative risks) may be diminished. Even within an active process of continuous risk identification, risk management at the program, project, and operations areas are traditionally approached from a prescriptive, process-based perspective. However, within complex systems such as portfolios, risks may not be managed in the traditional or simple sense. Complexity requires a less prescriptive approach. In many cases, the execution of risk response strategies at the portfolio level involves the establishment of projects within the portfolio's component programs or as part of continuing operations to address specific opportunities or threats (positive or negative risks) that have either materialized or have had a significant increase in the probability of occurrence as indicated by a trigger event occurring. There is an important distinction between portfolio risk management and risk management at the program or project level. In many cases, the portfolio manager should delegate risk response measures to subordinate programs or projects within the portfolio. A desired outcome from portfolio risk management is to utilize a structured risk planning and response effort in order to reduce management inaction and decision delay. Risk identification analysis and response planning acknowledge the limits of data and the lack of clear, unambiguous, and actionable information concerning many management factors at the portfolio level. Various possible risk scenarios are studied and response plans developed to limit the impact of the data and information disconnect described above. Through portfolio risk management, senior leadership and portfolio management staff are provided with courses of action or management options that assist in making decisions involving risk with incomplete information.

The importance of an appropriate selection of one project due to the combination of the selected projects for successful portfolio management is inevitable. Many companies try to implement a group of relevant projects as a portfolio to satisfy their synergy and economize their cost through efficient project management. Furthermore, it is needed to manage the risks of each project through the standard risk management process after the creation of the appropriate portfolio. The portfolio has an important role in managing a group of relevant projects so that they bring benefits and values. In the portfolio level, risk management requires a balanced attitude and management judgment exercises in two stages: the first stage is associated with the portfolio creation phase and the second one is allocated to the implementation phase of portfolio projects. We only benefit from the synergy and saving resulted from the portfolios projects management in the case of active risk management. A risk strategy response (RSS) is one of the most important processes of risk management. Therefore, selecting the appropriate projects and managing project risks are simultaneously two appropriate approaches to increase both revenue and profits of project-based organizations. In this research, the main aim is to choose an optimum portfolio of project investment considering its risk response cost and multi-term planning. Project portfolio selection observes the organization's objectives in a planning horizon without outpacing available resources. Schniederjans and Santhanam [1] classified the system's objectives and preferences as financial benefits, intangible benefits, availability of resources, and risk level of the project portfolio, so project risk assessment was a key element in their study [2].

Badri et al. [3] presented a binary goal programming model for the project selection of an information system. Wei and Chang [4] presented a portfolio choice model based on enterprise strategy considering customer's resource and capability, project performance and project delivery, and project risk constraints. Project risks are categorized into three types: market risk, technical risk, financial risk. In any aspect of a project, risk can emerge. The nature of risk is uncertainty. For each project, risks should be identified and analyzed, and to cope with these risks, proper RRSs must be employed [5–11]. Tang et al. [9] developed a new solution method to the lean 6-sigma portfolio management as a binary quadratic programming problem. Muriana and Vizzini [12] presented a certain method to determine the risk of the Work Progress Status for assessing and preventing project risk.

On the other hand, Rahimi et al. [13] proposed a mathematical model, in which different risks are considered for activities so that different responses can be selected for each risk. Also, the risk responses are not considered as independent, and responses are associated with each other. Indeed, choosing the responses, which overlap each other, can affect their results, time, cost, and quality of the project. The objective function used different evaluation criteria and tried to choose the optimum responses, which maximizes these evaluation criteria. Ben-David and Raz

[14] considered the cost of implementing strategies and incorporated them into an RRS selection problem. Ben-David et al. [15] extended their previous work by providing a mathematical model that facilitates computer implementation of the model. Because of the risk abatement actions, a selection problem is a complex one. Therefore, they proposed a branch-and-bound algorithm and two heuristic algorithms [16, 17]. Zhang and Fan [18] integrated all three key elements in project management (i.e., project expenditure, project planning horizon, and project quality). They proposed a new efficient solution for the mathematical model of the RRS.

Reviewing the aforementioned discussions and literature, we understand that there are gaps in (1) selecting the best projects portfolio that the effect of risk in selected projects is controlled [18], and (2) selecting projects to check the balance between the total cost of the selected projects and the profit of the selected projects, and all the predicted risk response effects. Furthermore, some of the parameters in the real-world are uncertain and can cause a high degree of uncertainty on a designed network [19].

To overcome and fulfill these gaps, for the first time, we develop a mathematical model for selecting the best projects and control risks of each selected projects under uncertainty. In this research, we investigate the trade-off between the total cost of the selected projects including all three types of resources (e.g., human, machine, raw materials) and implanting proper risk responses-and the net profit of the selected projects, and all the approximated risk response effects. The important items which this research contributes are as follows:

- Presenting a new two-objective binary mathematical model to choose an optimum portfolio and control risks of the selected projects.

- Introducing a new objective function for selecting projects with the maximum net profit and all the estimated risk response effects for each project.

- Developing a new multi-period, multi-project, and multi-resource model to control risks of the selected projects.

2. Problem description

We present a new model to select an optimum project portfolio tacking into account many constraints in the multi-period planning horizon. Also, this model can be used to select the RRSs. The portfolio selection problem of the project RRSs is combined with four basic concepts (i.e., project opportunity, work breakdown structure, risk event, and risk responses) as well as three key elements (i.e., schedule, quality, and cost) are considered in these concepts. These concepts are described as project scope, work breakdown structure, risk event, risk response. There is a strategy to respond r risk events. On the other hand, N project should be evaluated with their risk responses' effects to select an optimum portfolio. The optimal portfolio will be top j projects. All parameters of the mathematical model change dynamically. In this model, an optimum portfolio is selected considering its risk response expenditure. The most enticing RRSs can be acquired by solving the mathematical model. **Figure 1** depicts the process of portfolio RRSs.

In this section, we present notations and mathematical modeling in Sections 2.1 and 2.2, respectively.

It should also be mentioned that the definition of parameters of s_{ar}^{w}, s_{r}^{w}, q_{ar}^{w}, ε^{w}, δ^{w}, $\acute{T}_{max}$, Q_{max}, $\tilde{e}_{ar}$, q_{r}^{w}, $\overline{M}$, $\overleftrightarrow{M}$ can be found in Rahimi et al. [13]. Following is the mathematical mode.

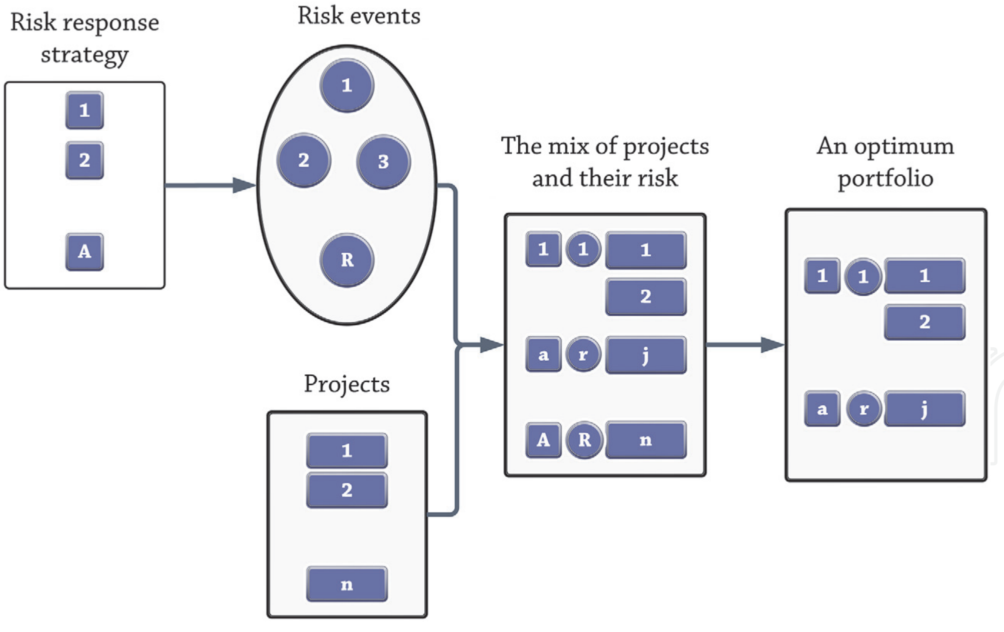

Figure 1.
Process of portfolio RRSs.

2.1 Mathematical programming

$$\mathrm{Max}Z_1 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt} \times \tilde{p}_{jt} + \sum_{j=1}^{n}\sum_{a=1}^{A}\sum_{r=1}^{R} z_{jar} \times \tilde{e}_{ar} \tag{1}$$

$$\mathrm{Min}Z_2 = \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{i=1}^{m} h_{ij}.\tilde{C}_{it} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{k=1}^{s} m_{kj}.\tilde{C}_{kt} + \sum_{t=1}^{T}\sum_{j=1}^{n} x_{jt}\sum_{o=1}^{z} r_{oj}.\tilde{C}_{ot} + \sum_{j=1}^{n}\sum_{a=1}^{A} \tilde{C}_a \max_r z_{jar} \tag{2}$$

s.t.;

$$\sum_{t=1}^{T} x_{jt} \le 1; \quad \forall j \tag{3}$$

$$\sum_{t=1}^{T} (t + d_{jt}).x_{jt} \le T + 1 + T_{max}; \quad \forall j \tag{4}$$

$$\sum_{j=1}^{n} h_{ij}x_{jt} \le H_{it}; \quad \forall i, t \tag{5}$$

$$\sum_{j=1}^{n} m_{kj}x_{jt} \le M_{kt}; \quad \forall k, t \tag{6}$$

$$\sum_{j=1}^{n} r_{oj}x_{jt} \le R_{ot}; \quad \forall O, t \tag{7}$$

$$\left(\sum_{i=1}^{m} h_{ij}.\tilde{C}_{it} + \sum_{k=1}^{s} m_{kj}.\tilde{C}_{kt} + \sum_{o=1}^{z} r_{oj}.\tilde{C}_{ot}\right) \times x_{jt} < \tilde{p}_{jt}, j = 1, 2, \dots, n; \quad \forall t \tag{8}$$

$$\sum_{j=1}^{n}\sum_{a=1}^{A}\tilde{C}_a \max_r z_{jar} + \left[\sum_{i=1}^{m} h_{ij}\tilde{C}_{it} + \sum_{k=1}^{s} m_{kj}\tilde{C}_{kt} + \sum_{o=1}^{z}\tilde{C}_{ot} r_{oj}\right] \times x_{jt} \le \tilde{B}_{jt}; \quad \forall r, j, t \tag{9}$$

$$\sum_{r=1}^{R} s_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(s_{ar}^w z_{jar}\right) \le \varepsilon^w; \quad \forall j, w \tag{10}$$

$$\sum_{r=1}^{R} q_r^w - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(q_{ar}^w z_{jar}\right) \le \delta^w; \quad \forall j, w \tag{11}$$

$$\sum_{r=1}^{R} s_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(s_{ar}^W z_{jar}\right) \le \acute{T}_{max}; \quad j = n \tag{12}$$

$$\sum_{r=1}^{R} q_r^W - \sum_{r=1}^{R}\sum_{a=1}^{A}\left(q_{ar}^W z_{jar}\right) \le Q_{max}; \quad j = n \tag{13}$$

$$\sum_{j=1}^{n} x_{jt}.\left(MARR_t - I_{jt}\right) \le 0; \quad \forall t \tag{14}$$

$$\sum_{j=1}^{n} x_{jt} \ge 0; \quad \forall t \tag{15}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} \le 1 \ (A_a, A_{\acute{a}}) \in \overset{\leftrightarrow}{M}; \quad \forall j, a, \acute{a}, r, \acute{r} \tag{16}$$

$$z_{jar} + z_{j\acute{a}\acute{r}} = 1 \ (A_a, A_{\acute{a}}) \in \overset{\leftrightarrow}{M}; \quad \forall j, a, \acute{a}, r, \acute{r} \tag{17}$$

$$z_{jar} - z_{j\acute{a}\acute{r}} \le 0 \ (A_a, A_{\acute{a}}) \in \overline{M}; \quad \forall j, a, \acute{a}, r, \acute{r} \tag{18}$$

$$z_{jar}, z_{j\acute{a}\acute{r}} \in \{0, 1\}; \quad \forall j, a, \acute{a}, r, \acute{r} \tag{19}$$

$$x_{jt} \in \{0, 1\}; \quad \forall j, t \tag{20}$$

Objective function value (OFV) (1) maximizes the NP of the selected portfolio and effects on all RRSa for each project of the selected portfolio. Objective function value (2) is minimizing the total cost of the chosen projects consisting of four terms. These terms are the human resource expenditure, the machine resource expenditure, the raw materials resource cost, and implementing the RRSs, respectively.

Constraint (3) ensures that each project selection will happen only one time on the planning horizon. Constraint (4) states that the completion time of each selected project is less than the planning horizon plus the upper bound for project delivery delay. Constraints (5)–(7) define the maximum limits of all three resources. Constraint (5) states that the number of human resources of all types needed for projects during selection cannot exceed the maximum available human resources for all types and all planning terms. Constraint (6) ensures that all machine-hour resources of all types needed for projects during selection do not exceed the maximum available machine-hour resources for all types and all planning terms. Constraint (7) ensures that all raw materials resources of all types needed for projects during selection do not exceed the maximum available raw materials resources of all types and for all planning terms. Constraint (8) certifies that the total cost of each selected project is less than its net profit for all planning terms. Constraint (9) certifies that the total cost of a selected project including human resource expenditure, machine resource expenditure, raw material cost, and implementing the RRSs, is less than its budget for all projects and all planning terms.

Constraint (10) certifies that, in each project, each work packages (except the last one) is completed in the due date, otherwise (if it takes more), it does not affect the schedule of its successors' start times. Constraint (11) ensures that, in each project, each work packages (except the last one) maintain a certain level of quality. Constraint (12) indicates that, in each project, the last work package must be finished in the project deadline. Constraint (13) indicates that in each project, the last work packages must conform to project quality standards. Constraint (14) ensures if a project is selected, it is attractive and that means the internal RoR of the chosen projects should be greater than or equal to the MARR. Constraint (15) indicates that in each period, projects can be chosen. Constraints (16)–(18) are about strategies. Constraint (16) ensures that strategies A_a, and $A_{\acute{a}}$prevent each other for each project. Constraint (17) ensures that for each project, only one strategy must be selected if strategiesA_a, and $A_{\acute{a}}$exclude each other. Constraint (18) states that projects cooperate if one strategy is chosen another strategy must be chosen too. Also, in constraint (19) attributes a binary variable for each project. Constraint (20) refers to binary decision variables.

2.2 Proposed uncertainty programming

Uncertainty in data can be grouped into two categories: randomness and fuzziness. Randomness originates from the random nature of data and Fuzziness refers to the vague parameters Infected with epistemic uncertainty-ambiguity of these parameters stems from the lack of knowledge regarding the exact value of these parameters. The proposed model for this problem is a fuzzy multi-objective non-linear programming (FMONLP). There are a number of adopted methods to transform this model into its equivalent crisp match, from which a two-phase approach is offered [13–20]. Firstly, using an efficient method introduced by Jimenez et al., [21], the basic model is transformed into an equivalent auxiliary crisp multi-objective model. Secondly, the fuzzy aggregation function, developed by [20], is used to solve the crisp multi-objective mode. To do this, a single-objective parametric model to find the final preferred compromise solution replaces the crisp multi-objective model.

Several methods have been proposed to convert a probabilistic model into an equivalent non-probabilistic one. Probabilistic constraints transform into non-probabilistic ones using fuzzy measures, which was introduced, in the literature review section. The possibility (Pos) and necessity (Nec) are the general fuzzy measures respectively showing the optimistic and pessimistic attitudes of the decision maker. The Pos measure shows the possibility degree of occurrence of a probabilistic event, and the Nec measure indicates the minimum possibility degree of occurrence of a probabilistic event. Certainty degree of occurrence of an uncertain event is measured by credibility (Cr), which equals the average of the Pos and Nec measures [22]. New fuzzy measure Me, which is a developed Cr measure is presented by [23]. The main advantage of this measure is its flexibility to avoid excessive views. In the following, the three measures of a fuzzy event, including possibility, necessity and credibility, are described. Variable ξ is determined as a fuzzy variable on probabilistic space $(\Theta, P(\Theta), Pos)$and its membership function, obtained from the probability measure Pos, is as follows:

$$(X) = Pos\{\theta \in \Theta | \xi(\theta) = x\}, x \in R \tag{21}$$

Set A is in $P(\Theta)$. The necessity and credibility measures of are defined as follows:

$$Nec\{A\} = 1 - Pos\{A^c\} \tag{22}$$

$$Cr\{A\} = \frac{1}{2}(Pos\{A\} + Nec\{A\}) \tag{23}$$

More details and descriptions of the fuzzy theory are explained in [22]. In this research, the Me-based probabilistic programming method is selected to deal with the uncertain parameters of the presented model. The fuzzy measure Me is defined, according to [22], as follows:

$$Me\ \{A\} = Nec\{A\} + \mathcal{E}\ (Pos\{A\} - Nec\{A\}) \tag{24}$$

Where ε as a parameter shows the optimistic-pessimistic attitude of a decision maker. Mathematical programming problem (25) with fuzzy parameters is as follows:

$$Min\, f(x, \tilde{c})$$

Subjected to

$$\begin{gathered} \tilde{A}x \geq \tilde{b} \\ \tilde{N}x \leq \tilde{d} \\ x \geq 0 \end{gathered} \tag{25}$$

In this notation $\tilde{c} = (\tilde{c}_1, \tilde{c}_2, \ldots, \tilde{c}_n)$,$\tilde{A} = [\tilde{a}_{ij}]_{m\times n}$,$\tilde{N} = [\tilde{n}_{ij}]_{m\times n}$, $\tilde{b} = \left(\tilde{b}_1, \tilde{b}_1, \ldots, \tilde{b}_n\right)^t$ and $\tilde{d} = \left(\tilde{d}_1, \tilde{d}_1, \ldots, \tilde{d}_n\right)^t$ represent the triangular fuzzy numbers which are used in the objective function and constraints, respectively. Furthermore, the fuzzy number $x = (x_1, x_1, \ldots, x_n)$ is the crisp decision vector, which shows the possibility distribution for fuzzy parameters.

To deal with the probabilistic objective functions and constraints, the expected value and chance-constrained operators based on the Me measure in this method are used. Accordingly, we can rewrite this model (26) as below:

$$Min\ E[f(x, \tilde{c})]$$

Subjected to

$$\begin{gathered} Me\left\{\tilde{A}x \geq \tilde{b}\right\} \geq \alpha \\ Me\left\{\tilde{N}x \leq \tilde{b}\right\} \geq \beta \\ x \geq 0 \end{gathered} \tag{26}$$

In this notation, E is the expected value operator, α and β are respectively the decision maker's minimum confidence level for satisfaction of probabilistic constraints. Jiménez et al. [21] defined the expected value operator based on Me measure as follows:

$$E[\xi] = \frac{1-\varepsilon}{2}\xi_1 + \frac{1}{2}\xi_2 + \frac{\varepsilon}{2}\xi_3 \tag{27}$$

According to [22] we can transform the aforementioned model (26) into two approximation models including the upper approximation model (UAM) and the lower approximation model (LAM). These models are presented as follows:

$$
(UAM)\begin{cases} \min\left(\frac{1-\varepsilon}{2}c_1+\frac{1}{2}c_2+\frac{\varepsilon}{2}c_3\right)x \\ A_{(2)}x+(1-\alpha)\left(A_{(3)}-A_{(2)}\right)x\geq b_2-(1-\alpha)\left(b_{(2)}-b_{(1)}\right) \\ N_{(2)}x-(1-\beta)\left(N_{(2)}-N_{(1)}\right)x\leq d_2+(1-\alpha)\left(d_{(3)}-d_{(2)}\right) \end{cases} \tag{28}
$$

$$
(LAM)\begin{cases} \min\left(\frac{1-\varepsilon}{2}c_1+\frac{1}{2}c_2+\frac{\varepsilon}{2}c_3\right)x \\ A_{(2)}x+\alpha\left(A_{(3)}-A_{(2)}\right)x\geq b_2+(1-\alpha)\left(b_{(3)}-b_{(2)}\right) \\ N_{(2)}x+(1-\beta)\left(N_{(3)}-N_{(2)}\right)x\leq d_2+\beta\left(d_{(2)}-d_{(1)}\right) \end{cases} \tag{29}
$$

Where ε is the optimistic-pessimistic parameter. Solving the LAM and UAM models provides the decision maker with the lower and upper bound of the optimal decision respectively. In this research, we use UAM models to solve problem. Accordingly, the auxiliary crisp equivalent of the presented model with triangular fuzzy parameters is presented as follows:

UAM:

$$
\begin{aligned} Max\ Z_1 = {} & \sum_{t=1}^{T}\sum_{j=1}^{n}x_{jt}\times\left(\frac{1-\varepsilon}{2}p_{jt(1)}+\frac{1}{2}p_{jt(2)}+\frac{\varepsilon}{2}p_{jt(3)}\right)+\sum_{j=1}^{n}\sum_{a=1}^{A}\sum_{r=1}^{R}z_{jar} \\ & \times\left(\frac{1-\varepsilon}{2}e_{ar(1)}+\frac{1}{2}e_{ar(2)}+\frac{\varepsilon}{2}e_{ar(3)}\right) \end{aligned} \tag{30}
$$

$$
\begin{aligned} Min\ Z_2 = {} & \sum_{t=1}^{T}\sum_{j=1}^{n}x_{jt}\sum_{i=1}^{m}h_{ij}.\left(\frac{1-\varepsilon}{2}C_{it(1)}+\frac{1}{2}C_{it(2)}+\frac{\varepsilon}{2}C_{it(3)}\right) \\ & +\sum_{t=1}^{T}\sum_{j=1}^{n}x_{jt}\sum_{k=1}^{s}m_{kj}.\left(\frac{1-\varepsilon}{2}C_{kt(1)}+\frac{1}{2}C_{kt(2)}+\frac{\varepsilon}{2}c_{kt(3)}\right) \\ & +\sum_{t=1}^{T}\sum_{j=1}^{n}x_{jt}\sum_{o=1}^{z}r_{oj}.\left(\frac{1-\varepsilon}{2}C_{ot(1)}+\frac{1}{2}C_{ot(2)}+\frac{\varepsilon}{2}C_{ot(3)}\right) \\ & +\sum_{j=1}^{n}\sum_{a=1}^{A}\left(\frac{1-\varepsilon}{2}C_{a(1)}+\frac{1}{2}C_{a(2)}+\frac{\varepsilon}{2}C_{a(3)}\right)\max_{r} z_{jar} \end{aligned} \tag{31}
$$

Subjected to

$$
\begin{aligned} & \left(\sum_{i=1}^{m}h_{ij}.\left(C_{it(2)}x-(1-\beta)\left(C_{it(2)}-C_{it(1)}\right)\right)\right. \\ & \quad +\sum_{k=1}^{s}m_{kj}.\left(C_{kt(2)}x-(1-\beta)\left(C_{kt(2)}-C_{kt(1)}\right)\right) \\ & \quad \left.+\sum_{o=1}^{z}r_{oj}.\left(C_{ot(2)}x-(1-\beta)\left(C_{ot(2)}-C_{ot(1)}\right)\right)\right)\times x_{jt} \\ & \quad \leq p_{jt(2)}+(1-\beta)\left(p_{ij(3)}-p_{ij(2)}\right) \end{aligned} \tag{32}
$$

$$\begin{aligned}
&\sum_{j=1}^{n}\sum_{a=1}^{A}\left(C_{a(2)}x-(1-\beta)\left(C_{a(2)}-C_{a(1)}\right)\right)\max_{r} z_{jar}\\
&\quad+\left[\sum_{i=1}^{m}h_{ij}\left(C_{it(2)}x-(1-\beta)\left(C_{it(2)}-C_{it(1)}\right)\right)\right.\\
&\quad+\sum_{k=1}^{s}m_{kj}\left(C_{kt(2)}x-(1-\beta)\left(C_{kt(2)}-C_{kt(1)}\right)\right)\\
&\quad\left.+\sum_{o=1}^{z}\left(C_{ot(2)}x-(1-\beta)\left(C_{ot(2)}-C_{ot(1)}\right)\right)r_{oj}\right]\times x_{jt}\\
&\quad\leq B_{jt(2)}+(1-\beta)\left(B_{ij(3)}-B_{ij(2)}\right)
\end{aligned} \tag{33}$$

Other Constraints

2.3 LAM

$$Max\ E[Z_1] \tag{34}$$

$$Min\ E[Z_2] \tag{35}$$

Subjected to

$$\begin{aligned}
&\left(\sum_{i=1}^{m}h_{ij}.\left(C_{it(2)}+(1-\beta)\left(C_{it(3)}-C_{it(2)}\right)\right)\right.\\
&\quad+\sum_{k=1}^{s}m_{kj}.\left(C_{kt(2)}+(1-\beta)\left(C_{kt(3)}-C_{kt2}\right)\right)\\
&\quad\left.+\sum_{o=1}^{z}r_{oj}.\left(C_{ot(2)}+(1-\beta)\left(C_{ot(3)}-C_{ot(2)}\right)\right)\right)\times x_{jt}\\
&\quad\leq p_{jt(2)}-(\beta)\left(p_{ij(2)}-p_{ij(1)}\right)
\end{aligned} \tag{36}$$

$$\begin{aligned}
&\sum_{j=1}^{n}\sum_{a=1}^{A}\left(C_{a(2)}+(1-\beta)\left(C_{a(3)}-C_{a(2)}\right)\right)\max_{r} z_{jar}\\
&\quad+\left[\sum_{i=1}^{m}h_{ij}\left(C_{it(2)}+(1-\beta)\left(C_{it(3)}-C_{it(2)}\right)\right)\right.\\
&\quad+\sum_{k=1}^{s}m_{kj}\left(C_{kt(2)}+(1-\beta)\left(C_{kt(3)}-C_{kt(2)}\right)\right)\\
&\quad\left.+\sum_{o=1}^{z}\left(C_{ot(2)}+(1-\beta)\left(C_{ot(3)}-C_{ot(2)}\right)\right)r_{oj}\right]\\
&\quad\times x_{jt}\leq B_{jt(2)}-(\beta)\left(B_{ij(2)}-B_{ij(1)}\right)
\end{aligned} \tag{37}$$

Other Constraints

2.4 Experimental results

The select Portfolio RRSs proposed in this study is a mixed-integer linear programming model. It worth noting that the general algebraic modeling system (GAMS) software is used to solve the mathematical model. In this section, a P.G. company (One of the huge companies in the field of construction) in Iran is investigated as a real-case study to validate the performance of the proposed select Portfolio RRSs model.

An efficient multi-objective method can be done as an efficient method for obtaining the satisfaction level for each OFVs according to the decision maker's preferences. For further explanations, the interested reader can refer to TH [20]. Two parameters in this method are very critical: relative importance of OFVs (i.e., weight factor) and coefficient of compensation. Details of the distribution functions of the parameters and the size of test problems are listed in **Table 1**. After that, the results on test problems for diverse values of ϑ andφ are shown in **Table 2**.

According to **Table 2**, the values of objective functions change based on the value of ϑ. The results indicate that satisfaction degrees displaying each objective function change based on the value of ϑ. In this table, the values of satisfaction degree of objective functions (1) and (2) for test problem 2 fluctuate between 0.841 and 0.965, and 0.848 and 0.961, respectively. The results show that by manipulating the value of ϑ, the decision-maker can make trade-offs between two objective functions and select an optimal pair. Generally, increasing the value of ϑ leads to higher allocated weights to acquire a higher lower bound for the satisfaction degree of objectives (λ_0).

Based on the acquired results and considering the budget and time limitations, the most appropriate strategy for responding to the risk work packages is provided in **Table 3**. In this test problem project 8 and 3 are selected. Appendix A. shows the amount of maximum allowed time reduction (day) and the quality of each activity (in percentage). The obtained quality of each activity under acceptable and ideal condition is assumed 90% and 99% respectively ($\delta^w \in [1\%, 10\%]$). Appendix B. illustrates the effect of implementing risk response strategies on risks cost reduction (if occurs).

Parameters	**Values**		
	First Problem	**Second Problem**	**Third Problem**
J	3	3	3
I	20	20	20
K	3	3	3
O	2	2	2
T	5	5	5
W	12	12	12
R	12	12	12
A	8	8	8
p_{jt}	(2 × 104,3.5 × 104)	(4 × 104,6 × 104)	(6 × 104,9 × 104)
e_{ar}	(5 × 103,104)	(8 × 103,2 × 104)	(1.8 × 104,5 × 104)
C_a	(103,5 × 103)	(104,2 × 104)	(3 × 104,5 × 104)
B_{jt}	(5 × 103,1.5 × 104)	(3 × 104,5 × 104)	(5 × 104,7.5 × 104)
C_{it}	(500,700)	(800,1000)	(1500,2000)
C_{kt}	(800,1500)	(2000,3000)	(4000,8000)
C_{ot}	(1000,2000)	(1000,2000)	(1000,2000)

Table 1.
Amount of the parameters by random generation.

Problem No.	ϑ	φ	$\mathcal{Z}_1$	$\mu_1(\mathcal{Z})$	$\mathcal{Z}_2$	$\mu_2(\mathcal{Z})$
1	0.6	0.3,0.7	33218.2	0.924	781.08	0.973
	0.6	0.5,0.5	32039.2	0.958	817.20	0.930
	0.6	0.7,0.3	31287.4	0.981	826.98	0.919
	0.4	0.3,0.7	34838.8	0.881	772.35	0.984
	0.4	0.5,0.5	32791.6	0.936	805.93	0.943
	0.4	0.7,0.3	30909.3	0.994	867.57	0.876
2	0.6	0.3,0.7	50448.4	0.892	1317.2	0.911
	0.6	0.5,0.5	48966.2	0.919	1345.3	0.890
	0.6	0.7,0.3	46632.1	0.965	1415.0	0.848
	0.4	0.3,0.7	53507.7	0.841	1248.6	0.961
	0.4	0.5,0.5	51903.1	0.867	1295.8	0.926
	0.4	0.7,0.3	47418.3	0.949	1393.7	0.861
3	0.6	0.3,0.7	70806.1	0.918	2098.6	0.953
	0.6	0.5,0.5	69370.3	0.937	2164.5	0.924
	0.6	0.7,0.3	67427.3	0.964	2171.5	0.921
	0.4	0.3,0.7	71982.2	0.903	2044.9	0.978
	0.4	0.5,0.5	69817.4	0.931	2148.2	0.931
	0.4	0.7,0.3	66598.3	0.976	2229.6	0.897

Table 2.
Results of test problem 1 ($\beta = 0.5$).

2.5 Managerial insights

Large construction companies mainly use the project to carry out their activities. Due to the limited resources of these companies, which can be considered project-based organizations, they have to decide on selecting, stopping projects and allocating resources, and have using portfolio management tools, consequently. Portfolio Risk Management is one of the common knowledge scopes in portfolio management with project portfolio decisions application. The primary purpose of risk management is to protect the organization against damages and to prepare the organization for possible future damage. Therefore, the risks should be met with proper risk responses. Risk management at the portfolio level supports the aforementioned goals in different ways.

Firstly, enables the portfolio manager to compare the risks of single projects in terms of risk feature reduction actions. This comparison allows to make difference between options and the single risk levels are clarified and the results of risk responses actions are reflected and facilitate the transfer of experiences between the projects. Secondly, the comparison of the public risks of the portfolio and its trend according to the life cycle of the project has been revealed. Clarity growth leads to preventing other project risks or increasing focus on risks that are prevalent in most of the projects. Thirdly, risk management reduces uncertainty by providing enough information to make decisions. As a result, estimations are more accurate, reliable, and reduce the chance of surprise and the rate of failures. Therefore, risk management should increase information clarity, detecting and clarifying problems, risk response capacity, and depth of information for decision making.

Optimal allocation in project 3	Risks	Work Packages (WP)
RR 27	R1	WP 1- WP 10
RR 17	R 5	WP 5- WP 10
RR 21	R 8	WP 5- WP 10
RR 10	R 9	WP 3- WP 4
RR 12	R 12	WP 1, WP 9, WP 10
RR 7	R 24	WP 2- WP 8
RR 22	R 25	WP 4- WP 6
RR 1	R 26	WP 6, WP 7, WP 9
Optimal allocation in project 3	Risks	Work packages
RRS 27	R 1	WP 1- WP 12
RRS 13	R 2	WP 1, WP 3- WP 10
RRS 14	R 4	WP 2- WP 12
RRS 11	R 7	WP 3- WP 12
RRS 21	R 8	WP 5- WP 12
RRS 10	R 9	WP 5- WP 12
RRS 30	R 10	WP 8, WP 10, WP 11
RRS 16	R 11	WP 3- WP 12

Table 3.
Solution allocation of RRs for projects 8 and 3.

3. Conclusion

In this research, a linear mixed-integer model was proposed to solve a project selection problem and provide RRSs. According to objective functions, this model firstly aims to select projects with the highest net profit and risk response effects. Secondly, these projects should be carried out with minimum resource and implanting risk responses costs. The model is solved to select the most desirable projects and risk response strategies to deal with risk events. The main contribution of this research is combining of project selection from a portfolio and calculation of risk response effect. In addition, because of environmental effects, some parameters (including the cost of human, machine, material, risk response effect, etc.) were considered as fuzzy numbers. Fuzzy Me measure is considered to deal with the uncertain parameters of the proposed model. To solve the model ten building project were studied, and Net profit and resources costs were considered as objective functions. Finally, optimal allocation of risk response strategies was determined. TH method was used to solve the model, which was coded in GAMS. Results showed that increasing budgets in sample problem, led to higher net profit and less projects costs. The sensitivity analysis of the case study showed the necessity of the trade-offs between maximizing profit and minimizing projects cost. At last, Pareto frontier was analyzed. Results indicate that this model can act as a powerful criterion and help project managers to increase desirable impacts of a solution before implementing the project. Also, uncertain parameters like robust programming can be determined to cover the limitations of the designed model. Moreover, since the presented model is categorized as an NP-hard problem, meta-heuristic algorithms may be utilized to solve the model.

Notations

Sets

j	Projects $j = 1, 2, \ldots, n$).
i	Human resources (HR) $(i = 1, 2, \ldots, m)$.
k	Machinery $(k = 1, 2, \ldots, s)$.
O	Material $(O = 1, 2, \ldots, z)$.
t	Time period $(t = 1, 2, \ldots, T)$.
w	Work packages$(w = 1, 2, \ldots, W)$.
r	Risk events (RE)$(r = 1, 2, \ldots, R)$.
a	Candidate RRSs$(a = 1, 2, \ldots, A)$.

Parameters

H_{it}	Max accessible HR i in time t (person-hours).
h_{ij}	Demand of HR i in j (person-hours).
$\tilde{M}_{kt}$	Max available machine-hour k in time t.
m_{kj}	Demand of machine-hour k in j.
R_{ot}	Max accessible material o in time t.
r_{oj}	Demand of material o in j.
B_{jt}	Maximum available project budget for j in period t.
$\tilde{C}_{it}$	Hourly cost of HR i in period t.
$\tilde{C}_{kt}$	Hourly cost of machine k in time t.
$\tilde{C}_{ot}$	Unit cost of material o in time$t$.
W_w	Work packages w.
R_r	Risk response (RR) r.
A_a	Candidate RRS a.
C_a	Cost of implementing risk response strategy a.
$\tilde{p}_{jt}$	Total Net Profit (NP) worth of j in time t.
I_{jt}	RoR for j in time t.
$MARR_t$	MARR during period t.
d_{jt}	Period of project j in time t.

Decision variables

x_{jt}	if project j is chosen for investment in time t, 1; otherwise, 0.
z_{jar}	1 if RRS a is applied for RE r for project j; 0, otherwise.

Appendix A: Projects activities, budget, costs, Maximum allowed time reduction (day) and the quality of each activity (percentage)

Appendix A.1

	Project 1									Project 2						
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W1	W2	W3	W4	W5	W6	W7
δ^w	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%

	Project 1									Project 2						
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W1	W2	W3	W4	W5	W6	W7
ε^w	14	8	10	15	10	8	14	14	12	14	11	14	11	11	11	8
C_{it}	22,000 (USD)									25,000(USD)						
C_{kt}	35,000 (USD)									30,000(USD)						
C_{ot}	30,000 (USD)									38,000(USD)						
B_{jt}	200 million (USD)									250 million (USD)						

Appendix A.2

	Project 3											
	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12
δ^w	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
ε^w	11	12	14	10	12	13	9	13	15	10	8	14
C_{it}	20,000 (USD)											
C_{kt}	35,000 (USD)											
C_{ot}	28,000 (USD)											
B_{jt}	270 million (USD)											

Appendix A.3

	Project 4							Project 5						Project 6				
	W1	W2	W3	W4	W5	W6	W7	W1	W2	W3	W4	W5	W6	W1	W2	W3	W4	W5
δ^w	10%	10%	10%	11%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
ε^w	10	10	12	12	13	9	10	12	13	9	13	14	10	10	12	12	14	9
C_{it}	25,000 (USD)							25,000 (USD)						20,000 (USD)				
C_{kt}	30,000 (USD)							35,000 (USD)						35,000 (USD)				
C_{ot}	35,000 (USD)							35,000 (USD)						38,000 (USD)				
B_{jt}	200 million (USD)							200 million (USD)						250 million (USD)				

Appendix A.4

	Project 7							
	W1	W2	W3	W4	W5	W6	W7	W8
δ^w	10%	10%	10%	10%	10%	10%	10%	10%
ε^w	8	11	14	11	13	13	12	14
C_{it}	25,000 (USD)							
C_{kt}	45,000 (USD)							
C_{ot}	28,000 (USD)							
B_{jt}	300 million (USD)							

Appendix A.5

	Project 8										Project 9						
	W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**
δ^w	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%	11%	11%	11%	11%	11%	11%	11%
ε^w	14	15	14	16	14	11	12	9	14	14	10	12	13	9	13	15	9
C_{it}	20,000(USD)										20,000(USD)						
C_{kt}	35,000(USD)										38,000(USD)						
C_{ot}	25,000(USD)										40,000(USD)						
B_{jt}	200 million (USD)										200 million (USD)						

Appendix A.6

	Project 10								
	W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**
δ^w	10%	10%	10%	10%	10%	10%	10%	10%	10%
ε^w	11	11	8	11	12	14	10	12	13
C_{it}	25,000(USD)								
C_{kt}	35,000(USD)								
C_{ot}	28,000(USD)								
B_{jt}	250 million (USD)								

B: the effect of implementation of risk response strategies on risks cost reduction (*10 USD)

Appendix B.1

		Risks									
		Risk 1	Risk 2	Risk 3	Risk 4	Risk 5	Risk 6	Risk 7	Risk 8	Risk 9	Risk 10
Risk responses strategies	Risk Response 1	3320	7260	—	—	—	—	—	—	—	—
	Risk Response 2	—	—	4530	—	—	—	—	7310	—	—
	Risk Response 3	—	—	9480	4790	5460	—	4450	—	—	10,020
	Risk Response 4	—	5230	—	—	—	5960	—	—	—	—
	Risk Response 5	3800	—	—	—	—	—	5010	—	—	—
	Risk Response 6	—	—	—	—	6140	5630	—	6730	—	—
	Risk Response 7	5840	5040	—	—	—	—	—	—	8300	—
	Risk Response 8	—	—	—	4800	—	—	—	7100	—	—
	Risk Response 9	—	7100	—	—	3960	—	—	6200	—	—
	Risk Response 10	—	—	7980	—	—	4560	—	—	9200	—
	Risk Response 11	—	—	—	4320	5070	—	8900	4070	—	8090
	Risk Response 12	—	—	—	—	9750	10,450	—	6470	5300	—
	Risk Response 13	—	7890	4600	4800	—	—	4500	—	—	4750

		Risks									
	Risk Response 14	4200	6540	—	9800	6540	4890	—	—	4750	9640
	Risk Response 15	—	—	—	6940	—	—	7310	4800	—	—
	Risk Response 16	5470	—	—	4580	6700	11,230	4500	4980	—	—
	Risk Response 17	—	4860	—	—	9870	7800	6940	7500	—	—
	Risk Response 18	—	7560	—	—	7460	8600	7120	—	—	—
	Risk Response 19	—	3980	4690	—	—	—	6400	—	—	—
	Risk Response 20	—	—	7310	4600	—	5600	—	—	—	—
	Risk Response 21	—	—	5740	—	9000	—	—	7510	4500	4500
	Risk Response 22	—	—	6210	—	4670	4810	6070	—	—	—
	Risk Response 23	—	4670	—	7900	9800	—	7240	—	—	—
	Risk Response 24	—	4120	3980	5600	—	—	—	3650	—	—
	Risk Response 25	—	—	7820	—	4680	7800	—	—	—	10,110
	Risk Response 26	—	—	6450	8210	—	8090	8000	—	—	—
	Risk Response 27	9200	—	6480	4040	—	—	5200	—	4860	—
	Risk Response 28	—	6390	—	—	4920	—	—	7500	—	—
	Risk Response 29	—	5890	—	6400	—	—	7560	—	—	—
	Risk Response 30	—	4620	3980	—	6540	—	4890	4040	—	10,200
	Risk Response 31	7200	—	7560	—	7560	—	3960	—	—	7200

Appendix B.2

		Risks					
		Risk 11	Risk 12	Risk 13	Risk 14	Risk 15	Risk 16
Risk responses strategies	Risk Response 1	9300	—	—	—	7200	4620
	Risk Response 2	—	—	4550	3500	—	—
	Risk Response 3	—	—	3900	—	—	—
	Risk Response 4	7220	—	7890	—	3560	4780
	Risk Response 5	—	9520	—	—	—	8630
	Risk Response 6	—	—	—	—	—	—
	Risk Response 7	—	9700	—	7560	—	—
	Risk Response 8	8200	9200	—	—	4560	—
	Risk Response 9	—	—	9400	5670	—	7200
	Risk Response 10	7500	10,400	11,630	4750	9600	7450
	Risk Response 11	5040	—	—	—	7500	8040
	Risk Response 12	—	11,230	—	—	—	7400
	Risk Response 13	—	—	—	7800	—	—
	Risk Response 14	8750	—	—	4620	10,400	—
	Risk Response 15	—	—	12,400	4590	6870	4700
	Risk Response 16	9500	—	—	10,400	—	—
	Risk Response 17	—	7800	—	—	—	9500
	Risk Response 18	—	8600	—	7500	—	—

	Risks						
	Risk Response 19	8620	—	—	—	—	—
	Risk Response 20	—	5600	—	—	9500	8720
	Risk Response 21	—	—	—	7120	—	—
	Risk Response 22	—	4810	9450	—	—	—
	Risk Response 23	8200	—	—	—	8620	—
	Risk Response 24	—	—	10,410	—	—	8300
	Risk Response 25	—	—	—	10,420	—	—
	Risk Response 26	—	—	7800	4860	—	—
	Risk Response 27	—	—	8600	—	8200	—
	Risk Response 28	—	—	—	—	—	8400
	Risk Response 29	4680	—	5600	4560	11,110	12,300
	Risk Response 30	—	7510	—	8600	—	—
	Risk Response 31	—	—	4810	—	—	—

Appendix B.3

		Risks								
		Risk 17	Risk 18	Risk 19	Risk 19	Risk 20	Risk 21	Risk 22	Risk 23	Risk 24
Risk responses strategies	Risk Response 1	3320	7260	—	—	—	—	—	—	—
	Risk Response 2	—	—	4730	4120	—	—	—	8510	—
	Risk Response 3	—	—	4850	4670	4230	—	4450	—	—
	Risk Response 4	—	5630	—	—	—	7640	—	—	—
	Risk Response 5	5700	—	—	—	—	—	5410	—	—
	Risk Response 6	—	—	—	—	5100	—	—	6730	—
	Risk Response 7	5220	4040	—	—	—	—	—	—	8300
	Risk Response 8	—	—	—	4210	—	—	—	7100	—
	Risk Response 9	—	9000	4690	—	10,200	—	9000	3320	4800
	Risk Response 10	4250	4670	7450	—	—	7310	4870	—	—
	Risk Response 11	—	9800	—	—	8510	4700	7200	—	—
	Risk Response 12	—	—	9600	—	—	4840	—	—	4500
	Risk Response 13	—	4680	—	7890	—	7120	4680	5700	—
	Risk Response 14	5600	—	—	—	—	6400	—	—	—
	Risk Response 15	—	—	—	4680	6730	—	—	5220	—
	Risk Response 16	—	4920	—	7420	—	—	4920	—	—
	Risk Response 17	—	—	4760	6900	7100	6070	—	—	6780
	Risk Response 18	6230	—	—	—	—	7240	—	4250	—
	Risk Response 19	5520	—	—	—	12,400	—	—	—	4700
	Risk Response 20	—	4890	—	—	—	—	4870	—	6970
	Risk Response 21	—	—	—	9640	—	8010	—	—	—

	Risks									
	Risk Response 22	—	—	6710	—	10,700	5400	—	—	—
	Risk Response 23	6200	—	—	—	—	7800	4790	9870	—
	Risk Response 24	3750	—	—	—	—	—	8920	6540	5470
	Risk Response 25	—	4790	—	—	—	3450	—	—	—
	Risk Response 26	—	9760	4500	—	11,450	—	—	4800	—
	Risk Response 27	—	7450	—	—	—	—	7890	—	—
	Risk Response 28	—	8960	—	4750	—	9700	—	—	—
	Risk Response 29	4200	4300	—	—	—	4780	7450	—	4600
	Risk Response 30	—	—	6710	—	10,010	—	—	4500	—
	Risk Response 31	—	—	7890	7200	9800	—	—	8040	—

Appendix B.4

		Risks									
		Risk 24	Risk 25	Risk 26	Risk 27	Risk 28	Risk 29	Risk 30	Risk 31	Risk 32	Risk 33
Risk responses strategies	Risk Response 1	—	—	9500	—	—	—	—	7800	7800	—
	Risk Response 2	—	—	—	—	9000	—	4200	—	3320	—
	Risk Response 3	—	9320	—	—	4670	—	—	—	—	—
	Risk Response 4	—	—	8620	—	9700	4230	—	—	—	—
	Risk Response 5	—	—	—	9520	—	—	—	10,400	—	—
	Risk Response 6	—	—	—	—	—	—	—	—	5700	—
	Risk Response 7	8300	—	—	9700	—	5100	—	7890	—	—
	Risk Response 8	—	—	8200	9200	—	—	—	5470	5220	8090
	Risk Response 9	4800	4580	—	—	4920	—	—	—	—	—
	Risk Response 10	—	7400	—	—	—	7500	—	—	—	4750
	Risk Response 11	—	6520	—	6970	6870	—	—	—	4250	9840
	Risk Response 12	4500	—	—	4580	—	8510	8090	12,300	—	—
	Risk Response 13	—	—	—	—	6980	—	—	—	—	—
	Risk Response 14	—	—	7310	—	—	—	4750	—	—	—
	Risk Response 15	—	—	4500	—	4120	—	9640	—	7560	—
	Risk Response 16	—	—	—	7450	3640	4800	—	7540	4520	—
	Risk Response 17	6780	—	7120	6420	—	9200	—	6420	—	—
	Risk Response 18	—	—	6400	—	—	3480	—	4120	—	7890
	Risk Response 19	4700	8090	—	—	—	5800	—	—	—	3320
	Risk Response 20	6970	—	—	4780	—	6700	—	—	6340	—
	Risk Response 21	—	4750	6070	—	6980	—	—	—	4120	—
	Risk Response 22	—	9640	7240	—	—	—	—	10,230	—	—
	Risk Response 23	—	—	—	—	—	—	4890	—	7890	5700
	Risk Response 24	5470	—	—	—	—	—	—	11,100	6420	—
	Risk Response 25	—	—	8000	—	6980	—	9560	—	—	5220

		Risks									
	Risk Response 26	—	—	—	7890	—	4780	6340	—	—	—
	Risk Response 27	—	—	—	—	—	—	7800	—	—	—
	Risk Response 28	—	—	7450	—	—	—	9870	—	—	10,500
	Risk Response 29	4600	8000	6320	—	—	8970	—	—	6740	—
	Risk Response 30	—	—	—	7120	9780	—	6700	—	—	—
	Risk Response 31	—	—	—	—	5700	—	—	7400	—	—

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