A risk-return based mathematical model for resource allocation with considering the process resilience and continuity

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Abstract

In recent high-risk and changing world, optimal resource allocation is significant, which in case of inappropriate resource allocation, will cause significant damage to organizations. In resource allocation and where there is a lack of resources, it is imperative to processes continue and the process's resilience and the risks posed by these lack and unsuitable allocations. If resource allocation is not done properly or is done in short supply, there will be consequences, e.g. processes do not continue properly or are not resilient, or the will be increase in the risks of the processes. In this paper, a novel integrated mathematical model has been developed for resource allocation with considering the process resilience and continuity. Thus, the objective functions of the model is defined according to the four measures of optimal resource allocation such as return, risk, resilience and process continuity. One of the results of the

integrated model is that in case of lack of resources, resources can be allocated with the highest return and minimum risk, and in case of critical conditions and lack of resources, their processes and activities do not stop.

Keywords: Risk analysis; resource allocation; process optimization; resilience; continuity.

1. Introduction

Undoubtedly, the current world is the world of organizations, and an organization without resources will not only have no concept, but it will not be possible to manage them either. When resources become scarce and demand outstrips supply, resource allocation becomes very important [1]. By optimally allocating resources, organizations achieve a tool to perform their strategies and plans. Achieving maximum output is one of the main efforts of the organization, and this tendency can be achieved by using optimization models. In formulation and resource allocation, modeling is a typical tool that can provide the necessary information for decisions to achieve goals. A resource allocation predicament is the optimal allocation of available resources between several activities. The meaning of optimization in allocation is maximizing output and profit, and minimizing risk, cost, or any other goal defined according to the conditions of the predicament.

Considering the importance of optimizing processes in dire economic conditions in some organizations and facilitating the implementation of organizational missions, addressing this issue has become more critical than ever. Due to the fact that in the current situation, organizations are more exposed to crises and also during the resource allocation in crisis conditions, disruptions may occur and resources are not optimally allocated, So organizations need a business continuity plan as well as resilience to function properly in crisis situations [2]. As seen in Figure (1), there is a main process that receives an input and after the operation is done, the output is produced. In the present problem, there is an assumption of lack of resources and it seeks to allocate resources to activities in a way that gives outputs with the highest return. In the resource allocation model, the resilience parameter is also considered, that resources may be allocated to one product but face the challenge of another product in the market. Therefore, the performance must be controlled, for this reason resilience has been added. And another concept under the title of continuity is considered, so that services and products can be delivered to the customer. Therefore, in this article, it seeks to allocate resources to processes through activities in such a way that the risks related to the activity and resources are controlled, and based on the output performance of the process, resilience can be raised in the process and the activities continue.

After the reviews in the articles in the fields of continuity and resilience, risk and resource allocation, it was observed that there are different mathematical methods to measure them:

In the area of resource allocation: fuzzy logic, data envelopment analysis models, heuristic approaches, system dynamics, discrete event simulation model, colored Petri nets, goal Programming, multiple-criteria decision analysis, linear programming and dynamic planning model.

In the field of resilience: fuzzy cognitive map, neural network, optimization models, structural equation modeling, structural equation modeling, conceptual frameworks and fuzzy logic model.

In the field of continuity: conceptual framework, fault tree and event tree model, optimization models.

In the field of risk: Event Tree Analysis, Bow-Tie, HAZOP and Fault Tree Analysis.

The following are the main contributions of the article:

- Considering portfolios including a combination of different allocations of resources to activities and finding the optimal portfolio.
- Formulating mathematical modeling for resource using the concepts of return and risk (Markowitz model) and process continuity and resilience (taking into account the lack of resources).
- Formulating mathematical modeling at the activities level (resource allocation model).

- Considering resources according to their nature (activity-oriented and output-oriented).
- Providing a decision-making tool to managers for resource allocation.

2. Literature Review

2.1. Operational resource allocation

Bower in 1970 conducted Peartmon resource allocation research, which was developed by Burgelman in 1983 [3,4]. Also, in 2004, resource allocation models were introduced for the first time by Lozano et al [5]. A mathematical model was presented in 2015 by Sahebjamnia et al. in the field of resource allocation in which they sought to maximize business continuity and resilience [6]. In 2018, Sahebjamnia et al. continued their previous research in the field of resource allocation and presented a new mathematical model taking into account indicators of recovery time and operational level of critical functions [7]. Ostadi et al., presented a model to determine the optimal amount of resources needed for activities in the textile industry. Resources included manpower and machines [8]. In 2018, Mokhtarian Daloie and Ostadi presented a model to improve the quality of health services in order to optimally assign human resources in shifts [9]. In 2020, Najarian and Lim presented a model for optimal budget allocation to the infrastructure components, which was considered an electrical production unit [10]. In 2020, Yu et al., discussed the optimal allocation of manpower resources and machinery to some hospital activities [11]. Deng et al., have presented a mathematical model in 2020 for the optimal allocation of resources, which deals with allocating defense resources and minimizing risk. [12]. In 2021, Ostadi et al., have presented a mathematical model for the allocation of resources in the event of a destructive event with the aim of increasing business continuity and resilience. Also, in this article, the effect of conflicting destructive events is also considered [13]. Also, in 2021, Mokhtarian Daloie & Ostadi have worked on the optimal allocation of technicians to weekly shifts using the Markowitz model (increasing return and reducing risk) [14]. In another article in 2022, the optimal allocation of nursing manpower to the days of the week, as well as the optimization of patients' waiting time for emergency treatment, has been discussed [15].

Khazaeli et al. presented a new approach to multi-project scheduling problem in order to allocate the budget as a limited resource and schedule the project portfolio simultaneously, taking into account the resource limitation [16].

2.2.Resilience

The resilience parameter was first expressed by Holling in 1973, and Holling's research is the basis of subsequent studies in this field [17]. Gong & You have presented a model to minimize capital cost and maximize resilience [18]. Sahebjamnia et al., presented an optimization model in 2018 for resilience in order to respond to several destructive events [7]. In 2019, Jain et al. presented a model using the analytical framework of process resilience considering the maximization of expected revenue and the minimization of cost [19]. In 2020, Najarian and Lim have presented an optimization model to increase infrastructure resilience for a series of destructive events under budget constraints [10]. Pishnamazzadeh et al. have presented a model to evaluate the resilience of the hospital using the resilience engineering approach [20]. Yarveisy et al have presented a new set of resilience criteria using the concept of reliability and system modeling approach [21]. In 2021, Fasey *et al.,* expressed the concept of resilience at the organizational level. Also, the purpose of this article was to identify the resilience characteristics of sports organizations [22].

In an article in 2021, a systematic review of organizational resilience structure that covers both operational and conceptual issues has been addressed [23]. Also, in 2022, the organization's resilience, business continuity and risk have been systematically investigated, and a conceptual framework for future research has been presented in this article [24]. In 2022, Plaisance has studied the global spread of the COVID-19 disease in arts and cultural organizations. The purpose of this article is to examine whether arts and cultural organizations can be resilient during this crisis or not [25].

Hamsal *et al*,. have investigated the effect of organizational resilience on hotel performance during the COVID-19 disease [26].

2.3.Business Continuity

For the first time in the 1970s, business continuity was proposed [27]. In 2019, Rezaei Soufi et al., have presented a model with the aim of minimizing the establishment cost of selected BCPs and maximizing the level of resilience [28]. Xing et al., proposed a dynamic business continuity assessment (DBCA) approach [29]. Another 2020 paper presents a framework for the elements that make up a business continuity management [30]. In 2021, Ostadi et al. have presented an optimization model for the resource allocation in the field of BCM. where the aim is to increase the value of business continuity and reduce the lack of resilience [13]. Al Ameri and Musa evaluated the relationship between business continuity management and organizational performance of Abu Dhabi government organizations by considering organizational resources. [31]. In 2021, Ranf *et al.*, have analyzed the concept of "business continuity management", analyzing the evolution of the concept of business continuity management and how to support organizations during the crisis of the of COVID-19 disease [32]. In 2022, Rodman has investigated the impact of increased remote work of employees during the COVID-19 disease on crisis management, risk and business continuity [33]. In Le and Nguyen's article, the negative effects of COVID-19 disease on the business continuity of companies have been evaluated [34]. In another article in 2022, factors affecting the business continuity during a crisis such as the COVID-19 disease have been examined [35].

2.4.Risk

Hertz used the risk for the first time in 1964. In the 1970s, Monte Carlo simulation and statistical methods were used for risk analysis [36]. In 2017, Vileiniskis & Remenyte-Prescott presented a framework-based simulation for risk prediction using an extension of the Petri Net model [37]. In 2019, Mutlu & Altuntas analyzed risk using Belief in Fuzzy Probability Estimations of Time algorithm and Fault Tree Analysis method [38]. In 2020, Ostadi et al presented a model using Genetic Algorithm and Markowitz model in the power market. In this paper, from the Markowitz model, considering the risk of acceptance in the market, the risk is considered for the proposed models [39]. Ostadi et al calculated the probability of accepting and the risk of not accepting the proposed price in the electricity market [40]. Ostadi et al., the allocation of human resources (technicians) to weekly shifts has been discussed. The purpose of this article is to increase return and minimize risk when allocating resources [41]. In 2021, Maia *et al*. improved the quality of operational risk estimation for power stations and increased efficiency in reducing it using multiple Criteria Decision Making models and methods [42]. Zhimeng and Jiazheng in 2021 analyzed the relationship between delay factors in ship maintenance and resource allocation using system dynamics theory. and has created a risk assessment model [43]. In another article by Ostadi *et al.*, a review of articles and research gaps and challenges in the field of risk has been reviewed with the purpose of understanding various researches in this field from different perspectives (Ostadi *et al.*, 2022). In 2022, Varshney conducted a study on the relationship between the large population of families and the risk of their death due to the disease of COVID-19 [44].

2.5.literature gap

According to the conducted research, the literature gaps are:

- In past researches, modeling has been at the macro level of processes or operational issues.
- In the resource allocation in lack conditions, the only index used is the amount of lack, and past research has not been done on index that can show the impact of these resources on the return and return outputs of processes.
- Risk has been considered in resource allocation research, but it has not been seen as an index in modeling.
- Failure to consider the indexes of risk, return, resilience and business continuity at the process level in the various allocations that can happen through activities.
- In previous researches, allocation models have been worked under uncertainty and risk conditions, but all of them have given the allocation first and then calculated the risk. That is (In this way), the risk issues have not shown themselves in the allocation process.

- So far, past research has focused on organizational resilience and business continuity, but having these concepts for the processes and activities of the organization does not exist and is considered as a gap.
- In other researches, there has been no classification of resources according to their nature. There is a difference between resources that some resources are spent on processes and some resources are spent directly on outputs.

3. Resource allocation model formulation in critical conditions

3.1. Assumptions

The assumption of the problem is that according to the critical conditions, there is a lack in at least one of the available resources.

Equation (1) is related to output-oriented resources and Equation (2) is related to activity-oriented resources. In these Equations, the left side is the required amount of resources and the right side is the amount of available resources.

$$\exists\sum_{o=1}^{O}\widehat{X}_{ok} \succ RO_K^E + RO_K^I \quad \forall K \tag{1}$$

$$\exists\sum_{o=1}^{O}\sum_{i=1}^{m}\sum_{j=1}^{n_i} X_{ijok'}^{t} \succ RA_{K'}^E + RA_{K'}^I \quad \forall K' \tag{2}$$

So:

Indices:

o	Index of output (o=1,…,O)
k	Index of output-oriented resource (k=1,…,K)
k'	lex of activity-oriented resource (k=1,…, $\boldsymbol{K'}$)
t	Index of time (t=1,…,T)

i	Index of process (i=1,…,m)
j	lex of activity (j=1,…,$\boldsymbol{n_i}$)
l	Index of operational level (l = 1, … , L)
s	Index of scenario (s=1,…,S)

Parameters:

(ijo)	A triad of activities j of process i to produce output o
$prob^s$	Scenario probability of S
γ_{jios}	*MTPD (*Maximum tolerable period distribution) for *(ijo)* and scenario S
γ_{os}	*MTPD* for output o and scenario S
λ_{jios}	*MBCO (*Minimum business continuity operation*)* for *(ijo)* and scenario S
Bg	Existing budget to provide external resources
W_o	Weight of each output
wo_k	Weight for *kth* resource (output-oriented resources)
$wa_{k'}$	Weight for $\boldsymbol{\acute{k}}$*th* resource (activity-oriented resources)
n_i	i is from 1 to m, and $\boldsymbol{n_i}$ is the activities associated with each process i.
α	$\boldsymbol{\alpha}$ is also a decimal number close to 1.
P_o	Demand for each o
r_{oks}	The consumption rate for output-oriented resources
$r_{jiotk's}$	The consumption rate for activity-oriented resources
ROE_{ks}	External available resource amount for output-oriented resource
ROI_{ks}	Internal available resource amount for output-oriented resource
$RAE_{k's}$	External available resource amount for activity-oriented resource

$RAI_{k's}$	Internal available resource amount for activity -oriented resource
$\widehat{x}_{oks}$	Required resource amount (output-oriented resources)
$\widehat{x}_{jiotk's}$	Required resource amount (activity-oriented resources)
COE_K	External resources cost *k* (output-oriented resources)
$CAE_{K'}$	External resources cost *k* (activity-oriented resources)
Z_{jio}	If (*jio*) is active will be one, otherwise zero

Variables:

Y_{jitsol}	If operational level (*jio*) at time *t* and scenario *S* is equal to *l* it will be one, otherwise zero
M_{jiot}	If (*jio*) at time t is active will be one, otherwise zero
XI_{oks}	Amount of allocated internal resource (output- oriented resources)
XE_{oks}	Amount of allocated external resource (output- oriented resources)
$XI_{jiotk's}$	Amount of allocated internal resource (activity- oriented resources)
$XE_{jiotk's}$	Amount of allocated external resource (activity- oriented resources)
W_{jiots}	The planned operational level for (ijo) at time *t* in scenario *S*
W_{os}	The planned operational level for output o in scenario *S*
υ_{jios}	The recovery time for activity-oriented resources
υ_{os}	The recovery time for output-oriented resources

3.2.Problem formulation

Therefore, the optimization model of resource allocation is as follows:

$$MinLR = \sum_{s=1}^{S} prob^{s} \sum_{t=1}^{T}\sum_{o=1}^{O} W_o \sum_{i=1}^{m}\sum_{j=1}^{n_i} M_{jiot} \times (L - W_{jiots}) + \sum_{s=1}^{S} prob^{s} \sum_{o=1}^{O} W_o \times (L - W_{os}) \tag{3}$$

$$MaxCA = \frac{\sum_{i=1}^{m} n_i - \sum_{s=1}^{S} prob^s \sum_{o=1}^{O} W_o \sum_{i=1}^{m} \sum_{j=1}^{n_i} \left(\frac{\upsilon_{jios}}{\gamma_{jios}} \right)}{\sum_{i=1}^{m} n_i} \tag{4}$$

$$MaxCO = 1 - \sum_{s=1}^{S} prob^s \sum_{o=1}^{O} W_o \times \left(\frac{\upsilon_{os}}{\gamma_{os}} \right) \tag{5}$$

$$Min(risk)_o = \sum_{s=1}^{S} prob^s \left(\prod_{k'=1}^{K'} \prod_{t=1}^{T} \prod_{i=1}^{m} \prod_{j=1}^{n_i} \frac{\widehat{X}_{jiok's} - (XI_{jiotk's} + XE_{jiotk's})}{\widehat{X}_{jiok's}} \times \Pr_o((XI_{jiotk's} + XE_{jiotk's}) \prec \widehat{X}_{jiok's}) \tag{6}$$

$\forall o$

$$Maz \ \mathrm{Re}O = \sum_{s=1}^{S} prob^s \sum_{k=1}^{K} W_k \sum_{o=1}^{O} W_o \frac{XE_{oks} + XI_{oks}}{\widehat{X}_{oks}} \tag{7}$$

$$Maz \ \mathrm{Re}A = \sum_{s=1}^{S} prob^s \sum_{k'=1}^{K'} W_k{}' \sum_{o=1}^{O} W_o \left(\frac{\sum_{t=1}^{T} \sum_{i=1}^{m} \sum_{j=1}^{n_i} \frac{XI_{jiotk's} + XE_{jiotk's}}{\widehat{X}_{jiotk's}} \times z_{jio}}{\sum_{i=1}^{m} \sum_{j=1}^{n_i} z_{jio}} \right) \tag{8}$$

s.t:

$$\sum_{o=1}^{O} XI_{oks} = ROI_{ks} \qquad \forall s,k \tag{9}$$

$$\sum_{o=1}^{O} XE_{oks} = ROE_{ks} \qquad \forall s,k \tag{10}$$

$$XE_{oks} + XI_{oks} \geq \alpha \times \widehat{X}_{oks} \qquad \forall s,k,o \tag{11}$$

$$XE_{oks} + XI_{oks} \prec \widehat{X}_{oks} \qquad \forall s,k,o \tag{12}$$

$$\sum_{t=1}^{T} \sum_{o=1}^{O} \sum_{i=1}^{m} \sum_{j=1}^{n_i} XI_{jiotk's} \leq RAI_{k's} \qquad \forall s,k' \tag{13}$$

$$\sum_{t=1}^{T}\sum_{o=1}^{O}\sum_{i=1}^{m}\sum_{j=1}^{n_i} XE_{jiotk's} \leq RAI_{k's} \qquad \forall s,k' \tag{14}$$

$$XE_{jiotk's} + XI_{jiotk's} \geq \alpha \times M_{jiot} \times \widehat{X}_{jiotk's} \qquad \forall i,j,o,t,s,k' \tag{15}$$

$$XE_{jiotk's} + XI_{jiotk's} \prec M_{jiot} \times \widehat{X}_{jiotk's} \quad \forall i,j,o,t,s,k' \tag{16}$$

$$\sum_{l=1}^{L}\sum_{o=1}^{O} Y_{jitsol} = 1 \qquad \forall i,j,t,s \tag{17}$$

$$\sum_{t=1}^{T}\sum_{l=1}^{L} l \times Y_{jitsol} \geq \lambda_{jios} \quad \forall i,j,o,s \tag{18}$$

$$\sum_{k=1}^{K} CE_k \sum_{o=1}^{O} XE_{oks} + \sum_{k'=1}^{K'} CE_k{}' \sum_{t=1}^{T}\sum_{o=1}^{o}\sum_{i=1}^{m}\sum_{j=1}^{n_i} XE_{jiotk's} \leq Bg \quad \forall s \tag{19}$$

$$\sum_{l=1}^{L} l \times Y_{jitsol} \geq W_{jiots} \quad \forall i,j,o,s,t \tag{20}$$

$$(T - \sum_{t=1}^{T}\sum_{l=1}^{L} Y_{jitsol} + 1) \leq \upsilon_{jios} \quad \forall i,j,o,s \tag{21}$$

$$\upsilon_{jios} \leq \gamma_{jios} \quad \forall i,j,o,s \tag{22}$$

$$\upsilon_{os} \leq \gamma_{os} \quad \forall o,s \tag{23}$$

$$\sum_{t=1}^{T} M_{jiot} = 1 \quad \forall i,j,o \tag{24}$$

$$\sum_{t=1}^{T} M_{jiot} - \sum_{t=1}^{T} M_{j'iot} = 0 \quad j \neq j' \qquad \forall i,j,j',o \tag{25}$$

$$\sum_{t=1}^{T} M_{jiot} \leq \sum_{t=1}^{T} M_{j''iot} \quad \forall i,j,j'',o \tag{26}$$

$$\sum_{t=1}^{T} M_{jiot} + \sum_{t=1}^{T} M_{j''iot} = 1 \quad j \neq j'' \qquad \forall i,j,j'',o \tag{27}$$

$$Y_{ijtsol},M_{jiot} \in \{0,1\} \quad \forall o,i,j,l,t,s \tag{28}$$

$$XE_{oks}, XI_{oks}, XE_{jiotk's}, XI_{jiotk's}, W_{jiots}, W_{os}, \upsilon_{jios}, \upsilon_{os} \geq 0 \quad \forall o,i,j,k,t,s \tag{29}$$

Considering that in the problem of the need for the required resource, the percentage of the required resource, the percentage of the allocated resource and the probability of occurrence were in the risk, to avoid complexity in the formulation of the desired model in the form of Equation (30) to (35) is given.

$$\widehat{X}_{oks} = P_o \times r_{oks} \quad \forall o,k,s \tag{30}$$

$$\widehat{X}_{jiotk's} = P_o \times r_{jiotk's} \quad \forall i,j,o,k',t,s \tag{31}$$

$$\Pr_o((XI_{jiotk's} + XE_{jiotk's}) \prec \widehat{X}_{jiotk's}) = \frac{XI_{jiotk's} + XE_{jiotk's}}{\widehat{X}_{jiotk's}} \tag{32}$$

$$\Pr_o((XI_{oks} + XE_{oks}) \prec \widehat{X}_{oks}) = \frac{XI_{oks} + XE_{oks}}{\widehat{X}_{oks}} \tag{33}$$

$$W_{jiots} = [L \times \sum_{k'=1}^{K'} \frac{XI_{jiotk's} + XE_{jiotk's}}{\widehat{X}_{jiotk's}}] \ \forall i,j,o,t,s \tag{34}$$

$$W_{os} = [L \times \sum_{k=1}^{K} \frac{XI_{oks} + XE_{oks}}{\widehat{X}_{oks}}] \ \forall o,s \tag{35}$$

The objective functions (3) minimizes the lack of process resilience. The objective functions (4) and (5) maximizes process continuity for output-oriented and activity-oriented resources, respectively. The objective function (6) minimizes risk. These risks can occur through activities, i.e., with an activity-oriented view of resources, or through outputs, i.e., output-oriented view of resources. The objective functions (7) and (8) maximize returns for output-oriented and activity-oriented resources, respectively. In return, the objective is to get the maximum response to demand. Constraints (9) and (10) ensures that according to critical conditions, the amount of total resources is greater than the amount of allocated resources. According to the organization and the amount of available and required resources, this constraint has two states, equal or unequal; If the amount of required resources is more than the amount of available resources, the relationship is equal, but if the amount of required resources is less than the amount of available resources, the relationship $\leq$ is established. Constraint (11) ensures that a minimum amount of output-oriented resources should be allocated to produce the product. Considering that there may be risks on the processes, constraint (12) shows that the required amount of resources may not be allocated and may be allocated less than that.

Constraints (13) and (14) ensures that according to critical conditions, the amount of total resources is greater than the amount of allocated resources. According to the organization and the amount of available and required resources, this constraint has two states, equal or unequal; If the amount of required resources is more than the amount of available resources, the relationship is equal, but if the amount of required resources is less than the amount of available resources, the relationship $\leq$ is established. Constraint (15) ensures that a minimum amount of activity-oriented resources should be allocated to produce the product. Considering that there may be risks on the processes, constraint (16) shows that the required amount of resources may not be allocated and may be allocated less than that. Constraint (17) ensures the allocation of only one operational level to each (ijo). Constraint (18) ensures that in order to avoid failure of the activity, if the tolerable time after the destructive event exceeds the allowed limit, it must have the minimum business continuity operation. Constraint (19) determines the range of budget to provide external resources. Constraint (20) determines the level of scheduled operation at any time. Constraint (21) determines how long the recovery time should be in case of failure. This range varies between 1 and T. Constraints (22 and 23) ensure that the value of Recovery time operation does not exceed MTPD. Constraint (24) is the constraint related to the activeness of an activity in the time interval (t = 1, 2...T). Constraints (26, 25, and 27) are activity prerequisite and activity synchronization. Constraints (28) and (29) ensure that the decision variables are non-negative or binary.

4. Numerical example

The selected industry is the textile industry in Iran and 3 resource of raw materials, machinery and manpower are considered. In the textile factory, its processes and activities are first identified, which shows the general outline of resource allocation in Figure (1). Table (1) also shows each output and activities and processes related to it. Figure (2) shows the overall outline of resource allocation to processes and outputs.

In the textile factory, for each critical operation, 10 operation levels were considered from 1 to 10, where the number 1 means that no resources are available and the number 10 means that all resources are available.

According to the interview with the experts in the textile factory, the probability of the scenario for optimistic conditions is 0.2, pessimistic 0.3 and realistic 0.5. Also, the amount of demand for output 1 in 3 week is equal to 37500 kg and for output 2 is equal to 172500 meters. The cost of manpower resource is 12000, machines resource is 300000 and raw material resource is 15000. The factory budget amount is 50000000. The weight for output 1 and 2 is equal to 0.6 and 0.4, respectively. The amount of available internal resources of manpower in the pessimistic scenario is equal to 27,200, in the realistic scenario it is equal to 29,600 and in the optimistic scenario it is equal to 31,200. The amount of available external resources of manpower in the pessimistic scenario is equal to 11,200, in the realistic scenario it is equal to 12,000 and in the optimistic scenario it is equal to 15,360. The amount of the internal available resource of the machinery in the pessimistic scenario is equal to 32400, in the realistic scenario it is equal to 37440 and in the optimistic scenario it is equal to 46800. The amount of the external available resource of the machinery in the pessimistic scenario is equal to 0, in the realistic scenario it is equal to 0 and in the optimistic scenario it is equal to 480. The amount of the available internal resource of raw materials in the pessimistic scenario is equal to 81,000, in the realistic scenario it is equal to 82,000 and in the optimistic scenario it is equal to 85,000. The amount of external available resource of raw materials is equal to 4000 in pessimistic scenario, equal to 5000 in realistic scenario and equal to 5000 in optimistic scenario. The *MTPD* value for output o is equal to 3 in all scenarios. The *MTPD* value for activities 1 to 10 is 3 in all scenarios and 2 for activities 11, 12, and 13. Tables (2) and (3) and (4) are related to the consumption rate and MBCO. Also, the amount of required resources is obtained through the following Equation.

$$\widehat{X}_{oks} = P_o \times r_{oks} \qquad \forall o, k, s \tag{36}$$

$$\widehat{X}_{jiotk's} = P_o \times r_{jiotk's} \qquad \forall i, j, o, k', t, s \tag{37}$$

To solve the problem, the assumption of the problem was first examined, and it was observed that there is a lack of raw materials. That is, the amount of the available resource of raw materials is less than the amount of the required resource, which can be seen in the table (5).

According to the textile factory case study, its outputs after solving can be seen in the table (6).
Due to the fact that there was no lack of activity-oriented resources, resources have been allocated to the amount of required of resources. The amount of output-oriented external allocated resources for output 1 in pessimistic scenario equals 70650, in realistic scenario equals 71250 and in optimistic scenario equals 40750 and for output 2 in pessimistic scenario equals 10350, in realistic scenario equals 10750 and in the optimistic scenario it is equal to 44250. The amount of output-oriented external allocated resources for output 1 is 4000 in the pessimistic scenario, 5000 in the realistic scenario, and 5000 in the optimistic scenario. The planned operational level for (*ijo*) at time t in scenario s is equal to 10, and the planned operational level for output-oriented resources for output 1 in the pessimistic scenario is equal to 9, also in the realistic and optimistic scenarios it is equal to 10 and for output 2 in the pessimistic scenario it is equal to 1, in the realistic scenario it is equal to 2 and in the optimistic scenario it is equal to 9. Activities 1 to 8 in period 1, activities 9 and 10 in period 2, and activities 11, 12, and 13 in period 3 are also active. that the recovery time scope of activities 1 to 10 for output 1 is equal to 2 and the recovery time scope of activities 1 to 10 for output 2 is equal to 3 and the recovery time scope of activities 11, 12 and 13 is equal to 1 and also the recovery time scope for All outputs are equal to 1. According to the output of the objective function, it can be seen that the continuity value is between 0 and 1, which according to Zheng Xiu in 2017, the disruption affected the resources, but they have been retrieved.

In the current state of factory, manpower resources and machines resources are allocated according to the optimal state of the model because there is no lack of resources, but the amount of raw materials resources is allocated as shown in table (7).

In Table (8), the optimal portfolio of resource allocation in optimal conditions and portfolio of resource allocation in the current state of the factory in optimistic, realistic and pessimistic scenarios are given, where the percentages are equal to the amount of resource of manpower, machines and raw material, respectively.

The use of the model of the present article has caused the lack of resilience to decrease from 3.99 (in the current state of the factory) to 3.278. Also, the return of output-oriented resources to increase from 3% (in the current state of the factory) to 67.2%. Also, the amount of process continuity to increase. According to the numbers of the textile factory, its outputs after solving can be seen in table (9).

In table (10), the discussion is that if the percentages in the composition of resources are changed, what risk and return can it create or how much can it reduce or increase the lack of resilience or continuity. So, in this part, a sensitivity analysis has been done on how much the risk will increase or decrease if the manager deviates from what is optimal. If a person uses the model of this article, it means that he has met the minimum risk. But a person may be a risk taker and wants to take more risk, so he goes to other modes. Now, in the table (10), different combinations of resource allocation percentages are given to show what happens the more it deviates from the optimal value. As can be seen in the table (10), when the manager allocates resources with a slight difference from the optimal state by accepting a percentage of risk, the output values also deviate from the optimal state and become weak.

4.1.sensitivity analysis

- γ_{os}: *MTPD for output o and scenario S*

By decreasing the value of γ_{os}, it is expected that the value of the process continuity will decrease, which according to the output of the value of the process continuity has decreased from the value (0.667) to the value (0.350).

- *Bg*: Existing budget to provide external resources

When the budget is reduced, it is expected that the amount of externally allocated resource and the level of planned operations and return will decrease and the amount of lack of resilience will increase. According to the obtained output, the amount of lack of resilience has increased from 3.278 to 3.571, also the level of planned operation of activity 13 have decreased from the value of 10 to the value of 8. The amount of external allocated resource is reduced, which is shown in Table (11).

- CAE_k: External resources cost k (activity-oriented resources)

With the increase in the cost of the external resource, it is expected that the amount of external resource allocated, the efficiency and the planned operation level will decrease and the lack of resilience will increase. According to the obtained output, the amount of lack of resilience has increased from 3.278 to 3.583, and the efficiency of activity-based resources has decreased from 100% to 99%. The level of planned operations has also decreased due to the increase in the cost of external resources and the lack of allocated resources, which in activity-oriented resources, the level of planned operations of activity 13 has decreased from 10 to 7. The amount of external allocated resource is reduced, which is shown in Table (12).

- $\hat{X}_{oks}$: Amount of required resource (output-oriented resources)

By reducing the amount of required resources, it is expected that the level of planned operations will increase and the lack of resilience will decrease. As can be seen, the amount of lack of resilience has decreased from 3.278 to 2.910 and the value of the planned operation level of output 1 in scenario 1 has increased from 9 to 10 and for output 2 in scenario 1 from 1 to 2.

Also, in this article, the Rial value of the lost opportunity of output production has been obtained to compare the optimal situation and the existing situation of the factory. According to table (13), it can be seen that in the optimal state, the amount of Rials of the lost opportunity of output production is much less compared to the existing situation.

$$\textit{Rial amount of lost opportunity to produce output} = \textit{Lost opportunity to produce output} * \textit{Rial amount} * \textit{Scenario probability} \quad (38)$$

5. Conclusion

This paper deals with the modeling of optimal resource allocation after an accident in a critical condition. The results show that the proposed approach is a suitable model for solving the problem of the lack of allocated resources in critical conditions using 4 parameters: return, resilience, continuity and risk. As seen in the modeling, resilience and continuity parameters are also included in the resource allocation model. The reason for adding resilience to the resource allocation model is that when the organization is faced with crisis conditions and the inputs are more than allowed, it can be found to what extent the processes of the organization are resilient. And considering that the goal is that the processes and activities related to them do not stop and the performance does not drop too much, and on the other hand, resilience depends on resources, so this parameter has also been used in the present model. Also, because in critical situations, organizations may face a lack of resources, the continuity parameter in the resource allocation model allows the organization to reach its maximum output and not stop despite the lack of resources. Therefore, when organizations face a lack of resources and are in crisis, the processes and activities related to it in organizations must be resilient and continuous. In the model of this article, risk and return parameters are also considered. In financial literature, the concept of Markowitz model is similar to the work done in this article. And because in the desired model, the combined portfolios include different allocations of resources according to risk and return, so it can be similar to Markowitz's model. Since organizations face a lack of resources in critical situations, the organization may face a series of risks and cause severe damage to the system. For this purpose, in the resource allocation model, risk and return parameters are considered to manage risk and losses. The present article sought to see both business continuity and resilience and risk in the model. If only the risk is considered, the process may be accepted with a risk, but the process may not continue. If only continuity is considered, it may lose resilience and not be able to return to performance conditions. Therefore, because resilience, risk and continuity are centered on uncertainties and risks are shared, so they must be considered in an integrated manner.

Ethical approval The work uses publicly available and non-identifiable information of the users. No ethical approval was needed.

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Conflict of interest The authors confirm there are no conflicts of interest.

Declarations

Consent to participate Not applicable, since no human participant was involved in the evaluation of our study.

Consent for publication Not applicable, since all datasets used in this study are released by third parties.

Author contributions:

Mahnaz Ebrahimi-Sadrabadi: Methodology, Software, Formal analysis, Writing - Original Draft

Bakhtiar Ostadi: Conceptualization, Resources, Writing - Review & Editing, Supervision

Ali Husseinzadeh Kashan: Software, Validation

Mohammad Mehdi Sepehri: Visualization, Investigation.

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Biographies

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Appendix A

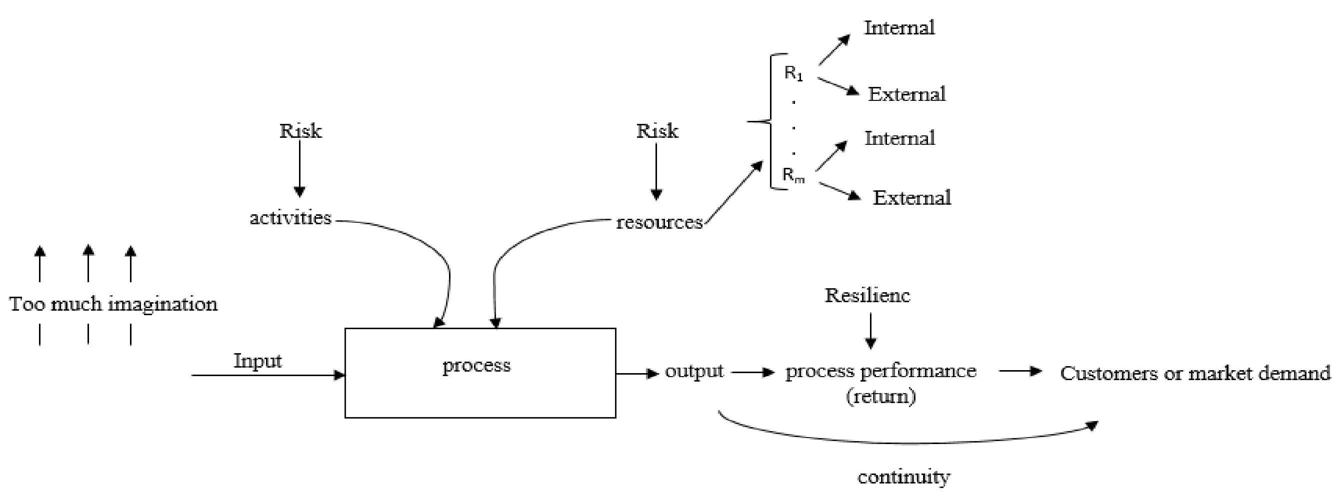

Figure 1. An outline of the idea of the article

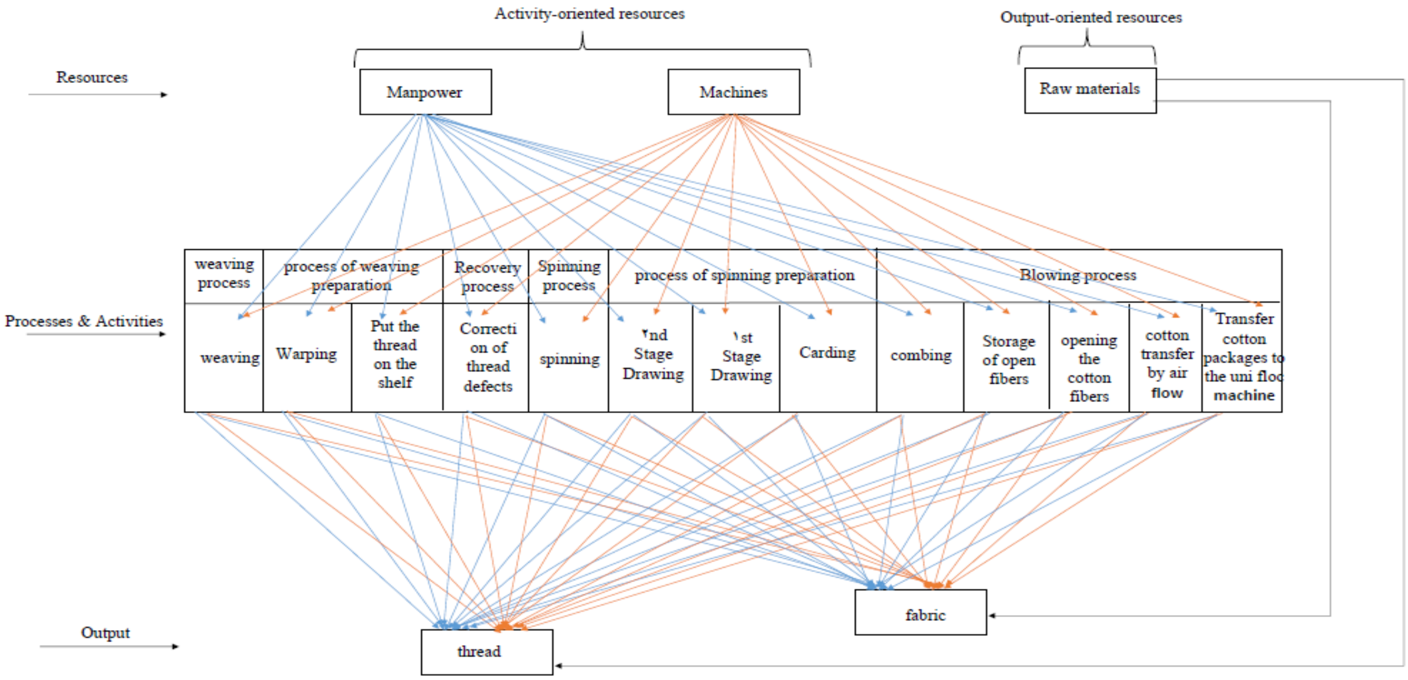

Figure 2. Outline of resource allocation

Appendix B

Table 1. The processes and activities required to produce each output

Output	Blowing process (*i*=1)					process of spinning preparation (*i*=2)			Spinning process (*i*=3)	Recovery process (*i*=4)	process of weaving preparation (*i*=5)		weaving process (*i*=6)
	Transfer cotton packages to the uni floc machine (*i*=1)	cotton transfer by air flow (*j*=2)	opening the cotton fibers (*j*=3)	Storage of open fibers (*j*=4)	combing (*j*=5)	Carding (*j*=6)	1st Stage Drawing (*j*=7)	2nd Stage Drawing (*j*=8)	Spinning (*j*=9)	Correction of thread defects (*j*=10)	Put the thread on the shelf (*j*=11)	Warping (*j*=12)	weaving (*j*=13)
thread (*O*=1)	1	1	1	1	1	1	1	1	1	1	0	0	0
fabric (*O*=2)	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 2. The consumption rate for output-oriented resources

r_{oks}	*K=1,s=1*	*K=1,s=2*	*K=1,s=3*
o=1	6	5	3
o=2	6	5	3

Table 3. The consumption rate for activity-oriented

Table 4. *MBCO for (ijo) and scenario S*

resources

$r_{jiotk's}$	t=1,2,3 $s=1$	t=1,2,3 s=2	t=1,2,3 s=3
i=1 , j=1,o=1, $k'=1$	20	17	15
i=1 , j=1,o=2, $k'=1$	20	17	15
i=1 , j=2,o=1, $k'=1$	15	12	10
i=1 , j=2,o=2, $k'=1$	15	12	10
i=1 , j=3,o=1, $k'=1$	16	13	11
i=1 , j=3,o=2, $k'=1$	16	13	11
i=1 , j=4,o=1, $k'=1$	13	10	9
i=1 , j=4,o=2, $k'=1$	13	10	9
i=1 , j=5,o=1, $k'=1$	80	70	60
i=1 , j=5,o=2, $k'=1$	80	70	60
i=2 , j=6,o=1, $k'=1$	70	65	60
i=2 , j=6,o=2, $k'=1$	70	65	60
i=2 , j=7,o=1, $k'=1$	120	100	90
i=2 , j=7,o=2, $k'=1$	120	100	90
i=2 , j=8,o=1, $k'=1$	150	140	130
i=2 , j=8,o=2, $k'=1$	150	140	130
i=3, j=9,o=1, $k'=1$	600	500	450
i=3 , j=9,o=2, $k'=1$	600	500	450
i=4 , j=10,o=1, $k'=1$	230	210	200
i=4 , j=10,o=2, $k'=1$	230	210	200
i=5 , j=11,o=2, $k'=1$	11	9	8
i=5 , j=12,o=2, $k'=1$	70	65	60
i=6 , j=13,o=2, $k'=1$	140	110	90
i=1 , j=1,o=1, $k'=2$	15	13	11
i=1 , j=1,o=2, $k'=2$	15	13	11
i=1 , j=2,o=1, $k'=2$	20	18	14
i=1 , j=2,o=2, $k'=2$	20	18	14
i=1 , j=3,o=1, $k'=2$	16	13	10
i=1 , j=3,o=2, $k'=2$	16	13	10
i=1 , j=4,o=1, $k'=2$	13	10	7
i=1 , j=4,o=2, $k'=2$	13	10	7
i=1 , j=5,o=1, $k'=2$	80	70	60
i=1 , j=5,o=2, $k'=2$	80	70	60
i=2 , j=6,o=1, $k'=2$	70	65	55
i=2 , j=6,o=2, $k'=2$	70	65	55
i=2 , j=7,o=1, $k'=2$	90	80	70
i=2 , j=7,o=2, $k'=2$	90	80	70
i=2 , j=8,o=1, $k'=2$	140	130	115
i=2 , j=8,o=2, $k'=2$	140	130	115
i=3, j=9,o=1, $k'=2$	300	250	220
i=3 , j=9,o=2, $k'=2$	300	250	220
i=4 , j=10,o=1, $k'=2$	130	110	90
i=4 , j=10,o=2, $k'=2$	130	110	90
i=5 , j=11,o=2, $k'=2$	40	35	20
i=5 , j=12,o=2, $k'=2$	18	165	145
i=6 , j=13,o=2, $k'=2$	260	240	220

λ_{jios}	S=1	S=2	S=3
i=1 , j=1,o=1	7	6	5
i=1 , j=1,o=2	7	6	5
i=1 , j=2,o=1	9	8	7
i=1 , j=2,o=2	9	8	7
i=1 , j=3,o=1	9	8	7
i=1 , j=3,o=2	9	8	7
i=1 , j=4,o=1	6	5	4
i=1 , j=4,o=2	6	5	4
i=1 , j=5,o=1,	6	5	4
i=1 , j=5,o=2	6	5	4
i=2 , j=6,o=1	7	6	5
i=2 , j=6,o=2	7	6	5
i=2 , j=7,o=1	8	7	6
i=2 , j=7,o=2	8	7	6
i=2 , j=8,o=1	6	5	4
i=2 , j=8,o=2	6	5	4
i=3, j=9,o=1	5	4	3
i=3 , j=9,o=2	5	4	3
i=4 , j=10,o=1	9	8	7
i=4 , j=10,o=2	9	8	7
i=5 , j=11,o=2	8	7	6
i=5 , j=12,o=2	6	5	4
i=6 , j=13,o=2	5	4	3

Table 5. Proof that the assumption of the problem is valid

S=1		S=2		S=3	
$\sum_{o=1}^{O} \hat{X}_{oks}$	$ROI_{ks} + ROE_{ks}$	$\sum_{o=1}^{O} \hat{X}_{oks}$	$ROI_{ks} + ROE_{ks}$	$\sum_{o=1}^{O} \hat{X}_{oks}$	$ROI_{ks} + ROE_{ks}$
195000	81000+4000= 85000	162500	82000+5000= 87000	97500	85000+5000= 90000

Table 6. Objective functions output

Output	process resilience	process continuity		Return		Risk	
		output-oriented resources	activity-oriented	output-oriented resources	activity-oriented	output-oriented resources	activity-oriented
O=1	3.278	0.667	0.338	67.2%	100%	4.5%	0%
O=2						10.6%	0%

Table 7. Amount of allocated external resource (output-based resources) by the textile factory

	s =1	*s =2*	*s=3*
O=1 , k=1	50000	45000	45000
O=2 , k=1	35000	42000	45000

Table 8. Optimal resource allocation portfolio

	Output	Percentage of resource allocation (optimal portfolio)	Percentage of resource allocation (in the current state of the factory)
Pessimistic scenario	thread (*O*=1)	{18%, 12%, 88%}	{18%, 12%, 50%}
	fabric (*O*=2)	{82%, 88%, 12%}	{82%, 88%, 50%}
Realistic scenario	thread (*O*=1)	{17%, 11%, 88% }	{17%, 11%, 52% }
	fabric (*O*=2)	{83%, 89%, 12%}	{83%, 89%, 48%}
Optimistic scenario	thread (*O*=1)	{16%, 11%, 51%}	{16%, 11%, 59%}
	fabric (*O*=2)	{84%, 89%,49%}	{84%, 89%,41%}

Table 9. Objective functions values in the current state of the factory

Output	process resilience	process continuity		Return		Risk	
		output-oriented resources	activity-oriented	output-oriented resources	activity-oriented	output-oriented resources	activity-oriented
O=1	3.99	0.550	0.230	3%	100%	0.2%	0%
O=2						1.8%	0%

Table 10. Different amounts of resource allocation

	Portfolio	Output	Percentage of resource allocation	process resilience	Return		Risk	
					output-oriented resources	activity-oriented	output-oriented resources	activity-oriented
Pessimistic scenario	Portfolio1	*O=1*	{18%, 12%, 70%}	4.45	62%	100%	*O*=1 (18%)	*O*=1 (0%)
		O=2	{82%, 88%, 30%}					
Realistic scenario		*O=1*	{17%, 11%, 60%}					
		O=2	{83%, 89%, 40%}				*O*=1 (20%)	*O*=1 (0%)
Optimistic scenario		*O=1*	{16%, 11%, 60%}					
		O=2	{84%, 89%, 40%}					
Pessimistic scenario	Portfolio2	*O=1*	{18%, 12%, 75%}	4.80	65%	100%	*O*=1 (10%)	*O*=1 (0%)
		O=2	{82%, 88%, 25%}					
Realistic scenario		*O=1*	{17%, 11%, 82% }					
		O=2	{83%, 89%, 18%}				*O*=1 (14%)	*O*=1 (0%)
Optimistic scenario		*O=1*	{16%, 11%, 49%}					
		O=2	{84%, 89%, 51%}					

Table 11. Amount of allocated external resource (activity-based resources)

$XE_{jiotk's}$	*t=2*	*t=3*

	$s=1$	$s=1$
i=4 , j=10,o=1, $k'=1$	947.917	
i=5 , j=11,o=2, $k'=1$		718.75

Table 12. Amount of allocated external resource (activity-based resources)

$XE_{jiotk's}$	*t=1* $s=1$
i=1 , j=5,o=2, $k'=1$	494.444
i=2 , j=6,o=2, $k'=1$	323.889
i=2 , j=7,o=2, $k'=1$	741.667

Table 13. Rial amount of the lost opportunity of output production

Rial amount of the lost opportunity of output production	Optimal situation			The existing state of the factory		
	S=1	S=2	S=3	S=1	S=2	S=3
O=1 O=2	48,154,050,000 Rial			64,436,250,000 Rial		