
Research on Emergency Resource Dispatching Model Based on Cost-Benefit Analysis

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Abstract

Benefit is usually the exclusive target in emergency management. But sometimes the cost needs to be thought of because it may be unworthy if the response is excessive. In the engineering of emergency management resource dispatching is an important problem, the objective of which is not only to transport resource to meet the demand as soon as possible, but also to get the high benefit with low cost. At the same time the potential emergencies need to be considered when dispatching resource for the demand because the derivative emergencies may happen at once. In this paper the mathematical programming model is proposed about the demand that has happened and that of the potential emergencies. The benefit and the cost are considered related to the time and the amount of resource. At last the algorithm of the model is discussed and future research is given.

Key words: Emergency management; Resource dispatching; Cost-Benefit Analysis; System Engineering;

1. Introduction

It’s clear that the process of emergency management has been seen as engineering because it’s consisted by many activities such as the location of the saver, the store of resource, the dispatching of resource, and so on \cite{1}. Also many branches of the government are involved and several kinds of instruments may be used. The branches need to collaborate to make the process of the emergency management well-off. Besides the object of emergency management is to get the whole success because the derivative emergency often occurs and many kinds of danger are interweaved. In the system, resource dispatching is an important activity because no activity can go on without resource. The time that resource reaches the demand and the amount are the most important factors related to the efficiency of emergency management.

There is much research in emergency resource management about single stage \cite{2, 3} and multi-stage \cite{4}, deterministic requirement\cite{5} and uncertainty requirement\cite{6}, and so on. Resource allocation model with time factor was proposed on the base of queuing theory and location theory. Following the certain Location Set Covering... 

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Problem, Vladimir Marianov and Charles Revelle [7] adopted the Queuing Probabilistic Location Set Covering Problem to calculate the probability that all servers in a given region were busy. Mamnoon Jamil et al [8] considered the Stochastic Queue Center Problem, which sought to locate a single facility in an $M/G/1$ queue operating environment. In brief, this service facility must return to the service center before it was going to serve again. Aiming at the actual course of fire extinguishing in a city, Chuanliang Jia et al [9] presented the resource allocation model based on multi-stage fire extinguishing progress. When large fire happened, resource must be dispatched from several firehouses. The model resolved the problem that the demand of resource changed in different phases.

Sherali, H.D. and Subramanian, S [10] considered the case that two emergencies or more may happen in the same district. Then emergency facilities and resource cannot satisfy the demand. Aiming at such a problem, they presented the opportunity cost of service and proposed the dispatching model of service vehicles on the base of it in order to make opportunity cost minimum. The outcome showed that the scheme to dispatch the nearest available vehicle to the emergency may not be the optimal choice under the condition of this uncertain demand. It differed greatly from that of previous incident response models. Kaan Ozbay et al [11] also considered the simultaneous potential traffic incident during disposing of one traffic incident. So the probability of simultaneous emergencies must be considered. They proposed the probabilistic programming models for response vehicle dispatching and resource allocation in traffic incident management. In [12] the cost and benefit of emergency management are discussed and the definitions of them are proposed. The cost includes the damage cost and the response cost. The benefit includes the visible benefit and the invisible benefit. Then the way to quantify the cost and benefit is given with loss of life expectancy because some kinds of the cost and benefit can’t be calculated directly. Then the degree of safety is studied. But in the paper the quantitative analysis is weak and the comparing of the cost and benefit is not thought of.

Because sometimes the cost needs to be thought of besides the benefit of the work in the practice of emergency management, they should be compared in order to make the decision of the degree of resource dispatching. At the same time the potential need should be considered. In this paper, the cost and the benefit of emergency management is studied in the mathematic model for resource dispatching in which the potential emergency is also discussed.

2. Problem description

Usually the object of emergency management is to lessen the loss as far as possible, including the lives, the property and so on. So the government often does its best to deal with the emergency no matter how much the resource is put into the work. It helps the work smoother with the absolutely abundant resource and shows the responsibility of the government. But the shortcoming of the manner comes into being in recent years because much of the resource is wasted and the running of too many enterprises is influenced. Sometimes little loss is lessened in the price of much more resource, even the lives. For example, a special kind of medicine may be produced for some disease and after the emergency management too much is remained. Because the medicine can’t be used for other diseases, it may only be wasted and even do harm to the environment. So the proper response is needed instead of excessive response. The cost and the benefit of emergency management should be discussed based on Cost-Benefit Analysis.

In Cost-Benefit Analysis, all kinds of the cost and the benefit are studied and the cost should be no more than the loss. It’s to maximize the safety with the least cost. The cost includes the direct cost and the indirect cost. For example, the loss of the lives and property, the resource used for response and the impact on other enterprises are the direct cost while the effect on the mental of the people and the public opinion is the indirect cost. Similarly the benefit includes the direct benefit and the indirect benefit. Especially the indirect cost and benefit may work in quite a long time. All kinds of cost and benefit should be quantified and be compared. Usually the cost and the benefit are also related to the amount of the resource used and the time that resource reaches the demand. Sometimes the time is more important than the amount of the resource because the sensibility to the emergency means the responsibility of the government.

Also the potential demand should be studied when dispatching resource for the emergency that has happened because emergency may continue to happen after that one. So some resource should be reserved for the potential demand or much loss will occur because no resource reaches it in time. Then the cost will be much more than the benefit of doing with the emergency that has happened. So part resource in a saver may be dispatched to the
emergency and others are for the potential demand while the demand of the emergency is met by several savers rather than only the nearest one. The amount of resource in each saver and the need of each emergency are the most important factors. Of course the need of the emergency that has happened should be thought of at first. The amount of the resource reserved for the potential demand is related to the extent of the emergency and the possibility. The probability will be used to show the importance of the potential demand.

In the following mathematic programming model the cost and the benefit of emergency management are discussed when studying the resource dispatching problem considering the potential demand based on Cost-Benefit Analysis.

3. Models

We suppose that the emergency has happened somewhere and may happen at other n-1 places before long. Then when we make the resource dispatching plan for the emergency that has happened based on resource allocation status, the amount of resource needed and the probability of the potential emergency at other places should be taken into account. So some resource is dispatched for the emergency that has happened and some may be reserved for the potential ones. The cost and benefit of the work are shown as the functions of the time and the amount of the resource.

\( i \) denotes the saver, \( i = 1, 2, \ldots, m \);

\( j \) denotes the places that need resource, \( j = 1, 2, \ldots, n \); here \( j = 1 \) for the place where emergency has happened, \( j = 2, \ldots, n \) for the places where potential emergency may happen;

\( a_i \) denotes the amount of resource in saver \( i \);

\( r_i \) denotes the amount of resource needed for the emergency;

\( x_{i1} \) denotes the amount of resource for the emergency from saver \( i \);

\( y_{i1} \) is a 0-1 variable denoting that whether resource is dispatched for the emergency from saver \( i \);

\( p_j \) denotes the probability of the potential emergency at place \( j \);

\( r_j \) denotes the forecasted amount of resource needed at place \( j \) if emergency occurs;

\( x_{ij} \) denotes the amount of resource for place \( j \) from saver \( i \);

\( y_{ij} \) is a 0-1 variable denoting that whether resource is dispatched from saver \( i \) to place \( j \);

\( t_{i1} \) denotes the time for resource from saver \( i \) to the emergency;

\( t_{ij} \) denotes the time for resource from saver \( i \) to place \( j \);

\( C(r_j, t_{ij}) \) denotes the total cost of emergency management;

\( B(r_j, t_{ij}) \) denotes the total benefit of emergency management.

The model is as follows.

\[
\begin{align*}
\text{Max} & \quad \sum_{j=1}^{n} \left( B(r_j, t_{ij}) - C(r_j, t_{ij}) \right) \\
\text{s.t.} & \quad \sum_{i=1}^{m} x_{i1} \geq r_1(t_{i1}) \\
& \quad \sum_{i=1}^{m} x_{i1} \geq p_j r_j(t_{ij}) \quad (j = 2, 3, \ldots, n) \\
& \quad x_{i1} + \sum_{j=2}^{n} x_{ij} \leq a_i \quad (i = 1, 2, \ldots, m)
\end{align*}
\]
In this model, formula (1) shows the objective function that maximizes the distance between the benefit and the cost of emergency management including dispatching resource from savers to the emergency that has happened and reserving for the potential emergencies with the probabilities. To meet the demand of all emergencies is shown in formula (2) and (3). The former means to meet the demand of the emergency that has happened by all savers. Similarly formula (3) means to meet the demand of the potential emergencies with the probability by the resource reserved in all savers for them. Also we know that the demand of each emergency is related to the time that resource reaches the emergency. If the resource is transported quickly and used for the emergency at once, the emergency can perish with less resource. Or much more resource is needed because the emergency develops to be not easily controlled. For each saver, the amount of resource dispatched or reserved for all emergencies should be no more than that in it, which is shown in formula (4). Formula (5) and (6) separately make sure that the emergency or each of the potential be served by at least one saver. The correlative relation of \( x_{ij} \) and \( y_{ij} \) is shown in formula (7) and (8). At last, formula (9) and (10) limit \( y_{ij} \) 0-1 variables.

The model is a linear mixed-integer programming model in which the 0-1 variables \( y_{ij} \) shows whether each saver dispatches resource to the emergency and the potential emergencies while \( x_{ij} \) and \( x_{ij} \) are general variables. \( p_j \) is the probability of the potential emergency to show the extent of reserved resource for it. For the emergency that has occurred, the probability is 1. Formula (7) and (8) express the consistency of the amount of resource dispatched and the corresponding dispatching status. That’s, if \( x_{ij} \) and \( x_{ij} \) are not zero, \( y_{ij} \) and \( y_{ij} \) must be 1 which means that saver \( i \) dispatches resource to the emergency or the potential emergency \( j \) and each emergency can be served by resource from at least one saver. While if \( y_{ij} \) and \( y_{ij} \) are zero, \( x_{ij} \) and \( x_{ij} \) must be 0.

In the model, the functions of the benefit and the cost \( B(r_j,t_{ij}) \) and \( c(r_j,t_{ij}) \) are needed to be given and the probability of the potential emergency \( p_j \) needs to be forecasted. At the same time the relation of the amount of resource needed for all emergencies ant the time needs to be given by logistic curve.

4. Calculating Example

Supposed that a flood disaster has attacked region 1, region 2 and region 3 are in danger too. According to the experience, the probability of region 2 being attacked is 0.4 and that of region 3 is 0.6. If the area is attacked, the demand of each emergency is related to the time. In order to simplify the model, we assume that the demand could be described by the function \( y = -74 \ln(x) + 180 \) in which \( x \) denotes the time for resources from savers. Now there are 3 savers can dispatch the resource to the attacked area and 800 units of resource in saver 1, 900 units in saver 2 and 600 units in saver 3. And we have known that the total cost of emergency management is shown
as \( C(r_j, t_{ij}) = r_j \times \sum_{i=1}^{m} t_{ij}^2 \), the total benefit of emergency management is shown as \( B(r_j, t_{ij}) = r_j / \sum_{i=1}^{m} t_{ij} \times 10 \). 

\((j = 1, 2, 3, \cdots, n)\)

The model is as followings

\[
\text{Max} \quad \sum_{j=1}^{n} \left( r_j / \sum_{i=1}^{m} t_{ij} - r_j \times \sum_{i=1}^{m} t_{ij}^2 \right)
\]

s.t. \( r_1 = -74 \ln(t_{11}) + 180 - 74 \ln(t_{21}) + 180 - 74 \ln(t_{31}) + 180 \)

\( r_2 = -74 \ln(t_{12}) + 180 - 74 \ln(t_{22}) + 180 - 74 \ln(t_{32}) + 180 \)

\( r_3 = -74 \ln(t_{13}) + 180 - 74 \ln(t_{23}) + 180 - 74 \ln(t_{33}) + 180 \)

\( x_{11} + x_{21} + x_{31} \geq -74 \ln(t_{11}) + 180 - 74 \ln(t_{21}) + 180 - 74 \ln(t_{31}) + 180 \)

\( x_{12} + x_{22} + x_{32} \geq (-74 \ln(t_{12}) + 180 - 74 \ln(t_{22}) + 180 - 74 \ln(t_{32}) + 180) \times 0.4 \)

\( x_{13} + x_{23} + x_{33} \geq (-74 \ln(t_{13}) + 180 - 74 \ln(t_{23}) + 180 - 74 \ln(t_{33}) + 180) \times 0.6 \)

\( x_{11} + x_{12} + x_{13} \leq 800 \)

\( x_{21} + x_{22} + x_{23} \leq 900 \)

\( x_{31} + x_{32} + x_{33} \leq 600 \)

\( y_{i1} + y_{21} + y_{31} \geq 1 \)

\( y_{i2} + y_{22} + y_{32} \geq 1 \)

\( y_{i3} + y_{23} + y_{33} \geq 1 \)

\( x_{ii} \leq 1000y_{i1} \quad (i = 1, 2, \cdots, m) \)

\( x_{ij} \leq 1000y_{ij} \quad (i = 1, 2, \cdots, m, \quad j = 2, \cdots, n) \)

\( y_{i1} = 0 \quad (i = 1, 2, \cdots, m) \)

\( y_{ij} = 0 \quad (i = 1, 2, \cdots, m, \quad j = 2, \cdots, n) \)

From the solution we get that the demand of region 1 is matched and the benefit of emergency management is quite bigger than the cost. But the cost of the potential demand is notable. But for the probability of the potential demand, the cost is reasonable.

5. Conclusions

In this paper the importance of the cost of emergency management is discussed and the component of the cost and benefit is given. The cost and the benefit of emergency management are considered in a mathematic programming model when studying the resource dispatching problem considering the potential demand based on Cost-Benefit Analysis. Aiming at the successive emergencies with the probabilities of the potential emergencies, the mathematic model is proposed to reach the balance between the emergency that has happened and the potential demand to a certain degree.

In future research, the transporting efficiency may be taken into account because it will affect the time resource reaches the emergency, and then the amount of resource needed by all emergencies. How to choose the appropriate paths and modals is studied. In addition, the demand of it may change in the course of disposing the emergency. It will also be considered in future work.

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References