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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, contraflowing 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 OCSP there are two approaches that can be used: zone scheduling and flow scheduling. Problem of contra flow and zone scheduling problem is basically an emergence 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.

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1. INTRODUCTION

According to [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. [2] 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. 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 [3] and center of regional science in [4] According to [2] and center of regional science in Viena [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, contraflowing traffic and gradual evacuation [6]. In [10] Shoulder-Lane line is used to accommodate traffic spikes in emergency evacuation plans. 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 out bound lanes. The outbound 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 mode. 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 [17], to implement contra-flow operations, there are two main problems that must be decided, namely optimal contraflow lane configuration problem (OCLCP) and optimal contraflow 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 [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 (vehicale-based) [19]. The problems of contra-flow and zone scheduling are essentially emergence 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, $N = NS \cup NT \cup ND$ (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 τ_{ij}, where *arc (i, j)* $\in A$. Here it is assumed that τ_{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_{ijt} 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

$$F_{1,N} = \sum_{i,j \in A} \tau_{i,j} \quad \forall i,j, with\ i \neq j \tag{2}$$

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 countercurrent counter-currents, 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 networkn

c_{ij} : The arc capacity *(i, j) (i = 1, ..., N; j = 1, ..., N with i ≠ j)* in the network

τ_{ij}: The free-flow time in the *arc (i, j) (i = 1, ..., N; j = 1, ..., N with i ≠ j)* in the decision variable network

x_{ijt} : 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_{ijt} : The opposite current evacuated from *node i* at the beginning of period *t* to node *j* at the end of *t* period, 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).

$$y_{ijt} \geq 1 \qquad \forall i, i = 1, \dots., N; i < j;\ \forall t = 1, \dots, T \tag{3}$$

$$y_{ijt} \geq 0 \qquad \forall i, i = 1, \dots., N; i < j;\ \forall t = 1, \dots, T \tag{4}$$

(3) Shows that the Contra Flow process 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 countercurrent counter-currents can be seen in.

$$Maximum\ z = \sum_{t=1}^{T} (T + 1 - t) O_t \tag{5}$$

$$O_t = \sum_{i=1}^{N-1} x_{iNt} + \sum_{i=1}^{N-1} y_{iNt} \qquad \forall t = 1, \dots, T \tag{6}$$

$$p_{k1} = p_{k0} - \sum_{j=1}^{N} x_{kj1} + \sum_{j=1}^{N} y_{jk1} \quad \forall k = 1, \dots., N - 1 \tag{7}$$

$$p_{kt} = p_{k(t-1)} - \sum_{j=1}^{N} x_{kjt} + \sum_{i=1}^{N} x_{ik(t-t_{ik})} + \sum_{j=1}^{N} y_{kjt} - \sum_{i=1}^{N} y_{ik(t-t_{ik})}\ \forall k = 1,., N; t > 1 \tag{8}$$

$$p_{kt} \leq v_k \qquad \forall k = 1, \dots, N;\ \forall t = 1, \dots, T \tag{9}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ijt} \leq c_{ij} e_{ijt} \qquad \forall i, j = 1, \dots., T; i \neq j \tag{10}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} y_{ijt} \leq c_{ij}(1-e_{ijt}) \qquad \forall i,j = 1,\ldots,T; i \neq j \tag{11}$$

$$x_{ijt} \geq 0, integer;\ \forall i,j = 1,\ldots,N; i \neq j;\ \forall t = 1,\ldots,T \tag{12}$$

$$O_t \geq 0\ integer\ \forall t = 1,\ldots,T \tag{13}$$

$$e_{ijt} = \{0,1\}\ \ \forall i,j = 1,\ldots,N; i \neq j;\ \forall t = 1,\ldots,T \tag{14}$$

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.

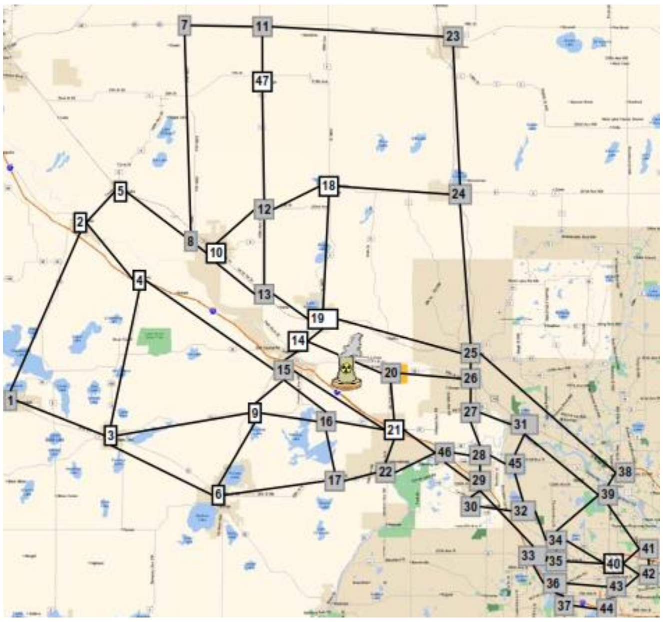

Figure 1. Node deployment on Minnesota dataset

Table 1. Node in 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

Arc Number	From Node	To Node	Arc Capacity	Travel 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

Arc Number	From Node	To Node	Arc Capacity	Travel Time
91	27	28	150	2
92	28	27	150	2
93	28	29	150	5
94	29	28	150	5
95	28	32	100	4
96	32	28	100	4
97	29	30	150	1
98	30	29	150	1
99	29	46	100	2
100	46	29	100	2
101	29	47	100	4
102	47	29	100	4
103	30	31	200	3
104	31	30	200	3
105	30	34	250	7
106	34	30	250	7
107	30	47	250	3
108	47	30	250	3
109	31	33	100	3
110	33	31	100	3
111	32	40	100	11
112	40	32	100	11
113	32	46	100	3
114	46	32	100	3
115	33	35	100	5
116	35	33	100	5
117	33	46	100	4
118	46	33	100	4
119	34	36	100	2
120	36	34	100	2
121	34	37	250	2
122	37	34	250	2
123	35	37	100	2
124	37	35	100	2
125	35	40	100	10
126	40	35	100	10
127	35	48	100	3
128	48	35	100	3
129	36	48	100	3
130	48	36	100	3
131	37	38	250	1
132	38	37	250	1
133	37	44	100	5
134	44	37	100	5
135	38	45	250	3
136	45	38	250	3
137	39	40	200	1
138	40	39	200	1
139	40	42	200	6
140	42	40	200	6
141	48	42	100	2
142	42	48	100	2
143	48	43	100	3
144	43	48	100	3
145	42	43	200	2
146	43	42	200	1
147	43	44	200	1
148	44	43	200	1
149	44	45	200	1
150	45	44	200	1
151	48	49	52439	0
152	49	48	52439	0

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.

```
<untitled>
MAX
0012 + 9024 +  17045 + 110516 + 501617 + 1201722 + 502221 + 802127 + 102726 + 1302639 + 103940 + 604042 + 204248 + 004849

subject to


O12 = 150
O24 = 150
O45 = 100
O516 = 250
O1617 = 100
O1722 = 100
O2221 = 100
O2127 = 100
O2726 = 150
O2639 = 200
O3940 = 200
O4042 = 200
O4248 = 100
O4849 = 52439

O12 >= 0
O24 >= 0
O45 >= 0
O516 >= 0
O1617 >= 0
O1722 >= 0
O2221 >= 0
O2127 >= 0
O2726 >= 0
O2639 >= 0
O3940 >= 0
O4042 >= 0
O4248 >= 0
O4849 >= 0
```

Figure 2. Testing with LINDO software for without contra-flow

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

```
LP OPTIMUM FOUND AT STEP      4
        OBJECTIVE FUNCTION VALUE
        1)      13150.00
```

VARIABLE	VALUE	REDUCED COST
O12	150.000000	0.000000
O24	150.000000	0.000000
O45	100.000000	0.000000
O516	250.000000	0.000000
O1617	100.000000	0.000000
O1722	100.000000	0.000000
O2221	100.000000	0.000000
O2127	100.000000	0.000000
O2726	150.000000	0.000000
O2639	200.000000	0.000000
O3940	200.000000	0.000000
O4042	200.000000	0.000000
O4248	100.000000	0.000000
O4849	52439.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	0.000000
3)	0.000000	9.000000
4)	0.000000	17.000000
5)	0.000000	11.000000
6)	0.000000	5.000000
7)	0.000000	12.000000
8)	0.000000	5.000000
9)	0.000000	8.000000
10)	0.000000	1.000000
11)	0.000000	13.000000
12)	0.000000	1.000000
13)	0.000000	6.000000
14)	0.000000	2.000000
15)	0.000000	0.000000
16)	150.000000	0.000000
17)	150.000000	0.000000
18)	100.000000	0.000000
19)	250.000000	0.000000
20)	100.000000	0.000000
21)	100.000000	0.000000
22)	100.000000	0.000000
23)	100.000000	0.000000
24)	150.000000	0.000000
25)	200.000000	0.000000
26)	200.000000	0.000000
27)	200.000000	0.000000
28)	100.000000	0.000000
29)	52439.000000	0.000000

NO. ITERATIONS=   4

Can be seen that based on the results of testing with Software LINDO then the maximum number of evacuated populations of 13150.

3.2. Testing for contra flow

For condition with Contra-Flow testing is done using LINDO software.

```
MAX
0O12 + 0O21 + 9O24 + 9O42 + 17O45 + 17O54 + 11O516 + 11O165 + 50O1617 + 50O1716 + 120O1722 + 120O2217+
50O2221 + 50O2122 + 80O2127 + 80O2721 + 10O2726 + 10O2627 + 130O2639 + 130O3926 + 10O3940 + 10O4039 + 60O4042 +
60O4240 + 20O4248 + 20O4842 + 00O4849 +00O4948
subject to
O12 = 150
O24 = 150
O45 = 100
O516 = 250
O1617 = 100
O1722 = 100
O2221 = 100
O2127 = 100
O2726 = 150
O2639 = 200
O3940 = 200
O4042 = 200
O4248 = 100
O4849 = 52439
O21 = 150
O42 = 150
O54 = 100
O165 = 250
O1716 = 100
O2217 = 100
O2122 = 100
O2721 = 100
O2627 = 150
O3926 = 200
O4039 = 200
O4240 = 200
O4842 = 100
O4948 = 52439
O12 >= 0
O24 >= 0
O45 >= 0
O516 >= 0
O1617 >= 0
O1722 >= 0
O2221 >= 0
O2127 >= 0
O2726 >= 0
O2639 >= 0
O3940 >= 0
O4042 >= 0
O4248 >= 0
O4849 >= 0
O21 >= 0
O42 >= 0
O54 >= 0
O165 >= 0
O1716 >= 0
O2217 >= 0
O2122 >= 0
O2721 >= 0
O2627 >= 0
O3926 >= 0
O4039 >= 0
O4240 >= 0
O4842 >= 0
O4948 >= 0
```

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.

```
LP OPTIMUM FOUND AT STEP     10

       OBJECTIVE FUNCTION VALUE

       1)      26300.00

  VARIABLE        VALUE          REDUCED COST
       O12       150.000000          0.000000
       O21       150.000000          0.000000
       O24       150.000000          0.000000
       O42       150.000000          0.000000
       O45       100.000000          0.000000
       O54       100.000000          0.000000
      O516       250.000000          0.000000
      O165       250.000000          0.000000
     O1617       100.000000          0.000000
     O1716       100.000000          0.000000
     O1722       100.000000          0.000000
     O2217       100.000000          0.000000
     O2221       100.000000          0.000000
     O2122       100.000000          0.000000
     O2127       100.000000          0.000000
     O2721       100.000000          0.000000
     O2726       150.000000          0.000000
     O2627       150.000000          0.000000
     O2639       200.000000          0.000000
     O3926       200.000000          0.000000
     O3940       200.000000          0.000000
     O4039       200.000000          0.000000
     O4042       200.000000          0.000000
     O4240       200.000000          0.000000
     O4248       100.000000          0.000000
     O4842       100.000000          0.000000
     O4849     52439.000000          0.000000
     O4948     52439.000000          0.000000
```

```
ROW   SLACK OR SURPLUS     DUAL PRICES
 2)         0.000000         0.000000
 3)         0.000000         9.000000
 4)         0.000000        17.000000
 5)         0.000000        11.000000
 6)         0.000000         5.000000
 7)         0.000000        12.000000
 8)         0.000000         5.000000
 9)         0.000000         8.000000
10)         0.000000         1.000000
11)         0.000000        13.000000
12)         0.000000         1.000000
13)         0.000000         6.000000
14)         0.000000         2.000000
15)         0.000000         0.000000
16)         0.000000         0.000000
17)         0.000000         9.000000
18)         0.000000        17.000000
19)         0.000000        11.000000
20)         0.000000         5.000000
21)         0.000000        12.000000
22)         0.000000         5.000000
23)         0.000000         8.000000
24)         0.000000         1.000000
25)         0.000000        13.000000
26)         0.000000         1.000000
27)         0.000000         6.000000
28)         0.000000         2.000000
29)         0.000000         0.000000
30)       150.000000         0.000000
31)       150.000000         0.000000
32)       100.000000         0.000000
33)       250.000000         0.000000
34)       100.000000         0.000000
35)       100.000000         0.000000
36)       100.000000         0.000000
37)       100.000000         0.000000
38)       150.000000         0.000000
39)       200.000000         0.000000
40)       200.000000         0.000000
41)       200.000000         0.000000
42)       100.000000         0.000000
43)     52439.000000         0.000000
44)       150.000000         0.000000
45)       150.000000         0.000000
46)       100.000000         0.000000
47)       250.000000         0.000000
48)       100.000000         0.000000
49)       100.000000         0.000000
50)       100.000000         0.000000
51)       100.000000         0.000000
52)       150.000000         0.000000
53)       200.000000         0.000000
54)       200.000000         0.000000
55)       200.000000         0.000000
56)       100.000000         0.000000
57)     52439.000000         0.000000

NO. ITERATIONS=      10
```

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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