Emergency Evacuation Model and Algorithm in the Building with Facilities

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Abstract: Emergency evacuation of the building would be necessary in case of an accident such as fire, toxic gas. In public buildings where the number of evacuees is difficult to estimate, the purpose of evacuation is to maximize the number of people transferred from the danger zone to safe destinations through exits within a given time horizon \(T\). In fact, considering such a situation that the evacuees are perhaps unfamiliar with building structure, some rescue workers should be arranged on some positions to guide evacuation. In this paper, based on above situation, we give an emergency evacuation model in the building with facilities which have same sizes. Then a series of algorithm are designed based on combination of dynamic network flows and location analysis. The algorithms can be realized by effectively decomposing static flow and calculating the numbers of all feasible locations on the paths. Finally, a numerical example is presented to show the effectiveness and feasibility of this algorithm.

Keywords: emergency evacuation; building; facilities; dynamic network flows; location analysis

1. Introduction

Many disasters, natural or man-made, have brought a great impact on human being. These disasters could result in severe life losses and property damages. It is a key task what we can do for the destroyed place and the wound when facing the disasters. Emergency evacuation has been receiving more and more attention in recent year. Evacuation planning is also critical for numerous important applications, e.g. disaster emergency management and homeland defense preparation. In many hazardous events, the best option is to relocate threatened populations to safer areas.

Evacuation is a common strategy in emergency management. The current models of evacuation can be divided into two categories, namely macroscopic model and microscopic model. Macroscopic models are mainly based on optimization approaches and do not consider any individual behavior during the emergency situation. These models are well-known to produce good lower bounds for the evacuation time. In some papers, evacuation route planning aims at finding paths in a given transportation network to minimize the time needed to move the threatened populations to safe destinations, and in others, to maximize the numbers of persons evacuated within a given time \(T\). Hamacher and Tjandra (2001) gave an extensive literature review of the models and algorithms which could be applied to evacuation problems. SAFE-R, a model studying the evacuation of a building, had been presented (Gupta, 2004). The algorithm was based on the network optimization theory and used graph theoretical approach to identify the number of paths available for movement of the people. A multiobjective approach was introduced about evacuation planning (Luís, 2009). The approach incorporated a multiobjective model into a geographical information systems–based decision support system that planners could access via the internet. Chen and Feng (2009) gave a fast flow control algorithm for real-time emergency evacuation in large indoor areas, which calculated evacuation paths in accordance with the floor plan and the total number of evacuees. Zhang et al. (2009) considered the emergency evacuation problem of multi-sources with the order of priority as well as the capacity constraints and gave a heuristic algorithm based on network optimization in graph theory.

Microscopic models, in which the individual evacuees' movement is emphasized, are based on simulation. These models are able to model the individual evacuee's parameters (e.g. walking speed, reaction time, physical ability) and the interaction among evacuees which influence their movement. In recent years there was a growing interest to microscopic simulation in building evacuation (Ren, 2008 and Nikolaos, 2010). Various types of agents and different attributes of agents are designed in contrast to traditional modeling. Agent-Based Modeling and Simulation was presented for simulating human and social behavior during emergency evacuation (Pan, 2007; Chen, 2008; Keith, 2008 and Ren, 2009).

Because different evacuation processes have different contexts, all the existing flow control algorithms for evacuation have their assumptions and limitations. Considering such a situation that an accident such as fire is happened in the large building, we need to evacuate the threatened populations in time. The number of evacuees of the public buildings is difficult to estimate, so we can model the evacuation problem as maximum dynamic network flow problem within time horizon \(T\). At the same time, when the evacuees are perhaps unfamiliar with
exits distribution, the management should reasonably arrange the rescue workers to take part into evacuation on some positions (e.g. intersection). Based on above background, we will discuss an emergency evacuation model in the building with facilities. The evacuation model with facilities was first given by Hamacher et al. (2011). Hamacher et al. combined dynamic network flows and location analysis to predict and evaluate evacuation. There were three exact algorithms for the single facility version 1-FlowLoc(flow location) of this problem and a mixed integer programming formulation and a heuristic algorithm for multi facilities q -FlowLoc. In this paper, we will give more effective algorithms for the emergency evacuation model with facilities which have same sizes.

The rest of the paper is organized as follows. In Section 2, some related concepts are illustrated and the problem formulation is provided. Section 3 describes the algorithms based on the combination of dynamic network flow and location analysis. The key of the algorithms is to find out the number of all feasible locations of each path by using path matrix. In Section 4, we present the experimental design and performance evaluation. We summarize our work and discuss future directions in Section 5.

2. Problem Description and Mathematical Model

2.1 Dynamic Network Flow Problem

To keep the paper self-contained, we give a brief introduction about dynamic network flow theory. In some applications such as scheduling of people, jobs, or projects, or the carryover of inventory of a product from one time period to another, time is an essential ingredient. In these instances, to account properly for evolution of the underlying system over time, we need to use dynamic network flow models. The maximum dynamic flow problem is a variant of maximum flow problem. We consider a network $N = (V, E, c, \tau, s, d)$ with capacities $c: E \to N$, travel times $\tau: E \to N$ and two distinct nodes $s, d \in V$, the source and sink. In the maximum flow problem, we maximize the number of flow units that can pass through the network from source $s$ to sink $d$ per unit time while satisfying the arc capacities $c_{ij}$. In the dynamic flow problem, we maximize the total number of flow units that can be sent from source $s$ to sink $d$ in $T$ time periods while satisfying arc capacities $c_{ij}$ and arc traversal time $\tau_{ij}$.

We denote $\text{pred}(i) := \{ j | (j, i) \in E \}$ and $\text{succ}(i) := \{ j | (i, j) \in E \}$, where we assume without loss of generality that $\text{pred}(s) = \text{succ}(d) = \emptyset$.

**Definition 1.** (Hamacher, 2011) A dynamic $s-t$-flow with time periods $T$ is a function $x: E \times \{0, 1, \ldots, T\} \to \mathbb{R}^+$ satisfying the

- flow conservation constraints: For all $i \neq s, d \in V, t \in \{0, 1, \ldots, T\}$
  \[
  \sum_{k \in \text{pred}(i) \cap \{0, \ldots, t\}} x_{ik}(t) - \sum_{j \in \text{succ}(i) \cap \{0, \ldots, t\}} x_{ji}(t) \geq 0,
  \]
- and the
  \[
  \sum_{k \in \text{pred}(i) \cap \{0, \ldots, t\}} x_{ik}(t) - \sum_{j \in \text{succ}(i) \cap \{0, \ldots, t\}} x_{ji}(t) = 0,
  \]

and the

- capacity constraints:
  \[
  0 \leq x_{ij}(t) \leq c_{ij}, \forall (i, j) \in E, t \in \{0, 1, \ldots, T\}.
  \]

Assuming $\text{pred}(s) = \text{succ}(d) = \emptyset$, the flow value of a dynamic $s$-$t$-flow is defined as

\[
\text{val}_t(f) = \sum_{k \in \text{pred}(d) \cap \{0, \ldots, t\}} \sum_{j \in \text{succ}(d) \cap \{0, \ldots, t\}} x_{kj}(t) - \sum_{j \in \text{succ}(i) \cap \{0, \ldots, t\}} \sum_{i \in \text{pred}(i) \cap \{0, \ldots, t\}} x_{ij}(t).
\]

In the dynamic network flow models, the function value $x_{ij}(t)$ means the flow (e.g. the number of evacuees moving at time $t$) that leave node $i$ at time $t$ and reach node $j$ at time $t + \tau_{ij}$. The inequality in (1) indicates that it is possible to wait in the nodes. The equality in (2) means that the total number of flow should be balance at the end of the evacuation.

**Definition 2.** (Hamacher, 2011) A dynamic $s$-$t$-flow is called a maximum dynamic $s$-$t$-flow (with respect to $T$) if it maximizes the flow value $\text{val}_t(f)$ for given time horizon $T$.

In evacuation planning evacuees are modeled by unit of flow. The maximum dynamic flow gives an answer to the question of how many evacuees can be sent from the starting point to safety within a given time horizon $T$. In this paper, we would use temporally repeated flow technique to solve maximum dynamic flow problem. In order to solve the maximum dynamic flow problem, and thus find the maximal number of persons, which can be evacuated within $T$ time periods from a given building, we only have to solve a minimum cost flow problem in the static network.
The next theorem shows that the maximum dynamic flow problem can be solved as a minimum cost flow problem (MCPF) in the static network.

**Theorem 1.** (Hamacher, 2001) Finding a maximum dynamic flow is equivalent to solving a MCPF. In particular, the temporally repeated flow obtained from the chain decomposition of any minimum cost flow is a maximum dynamic flow.

Let \( f \) be a feasible static flow in network \( N \) and be decomposed into \( l \) chain flows \( f_{1}, f_{2}, \ldots, f_{l} \) on \( P_{1}, P_{2}, \ldots, P_{l} \) such that \( \text{val}(f) = \sum_{k=1}^{l} \text{val}(f_{k}) \). The associated temporally repeated flow sends \( \text{val}(f_{k}) \) flow units along \( P_{k} \) at time periods \( 0,1, \ldots, T-\tau(P_{k}) \), where \( \tau(P_{k}) = \sum_{(i,j) \in P_{k}} \tau_{ij} \). We can calculate the value of the maximum dynamic flow as \( \text{val}_{T}(f) = \sum_{k=1}^{l} (T-\tau(P_{k})) \text{val}(f_{k}) \) at time \( T \).

**Theorem 2.** (Hamacher, 2011) The flow value of a temporally repeated and maximum dynamic flow is equal to \( \text{val}_{T}(f) = T \cdot \text{val}(f) - \sum_{(i,j) \in k} \tau_{ij} x_{ij} \)

and thus independent of the path decomposition of the static flow. A maximum temporally repeated flow can be calculated with a minimum cost calculation in the static network with one additional edge from the sink to the source.

Theorem 2 shows the maximum dynamic flow within a given time horizon \( T \) can be got when maximum flow of the static network is known. But placing the facilities on some edges in the evacuation network will obviously have an impact on the design of evacuation plans. This can result in a smaller maximum flow value on the edges. So it is important to maintain as many source-sink paths as possible, which reduces the danger of traffic jams and gives rescue workers better possibilities to reach the danger area. In the next part we give the evacuation model which has the same size facilities, aiming at redesing the evacuation route planning such that the reduction of the original maximum flow value is as small as possible.

### 2.2 Evacuation Model with Facilities

In the evacuation problem we have only one sink node by connecting all the exit nodes to one artificial node by artificial edges and assign the artificial edges with capacities \( \infty \), travel times \( 0 \). Without loss of generally, the evacuation problem discussed in the paper can be modeled as single source/single sink network flow problem, which would be combined with location analysis.

Location analysis was introduced as a new tool in evacuation modeling by Hamacher et al. (2011). They discussed flow location problem with single source/single sink. In an evacuation network the capacity of an edge corresponds to the width of the street modeled by this edge. A facility corresponds, for example, to a fire engine placed in the street. Since the facility has a certain width, the capacity of the street is reduced by the size of the facility. In the \( q \)-FlowLoc(flow location) problem we would find \( q \) edges to locate the facilities \( p \in P \) with the size \( r_{p} \) such that the reduction of maximum flow value is as small as possible.

Hamacher et al. presented three exact algorithms to solve the single facility version \( 1 \)-FlowLoc of this problem and compare their running times. After proving the NP-completeness of the multi facilities \( q \)-FlowLoc problem, a mixed integer programming formulation and a heuristic for \( q \)-FlowLoc were proposed.

In this paper, we consider facilities correspond to rescue workers. Because the evacuees may be unfamiliar with exits distribution, the rescue workers would be arranged on some edges (e.g. intersection) to guide evacuation. We can regard emergency evacuation model with rescue workers as the \( q \)-FlowLoc(flow location) model with the same facility size \( r_{p} = 1 \). The problem aims at finding some edges to locate the facilities such that the reduction of the original maximum flow value is as small as possible.

Let \( N = (V,E,c,\tau,s,d) \) be a graph with \( n \) vertices and \( m \) edges, source \( s \) and sink \( d \), having upper capacities \( c : E \rightarrow N \) travel times \( \tau : E \rightarrow N \). Let \( L \in E \) denote the set of all feasible locations with the size \( |L| \), where the facilities would be placed. There are \( q \) available facilities which would be placed on the locations in the evacuation. The variable \( x_{ij} \) is denoted the flow value on edge \((i,j)\), and \( y_{ip} \) is a binary variable which equals to one, if the \( r \)th facility is placed on edge \((i,j)\), zero else. \( \delta_{r}(P_{k}) \) equals to one if edge \((i,j)\) is contained in the path \( P_{k} \), and is zero otherwise.

Using the notation introduced above, the problem can be formulated as follows.

\[
\max \text{val}_{T}(f) = T \cdot \text{val}(f) - \sum_{(i,j) \in L} \tau_{ij} x_{ij} \quad (5)
\]
\[ \text{s.t. } \sum_{i=1}^{n} \frac{\text{val}(f_{ij})}{\text{val}(f)} = \text{val}(f) \quad (6) \]

\[ \sum_{(i,j) \in E} x_{ij} = \sum_{(j,i) \in E} x_{ji}, \quad \forall (i, j) \in E \quad (7) \]

\[ \sum_{j \notin \text{pred}(i)} x_{ij} - \sum_{j \in \text{succ}(i)} x_{ij} = 0, \quad \forall i \in V, i \neq s, d \quad (8) \]

\[ \sum_{(i,j) \in E} y_{ij} = 1, \quad r = 1,2,\ldots,q \quad (9) \]

\[ \sum_{r=1}^{q} y_{ij} \leq 1, \quad \forall (i, j) \in L \quad (10) \]

\[ 0 \leq x_{ij} + y_{ij} \leq c_{ij}, \quad \forall (i, j) \in E, r = 1,2,\ldots,q \quad (11) \]

\[ 0 \leq x_{ij} \leq c_{ij}, \quad \forall (i, j) \in E \setminus L \quad (12) \]

\[ y_{ij} = 0 \text{ or } 1, \quad (i, j) \in L, r = 1,2,\ldots,q \quad (13) \]

In the evacuation model with facilities, we try to select \( q \) edges from \( L \) to locate the facilities and calculate the fact flow value \( x_{ij} \) on the every edge \( (i,j) \in E \) such that the objective function (5) would be maximum. That means the reduction of the original maximum flow value is as small as possible. Constraints (6)-(8) are flow-conservation constraints. Constraint (9) means each facility should be placed on only one edge from \( L \). Constraint (10) means at most one facility on any edge \( (i,j) \in L \). Constraints (11)-(12) suggest \(|L| \geq q \) at the same time. Constraints (11)-(12) impose the upper and lower bounds.

3. Algorithm design

In this section we will give a series of algorithms which should be used to solve the evacuation model with facility. First a maximum dynamic flow can be found based on theorem 1, and some edges should be identified from the set \( L \), where the facilities should be placed in fact. If the edge is satisfied with \((i,j) \in L \) and \( x_{ij} = 0 \), we will remove it from \( L \). It is not necessary to place facilities because no evacuee would pass the edge \((i,j) \).

Algorithm 1

1: Input network \( N = (V, E, c, \tau, s, d) \), feasible locations \( L \).
2: Apply a minimum cost flow algorithm to the original static network \( N \).
   
   Let \( f^* \) be an optimal solution and record the fact flow value \( x_{ij} \) on the edge \((i,j) \in E \).
3: Let \( L_0 = L - \{ e = (i,j) \mid x_{ij} = 0 \} \).
4: Output \( L_0, f^*, x_{ij} \).

The set of all feasible edges \( L \) discussed in the next section refers to the set \( L_0 \) got from the algorithm 1. If \( q \geq |L_0| \), it means there are enough facilities to place on the location so that evacuation planning would be completed successfully. Without loss of generality, we suppose \( q < |L_0| \). We consider to design an algorithm how to place the facilities on the reasonable edges when \( q < |L_0| \). The location yielding the smallest change on the maximum flow value is returned as optimal solution.

A maximum flow is calculated and it is checked, whether there exist some edges \((i,j) \in L \) with residual capacity large enough to place a facility. If enough capacity is generated, the facility is placed on the edge and the location is returned as optimal. If no such edges exist, the edges with the smallest influence on the flow value are returned. Suppose we choose a path \( P_1 \) with the travel time \( \tau(P_1) \) to place some facilities. If there are some edges \((i,j) \in L \) on the path \( P_1 \) are saturated, it will inevitably lead to the flow value decrease. We can get the change of the objective function.

\[ \Delta \text{val}_T(f) = T \cdot \text{val}(f) - \sum_{(i,j) \in E} \tau_{ij} x_{ij} - ((T \cdot \text{val}(f) - 1) - \sum_{(i,j) \in E} \tau_{ij} x_{ij}) = T - \tau(P_1), \quad (14) \]

where \( x_{ij} = \begin{cases} x_{ij} & (i,j) \notin P_1 \\ x_{ij} - 1 & (i,j) \in P_1 \end{cases} \).

From the formula (14), we can draw the conclusion that the number of paths selected should be as little as possible, which means the paths contain the locations as many as possible. On the other hand, we also hope to choose the path more length such that the dynamic network flow value would be less influenced.

Algorithm 2 can be given based on the above description.

Algorithm 2

1: Input \( L, f^*, x_{ij} \) got from algorithm 1, constant \( q \) and \( Q = \emptyset \).
2: Decompose $f'$ into $l$ chain flows $f_{r_1}, f_{r_2}, \ldots, f_{r_l}$ on $P_1, P_2, \ldots, P_l$ such that 

$$\text{val}(f') = \sum_{i=1}^{l} \text{val}(f_{r_i}).$$

3: Let $c_\alpha := c_\alpha - x_\alpha$ for all $e = (i, j) \in L$.

4: Sort the capacities according their size $c_\alpha \geq c_\beta \geq \ldots \geq c_{\alpha_i}$.

5: If $|q| \geq q$, then select any $q$ edges from $L$ to locate the facilities, $f' = f'$, $Q = \{ q \text{ edges from } L \}$, turn step 11, else find a constant $h$ satisfied $c_\alpha \geq 1$ and $c_{\alpha+1} = 0$.

6: If $h > q$ then select any $q$ edges from $\{e_1, e_2, \ldots, e_k\}$ to locate the facilities, $f' = f'$, $Q = Q \cup \{ q \text{ edges from } \{e_1, e_2, \ldots, e_k\} \}$, turn step 11, else select the edges $e_1, e_2, \ldots, e_k$ and let $q := q - h$, $L := L - \{e_1, e_2, \ldots, e_k\}$, $Q := Q \cup \{ e_1, e_2, \ldots, e_k \}$.

7: Calculate the path matrix $R$ of $P_1, P_2, \ldots, P_l$ and $E$ of the network $N$.

8: Give a vector $\beta$ with component $h_i = 1$ for the edge $e_i \in L$, zero else and calculate $\alpha = R \cdot \beta$, then select the max component $a_k$ of $\alpha$ with the longest travel time $\tau(P_1)$.

9: If $q \leq a_k$, then select $a_k$ edges $\in L$ on the road $P_i$ to locate the facilities, $\text{val}(f') := \text{val}(f') - 1$, $x_\gamma := x_\gamma - 1$ for any $e = (i, j) \in P_i$, $Q := Q \cup \{ q \text{ edges from } L \}$, turn step 11, else select $a_k$ edges $\in L$ on the road $P_i$ to locate the facilities, let $Q := Q \cup \{ a_k \text{ edges from } L \}$ on the road $P_i$, $L := L - \{ a_k \text{ edges from } L \}$ on the road $P_i$.

10: Let $q := q - a_k$, if $q = 0$ then turn step 11, else turn step 8.

11: Output location $Q$, $f'$.

In the algorithm 1, we can get a maximum dynamic flow in $O(n^l)$ by applying one of the variants of push-relabel algorithms (Hamacher, 2011), and update the set $L$ in $O(l)$. The flow decomposition algorithm runs in $O(nm)$ time (Ahuja, 2005). The running time of the latter part of algorithm 2 is dependent on numerical comparison, which can be done in $O(|L| \log |L|)$ time. The worst case running time of algorithm 2 from step 8 to step 10 is dominated by the constant $q$. Therefore we can complete the algorithm 1 and algorithm 2 with running time $O(n^3 + nm + q |L| \log |L|)$. Hamacher et al. discussed general $q$-FlowLoc problem and gave a heuristic algorithm for dynamic $q$-FlowLoc problem with the time $O(|L| \log n^2)$ (2011). In the heuristic algorithm, 1-FlowLoc problem based on maximum network flow would be repeated computation. But in this article we consider a kind of special situation with the facility size $r_1 = 1$. The key of the algorithm 2 is to find out the number of locations of each path, instead of repeating to calculate the maximum network flow, which can reduce unnecessary repetition.

4. Application of the model

The numerical example presented in this section highlights the modeling techniques and model formulation of the evacuation model as discussed in the preceding sections. As illustrated in Fig. 2, the test network has 18 nodes and 26 directed edges. The node $s$ is the source and the nodes $D_i (i = 1, 2, \ldots, 5)$ are five exits. We can connect all the exit nodes to one artificial node $d$ by artificial edges and assign the artificial edges with capacities $\infty$, travel times 0. The numbers in brackets respect the upper capacities and travel times corresponding to the edges. $L = \{e_2, e_3, e_5, e_6, e_8, e_9, e_{10}, e_{11}, e_{12}, e_{13}, e_{14}, e_{15}, e_{16}, e_{17}, e_{18}, e_{19}, e_{20}, e_{21}, e_{22}, e_{23}, e_{24}, e_{25}, e_{26} \}$ means the set of all feasible edges with the size 8, where the rescue workers would be placed. There are 4 available facilities (e.g., rescue workers who can take part in the evacuation).

The algorithm 1 in the modeling exercise is to apply a minimum cost flow algorithm to the original static network $N$. We can get $val(f) = 36$ and the variable $x_{ij}$ on edge $(i, j)$ is showed as follows:

$x_1 = 6, x_2 = 18, x_3 = 8, x_4 = 4, x_5 = 4, x_6 = 0, x_7 = 6, x_8 = 4, x_9 = 4, x_{10} = 8, x_{11} = 4, x_{12} = 3, x_{13} = 6, x_{14} = 4, x_{15} = 0, x_{16} = 0, x_{17} = 8, x_{18} = 0, x_{19} = 0, x_{20} = 7, x_{21} = 3, x_{22} = 7, x_{23} = 4, x_{24} = 0, x_{25} = 0, x_{26} = 11.$

The edges set $L$ can be updated as $L = \{e_2, e_3, e_{12}, e_{13}, e_{14}, e_{17} \}$.

In the next task it is desired to calculate the maximum number of evacuees who can reach the safety during the given time horizon $T = 15$ when some rescue worker would take part in the evacuation.
Step 2 of the algorithm gives the following chain flows as showed in table 1.

<table>
<thead>
<tr>
<th>Path number</th>
<th>The road $P_i$</th>
<th>travel time of $P_i$</th>
<th>The value of $P_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_1$</td>
<td>$s \rightarrow v_5 \rightarrow v_4 \rightarrow D_2$</td>
<td>$\tau(P_1) = 4$</td>
<td>$val(f_i) = 4$</td>
</tr>
<tr>
<td>$P_2$</td>
<td>$s \rightarrow v_5 \rightarrow v_{10} \rightarrow D_3$</td>
<td>$\tau(P_2) = 6$</td>
<td>$val(f_i) = 6$</td>
</tr>
<tr>
<td>$P_3$</td>
<td>$s \rightarrow v_6 \rightarrow v_{12} \rightarrow D_4$</td>
<td>$\tau(P_3) = 7$</td>
<td>$val(f_i) = 4$</td>
</tr>
<tr>
<td>$P_4$</td>
<td>$s \rightarrow v_6 \rightarrow v_{11} \rightarrow v_{10} \rightarrow D_5$</td>
<td>$\tau(P_4) = 8$</td>
<td>$val(f_i) = 4$</td>
</tr>
<tr>
<td>$P_5$</td>
<td>$s \rightarrow v_5 \rightarrow v_6 \rightarrow v_{12} \rightarrow D_4$</td>
<td>$\tau(P_5) = 9$</td>
<td>$val(f_i) = 4$</td>
</tr>
<tr>
<td>$P_6$</td>
<td>$s \rightarrow v_6 \rightarrow v_{11} \rightarrow v_{12} \rightarrow D_4$</td>
<td>$\tau(P_6) = 9$</td>
<td>$val(f_i) = 4$</td>
</tr>
<tr>
<td>$P_7$</td>
<td>$s \rightarrow v_6 \rightarrow v_1 \rightarrow v_2 \rightarrow D_4$</td>
<td>$\tau(P_7) = 9$</td>
<td>$val(f_i) = 3$</td>
</tr>
<tr>
<td>$P_8$</td>
<td>$s \rightarrow v_5 \rightarrow v_3 \rightarrow v_2 \rightarrow D_4$</td>
<td>$\tau(P_8) = 10$</td>
<td>$val(f_i) = 4$</td>
</tr>
</tbody>
</table>

First we place two rescue workers on the edges $e_{12}, e_{17}$ because their residual capacities are large enough to place a rescue worker. Then the vector $\alpha = (2,0,0,0,1,0,2,2,2)'$ would be obtained by utilizing step 8. According to step 8 and step 9, the edges $e_2, e_{14}$ on the road $P_9$ would be selected to place the two rests of rescue workers. With the end of the algorithm 2, the location $Q = \{e_2, e_{12}, e_{14}, e_{17}\}$ is returned and the objective function value is 265.

5. Conclusions

How to evacuate people efficiently and effectively in an emergency is always an important issue. There were a large number of articles of studies to study evacuation by using network flow, but combination with the location analysis was first introduced as a new tool in evacuation modeling by Hamacher et al. In this paper, we formulate the building evacuation with the same size facilities (e.g., rescue workers), which can be a special situation of FlowLoc problem. Considering such a situation that the evacuees are perhaps unfamiliar with the building structure, or other situation that some unexpected accidents perhaps happen in evacuation process, evacuation model with rescue workers would be more practical significance. Combination of network flow and location analysis would also be applied in other evacuation models with different objective function, about which more studies should be needed.

References


