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Planning Evacuation Routes in Rise Buildings Using Maximum Dynamic Flow Approach

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Abstract. Planning evacuation route is one important aspect in disaster management. This research study a problem to determine optimal evacuation routes in rise buildings. we model a problem to maximize the number of people that must be evacuated from several points to some assembly points in a short period of time using maximum dynamic ow approach. The evacuation routes are determined using Temporally Repeated Flows approach based on the Maximum Dynamic Flow Problems. By representing the building as a static network, the shortest routes are calculated from each source node to the destination nodes. Then, the ow distribution is repeated along the chain of the static network for each time unit. We test our model to construct evacuation route plans in the building of Faculty of Mathematics and Natural Sciences Education (Main Builiding) Universitas Pendidikan Indonesia. The results show that the model pro duces evacuation routes that can be maximize the number of evacuees in short time. Thus, it can be concluded that the building has a good structure in supporting the evacuation process when a disaster occurs.

Keywords: Evacuation route, maximum dynamic fow problem, network, temporally repeated flow

Introduction

As one of the important aspects in disaster management, evacuation routes are needed to move evacuees from the disaster location to a safety location for further treatment. The evacuation process must be carried out as quickly as possible so that the number of disaster victims can be minimized. Therefore, it is necessary to plan an optimal evacuation route with the fastest evacuation time that can evacuate people as many as possible.

Evacuation problems can be found in several different systems, such as build- ings, regions, and transportation carries. Thus, the system structures such as population and their behaviors, dangerous locations, and assembly points, will influence evacuation planning in the related system. This research focus on evac- uation route planning in rise buildings. Thus, building components such as room size, corridor size, stair width, and the location of assembly points will influence the evacuation routes.

The problem for determining the optimal evacuation route can be solved using mathematical models. Some models that are often used include Cellular Automata [1],

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Agent-based [2], [15], and dynamic flow network [3–7]. On build- ing evacuation problem, the dynamic Flow network works by representing the building and its components as a static network G. Then, a dynamic network G_T is constructed as the time expanded version of G. The dynamic network flows will correspond to evacuation processes [1].

One method that can be used to determine the optimal evacuation routes using dynamic Flow network approach is the Maximum Dynamic Flow Model (MDFM). This model aims to maximize the number of evacuees that can be evac- uated within a certain time span. There are several previous studies that discuss the Maximum Dynamic Flow Model. Ford and Fulkerson [12] presented a model and computational algorithm to examine the maximal amount of goods that can be transported from one node to another in each time. The dynamic maximum flow problem on a network with capacities depending on time, fixed transit times on the arcs, and a given time [16]. The maximum flow problem in a dynamic network with the static approach [17]. Darmawan [10] constructed a tsunami evacuation route using the maximum dynamic flow problem approach. Nath, et. al [4] considered a problem of identifying the optimal facility locations in evacuation planning so that the quickest time is minimum. Based on [4], the Maximum Dynamic Flow Problem (MDFP) can be solved by solving the Minimum Cost Flow Problem (MCFP) on a static network G. In this case, MCFP is solved to find the shortest distance between all nodes. Furthermore, the flow distribution is repeated along the chain of the static network for each time unit in the time span T. This approach is known as the Temporally Repeated Flow approach [4]. This research will determine the optimal evacuation route using a Maximum Dynamic Flow Problem (MDFP) based model with a Temporally Repeated Flow (TRF) approach that refers to research [4]. Different from [10] who implemented MDFP to determine the tsunami evacuation route in Sanur Village, this research will implement MDFP to determine the evacuation route in Rise Buildings.

2 Methodology

The first step in determining the evacuation routes in a building is to represent the building layout as a static network $G = (N, A)$, where N is a set of nodes and A is a set of arcs. The nodes represent rooms and lobbies, while the arcs represent routes between nodes such as stairs and hallways. The nodes consist of source nodes, intermediate nodes, and destination nodes. The source nodes are points in the building with a high density of evacuees. The destination nodes are assembly points outside the building. The intermediate nodes are nodes that connect the source nodes to the destination nodes. Each arc has two attributes, which are travel times (λ_{ij}) and capacities (b_{ij}). The travel time indicates the time needed to travel from one node to another. The arc capacity represents the number of evacuees who can pass through the arc. Every arc always has a direction to the nearest destination node. Fig. 1 illustrates an example of a building layout and its static network representation with given arc attributes.

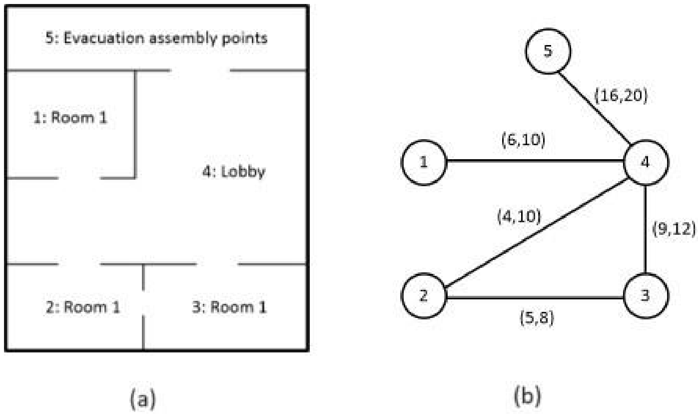

Fig. 1. a). Example of building layout. (b). Static network representation of the building layout with known arc's attributes.

The aim of this research is to determine the optimal evacuation routes, that are the evacuation routes that can maximize the number of evacuees within a given period.

Given T as the maximum time to evacuate. We define the variable x_{ij}(t) as the number of evacuees moving from location i at time t to location j at time $j + \lambda_{ij}$. Let S and D be the room/lobby and the assembly points, respectively. Since we want to maximize the number of people that evacuated to the assembly point, the objective function of the optimization model is defined bellow:

Maximize:
$$\sum_{t=0}^{T} \sum_{\in N-D} \sum_{d \in D} x_{id}\left(t\right) \tag{1}$$

Subject to:
$$0 \le x_{ij}(t) \le x_{ij}, t = 0, \cdots, T - \lambda_{ij}, \forall (i,j) \in \mathrm{A} \tag{2}$$

Suppose $G = (N, V)$ is a network with a set of nodes N and a set of arcs A. A chain is defined as a sequence of nodes $\left\{i_1, \cdots, i_k\right\}$, $k \ge 2$ such that $\left(i_j^{i}, i_{j+1}\right) \in A$ and $i_j \ne i_{j'}$ for $j, j' = 1, \cdots, j-1$. In other words, a chain does not have repeated nodes. A chain flow $\gamma = \left\langle \left|P\right|, P \right\rangle$ is a static flow of value $\left|P\right|$ along the chain P. Suppose $\Gamma = \left\{P_1, \cdots, P_l\right\}$ is a set of chain flows and $\left|P\right|$ is the chain flow along the chain P_i. Γ is a chain decomposition of a static flow f, if $\sum_i^l \left|P_i\right| = f$ [13]. Thus, flows in a network can be decomposed into chain flows, and it is possible to include cycle flows.

In this research, MDFP will be solved by Minimum Cost Flow Problem (MCFP) approach based on the research in [13] who states that solving an MDFP is equivalent to solving an MCFP problem. In particular, the temporally repeated flow obtained from the chain decomposition of a minimum cost flowis a maximum dynamic flow. Ahuja et al. (1993) [8] stated that the maximum dynamic flows problem can be solved using the minimum cost flow problem on static networks. Thus, finding the maximum number of evacuees that can be evacuated at time T from a building is similar by solving the minimum cost flow problem on a static network with the following steps:

1. Solve minimum cost ow problem to obtain the optimal solution x^*
2. Decompose x^* into k chain flows $P_1, \cdots, P_k$ such that $x^* = \sum_{i=1}^{k} |P_i|$
3. Repeat for each chain network P_1 from $t = 0, \cdots, T + 1 - \lambda(P_i)$.

The minimum cost flow problem in static networks can be viewed as a prob- lem for finding the shortest path, that is the quickest path from source nodes to assembly points. In this research, the minimum cost flow problem will be solved by applying Dijkstra's Algorithm [5]. Given a static network $G = (V, E)$ with $V = \{\upsilon_1, \cdots, \upsilon_n\}$ and λ_{ij} as the travel time from υ_i *i* to υ_j. Suppose we want to find the fastest time from the source node v_1 to a assembly point z. We define L as the set of nodes that have been selected, and D_j Suppose as the the fastest time from υ_i *i* to υ_j. Let N_A be the neighbor of the nodes in A. The Dijkstra's Algorithm works as follows:

1. Initialization $L = \{v_1\}$, $V = \{v_2, \cdots, v_n\}$, $D_1 = 0$, $D_i = \infty$, $\forall_i \in V - L$.
2. Find N_L.
3. While $z \notin L$ do
   - 3.1 For all $v_1 \in L$, choose $v_k \in N_L - L$ such that $\lambda_{ik} = \min \{\lambda_{ij} | v_i \in L, v_j \in N_L - L\}$.
   - 3.2 For all $v_l \in L$ which are the neighbors of v_k, if $D_l > D_l + \lambda_{lk}$, then $D_l = D_l + \lambda_{lk}$.
   - *3.3* Set $L = L \cup v_k$.
4. Stop.

3 Computational Experiments

We implemented the model and solution technique to determine the optimal evacuation route in FPMIPA A Building of Universitas Pendidikan Indonesia (UPI). The building has five floors and two assembly points at outside the build- ing. In our network representation, we use 28 source nodes as evacuation pointsas shown in Table 1, 50 intermediate nodes, and 2 destination nodes. The evac- uation points of the North, East, South, and West wings refer to rooms in the center of each wing such as classrooms, lecturer rooms, laboratories, auditoriums,canteens, and prayer rooms, and the corners of the building refer to restrooms. There are four main hallways for each floor that correspond to the wings of the building, namely North, East, South, and West Hallway. There are also stairs in each wing as shown in Table 2. The detail explanation for the source nodes and the destination nodes is shown in Table 3.

Table 1. Evacuation points in FPMIPA A UPI building.

Floor	Evacuation Point	Total
1,2,3	North, East, and West wings, Northeast, Southeast, Southwest, and Northwest corners	21
4	North and East wings, and Northeast and Northwest corners	4
5	North wing, Northeast and Northwest corners	3

Table 2. Stair access specifications for each wing of the building.

Wing	#Stairs	Floor Access
North	2	1,2,3,4,5
East	1	1,2,3,4
South	1	1,2,3
West	2	1 and 2 for Northwest section, 1, 2, and 3 for Southwest section

We found that the estimation of wing hallway length is 45 meters, and the wing hallway width is 1.8 meters. Each stair has 30 steps, each 0.3125 meters wide. We assume that the human walking speed is 1.25 m/s based on research in and 0.625 m/s when using stairs based on research in [15]. It is also assumed that the average space occupied by a person in a dense crowd situation is 0.4 m2according to [11], and each step of the stairs can only be occupied by a maximumof two people. This data is used to calculate the attribute of arcs in our network. The detail network representation is shown in Fig. 2.

The first step to solve MDFP is to apply Dijkstra's Algorithm for determining the shortest path from each source node to the destination node on the static network. The results of the shortest parts resulted Dijkstra's are summarizedin Table 3. After we calculated the shortest parts, we construct dynamic flow network by implementing the temporally repeated flow Algorithm to obtain the composition of the flow distribution on the static network. We assume that 1 unit of time T is equal to 31 seconds. Since the longest path need 186 secondsto an assembly point, we obtain the time range $T = 186/31 = 6$. The complete results of the dynamic flow networks are summarized in Table 3 and the optimal evacuation routes on the building is illustrated in Fig. 2.

We obtain that the minimum evacuation time required to evacuate the peo- ple in the building is 186 seconds for evacuate 2364 people. Thus, it can be concluded that the evacuation routes are currently optimal the evacuation canbe carried out in a short time and it can evacuate large numbers of evacuees. This is because each wing on each floor has at least one stair access, so that the evacuation process can run effectively and efficiently. Until now, there is no in formation regarding the number of occupants of the building during peak hours. We estimate that during peak hours all the rooms are full by 2000 students, 200 lecturers and 100 educational sta . then it can be concluded that using our evacuation route, all building occupants can be evacuated.

4 Conclusion

This research studies a problem to determine the optimal evacuation route in rise Buildings. The problem can be solved using the MDFP method with the TRF approach. The computational experience on FPMIPA A Building UPI shows that the time needed to evacuate all building occupants is 3 minutes and 6 seconds with the maximum total evacuees that can be evacuated is 2364 people. Thus, it can be concluded that the model produces optimal evacuation routes because the evacuation can be done in a short time with the large number of evacuees. For future researchers, it is recommended to expand the evacuation time span to get more realistic results.

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