Congestion-minimal and Traffic-adaptive Platooning Evacuation

Manki Min
Computer Science Program
Louisiana Tech University
Ruston, Louisiana 71272
mankimin@latech.edu

Sunho Lim
T^{2}WISTOR: TTU Wireless Mobile Networking Laboratory
Dept. of CS
Texas Tech University
Lubbock, TX 79409
sunho.lim@ttu.edu

***Abstract*—In this paper, we present generalized and flexible problem formulations for safe and optimal evacuation routing with contraflow in transportation network. Avoiding the time-dependent formulation as seen in existing problem formulation, a more concise description of the evacuation routing is allowed. By considering the safe following distance and the travel speed as variables, a more flexible evacuation solution can be obtained. We present two problems in evacuation routing: to minimize the evacuation time and to determine contraflow for optimal evacuation and their mathematical formulations. We also show how the existing solutions can be used as the starting point of solving the new problems. We also briefly discuss one possible application of the proposed problems/solutions into another similar problem of mass transportation routing from an event parking.**

***Index Terms*—safe and traffic-adaptive platooning; minimum time evacuation routing; contraflow; mass platooning transportation routing**

I. INTRODUCTION

More and more natural disasters are causing tremendous damage of property and loss of human life in the United States (U.S.). In the last few years, we have observed the devastating impact of huge hurricanes landed in the U.S. Recent consecutive hurricanes Harvey and Irma hit the fourth largest city, Houston in Texas, and southern Florida in the U.S. in the late summer of 2017, causing more than 200 deaths and $290 billion in economic damage [1]. The property damage and disruption from Hurricane Florence, which quickly reached category 5 in the summer of 2018, is roughly estimated to total at least $24 billion [2]. Another powerful category 5 hurricane, Dorian, slammed into the Bahama and at least 1 million people evacuated their coast of Florida, Georgia, and South Carolina in the summer of 2019 [3].

Due to the huge impact of hurricanes, a mandatory evacuation conducted before hurricanes land is essential. The preparation of evacuation route plans should take into consideration the geographic scale and length of warning. Since hurricanes can be predicted well in advance in the sense of path and category, casualties caused by them could be reduced significantly through an early evacuation. A recent poll of the U.S. national security leaders showed a consensus on the urgency of developing a natural disaster defense system [4]. According to the poll, climate change was chosen as one of the top five threats to the U.S. and its interests.

To effectively and efficiently accommodate the evacuation needs, we propose a more flexible, generalized problem to ease the evacuation process by providing the evacuation routing plan and/or contraflow scheme to expedite the evacuation process. Our contribution is two-fold: 1) we proposed a new, more realistic problem to minimize the evacuation time, and 2) we presented a starting point to solve the proposed problems by showing how the existing algorithms can be configured.

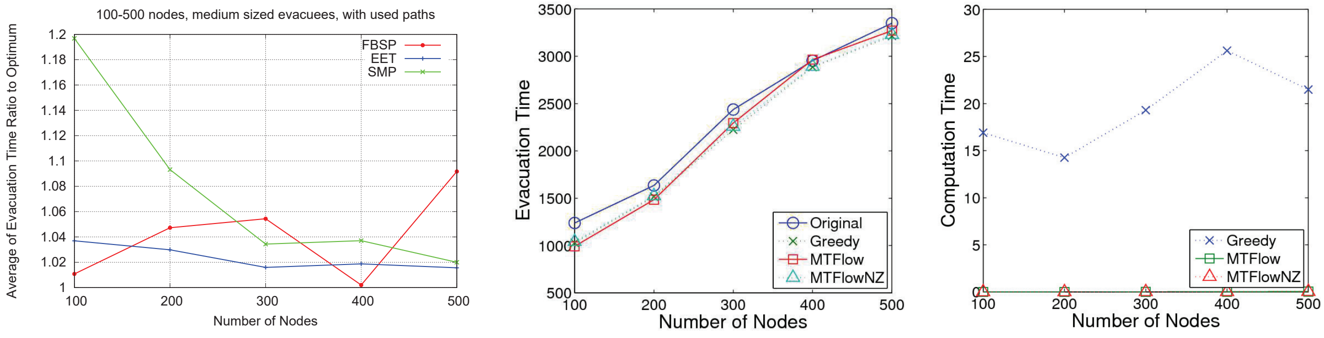
The rest of this paper is constructed as follows: Section II briefly summarizes the existing problems for (contraflow) evacuation routing and their solutions. New, generalized problems are introduced in Section III and are analyzed in terms of possible solutions in Section IV. Finally Section V concludes this paper.

II. RELATED WORK

Many instances of an evacuation problem require the evacuation scenarios as well as the evacuation routes for many reasons such as to use the scenarios to anticipate the traffic bottleneck or to convince the evacuees on the road that the computed evacuation routes will be the best choice for them. Such a problem is denoted as Minimum Time Evacuation Planning problem (MTEP) and formulated as follows:

> Given a transportation network, directed graph G(N, E), each node has an initial occupancy, and each directed edge has a capacity, a travel time, and the network has source and destination nodes. The problem is to find a **sequence of timed evacuation paths** that *minimizes the evacuation time*, where each timed evacuation path has information such as source node, destination node, travel time, capacity, and start time for each edge along the path.

Theoretical approaches such as Polynomial-Time Approximation Scheme to handle MTEP problem was studied in [5]. Using Game Theory, Nash equilibrium based routing is presented in [6]. A MIP formulation for general time-expanded graphs is presented in [7] and only the results for the small network size is provided. A multi-objective LP formulation using pre-calculated k-shortest paths is presented in [8] but the computation was performed on a small-sized network. A multi-objective multi-commodity flow MIP formulation is



(a) (b) (c)

Fig. 1: (a) Medium-size (10K-100K evacuees) input results for MTEP; (b) Evacuation time for CMET; (c) Execution time for CMET

presented in [9] and computational results for a small-sized network is given. Heuristic algorithms for the (contraflow) evacuation routing have been studied as well. Capacity Constrained Route Planner (CCRP) algorithm [10] is an improved version of MRCCP with smaller computation time than MRCCP. The use of this time aggregated model [11] instead of the time expanded network model has advantages such as smaller running time and memory complexity than those of time expanded network algorithms. CCRP++ algorithm based on CCRP was proposed in [12] that further reduces the time for pathfinding by storing the previous paths. The running time of CCRP is at least $O(mn \lg n)$ where m is the total number of evacuees in the network and n is the number of nodes but this is a very loose bound [13]. The running time of CCRP++ is at least $O(n^2 m^2)$, where n is the number of nodes and m is the number of evacuees in the network [13].

A relaxed LP formulation of MTEP problem was presented in [14] which is used in a logarithmic iterative algorithm to find the exact minimum evacuation time using only the given set of paths. Using the relaxed LP-based algorithm, we can compute how close each heuristic solution is to the optimal solutions under the assumption that only the same set of paths are used and this ratio clearly shows how optimally each heuristic used the paths found to reduce the evacuation time. What is not observed by this relaxed LP-based algorithm is how optimal each heuristic's solution is (regardless of paths used/found) which inherently has exponential computation time.

Our previous research on evacuation has focused on the algorithms without using time-expanded graphs and we designed algorithms that compute MTEP solutions using different objectives to choose a path for each evacuee [13], [15] or using a relaxed LP formulation based iterative algorithm to find the minimum evacuation time considering only the given path [14].

Extreme congestion of vehicular traffic was observed during the evacuation for Hurricane Rita in 2005 and maximizing road capacity by using contraflow lanes is one of the effective means of resolving such congestion. The optimization problem of Contraflow scheme to Minimize Evacuation Time (CMET) is based on the network reconfiguration problem using contraflow and can be formulated as follows:

> Given a transportation network, directed graph G(N, E), each node has an initial occupancy, and each directed edge has a capacity, travel time, and the network has source and destination nodes. The problem is to find a **contraflow network configuration** (i.e., the complete set of desired directions for edges) that *minimizes evacuation time*, which is denoted as a contraflow evacuation time to be distinguished from a general evacuation time.

The CMET problem has been proven NP-hard [16] and the MTEP problem does not yet have algorithms scalable to the number of evacuees; in other words, with a large number of evacuees, the existing algorithms do not compute the optimal evacuation path efficiently. The main reason for the complexity of the problems come from the fact that a single (or a group of) path(s) obtained from a well-known algorithm such as Dijkstra's shortest path algorithm cannot be repeatedly applied to get a better evacuation time due to its lack of consideration of the effect of a single evacuation route to the entire transportation network. Despite the growing importance of the problem, little research on contraflow has extended beyond managerial and operational aspects, such as signal control, merging, and cost. When the implementation/operation of contraflow schemes can be automated, i.e. every vehicle can automatically receive such a contraflow scheme without the manual help, the solutions to CMET will find a much bigger synergistic advantage by allowing (almost) real-time evacuation control. The CMET problem can be represented as the MIP formulation in [16]. Due to its high computational complexity, instead of solving the MIP directly, we have studied many contraflow heuristic algorithms [17].

A contraflow evacuation algorithm for CMET was presented in [17] which does not rely on iterative repetitions for the identification of contraflow edges, as is the general case with CCRP-based algorithms [18], [19]. Three MTEP algorithms, FBSP, EET, and SMP [13], [15], are compared in Subfig. 1(a) in terms of evacuation times with medium-sized input of 10K-100K evacuees. In the paper, two MTEC algorithms (greedy algorithm and MTFlow [17]) were compared, in terms of evacuation time in Subfig. 1(b) and computation time in Subfig. 1(c). The comparison shows that EET algorithm outperforms other algorithms in most cases for MTEP problem and MTFlow algorithm shows slightly better results than the greedy algorithm using a significantly smaller amount of time.

III. PROPOSED PROBLEMS

Preparing for an expected hurricane, evacuation routes can be optimized by using contraflows considering each road's capacity (number of lanes) and travel time (computed by a combination of its distance and traffic speed) to minimize the evacuation time. Since the traffic speed can be affected by the average distance of vehicles, i.e. congestion, by correlating them we can design a more accurate real-time evacuation routing/monitoring scheme with the help of real-time traffic monitoring. The typical long-distance evacuation routes occupied by the abnormally high volume of vehicles tend to suffer from tremendous traffic jams that will elongate the entire evacuation time. Research regarding the traffic jams [20]–[23] has found that the traffic jams can happen more often when the vehicles frequently change their speeds based on the cars in front than when the vehicles move at slower but steady speeds. One of the observations here is that each decelerating or stopping of a vehicle will generate a delay (partly caused by the inherent delay of the human sensing mechanism) that will be amplified into the cars behind so that the traffic jams will increasingly propagate toward the vehicles in the back. In a normal situation, this type of traffic jams won't stay long since the input (the volume of the traffic that enters this traffic jam area) to the traffic jams won't be bigger than the output (the exiting traffic volume) of the traffic jams as in the case of rush hour traffic jams that temporarily have bigger input than output. However, in a special situation as in disaster evacuations, the input to the traffic jams will quickly exceed the output of the traffic jams to the level that jam area expands too quickly and hence the entire march of evacuation rapidly converge to a stop. In this paper, we are focusing on this aspect to provide a traffic jam minimal solution to the evacuation routing problem using contraflow.

As presented in the study on traffic jams [22], [23], maintaining the traveling speed is the most beneficial to reduce the entire travel time. To maintain the traveling speed, in other words, to avoid stop-and-go situations, it is critical for each vehicle to maintain enough space in front and back. To achieve this goal of maintaining space, the two-second rule will be applied to our design of the traffic network. In our network, we assume that the traffic is following α second rule ($0 < \alpha \leq 2$) so that each vehicle will maintain the α second distance from the vehicle ahead. As in Subfig. 2 (a), the α second rule allows us to interpret the following distance fd feet between the two consecutive cars traveling at the speed of v miles/hours as a function of both v and α as follows:

$$fd(v, \alpha) = v \cdot 5280 \cdot \frac{\alpha}{3600}.$$

Based on our distance function, we can estimate the full traffic flow (or volume) tf cars for the entire road with l lanes and distance of d miles where vehicles are traveling at the speed of v miles/hours maintaining α second rule as a function of v, α, d, and l as follows:

$$tf(v, \alpha, d, l) = \frac{l \cdot d \cdot 3600}{v \cdot \alpha}.$$

Our model will assume that the current traffic information is regularly available for each edge, but if not our model can use the speed limits instead, which will be used to determine the traveling speed of each edge.

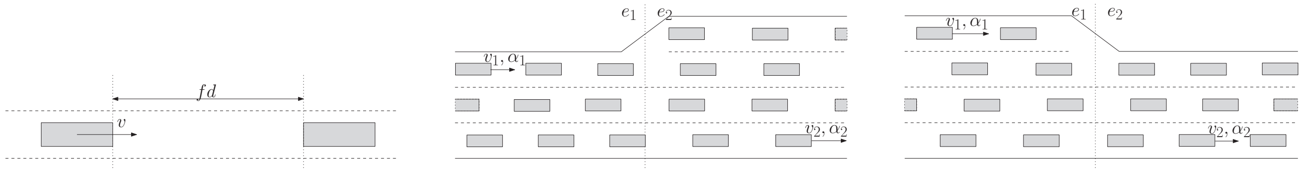
Subfig. 2 (b) and (c) show the possible scenarios at the junction of two different types of roads such as a local road and a highway. To minimize the congestion, we want to maintain the zero-sum of the flow of incoming/outgoing traffic at each joint of the roads, and in case of joining another road with different numbers of lanes will affect the traffic speed and/or α. In Subfig. 2 (b), vehicles were traveling on the three-lane road e_1 at the speed of v_1 maintaining α_1 second rule and moving onto a four-lane road e_2 at the speed of v_2 maintaining α_2 second rule, resulting in a larger following distance which can be achieved by either increasing the traveling speed or increasing α. Subfig. 2 (c) shows the four-lane road meeting a three-lane road and the following distance now reduces to maintain the traffic flow. For the one-mile segments of c_1-lane e_1 and c_2-lane e_2, we must have $tf(v_1, \alpha_1, 1, l_1) = tf(v_2, \alpha_2, 1, l_2)$, hence we get the following equation:

$$\frac{c_1}{c_2} = \frac{v_1 \cdot \alpha_1}{v_2 \cdot \alpha_2}.$$

In case multiple incoming edges and multiple outgoing edges meet at a junction, we can generalize the above idea as follows:

$$\frac{\displaystyle\sum_{e \in IE} e.c}{\displaystyle\sum_{e \in OE} e.c} = \frac{\displaystyle\sum_{e \in IE} e.v \cdot e.\alpha}{\displaystyle\sum_{e \in OE} e.v \cdot e.\alpha},$$

where IE, OE are the set of incoming, outgoing roads (or edges) at the junction, respectively, $e.c, e.v, e.\alpha$ are the edge e's number of lanes (or capacity), traveling speed, and α parameter, respectively. By allowing different α parameters and/or traveling speeds for different road segments, we can get a more flexible evacuation plan especially. One of the advantages of our model is its ability to take into consideration the safe braking distance factor into the calculation of traveling speeds that can reduce the chance of traffic jams. This perspective changes the entire evacuation process by maximizing road utilization. As an example, let's consider the subfigure (b) and assume that the distances of both e_1 and e_2 are 60 miles and the speed limits of e_1 and e_2 are 45 mph and 60 mph, respectively. Considering only those two edges, the minimum time to evacuate 3600 vehicles from the source of e_1



(a) (b) (c)

Fig. 2: (a) α second rule and distance between cars; (b) Traffic flow change at fan-out; (c) Traffic flow change at fan-in

$$\min \quad \max_{n\in T, e \int I_n} e.et \tag{1}$$

$$\text{s.t.} \quad e.\alpha \geq A, \quad \forall e \in E \tag{2}$$

$$e.v \leq e.V, \quad \forall e \in E \tag{3}$$

$$e.u \leq e.tf, \quad \forall e \in E \tag{4}$$

$$e.u \geq \frac{e.tf}{\sum_{n\in S} n.IO}, \quad \forall e \in E \tag{5}$$

$$e.c = (1 - e.f) \times e.C + e^R.f \times e^R.C, \quad \forall e \in E \tag{6}$$

$$\frac{\sum_{e\in I_n} e.v \times e.\alpha}{\sum_{e\in O_n} e.v \times e.\alpha} = \frac{\sum_{e\in I_n} e.c}{\sum_{e\in O_n} e.c}, \quad \forall n \in N \setminus (S \cup T) \tag{7}$$

$$e.et \geq \left\lceil \frac{e.tf}{e.c} - 1 \right\rceil \times e.\alpha + \frac{e.D}{e.v} \times 3600, \quad \forall e \in O_s,\ \forall s \in S \tag{8}$$

$$e_o.et \geq e_i.u \times \left(e_i.et + \frac{e_o.D}{e_o.v} \times 3600 \right), \quad \forall e_o \in O_n, e_i \in I_n,\ \forall n \in N \setminus (S \cup T) \tag{9}$$

$$\sum_{e\in O_s} e.tf = s.IO, \quad \forall s \in S \tag{10}$$

$$\sum_{n\in T} \sum_{e\in O_n} e.tf = \sum_{n\in S} n.IO \tag{11}$$

$$\sum_{e\in I_n} e.tf = \sum_{e\in O_n} e.tf, \quad \forall n \in N \setminus (S \cup T) \tag{12}$$

$$e.u, e.f \in \{0, 1\}, \quad \forall e \in E \tag{13}$$

Fig. 3: Mathematical formulation for CATP

to the destination of e_2 with the capacity of 3 using Combined Evacuation Time (CET) formula [14] is

$$\left\lceil \frac{3600 + \left(\frac{60}{45} \times 3 + 1 \times 3\right) \times 1800}{3} \right\rceil - 1 = 5399 \text{ unit times,}$$

using the unit time of 2 seconds. Now applying the 2 second rule to the traffic, we can satisfy

$$\frac{45 \times 2}{60 \times 2} = \frac{3}{4},$$

hence the minimum time from e_1 to e_2 to move 3600 vehicles is now

$$\left\lceil \frac{3600}{3} - 1 \right\rceil \times 2 + \left(\frac{60}{45} + \frac{60}{60} \right) \times 3600 = 10798 \text{ seconds,}$$

which is essentially the same result as the CET result of 5399 unit times. In addition to containing the existing problems, the new idea can handle more flexible, and hence more realistic problem instances: with variable safe distance parameter α and travel speed for each edge. The CET formula assumes that every vehicle will move at the same speed, but that may not be optimal in some cases especially speed limits can be waived in such an exceptional emergency. For example, by increasing the travel speed of e_1 to 60 mph beyond its speed limit of 45 mph, then by adjusting $e_1.\alpha$ accordingly ($\frac{3}{4} \times e_2.\alpha$) we can increase the traffic volume and hence we can reduce the total evacuation time to 9598 seconds. Another realistic situation that CMET/MTEP solutions will fail to handle properly is the case when the speed limits cannot be maintained, mainly due to the massive traffic volume on each edge to dramatically reduce the traveling speed. In that case, as opposed to the previous analysis, the real evacuation time will be much longer than the CET-based time.

Now we present the problem of Contraflow scheme to minimize A second rule-based Traffic-adaptive Platooning evacuation Time (CATP), defined as below:

$$\min \quad \max_{n\in T, e \int I_n} \quad e.et \tag{14}$$

$$\text{s.t.} \quad e.\alpha \geq A, \quad \forall e \in E \tag{15}$$

$$e.v \leq e.V, \quad \forall e \in E \tag{16}$$

$$e.u \leq e.tf, \quad \forall e \in E \tag{17}$$

$$e.u \geq \frac{e.tf}{\sum_{n\in S} n.IO}, \quad \forall e \in E \tag{18}$$

$$\frac{\sum_{e\in I_n} e.v \times e.\alpha}{\sum_{e\in O_n} e.v \times e.\alpha} = \frac{\sum_{e\in I_n} e.C}{\sum_{e\in O_n} e.C}, \quad \forall n \in N \setminus (S \cup T) \tag{19}$$

$$e.et \geq \left\lceil \frac{e.tf}{e.C} - 1 \right\rceil \times e.\alpha + \frac{e.D}{e.v} \times 3600, \quad \forall e \in O_s,\ \forall s \in S \tag{20}$$

$$e_o.et \geq e_i.u \times \left(e_i.et + \frac{e_o.D}{e_o.v} \times 3600 \right), \quad \forall e_o \in O_n, e_i \in I_n,\ \forall n \in N \setminus (S \cup T) \tag{21}$$

$$\sum_{e\in O_s} e.tf = s.IO, \quad \forall s \in S \tag{22}$$

$$\sum_{n\in T} \sum_{e\in O_n} e.tf = \sum_{n\in S} n.IO \tag{23}$$

$$\sum_{e\in I_n} e.tf = \sum_{e\in O_n} e.tf, \quad \forall n \in N \setminus (S \cup T) \tag{24}$$

$$e.u \in \{0, 1\}, \quad \forall e \in E \tag{25}$$

Fig. 4: Mathematical formulation for MAEP

> Given a constant A and a transportation network, directed graph G(N, E), each node has an initial occupancy and each directed edge has a number of lanes (capacity), a traveling distance, a speed limit, and a traffic traveling speed, and the network has source and destination nodes. The problem is to find a **contraflow configuration** that *minimizes the platooning evacuation time* to move all evacuees from the source nodes to destination nodes using the traffic-adaptive speeds lower-bounded by A second rule.

The problem of CATP can be mathematically formulated as in Figure 3[1]. In the formulation, the inequalities (4) and (5) ensure the binary variable $e.u$ will be set if and only if there is traffic on the edge e. The equation (6) adjusts the real capacity of the edge e based on another binary variable $e.f$ that will be set if and only if e is reversed. The aforementioned observation of the speed and safe parameter relation is encoded in the equation (7) to ensure the constant flow of the incoming and outgoing traffic at every node. The elapsed time for each edge is computed as in the inequalities (8) and (9), where (8) is only for the outgoing edges from the source nodes. Finally, the equations (10)-(12) ensure that all the input (in terms of traffic) into the network will be evacuated to the destination nodes at the end of the evacuation.

The counterpart of CATP problem into evacuation routing is the problem of Minimum A second rule-based traffic-adaptive Evacuation time Planning (MAEP) and is defined as follows:

> Given a constant A and a transportation network, directed graph G(N, E), each node has an initial occupancy and each directed edge has a number of lanes (capacity), a traveling distance, a speed limit, and a traffic traveling speed, and the network has source and destination nodes. The problem is to find a **set of pair of traffic speed and α parameter for each edge** that *minimizes the evacuation time*, where each edge is used for the evacuation to ensure the predetermined safety constraint such as A second rule and speed limits.

Being generalized versions, CATP/MAEP inherits the complexity of the underlying problems CMET/MTEP, i.e. NP-hard.

Since CATP allows real-time traffic conditions to affect the evacuation time, with the help of continuous input of traffic information through vehicular networking, we can expect to have a highly effective evacuation procedure by the solution of CATP. With the help of continuous dissemination of the surrounding traffic condition and the evacuation routes, each evacuee in a vehicle can ensure the optimality of the

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[1] The variables are defined as follows: N := set of nodes; S, T := set of source and destination nodes; E := set of edges; I_n, O_n := set of incoming/outgoing edges to/from node n; $e.\alpha := \alpha$ value of edge e; $e.V$:= speed limit or current traffic speed of e; $e.u := 1$ if e is used for the evacuation, (0 o.w.); $e.tf$:= total traffic volume on e during the evacuation; e^R := the reverse edge of e; $e.f := 1$ if e is flipped for contraflow, (0 o.w.); $e.C$:= original capacity (without contraflow) of e; $e.c$:= capacity (including contraflow) of e; $e.et$:= elapsed time when last vehicle arrives at the destination e during evacuation; $e.D$:= traveling distance of e; $e.v$:= traveling speed on e; $n.IO$:= initial occupancy in n. Note that α, u, tf, f, c, et, and v are variables and the rest are constants.

announced routes through the ability to see an immediate increase of the evacuation time at each attempt to deviate from the announced routes.

The MAEP problem can be mathematically formulated as in Figure 4. The difference between CATP and MAEP is with the capacity of each edge. In CATP, the edge capacity is a variable, depending on the contraflow, while it is a constant in MAEP.

CATP/MAEP problem cannot be solved directly by the algorithms for CMET/MTEP problems because of the different weights for the edge. The former uses the dynamic weight of traveling speed which depends on the current traffic of the road (edge) while the latter uses the static weight of traveling time. So there is a chance that even after calculating an evacuation routing using CMET/MTEP algorithms, the actual evacuation time may be completely off from the solution. The main reason for this discrepancy comes from the fact that the static edge weight does not reflect the dynamic traffic information and our newly proposed problem CATP is supposed to manage the dynamic traffic-adaptive traveling speed as one of the variables in the problem in a safe, congestion-minimal way. The resulting problem will not be linear any more since a new type of constraint will include the multiplication of variables.

If algorithms for CMET/MTEP were used to find solutions to routing fully automated vehicles, then the hidden factor of traffic jam propagation might not be as significant as we can observe. In fact, the proposed evacuation routing will best work in fully automated vehicles' networks by removing such hidden and human-related costs and errors. As a stepping stone to the solutions for such an ideal environment that involves many more components than our assumption in this paper, we are proposing to handle such hidden costs first by attempting to reduce the traffic jam propagation with the help of safe-and-steady-speed platooning. Then we are expecting to be able to define and solve variant problems based on CATP to improve the overall evacuation efficiency in more realistic perspectives as well as to generalize and extend the problem for different applications that require massive transportation such as event parking exiting routing.

IV. ANALYSIS OF PROBLEMS

In this section, we first discuss how to approach the new problems by modifying the existing solutions and using it as the starting point. Then we will briefly discuss how the new problems can be used for other mass transportation routing, using event parking exit routing as one such example.

The difference between CATP/MAEP and CMET/MTEP lies in the fact that the edge's travel time can vary by the path to which it belongs to and hence the solutions to CMET/MTEP cannot be directly applied to CATP/MAEP. We can begin by solving the CATP problem and MAEP problem with the fixed value of either traveling speed or α. With at least one of those variable fixed (constant), we can get almost all constraints in the formulation as linear except those for elapsed time ($e.et$). The elapsed time can be computed by Combined Evacuation Time (CET) [14]. Then we can compare the solutions with constant speeds and the solutions with constant α. Based on the comparison, we can refine the initial version of our algorithm (which is a modification of the algorithms of MTEP/CMET). Using the transportation network model, we can apply the solutions for the MTEP and CMET by modifying the edges' travel time as described in Section III.

When we fix one of the two variables, we can see that the other non-fixed variable is expected to be either the maximum possible value or minimum possible value to reduce the total evacuation time. For example, when we fix the traveling speed, from the inequalities (8), (9), (20), and (21), then we want to keep $alpha$ values at the minimum possible values. On the other hand, when α is fixed, those same inequalities show that we want to keep the traveling speed at the maximum possible values. When we want to fix at least one of those two variables, the existing solutions can be easily modified to serve these new problems.

If we want those two variables to be both parameters, then we can handle the more flexible and more realistic problem for the evacuation routing with contraflow where each road segment can utilize different settings of the traveling speed and/or safe distance parameter and handle traffic jams more effectively. The initial solution to this version of the problem could be to use a binary search approach with a fixed speed/α version of the problems similar to the iterative algorithm in [14].

There are many situations where multiple vehicles share the same destination and the same transportation network and in most such cases, the transporting time needs to be minimized. We can generalize the findings from CATP study so that the solution can be easily adapted to such applications with minimal modification.

One of the target applications of the problems/solutions is the event parking exit routing which will dramatically increase the traffic jam especially at the time of exiting. To ease the routing around the parking lot, staff members will typically guide the vehicles on which way to go. However, without the knowledge of the traffic in the entire parking area and its surrounding area, it is far from optimal for the staff to effectively guide the vehicles entering or exiting the parking lot. Among those two possible situations, we can first attempt to resolve the exiting situations by a modified algorithm based on the solutions to CATP/MAEP. We can model the parking and surrounding area into a transportation network with parking area as source nodes and major intersections to the bigger roads as destination nodes and apply a similar algorithm to the network to minimize the parking lot exit time.

In addition to the event parking exit routing, the problems/solutions of CATP/MAEP can be generalized and applied to many other problems such as logistics routing where groups of vehicles move towards the same destination to minimize the transporting time (in this case MAEP will be applied instead of the contraflow schemes). As long as the problem can be modeled as a transportation network with multiple source nodes and destination nodes to minimize the group/massive transporting time, then CATP/MAEP can be modified to solve the problem.

V. CONCLUSION

In this paper, we proposed two flexible, generalized problems of evacuation routing with contraflow: C*A*TP and M*A*EP. The solutions to the proposed problems will help to handle various evacuation situations more flexibly and realistically by adjusting traveling speed and safe distance for each edge individually.

The future work includes 1) the design and evaluation of a set of scalable algorithms that calculate contraflow configuration that leads to the minimum-time-spent congestion-minimal platooning evacuation and 2) the generalization of the problem and extension of the algorithm to various applications such as massive exit routing from an event parking. Inherently the evacuation routing problem (regardless of the versions) has a common goal as in much other transportation routing and this property gives the group/massive transportation routing a perfect fit for the generalized framework.

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