AN OPTIMIZATION MODEL FOR EMERGENCY VEHICLE LOCATION WITH CONSIDERATION OF DISPATCHING BOARD AREA

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Abstract. This paper aims to develop location opitimization and dispatching optimization techniques for emergency vehicles. In this research, Firstly, we seek to propose a optimization model for minimizing the total response time of vechicles to find the optimal emergency vehicles location solution. Then, we generate the some scenarios to consider the uncertainty conditions and do numerical experiment. The numerical experiment results show that the proposed model achieves a good performance and worked well.

Keywords. emergency vechicle location and dispatching, optimization, uncertainty, broad area.

1. INTRODUCTION

The emergency services are organizations which ensure public safety and health by addressing different emergency incidents such as earthquake, typhoon, fire, traffic accident without taking a rest 24 hours, 365 days. Besides, the emergency demand in emergency services is covered by the EVs lcoated at fixed points, therefore, the location of EVs is important in service quality level. The main challenge in emergency services is to minimize the time it takes to respond to demands(the time between emergency call receipt and EVs arrival to the demand point). In recent years, the emergency vehicles(EVs) tend to lengthen the average response time to the demand point because of the lack of emergency stations and EVs in the suburbs. On the other hand, if we can loacte more EVs in more emergency stations, EVs can shorten the travel time to the demand point, but at the same time cost must also be considered. Accordingly, it is necessary to balance these two apects and develop a more effective EV location planning.

Moreover, as the uncertainly commonly exists int the real world. The unpredictability of the time and place of emergency demand is the main issue in the EV location. Therefore, we should consider the uncertainty when we seek to make a decision for the EV location as follows:

- The uncertainty of call-in time and the demand point location
- The uncertainty of the emergency vehicle travel time
- The uncertainty of service time at demand point

According to the Japan Fire and Disaster Management Agency Heisei 29th edition fire fighting white paper(**?**) pointed out that it is necessary to promote cooperation between EVs in order to secure and enrich the necessary firefighting power even in areas where it is difficult to immediately promote cooperation in board area.In this research, we develped an optimization model for finding the optimal EVs location solution with consideration of dispatching board area.

In Section 2, the process of emergency response system is described in detail. Then, A mathematical model will be proposed in Section **??**. In order to verify the performance of the proposed model, a simple numerical example is presented and solved in Section **??**. In order to apply it to real world, a case will in Section **??**. Finally, we draw a conclusion in Section **??**.

2. THE PROCESS OF EMREGENCY RESPONSE SYSTEM

The process of emregency response system usually covers a sequence of activities as shown as follows:

1. The call (demand) comes to the system.
2. The severity of the call is estimated.
3. The dispatcher evaluates the system status and determines the appropriate EV to dipatch.
4. Upon EV arrives at demand point and starts doing servcie.
5. After completing service at demand point, EV may moves to the next demand point or returns back emergency station to await another call.

In this research, we assumed that once the service is completed at demand point, the EV must return back emergency station as shown in Fig. 1.

In this research, the time between emergency call receipt and EVs arrival to the demand point, we call it response time. Besides, from call-in time to return time for EVs, we call it unavailable time for EVs and that is emergency vechicle is dispatched in one dispatch as shown in Fig. 2. An EV is unavaliable if one of the following conditions is fulfilled:

- The EV is on its way to serve a demand
- The EV is serving a demand
- The EV is returning to the station

because EV unavaliable in some time periods, we must dis-

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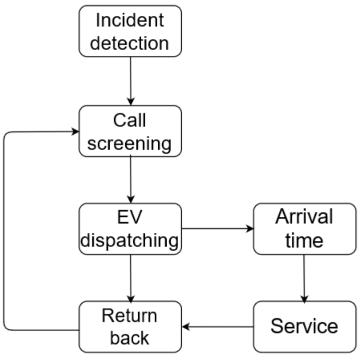

Fig. 1 The process of emergency response system

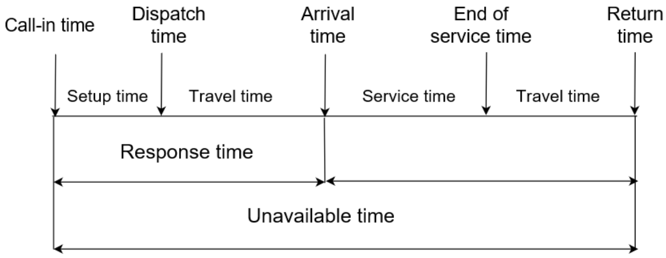

Fig. 2 Reseponse time and unavailable time of an emergency vehicle

patch avaliable EV when another emergency incident happend and the EV may be dispatched in board area.

3. MATHEMATICAL FORMULATION

The mathematical formulation of the proposed model is discussed in this section.

3.1. Nomenclature

The nomenclature used to descripe the proposed model is illustrated in this subsection.

- Indices
  - I : Set of emergency sations indexed by $i \in \{1, 2, \ldots, I\}$.
  - J : Set of demand points indexed by $j \in \{1, 2, \ldots, J\}$.
  - K : Set of emergency vehicles indexed by $k \in \{1, 2, \ldots, K\}$.
  - N : Set of the number of dispatch indexed by $n \in \{1, 2, \ldots, n_{\max}\}$($n_{\max}$:The maximum number of dispatch of each emergency vehicle).
  - A : Set of scenario indexed by $a \in \{1, 2, \ldots, A\}$.
- Parameters
  - $u_{a,j}$: Call-in time of demand point j under scenario a.
  - $t_{a,i,j}$: Travel time between emergency station i and demand point j under scenario a.
  - $s_{a,j}$: Service time of emergency vehicle k at demand point j under scenario a.
  - M_1/M_2 : Sufficient and large constant number.
  - e : Standard setup time.
  - P_a : The probablility of scenario a.
- Decision variables
  - $x_{a,j,n,k}$: Binary decision variable that takes the value 1 if emergency vehicle k is dispatched to demand point j in the number of dispatch n under scenario a,and 0 otherwise.
  - $y_{i,k}$: Binary decision variable that takes the value 1 if emergency vehicle k is assigned to emergency satation i, and 0 otherwise.
  - $c_{a,n,k}$: Dispatch time of emergency vehicle k in the number of dispatch n under scenario a.
  - $\bar{t}_{a,n,k}$: Travel time of emergency vehicle k in the number of dispatch n under scenario a.
  - $v_{a,n,k}$: Arrival time of emergency vehicle k the number of dispatch n under scenario a.
  - $z_{a,n,k}$: End of service time of emergency vehicle k in the number of dispatch n under scenario a.
  - $w_{a,n,k}$: Return time of emergency vehicle k in the number of dispatch n under scenario a.
  - $p_{a,j,n,k}$: Response time of emergency vehicle k is dispatched to demand point j in the number of dispatch n under scenario a.

3.2. Constrained conditions

$$\sum_{i \in I} y_{i,k} = 1 \quad (k \in K) \tag{1}$$

$$\sum_{n \in N, k \in K} x_{a,j,n,k} = 1 \quad (a \in A, j \in J) \tag{2}$$

$$\sum_{j \in J} x_{a,j,n,k} \leq 1 \quad (a \in A, n \in N, k \in K) \tag{3}$$

$$\sum_{n \in N} x_{a,j,n,k} \leq 1 \quad (a \in A, j \in J, k \in K) \tag{4}$$

$$c_{n,k} \geq \sum_{j \in J} x_{a,j,n,k} u_{a,j} + e \quad (a \in A, n \in N, k \in K) \tag{5}$$

$$\bar{t}_{a,n,k} \geq t_{a,i,j} - (1 - y_{i,k})M_1 - (1 - x_{a,j,n,k})M_1 \quad (a \in A, i \in I, j \in J, n \in N, k \in K) \tag{6}$$

$$v_{a,n,k} \geq c_{a,n,k} + \bar{t}_{a,n,k} \quad (a \in A, n \in N, k \in K) \tag{7}$$

$$z_{a,n,k} = v_{a,n,k} + \sum_{a \in A, j \in J} x_{a,j,n,k} s_{a,j} \quad (a \in A, n \in N, k \in K) \tag{8}$$

$$w_{a,n,k} = z_{a,n,k} + \bar{t}_{a,n,k} \quad (a \in A, n \in N, k \in K) \tag{9}$$

$$w_{a,n-1,k} + e \leq c_{a,n,k} \quad (a \in A, n \in N, k \in K : n \geq 2) \tag{10}$$

$$v_{a,n,k} \geq c_{a,n,k} \quad (a \in A, n \in N, k \in K) \tag{11}$$

$$z_{a,n,k} \geq v_{a,n,k} \quad (a \in A, n \in N, k \in K) \tag{12}$$

$$w_{a,n,k} \geq z_{a,n,k} \quad (a \in A, n \in N, k \in K) \tag{13}$$

$$p_{a,j,n,k} \geq v_{a,n,k} - u_{a,j} - (1 - x_{a,j,n,k})M_2 \quad (a \in A, j \in J, n \in N, k \in K) \tag{14}$$

$$\bar{t}_{a,n,k} \geq 0 \quad (a \in A, n \in N, k \in K) \tag{15}$$

$$p_{a,j,n,k} \geq 0 \quad (a \in A, j \in J, n \in N, k \in K) \tag{16}$$

Constraint (1) ensures the emergency vehicles are assigned to emergency station. Constraint (2) ensures the emergency vehicle is dispatched to demand point. Constraint (3) ensures each emergency vehicle can only dispatch at most one time in each number of dispatch. Constraint (4) ensures each emergency vehicle can only be dispatched at most one time in every number of dispatch for each demand point. Constraint (5) ensures the standard setup time when each emergency vehicle will be dispatched. if emergency vehicle k is dispatched to demand point j in the number of dispatch n at scenario $a(x_{a,j,n,k} = 1)$ and emergency vehicle k is assigned to emergency station $i(y_{i,k} = 1)$, Constraint (6) is $\bar{t}_{a,n,k} \geq t_{a,i,j}$ and $\bar{t}_{a,n,k}$ shows travel time between emergency station and demand point. Constraint (7) shows the arrival time of emergency vehicle to demand point. Constraint (8) shows the end of service time of emergency vehicle at demand point. Constraint (9) shows the return time of emergency vehicle. Constraint (10) shows the relationship between the return time of emergency vehicle and the next dispatch time of emergency vehicle. Constraints (11),(12),(13) show the order of time variables. if emergency vehicle k is dispatched to demand point j in the number of dispatch n under scenario $a(x_{a,j,n,k} = 1)$, constraint (14) is $p_{a,j,n,k} \geq v_{a,n,k} - u_{a,j}$ and $p_{a,j,n,k}$ shows the response time. Constraints (15),(16) ensure the continuous variable nonnegative.

3.3. Objective function

$$f = \sum_{a \in A} \left(P_a \cdot \sum_{j \in J, n \in N, k \in K} p_{a,j,n,k} \right)$$

3.4. Mathematical model

The mathematical model is presented as follows:

$$(\star) \left| \begin{array}{ll} \text{minimize} & f \\ \text{subject to} & (1) \sim (16) \end{array} \right.$$

4. NUMERICAL EXPERMINT

In this section, we will solve a numerical instance generated by random in order to demonstrate the performance and to validate the proposed model.

4.1. Parameter generation

We will generate a $L \times W$ rectangular region and the candidate location of emergency stations will be fixed on it(as shown in Fig.3).

The assumption of each parameter is shown as follows:

- The number of emergency demands follow a possion distribution function defined by $P(\lambda 1)$ and the location of emergency demands follow a uniform distribution $U[L, W]$.
- The Call-in time $u_{a,j}$ follows a exponential distribution function defined by $P(\lambda 1)$ during one day.
- The distances $d_{i,j}$ between emergency stations and emergency demands are measured in the Euclidean sense and the emergency vehicle average speed is V. Besides, we will consider the uncertainty of travel time. Hence, we define a parameter $r_{i,j}$ follows a uniform distribution function defined by $U\left[\underline{l}, \overline{u}\right]$ that means the time besides $d_{i,j} \div V$. Accordingly, we defined $t_{a,i,j} = \{d_{i,j} \div V + r_{i,j}\}$
- The service time $s_{a,j}$ follows a exponential distribution function defined by $P(\lambda 2)$.

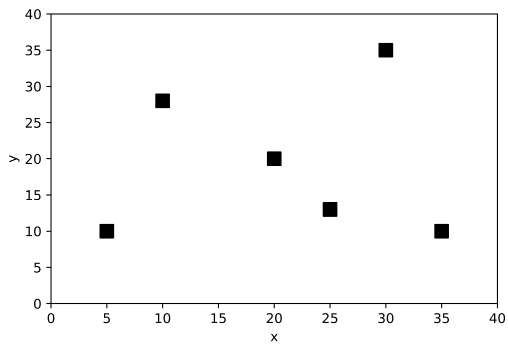

Fig. 3 The candidate location of emergency stations

Table 1 Parameter values in parameter generation

Param	L	W	V	$\underline{l}$	$\overline{u}$	$\lambda 1$	$\lambda 2$
Value	40	40	50	0	15	10	20

Table 2 Description of the instance

	Case 1	Case 2	Case 3
The number of emergency stations	40	40	12
The total number of emergency demands	40	40	12
The number of emergency vehicles	40	40	12
The average response time	40	40	12

4.2. Computation results

We solve the mathematical model ($\star$) using the Gurobi Optimizer version 7.0.1 as the mixed-integer program solver and the computation enviroment as shown in Table. 3.

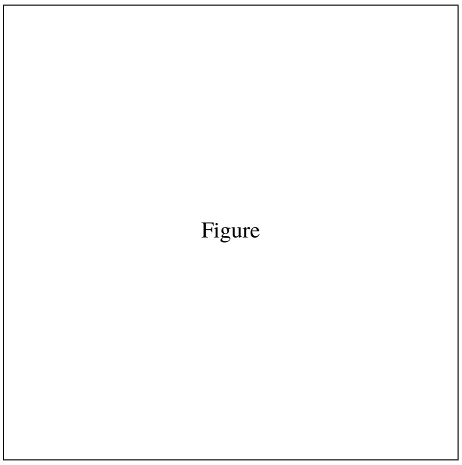

Fig. 4 Title of figure, left justified, subsequent text indented as in this example

Table 3 Computation enviroment

OS	Microsoft Windows 10 Home
CPU	Intel(R) Core(TM) i7-6600U CPU
Memory	16.0GB
Solver	Gurobi Optimizer version 7.0.1

Table 4 Computation results

Case number	Case 1	Case 2	Case 3
Case 1	40	40	12
Case 2	40	40	12
The number of emergency vehicles	40	40	12
The average response time	40	40	12

5. SENSITIVITY ANALYSIS

6. CONCLUSIONS AND FUTURE WORK

Number the figures and tables and give them short informative captions. The style of captions should obey the descriptions in the captions of Fig. 4 and Table 5. Use “Figure” at the beginning of a sentence and “Fig.” otherwise, e.g., “Figure 4 shows. . . ”; “. . . is depicted in Fig. 4.”

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Equations are centered and numbered consecutively, from 1 upwards, e.g., equations (17) and (18) that are defined by

Table 5 Title of table, left justified, subsequent text indented

1234	Normal	OK
3323	Normal	OK
342	Normal	OK
234	Normal	OK

$$f(x) = 3x^2 + 2x \tag{17}$$

and

$$g(x) = 5x + 3. \tag{18}$$

7. REFERENCES

Citing publications When a publication is referred to in the text, enclose the authors’ names and the year of publication within round brackets, e.g., (Kyoto and Shiga, 1994). For one author, use author’s surname and the year (Osaka, 1996). For two authors, give both names and the year (Kyoto and Shiga, 1994). For three or more authors, use the first author, plus “et al.,” and the year (Kobe et al., 1995a). When giving a list of reference, separate them using semicolons (Kobe et al., 1995b; Kyoto and Shiga, 1994; Osaka, 1995). (With LaTeX, this is realized just by typing, e.g., “`\cite{kobe95b,kyoto,osaka95}`,” where kobe95b, kyoto, osaka95 are labels of papers.)

Put only the year in brackets when referring to the author(s) of referenced publication as noun (e.g., “This work was first developed by Kyoto and Shiga (1994), and later expanded by Kobe et al. (1995b), who demonstrated that. . . ”). (With LaTeX, use for this purpose `\citeasnoun` instead of `\cite`, e.g., typing “`\citeasnoun{kobe95b}`” results in “Kobe et al. (1995b)”, while “`\cite{kobe95b}`” results in “(Kobe et al., 1995b),” where kobe95b is the label of the paper.)

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