# Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 13 (15): 2929-2932, 2013
ISSN 1812-5654 / DOI: 10.3923/jas.2013.2929.2932

# Study on Crowd Emergency Evacuation Model after the Leakage of Hazardous Waste

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**Abstract:** After Leakage of Hazardous Waste, the orderly organization disaster area evacuation is of great significance in reducing personnel injuries and deaths. Evacuation process in the study population, the research road network with impedance characteristics evacuation to establish the source of the model as the objective function, the establishment of large-scale evacuation of the city evacuated total shortest crowd emergency evacuation. Due to the complexity of the model, the Insert difference detection algorithm to solve the model. The examples show that the model and the algorithm have a certain practicality.

**Key words:** Crowd dispersal, impedance, emergency, insert difference detection algorithm, time shortest

## INTRODUCTION

Recently, the management is becoming more difficult along with the increase of hazardous waste, which would bring great harm to environment and society. For example, thousands of barrels of hazardous waste appear in Haohui Guoyang and Lixin counties in Anhui province in China. Some leaked chemical substance, such as dichloroethane and methanol, already made water pollution as long as 10 km. Ministry of Environmental protection has carried on the investigation and some responsible person has been detained. The incident has not caused casualties for in-time disposal measures. More dangerously, once hazardous waste leaks, it is easier to case injury to surrounding crowd. Therefore, Study on crowd emergency evacuation model after the leaking of hazardous waste will help reduce the impact. Yang *et al.* (2011) considered the capacity limit of building path when building the model and design algorithm using the idea of the shortest path. Li and Chen (2012) built a double evacuation model mixed person with car, including the upper for shortest evacuation time and the bottom for the objective of highest efficiency. Zhang *et al.* (2005) forecasted the behavior before evacuation and convey a questionnaire on behavior decision and the conclusion is the forecast is fit with the survey. Wang *et al.* (2008) concluded different evacuation model and state GIS direct massive crowd evacuation study. Yuan and Wang (2008) builded time continuous decreasing function model, total time as objective and solved the model with Dijkstra algorithm. Xiao *et al.* (2001) built the feasibility and equivalent length model about evacuation path of toxic gas leakage and solved the model by k shortest path. Bibliography studied models and algorithms of evacuation of hurricanes and other disaster. Tufekci (1995) and Farahmand (1997) are studying evacuation under the given speed. But the truth is that the speed varies for the obstruction of evacuees and building. Study on evacuation after the leakage of hazardous waste is less. The paper builds multi-person emergency evacuation model after the leakage of hazardous waste. The model considers impedance factor and complicity of the model itself, solves by insert difference detection algorithm.

## BUILD THE MODEL

Different disasters have its characteristics in evacuation, therefore emergency evacuation model has distinctiveness. The paper builds multi-person emergency evacuation model considering the leakage of hazardous waste. Several assumptions of the model as follows:

- Rank the evacuate priority according to the damage of disaster
- Capacity limitation of paths and modes in the network of emergency evacuation road
- No return and circle in the process of emergency evacuation
- First in first out principle of evacuees in emergency evacuation route
- Flow conservation principle in emergency evacuation route

G = (V, E) is emergency evacuation route after the leakage of hazardous waste among V is the set of

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vertices, the set of disasters are $S = \{S_a | a = 1, 2, ..., A\}$, the set of nodes in emergency evacuation route is $N = \{N_a | b = 1, 2, ..., B\}$, the set of safe collection is $D = \{D_r | r = 1, 2, ..., R\}$:

E : Arc set of emergency evacuation route; $e_{ij}$ is path between vertex of $n_i$, $n_j$ in emergency evacuation route, $\in V$
$K_a$ : The priority number of $S_a$;
$ACS_a$ : The number to be evacuated of $S_a$
$MCN_i$ : The maximum capacity of $n_i$, $n_j \in V$
$MC_{ij}$ : The maximum capacity of $e_{ij}$
$CN_i$ (t) : The capacity of $n_i$ at t, $n_i \in V$
$C_{ij}$ (t) : The capacity of $e_{ij}$, at any time of t
$t_{ij}$ : The time needed for crossing $e_{ij}$
$t^k{}_a$ (n) : The time needed from $S_a$ to $n_i$ by the path of k
$T_0$ : The evacuation start time of evacuation
$T_a$ : The evacuation end time of $S_a$
T : The time that all person evacuated to safety zone in emergency evacuation route
$P^k{}_a$ : Path k of $S_a$
$f^k{}_a$ : The flow of $P^k{}_a$
$n^{kl}{}_{aac}$ : The intersection between path k of $S_a$ and path l of $S_{ac}$ and the priority number of $S_{ac}$ is higher than that of $S_a$,
$x^a{}_{ij}$ (t) : Means entering $e_{ij}$ at evacuation time t, $t+t_{ij}$ is the number of evacuees reaching vertex $n_j$ coming from $S_a$:

$$Ts_i = t_j + t_p - t_{ZC}$$

$Ts_i$ is the delay time caused by congestion impedance of emergency evacuation net, $t_j$ is the time spent from evacuation normal speed to lining up, $t_s$ is the time spent from lining up to recovering normal evacuation speed $t_p$ is waiting time caused by impedance $t_{ZC}$ is the passing time under normal condition.

β is impedance decision variable, when exist impedance β = 1, or β = 0.

$$+\beta\ Ts_i \tag{1}$$

$$\text{Min}\sum_{t=0}^{T}\sum_{a\in S}\sum_{i\in D}K_a t x_{i0}^{(a)}(t) \tag{2}$$

$$y^{(a)}{}_a(0) = ICS_a \tag{3}$$

$$y^{(a)}{}_i(0) = 0,\ i\in N \tag{4}$$

$$x^a{}_{ij}(0) = 1,\ i\in N,\ j\in N \tag{5}$$

$$\sum_{a=1}^{A} y_i^{(a)}(t) < MCN_i \tag{6}$$

$$\sum_{a=1}^{A} x_{ij}^{(a)}(t) < MC_i \tag{7}$$

$$y_i^{(a)}(t) < MCN_i - \sum_{a=1}^{a-1} y_i^{ac}(t) \tag{8}$$

$$x_{ij}^{(a)}(t) < MC_{ij} - \sum_{ac=1}^{a-1} x_{ij}^{ac}(t) \tag{9}$$

$$\begin{gathered}\sum_{n_i\in V} y_i^{(a)}(t) + \sum_{e_{ij}\in E} x_{ij}^{(a)}(t) = ICS_a \\ y_i^{(a)}(t+1) - y_i^{(a)}(t) = \sum_{k\in pred(i)} x_{ki}^{(a)}(t - t_{ki}) - \sum_{j\in succ(i)} x_{ij}^{(a)}(t)\end{gathered} \tag{10}$$

$$x_{ij}^{(a)}(t) \geq 0,\ y_i^{(a)}(t) \geq 0 \tag{11}$$

$$\begin{gathered}pred(i) \in \{j | (j,i) \in E\} \\ succ(i) \in \{j | (i,j) \in E\}\end{gathered} \tag{12}$$

Equation 1 means the time spent by evacuating all people to safe zone. Equation 2, 3 and 4 are initial states of evacuation net. Equation 5 and 6 represent capacity limitation of $n_i$ and $e_{ij}$ at the time t. Equation 7 is sequence order of $n_i$ at time t in evacuation. Equation 8 is sequence order of $e_{ij}$ at time t in evacuation. Equation 9 is evacuees conservation at time t. Equation 10 is first in first out evacuation principle. Equation 11 is non-negative decision variables.

## INSERT DIFFERENCE DETECTION ALGORITHM

**Definition of difference:** Assume a feasible $route_i$ ($P_0$, $P_1$, ..., $P_{i-1}$, $P_i$), $P_{i+1}$, ..., $P_n$, $P_0$), $p_0$ is parking lot, $P_i$ (i = 1, 2,..., n) is point of customers that vehicles to be pick up or delivery, $B_i$ and $L_i$ (i = 1, 2, ..., n) are, respectively the earliest start time and the latest start time of vehicle operation, the start time of operation should keep in [$B_i$, $L_i$] at $P_i$. Vehicle can reach earlier, but operate only from time $B_i$, $B_0$ and $L_0$, respectively delegate open time and close time of $P_0$ all vehicles should complete job before $L_0$ and come back to parking lot. $S_i$ is the service time at $P_i$, $T_{i-1,\, i}$ is the time vehicle spent from $P_{i-1}$ to $P_i$, $Wait_i$ is waiting time $P_i$.

**Definition 1:** We definite the earliest time at $P_i$ is $EF_i$ and $Ef_i = \text{Max}(B+S_i, Ef_{i-1}+T_{i-1,\, I}+S_i)$, (I = 1,2,..., n)

**Definition 2:** The latest time at $P_i$ is $LS_i$ , $LS_i = \text{Min}(Li, LS_{i+1}-T_{i,\, i+1}-S_i)$.

For there is no service at $P_0$, $S_0 = 0$, then $EF_0 = e_0$, $LS_0 = l_0$ the value of EF and LS in $route_i$ can calculate through the value of $EF_0$ and $LS_0$ by forward or inverse calculation.

Assume any two points $P_{i-1}$ (- = 1, 2, ..., n) in route$_i$, the earliest finish time $EF_{i-1}$ means the early time that vehicles finish services of each point from $P_0$ to $P_{i-1}$, while $LS_i$ means the latest start time at $P_i$ to finish service from $P_i$ to $P_n$. If point or sub-path is inserted between $P_{i-1}$, $P_i$, only after insertion the new $LS_{inew}$ of $P_i$ no more than original $LS_i$, then the time feasibility of point of the original would keep the same. Based on above definition, the definition of deference is.

**Definition 3:** Assume $p_i$ and $p_j$ are any two points in route$_i$ (I, j = 0, 1, 2, ..., n) j>i, $LS_i$ is the latest start time of $p_j$, $EF_i$ is the earliest finish time of $p_i$, then the difference is $TD_{ij} = LS_j - EF_i$.

### Necessary and sufficient condition of inserting difference

**Theorem 1:** Assume a feasible route route$_i$ ($P_0$, $P_1$, ..., $P_{i-1}$, $P_i$, $P_i$+1, ... $P_n$, $P_0$), (i = 1, 2, ..., n) the necessary and sufficient condition of inserting $p_i$ into $P_{i-1}$, $P_i$ is $EF_j = S_j < L_j$, $TD_{i-1,i} \geq T_{i-1,j} + S_j + T_{j,i} + Wait_j$.

**Analyze calculating complexity of insert difference detection algorithm:** Assume there is routei ($P_0$, $P_1$, ..., $P_{i-1}$, $P_i$, $P_{i+1}$, ..., $P_n$, $P_0$) with n customers, $P_0$ is distribution center, inserting $P_j$ into route$_i$. Considering the worse condition, the feasible insertion point lies the last position, then the number of insert difference detection algorithm is: Calculate each EF, LS and the calculating number of Wait is 3 (n+2) and calculating $Ef_j$, n+1 times, according to theorem 1 the number of detection is 2 (n+1) and total calculating number 6n+9 times, so time complexity is o (n) and space occupy is 3 (n+2). However, insert forward values detection should detect every position and firstly calculate and detect forward values from current position to final position. Then, the time complexity is o ($n^2$), LS does not need in insert forward values detection and all space occupancy is 2 (n+2). Therefore, when n is bigger, insert difference detection is faster, which reflects the optimization idea of time-space. Framework of insert difference detection algorithm Assume route$_i$ ($P_0$, $P_1$, ..., $P_{i-1}$, $P_i$, $P_{i+1}$, ..., $P_n$, $P_0$), (i = 1,2,..., n) is route i of current solution x, $P_0$ is distribution center, then detection process of inserting $P_j$ into route i of current solution are as follows:

- **Step 1:** Choose insertion position $P_{i-1}$, $P_i$ (i = 1, 2, .., n) randomly or using a heuristic idea
- **Step 2:** Calculate $ES_j$ $EF_j$, $Wait_j$, $TD_{i-1,i}$ and $ES_j = Max(B_j, EF_{i-1}+T_{i-1,j})$, $Wait_j = (0, B_j)$ calculating method of $TD_{i-1,i}$ and $EF_j$ see theorem 1 and definition 1
- **Step 3:** Conduct further detection by theorem, if meet then insert and update value EF and ES of route, otherwise return step 1and detect next position

## EXAMPLE

Figure 1 is emergency evacuation net after the leakage of hazardous waste. Z1, Z2, Z3 and Z4 are emergency evacuation points. D1 and D2 are assembly points. In the arc, the first number means the maximum capacity of arc, the second number the evacuation time and see Table 1. After leakage, people required by four emergency evacuation points are 1200, 800, 800 and 1400 separately. The priority level is Z1>Z2>Z3>Z4. The evacuation capacity D1and D2 received is infinite.

On the condition of Intel(R)/CPU2.4GHz/2G, the paper uses Matlab7.0 program to solve the model. Finally the running time is 87.7S£¬iteration times are 1322. Table 2 is the result.

On the condition of Intel(R)/CPU2.4GHz/2G, the paper uses MATLAB 7.0 program to solve the model. Finally the running time is 87.7 sec, iteration times are 1322. Table 2 is the result. Pay attention to key points 2 and 4 in evacuation process, for its capacity is limited. Key points 2 and 4 need be dredged to avoid congestion and stampede.

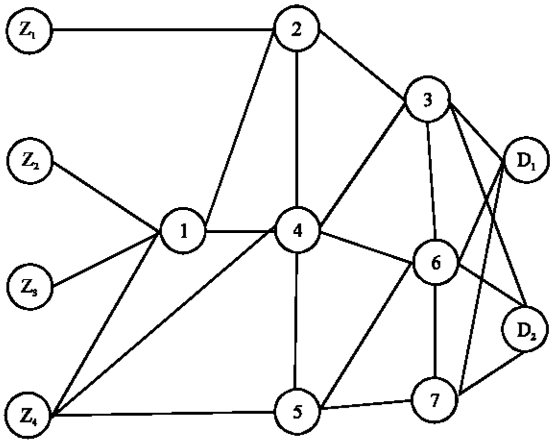

Fig. 1: Emergency evacuation net

Table 1: Characteristics of emergency evacuation net

| Arc | (Capacity, time) | Arc | (Capacity, time) | Arc | (Capacity, time) |
|---|---|---|---|---|---|
| Z12 | (120, 20) | 14 | (160, 23) | 57 | (180, 26) |
| Z21 | (140, 25) | 23 | (320, 28) | 3D1 | (175, 37) |
| Z31 | (140, 25) | 24 | (220, 33) | 3D2 | (255, 45) |
| Z41 | (190, 45) | 43 | (220, 17) | 36 | (325, 48) |
| Z44 | (155, 37) | 46 | (270, 20) | 6D1 | (120, 16) |
| Z45 | (170, 32) | 54 | (180, 15) | 6D2 | (160, 37) |
| 12 | (400, 20) | 56 | (170, 18) | 7D1 | (170, 38) |
| 76 | (400, 20) | 7D2 | (170, 30) | | |

Table 2: Evacuation results

| Origin | Route | Flow | Total time | Origin | Route | Flow | Total time |
|---|---|---|---|---|---|---|---|
| Z1 | Z1→2→3→D1 | 236 | 170 | Z3 | Z3→1→2→3→D1 | 210 | 220 |
| | Z1→2→3→D2 | 437 | 372 | | Z3→1→2→3→D2 | 116 | 118 |
| | Z1→2→3→6→D1 | 347 | 336 | | Z3→1→2→3→6→D1 | 0 | 0 |
| | Z1→2→3→6→D2 | 0 | 0 | | Z3→1→2→3→6→D2 | 0 | 0 |
| | Z1→2→4→3→D1 | 180 | 173 | | Z3→1→2→4→3→D1 | 0 | 0 |
| | Z1→2→4→3→D2 | 0 | 0 | | Z3→1→2→4→3→D2 | 0 | 0 |
| | Z1→2→4→6→D2 | 0 | 0 | | Z3→1→2→4→6→D2 | 0 | 0 |
| | Z1→2→4→6→D1 | 0 | 0 | | Z3→1→2→4→6→D1 | 0 | 0 |
| Z2 | Z2→1→2→3→D1 | 210 | 220 | | Z3→1→4→3→D1 | 113 | 102 |
| | Z2→1→2→3→D2 | 116 | 118 | | Z3→1→4→3→D2 | 117 | 110 |
| | Z2→1→2→3→6→D1 | 0 | 0 | | Z3→1→4→6→D2 | 104 | 105 |
| | Z2→1→2→3→6→D2 | 0 | 0 | | Z3→1→4→6→D1 | 112 | 84 |
| | Z2→1→2→4→3→D1 | 0 | 0 | Z4 | Z4→1→2→4→6→D2 | 0 | 0 |
| | Z2→1→2→4→3→D2 | 0 | 0 | | Z4→1→2→4→6→D1 | 0 | 0 |
| | Z2→1→2→4→6→D2 | 0 | 0 | | Z4→1→4→3→D1 | 0 | 0 |
| | Z2→1→2→4→6→D1 | 0 | 0 | | Z4→1→4→3→D2 | 0 | 0 |
| | Z2→1→4→3→D1 | 113 | 102 | | Z4→1→4→6→D2 | 0 | 0 |
| | Z2→1→4→3→D2 | 117 | 110 | | Z4→1→4→6→D1 | 0 | 0 |
| | Z2→1→4→6→D2 | 104 | 105 | | Z4→4→3→D1 | 0 | 0 |
| | Z2→1→4→6→D1 | 112 | 84 | | Z4→4→3→D2 | 0 | 0 |
| Z4 | Z4→1→2→3→D1 | 288 | 276 | | Z4→4→6→D2 | 0 | 0 |
| | Z4→1→2→3→D2 | 0 | 0 | | Z4→4→6→D1 | 362 | 219 |
| | Z4→1→2→3→6→D1 | 0 | 0 | | Z4→5→4→3→D1 | 0 | 0 |
| | Z4→1→2→3→6→D2 | 0 | 0 | | Z4→5→4→3→D2 | 0 | 0 |
| | Z4→1→2→4→3→D1 | 0 | 0 | | Z4→5→4→6→D2 | 0 | 0 |
| | Z4→1→2→4→3→D2 | 0 | 0 | | Z4→5→4→6→D1 | 0 | 0 |
| | Z4→5→6→D2 | 0 | 0 | | Z4→5→7→D1 | 0 | 0 |
| | Z4→5→6→D1 | 424 | 66 | | Z4→5→7→6→D2 | 0 | 0 |
| | Z4→5→7→D2 | 327 | 264 | | Z4→5→7→6→D1 | 0 | 0 |

## CONCLUSIONS

From the above analysis, we can draw some conclusions as follows:

- After leakage of hazardous waste, multi-person emergency evacuation model should consider impedance factor to reality and solve by insert difference detection algorithm
- By example, not all evacuation route in net will evacuate. In evacuation, we should pay attention to key points and persuasion of key routes
- Further study should focus on better algorithms, constraints closed to actual and consider herd behavior in evacuation

## ACKNOWLEDGMENT

This study is supported by National Social Science Fund of China (Grant No. 13CGL127), Sichuan Science and technology project (Grant No. 2013ZR0041), Chengdu Science and technology project (Grant No. 12RKYB087ZF-002), china society of logistics research project (Grant No. 2013CSLKT107).

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