Model of emergence evacuation route planning with contra flow and zone scheduling in disaster evacuation

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ABSTRACT
Evacuation is characterized by rapid movement of people in unsafe locations or disaster sites to safer locations. The traffic management strategy for commonly used evacuations is the use of Shoulder-Lane, contra flowing traffic and gradual evacuation. Contra flow has been commonly used in traffic management by changing traffic lanes during peak hours. To implement the contra flow operation, there are two main problems that must be decided, namely optimal contraflow lane configuration problem (OCLCP) and optimal contraflow scheduling. Within the OCLCP there are two approaches that can be used: zone scheduling and flow scheduling. Problem of contra flow and zone scheduling is basically an emergency evacuation route planning (EERP) issue. This research will discuss EERP with contraflow and zone scheduling which can guarantee the movement of people in disaster area to safe area in emergency situation.

Keywords: Contra flow, Emergence evacuation, Route planning, Zone scheduling

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1. INTRODUCTION
According to Caragliu et al. [1], a city said to be a smart city is when human and social capital investment and information and communication technology (ICT) promote sustainable economic growth and high quality of life, with prudent, participatory natural resource management. Smart city seeks to improve performance through the implementation of flexible and efficient, sustainable networking and traditional services with the use of information technology, digital and telecommunications and is expected to create smarter cities that are greener, safer, faster and more friendly. Smart city is seen as a concrete improvement effort and can be applied in various parts of the world [2]. For example, priorities in northern europe with minimal crime would be different from those near the equator. In general, the problem solved is described in several key areas [3]. The focus of this research is the handling of a safe city. Aspect of smart city by Lacinak and Ristvej [3] and Center of regional science in [4]. According to Mohanty et al. [2] and Center of regional science in Vienna [4], it consists of: smart transport, smart energy, smart technology, smart living, smart environment, smart citizens and education, smart economy, smart government and safe city. Safe city as part of smart city, covers all aspects of safety within the city. On the other hand, smart technology has many uses in the safety field to build a safe city system. Safe city is an integration of technology and the natural
environment enhances the effectiveness of the process of handling the threat of crime and terror, to enable the availability of a healthy environment for citizens, and access to health, rapid response to emergencies [5]. Another aspect is evacuation support. In [6] is discussed the application of disaster traffic management to support evacuation support. Where the evacuation process should minimize delay and maximize security. Evacuation is characterized by rapid and rapid movement of people in unsafe locations or disaster sites to safer locations. The important thing to note is the absence of congestion and chaos during the evacuation process [7]. Basically, the traffic network is not designed to handle emergencies like a disaster because it is considered not financially practical. Generally, people affected by disasters will try to get out of the disaster-affected area immediately and this may cause chaos that affects the disruption of the evacuation process [8]. The previously stated conditions make it clear that disaster traffic management in the form of traffic management during a disaster is a necessity and there are several traffic management strategies that can be used [9].

The most commonly used evacuation strategy for traffic management is the use of shoulder-lane, contra flowing traffic and gradual evacuation [6]. Shoulder-Lane line is used to accommodate traffic spikes in emergency evacuation plans [10]. They develop urban and rural plans, each operating with a shoulder-lane evacuation path, with some drawbacks in its application. Contra flow has been commonly used in traffic management by changing traffic lanes during peak [11]. Current contra flow techniques are like one-lane, two-lane, and all-lane contra flow. In general, the implementation of contra flow during the evacuation process is to reverse all in-bound lanes into outbound lanes. The out bound line is a generally busy line, and the in-bound line is a relatively empty line of [12]. In the event of a disaster, the population is at risk of being evacuated to safety as soon as possible, the highway is the main node. Effective traffic management strategies are needed to manage the increasing demand for roads significantly during evacuation and contra flow strategies. Under these conditions the intelligent transportation systems (ITS) tool can be applied, such as message delivery and street signing typically used to support the contra flow strategy [13]. The research conducted by Stephen [12], produced several scenarios that could be used to support the contra flow strategy, particularly in relation to the utilization of the in-bound and out-bound paths. Existing problems will become more difficult when there are several out-bound paths leading to the same path, which will certainly lead to congestion when the evacuation process. Existing issues will be more difficult when there are several out-bound paths leading to the same path, which will certainly lead to congestion when the evacuation process should be done as soon as possible [14]. The development of real-time evacuation model is very important because individual behavior can not be assumed to replicate from previous travel patterns [15]. Research conducted by [16] tries to overcome this congestion problem by calculating the level of congestion and mapping capacity of the evacuation path.

According to Meng et al. [17], to implement contra flow operations, there are two main problems that must be decided, namely optimal contra flow lane configuration problem (OCLCP) and optimal contra flowing scheduling problem (OCSP). OCLCP aims to determine the candidate of a redirected path to minimize traffic threshold and OCSP aims to determine the start time and duration of the operation. The first research on OCSP mapping has been done by Chen and Zhan [18], which suggests that there are two approaches that can be used: zone scheduling and flow scheduling. In zone scheduling, zone settings are based on importance. Zones can be set so that a zone is only not allowed to be evacuated until a focused zone has been evacuated or evacuation time of each zone can be set by time. On the other hand, flow scheduling is a scheduling process based on the availability of evacuation facilities (vehicle-based) [19]. The problem of contra flow and zone scheduling is essentially emergency evacuation route planning [20].

2. RESEARCH METHOD

Route planning is a common process of community movement in disaster areas to safe areas in emergency situations. This issue can be formulated as follows. Suppose Graph $G (N, A)$ presents a network representing the intended area, which consists of roads, rural roads, and together with intersections. $A$ is a set of arcs that represent roads and arterial roads. The set of $N$ nodes is divided into three subsets, namely:
- Source node (initial evacuation) denoted by $NS$
- The transfer node or the intermediate node denoted by $NT$, and
- The final node (or secure destination) denoted by the $ND$

So, $N = NS \cup NT \cup ND$ \hfill (1)

The intermediate node presents where the evacuation flow is collected (merged) or crossed (crossing). Each arc in $A$ is expressed as an arc $(i, j)$, which is an arc connecting nodes $i$ and $j$. This is called a static network because every arc in the network presents only a stationary relationship from one node to another node in the network. $X \in N$ is the set of nodes that represent the locations occupied by the evacuated.
With respect to each arc and node there are parameters. Each node k presents the location in
the network with the initial population \( p_k \) and \( v_k \) capacity. For each arc \((i, j)\), given the capacity of \( c_{ij} \), where \((i, j) \in A \). The capacity of an arc is the number of currents per unit of time, assuming no congestion occurs. In the case of a lane-based road network, capacity is the number of vehicles per hour per line. For each arc, travel time \( \tau_{ij} \), where \((i, j) \in A \). Here it is assumed that \( \tau_{ij} \) is constant and is the average velocity for the arc \((i, j)\) when the free arc (empty) of evacuation. This parameter is always referred to as free flow velocity or lead time for arcs \((i, j)\). The \( x_{ij} \) variable is the number of evacuations (people) moving from node \( i \) at the beginning of the period to node \( j \) at the end of the period. The objective is to maximize the number of people coming out of the disaster source node to the destination as quickly as possible.

The lower limit at the time of completion of evacuation in the network is the number of arcs of grace period starting from the nearest node at the source of the disaster to the destination node with the furthest from the source of the disaster. If node 1 is the source node that connects all nearby nodes to the source of the disaster and Node \( N \) is the furthest destination node, the lower limit can be calculated by

\[
F_{1,N} = \sum_{i,j \in A} \tau_{ij} v_{ij} \text{ with } i \neq j
\]  

In particular, the arc capacity, which represents the number of evacuate persons who can pass through an arc per unit of time, is always assumed to be constant. However, in realistic terms, the arc capacity is not constant. In fact, the capacity of a given arc is a function of the number of entities present in the arc at a given time. Including flow-dependent capacity to change the network flow problem becomes a network flow issue with additional constraints. For single flow problems with countercurrents, the model for the basic problem is modified to find the reconfiguration network and identify the best direction for each arc in order to maximize the evacuation flow out of the network. The proposed model reverses the trip arc and relocates available arc capacity.

Parameter:
- \( T \): Total number of periods to clean the transport network
- \( N \): The total number of nodes in the transport network, \( N = |N| \)
- \( p_{k0} \): Population evacuated at node \( k \) \((k = 1, ..., N)\) in the network before evacuation begins
- \( v_k \): Capacity node \( k \) \((k = 1, ..., N-1)\) in the network
- \( c_{ij} \): The arc capacity \((i, j) (i = 1, ..., N; j = 1, ..., N \text{ with } i \neq j)\) in the network
- \( \tau_{ij} \): The free-flow time in the arc \((i, j) (i = 1, ..., N; j = 1, ..., N \text{ with } i \neq j)\) in the decision variable network
- \( x_{ij} \): Evacuation current from node \( i \) at the beginning of period \( t \) (end of period \( t-1)\) to node \( j \) at the end of period \( t \) (period start \( t+1)\);
- \( y_{ij} \): The opposite current evacuated from node \( i \) at the beginning of period \( t \) to node \( j \) at the end of period \( t \), This variable is 1, if the evacuation flows normally during the interval; worth of 0 if not
- \( p_{kt} \): Population evacuated at node \( k \) \((k = 1, ..., N)\) in the network at the end of the period \( t \)
- \( o_t \): The amount evacuated clearing the network at the end of the period \( t \)

Considering the smoothness of the contra flow process, it can be done by using (3) and (4).

\[
y_{ij} \geq 1 \quad \forall i, i = 1, ..., N; t \geq j; \forall t = 1, ..., T
\]  

(3)

\[
y_{ij} \geq 0 \quad \forall i, i = 1, ..., N; t \geq j; \forall t = 1, ..., T
\]  

(4)

The (3) shows that the Contra Flow Route runs normally and (4) indicates that the Contra Flow process is not running normally. In relation to (3) and (4) then the problem of a single flow with countercurrents can be seen in.

\[
Maximum \ z = \sum_{t=1}^{T} (T + 1 - t) o_t
\]  

(5)

\[
o_t = \sum_{i=1}^{N} x_{INT} + \sum_{j=1}^{N} y_{INT} \quad \forall t = 1, ..., T
\]  

(6)

\[
p_{kt} = p_{k0} - \sum_{j=1}^{N} x_{kjt} + \sum_{j=1}^{N} y_{jkt} \quad \forall k = 1, ..., N - 1
\]  

(7)

\[
p_{kt} = p_{k(t-1)} - \sum_{j=1}^{N} x_{kjt} + \sum_{i=1}^{N} x_{ikt} - \sum_{j=1}^{N} y_{jkt} - \sum_{i=1}^{N} y_{ikt} \quad \forall k = 1, ..., N; t > 1
\]  

(8)

\[
p_{kt} \leq v_k \quad \forall k = 1, ..., N; \forall t = 1, ..., T
\]  

(9)

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\[
\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ijt} \leq c_{ij} e_{ijt} \quad \forall i, j = 1, \ldots, T; i \neq j \tag{10}
\]
\[
\sum_{i=1}^{N} \sum_{j=1}^{N} y_{ijt} \leq c_{ij}(1 - e_{ijt}) \quad \forall i, j = 1, \ldots, T; i \neq j \tag{11}
\]
\[
x_{ijt} \geq 0, \text{integer}; \forall i, j = 1, \ldots, N; i \neq j; \forall t = 1, \ldots, T \tag{12}
\]
\[
o_t \geq 0 \text{ integer} \forall t = 1, \ldots, T \tag{13}
\]
\[
e_{ijt} = \{0,1\} \quad \forall i, j = 1, \ldots, N; i \neq j; \forall t = 1, \ldots, T \tag{14}
\]

3. RESULTS AND DISCUSSION

In the evacuation process should be able to minimize the delay and maximize the people who can be evacuated. Contra flow performance measurements were performed in the form of maximizing the number of evacuated populations from a disaster site for the same time period compared to the absence of contra-flow. The data source for the evacuation problem to be used in this study is the Nuclear Power Plant Area in Monticello, Minnesota. Data in Monticello, Minnesota the dataset itself was collected by [21]. Minnesota Dataset has 49 nodes. The Minnesota dataset has 49 nodes as can be seen in Figure 1 [21]. The data for each node in the Minnesota dataset can be seen in Table 1.

Figure 1. Node deployment on Minnesota dataset

| Arc Number | From Node | To Node | Arc Capacity | Travel Time |
|------------|-----------|---------|--------------|-------------|
| 1          | 1         | 2       | 150          | 0           |
| 2          | 2         | 1       | 150          | 0           |
| 3          | 2         | 3       | 150          | 18          |
| 4          | 3         | 2       | 150          | 18          |
| 5          | 2         | 4       | 150          | 9           |
| 6          | 4         | 2       | 150          | 9           |
| 7          | 3         | 5       | 250          | 6           |
| 8          | 5         | 3       | 250          | 6           |
| 9          | 3         | 6       | 150          | 5           |
| 10         | 6         | 3       | 150          | 5           |
| 11         | 4         | 5       | 100          | 17          |
| 12         | 5         | 4       | 100          | 17          |
| 13         | 4         | 7       | 150          | 10          |
| 14         | 7         | 4       | 150          | 10          |
| 15         | 4         | 10      | 100          | 15          |
| 16         | 10        | 4       | 100          | 15          |
| 17         | 5         | 16      | 250          | 11          |
| Number | Source | Destination | Distance | Time |
|--------|--------|-------------|----------|------|
| 18     | 16     | 5           | 250      | 11   |
| 19     | 6      | 9           | 200      | 9    |
| 20     | 9      | 6           | 200      | 9    |
| 21     | 7      | 10          | 150      | 8    |
| 22     | 10     | 7           | 150      | 8    |
| 23     | 7      | 18          | 100      | 7    |
| 24     | 18     | 7           | 100      | 7    |
| 25     | 8      | 9           | 150      | 17   |
| 26     | 9      | 8           | 150      | 17   |
| 27     | 8      | 12          | 150      | 6    |
| 28     | 12     | 8           | 150      | 6    |
| 29     | 9      | 11          | 200      | 2    |
| 30     | 11     | 9           | 200      | 2    |
| 31     | 10     | 16          | 150      | 5    |
| 32     | 16     | 10          | 150      | 5    |
| 33     | 10     | 17          | 100      | 3    |
| 34     | 17     | 10          | 100      | 3    |
| 35     | 11     | 13          | 100      | 3    |
| 36     | 13     | 11          | 100      | 3    |
| 37     | 11     | 14          | 200      | 4    |
| 38     | 14     | 11          | 200      | 4    |
| 39     | 12     | 24          | 150      | 15   |
| 40     | 24     | 12          | 150      | 15   |
| 41     | 12     | 41          | 100      | 9    |
| 42     | 41     | 12          | 100      | 9    |
| 43     | 13     | 14          | 100      | 8    |
| 44     | 14     | 13          | 100      | 8    |
| 45     | 13     | 19          | 100      | 6    |
| 46     | 19     | 13          | 100      | 6    |
| 47     | 13     | 41          | 100      | 8    |
| 48     | 41     | 13          | 100      | 8    |
| 49     | 14     | 20          | 200      | 5    |
| 50     | 20     | 14          | 200      | 5    |
| 51     | 15     | 16          | 150      | 1    |
| 52     | 16     | 15          | 150      | 1    |
| 53     | 15     | 20          | 150      | 4    |
| 54     | 20     | 15          | 150      | 4    |
| 55     | 15     | 21          | 100      | 9    |
| 56     | 21     | 15          | 100      | 9    |
| 57     | 16     | 17          | 100      | 5    |
| 58     | 17     | 16          | 100      | 5    |
| 59     | 16     | 22          | 250      | 9    |
| 60     | 22     | 16          | 250      | 9    |
| 61     | 17     | 18          | 100      | 8    |
| 62     | 18     | 17          | 100      | 8    |
| 63     | 17     | 22          | 100      | 12   |
| 64     | 22     | 17          | 100      | 12   |
| 65     | 18     | 23          | 100      | 11   |
| 66     | 23     | 18          | 100      | 11   |
| 67     | 19     | 20          | 100      | 11   |
| 68     | 20     | 19          | 100      | 11   |
| 69     | 19     | 25          | 100      | 12   |
| 70     | 25     | 19          | 100      | 12   |
| 71     | 20     | 26          | 200      | 12   |
| 72     | 26     | 20          | 200      | 12   |
| 73     | 21     | 22          | 100      | 5    |
| 74     | 22     | 21          | 100      | 5    |
| 75     | 21     | 27          | 100      | 8    |
| 76     | 27     | 21          | 100      | 8    |
| 77     | 22     | 23          | 100      | 3    |
| 78     | 23     | 22          | 100      | 3    |
| 79     | 22     | 47          | 250      | 9    |
| 80     | 47     | 22          | 250      | 9    |
| 81     | 23     | 47          | 150      | 5    |
| 82     | 47     | 23          | 150      | 5    |
| 83     | 24     | 25          | 200      | 11   |
| 84     | 25     | 24          | 200      | 11   |
| 85     | 25     | 26          | 200      | 13   |
| 86     | 26     | 25          | 200      | 13   |
| 87     | 26     | 27          | 150      | 1    |
| 88     | 27     | 26          | 150      | 1    |
| 89     | 26     | 39          | 200      | 13   |
| 90     | 39     | 26          | 200      | 13   |

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3.1. Testing for non-contra flow

For situations without contra flow testing is done using LINDO software as can be seen in Figure 2.
3.2. Testing for contra flow

For condition with contra flow testing is done using LINDO software.

The results of testing with software LINDO gives the following results.

\[
\begin{array}{ccc}
\text{LP OPTIMUM FOUND AT STEP} & 4 \\
\text{OBJECTIVE FUNCTION VALUE} & 28150.00 \\
\text{VARIABLE} & \text{VALUE} & \text{REDUCED COST} \\
012 & 150.000000 & 0.000000 \\
024 & 150.000000 & 0.000000 \\
046 & 100.000000 & 0.000000 \\
0516 & 250.000000 & 0.000000 \\
01217 & 100.000000 & 0.000000 \\
02221 & 100.000000 & 0.000000 \\
02127 & 100.000000 & 0.000000 \\
02726 & 150.000000 & 0.000000 \\
02826 & 200.000000 & 0.000000 \\
03840 & 200.000000 & 0.000000 \\
04042 & 200.000000 & 0.000000 \\
04242 & 100.000000 & 0.000000 \\
04849 & 52435.000000 & 0.000000 \\
\end{array}
\]
The results of testing with Software LINDO gives the following results. Can be seen that based on the test results with Software LINDO then the maximum number of evacuated population of 26300.
4. CONCLUSION

Based on the test result, it was found that for the emergency evacuation route planning problem, the process with contra flow and zone scheduling can increase the capacity of evacuated population. This increase is due to the diversion from the inbound line into the outbound lane.

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