International Journal of Transportation
Vol.4, No.2 (2016), pp.69-80
http://dx.doi.org/10.14257/ijt.2016.4.2.05

Optimizing Intermediate Crossovers and Ramp Closures for Hurricane Evacuation

Yohan Chang[1] and Praveen Edara[2]

[1,2]*University of Missouri-Columbia*
[1]*ychang@mail.missouri.edu*, [2]*edarap@missouri.edu*

Abstract

Current hurricane evacuation plans of coastal states in the United States do not actively coordinate the provision of contraflow access points and ramp closure locations on evacuation routes. In this paper, contraflow and ramp closure techniques are integrated and optimized to achieve higher evacuation efficiency. A simulation-based optimization framework for identifying the intermediate crossover between regular and contraflow lanes and ramp closure locations is proposed. The framework is applied to a case study of Hampton Roads, Virginia; using models developed based on evacuee behavioral data and transportation network and traffic control data. Two heuristic solution approaches, Genetic algorithm and Tabu search, are applied to determine optimal intermediate crossover and ramp closure locations for the case study network. The importance of each crossover and ramp closure location included in the optimal solution was also determined.

Keywords: *hurricane evacuation, intermediate crossovers, contraflow, heuristic algorithm, dynamic traffic assignment*

1. Introduction

Traffic management techniques are an integral part of hurricane evacuation plans of coastal states in the United States. A synthesis of practices for traffic management and control for hurricane evacuation adopted by agencies in the coastal states was presented by Wolshon *et al.*, (2005). They provided an extensive discussion of various aspects of contraflow operations including their design (*i.e.*, origin and termination), management, enforcement, costs, safety, and accessibility. They also discussed various Intelligent Transportation System techniques that states either deployed or were interested in deploying during evacuations. These include close circuit television for real-time traffic monitoring, highway advisory radio and dynamic message signs for traveler information, and traffic count stations for measuring traffic flows. Other forms of traffic control techniques such as adaptive signal control, integrated corridor management, ramp closures and metering allow public agencies to efficiently evacuate the impacted population. A contraflow facility in which the direction of traffic on one or more travel lanes is reversed to increase the outbound capacity is a major component of hurricane evacuation plans of many coastal states. Typical contraflow plans have one upstream crossover routing vehicles into the contraflow lanes and one downstream crossover routing vehicles back into the regular lanes. Contraflow was implemented for the first time in Maryland in 1985 during hurricane Gloria. Later, contraflow was also implemented during hurricane Georges in 1998 and hurricane Floyd in 1999. Now, almost every coastal state has a contraflow plan for hurricane evacuation (Fang and Edara, 2014).

Previous literature evaluated the performance of contraflow facilities using traffic simulation. Chiu *et al.*, (2008) analyzed contraflow facilities for evacuating the Houston and Galveston areas and found the contraflow facilities to improve travel times by 14%. A simulation analysis of evacuation of Ocean City, Maryland, by Zou *et al.*, (2005) showed

ISSN: 2287-7940 IJT

that the contraflow facilities alleviated congestion and improved throughput. Theodoulou and Wolshon (2004*)* modeled the New Orleans evacuation and evaluated I-10 lane reversal plan using simulation. The study recommended a better road control layout for the entering point of contraflow lanes. Lim (2003) evaluated six different contraflow termination point designs to determine the most effective design. Collins (2008) evaluated five different alternatives with different number of contraflow lanes on I-4 in the west central Florida region and found that reversing all inbound lanes was the most effective alternative. In summary, previous studies mainly focused on two aspects of contraflow facilities: 1) to evaluate the effectiveness of contraflow facilities in terms of mobility, and 2) the effect of different geometric designs of the entry and termination points of contraflow on their performance.

One area that has been less explored in previous research is that of maximizing the utilization of contraflow facilities. Most of the contraflow plans currently used by coastal states have a single entrance and a single termination point. A few plans allow traffic to exit contraflow lanes at intermediate locations, to access road side services such as gas stations. One pertinent question related to existing contraflow plans is: Does the single entry and termination access point design offer the best utilization of contraflow facilities in terms of evacuation efficiency? One study conducted by Dixit *et al.*, (2008) compared four strategies of one and two crossovers selected from three candidate locations on I-4 in Florida. The simulation results showed that having multiple crossovers improved the network performance. Fang and Edara (2014) investigated how to optimize the efficiency of contraflow facilities. Specifically, the mobility impact of additional intermediate crossovers between the beginning and termination of contraflow was examined. They proposed an iterative elimination heuristic algorithm, which is provides a systematic approach to determine the critical intermediate crossover locations that provide the maximum improvement in evacuation performance.

Traffic control plans of some coastal states also include closure of certain entrance ramps of freeway evacuation routes to improve clearance times and/or travel times. Ramp metering techniques are also used to control the traffic flow entering the freeway evacuation route at different entrance ramps (Edara *et al.*, 2010). Machiani *et al.*, (2013) proposed a procedure to optimize the ramp closure locations for no-notice evacuation. They modeled the ramp closure problem as a bi-level optimization problem with ramp closure in the upper level and traffic assignment in the lower level under additional constraints. They illustrated their procedure on a road network consisting of regions from Washington D.C. and Maryland. Simulated annealing was used in conjunction with a mesoscopic simulator to illustrate the performance of the developed procedure.

Although current evacuation plans of states incorporate both contraflow on some facilities and ramp closures, there is no evidence that these plans actively coordinate the two techniques. Due to the sharing of common resources such as infrastructure funding, enforcement personnel to operate, it is argued that coordinating the contraflow and ramp closure locations for a freeway facility would result in best utilization of resources. In this paper, contraflow and ramp closure techniques are integrated and optimized to achieve higher evacuation efficiency. A framework to use simulation-based optimization methods for identifying the intermediate crossover and ramp closure locations is proposed. The framework is applied to a case study of the Hampton Roads region evacuation using a model developed based on evacuee behavioral data and real-world network and traffic control data.

2. Optimization Framework

2.1. Formulation

Ramp closures and intermediate crossover decisions both involve similar considerations such as personnel resources required for enforcement, equipment needs, financial costs, etc. In this paper, we jointly optimize both ramp closures and intermediate crossovers for a study region. A formulation of the objective function and constraints is presented in equations (1) to (8). Equation (1) represents the objective function to minimize total travel time in the network. The travel time is a function of the location of crossovers, ramp closures, and the assignment of origin-destination trips. Node and link flow conservation constraints are shown in equations (2) and (4) and capacity constraint is shown in equation (3). Budget constraints are presented in equations (5) and (6) for crossovers and ramps, respectively. Equation (7) indicates binary variables for crossover and ramp closure for each candidate location. If a crossover or a ramp is closed, the binary variable takes a value of 1 and otherwise it takes a value of 0.

Objective function:

$$min\, z = \sum_t^T \sum_a^A \int_0^{x^{ta}} \lambda_{ta}(\omega) d\omega \tag{1}$$

Subject to:

$$\sum_b d^{tb} = \sum_c m^{tc} + I_n^t - O_n^t \qquad \forall t, n, c, b, c \in C(n), b \in B(n) \tag{2}$$

$$m^{ta} \leq g_a(x^{ta}) \qquad \forall t \in T, a \in A \tag{3}$$

$$x^{t+1\, a} = x^{ta} + d^{ta} - m^{ta} \qquad \forall t \in T, a \in A \tag{4}$$

$$\sum_j^J C_j \leq M \qquad \forall j \in J \tag{5}$$

$$\sum_k^K R_k \leq N \qquad \forall k \in K \tag{6}$$

$$C_j, R_k \in \{0,1\} \qquad \forall j \in J, k \in K \tag{7}$$

$$x^{ta}, m^{ta}, d^{ta}, M, N \geq 0 \qquad \forall t \in T, a \in A \tag{8}$$

Where,

x^{ta} = number of evacuees on link *a* at the beginning of time interval *t*,

$\lambda_{ta}(x^{ta})$ = cost of traveling link *a* at time interval *t*,

C_j = binary variable indicating if intermediate crossover *j* is closed or open (C_j= 1 if closed, 0 if open),

R_k = binary variable indicating if ramp *k* is closed or open (if R_k = 1 if closed, 0 if open),

M, N = given budget for crossovers and ramp closures,

d^{tb} = the number of evacuees entering link *b* in interval *t*,

m^{tc} = the number of evacuees exiting link *c* in interval *t*,

I_n^t = the number of evacuees originating from node *n* in interval *t*,

O_n^t = the number of evacuees reaching destination at node *n* in interval *t*,

$B(n), C(n)$= set of links entering and exiting node *n*, and

$g_a(x^{ta})$ = exit function, (i.e. maximum number of evacuees that can exit from link *a* at time t)

2.2. Solution Approach

One approach to solve the proposed formulation is to first optimize the intermediate crossover locations and then optimize ramp closure locations. Mathematically, this may not result in the optimal crossover and ramp closures that would result from jointly optimizing the crossover and ramp closures. However, this simplistic approach is chosen since the costs associated with adding new crossovers involve significant construction costs, which are not factored in determining ramp closures since only existing ramps are considered. Ramp closure costs only involve operational and enforcement.

Heuristic algorithms have been used in prior evacuation research for solving similar bi-level combinatorial optimization problems (see Xie and Turnquist, 2011, Machiani *et al.*, 2013, and Fang and Edara, 2014). One reason for selecting heuristic algorithms is the ease of evaluating the objective function value. Typically, a heuristic methodworks with a solution (or a population of solutions) in each step. The objective function value is obtained by first generating the road network representative of the solution and then evaluating its performance using a simulation-based dynamic traffic assignment (DTA). Due to the need to use simulation to evaluate objective function value for a real-world road network, it is challenging to use traditional optimization methods such as integer programming. Therefore, two heuristic algorithms, Genetic Algorithms (GA) and Tabu Search (TS), are used in this paper. Both GA and TS (Glover, 1990) have been shown to avoid getting trapped in the local optima and producing global optimal or near optimal solutions. GAtechnique has been widely used in transportation research for location problems (Edara *et al.*, 2011). Based on Darwin's theory of Natural Selection, GA mimics human evolutionary behaviors to achieve the best solution. A basic primer of the GA technique is available in Mitchell (1998) and a transportation application can be found in Edara *et al.*, (2011). A binary notation was used to define GA chromosomes with value 0 (zero) in a gene representing "closure" for intermediate crossover or ramp and value 1 representing "open" for each facility.

A flow chart of the general heuristic approach used in this study is shown in Figure 1. The left side of the flow chart applies to GA and the right side to Tabu Search (TS). GA process begins by defining some parameters such as crossover rate, mutation rate, and convergence criteria. The first generation population is generated using random selection while satisfying a given budget for crossovers and ramp closures. The next generation population is generated using Elitist selection (Cox, 2005), and by performing random point crossover and mutation. The current generation solutions are evaluated using DTA. This iterative process is repeated until the convergence criteria are met.

Tabu search has been used in evacuation research by Tuydes and Ziliaskopoulos (2006), Xie et al. (2009), and Xie and Turnquist (2011). Glover (1990) explains the steps involved in TS. A candidate list of moves is created, each move resulting in a new solution from the existing solution. Based on certain admissibility criteria (Tabu restrictions and aspiration), the best admissible candidateis determined. If the best admissible candidate is better than the existing solution, it becomes the new best solution. While the Tabu restrictions prevent the search from revisiting already visited solutions, the aspiration criteria ensures that some otherwise Tabu solutions satisfying aspiration criteria are included in the allowed set of solutions. As shown in Figure 1, the search process starts with a randomly generated initial solution that is evaluated using DTA. The initial solution is designated as the current best solution and added to Tabu list. In the next step, best admissible candidate is generated using the established admissibility criteria and by evaluating the objective function using DTA. This iterative process is repeated until the convergence criteria are met. One example of convergence criteria is: if there is no improvement in the objective function value in the current iteration (i) from the previous iteration (i-1) for a certain number of iterations, the algorithm has converged to its best solution.

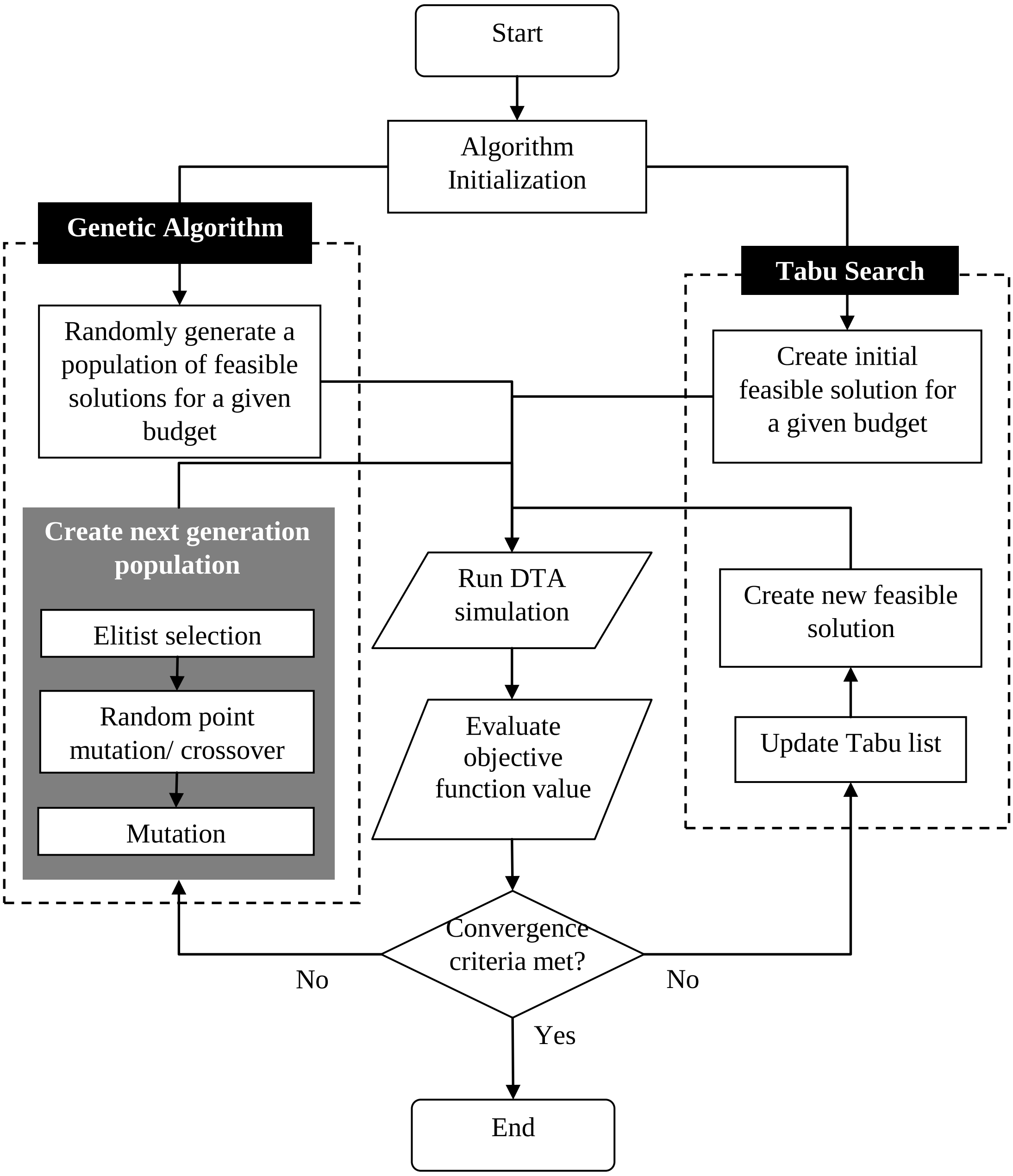


Figure 1. Flow Chart for Heuristic Solution Approach

3. Case Study: Hampton Roads, Virginia

3.1. Study Network and Simulation Model

In this section, the proposed simulation-based optimization framework is applied to a real-world evacuation scenario of a portion of the Hampton Roads region in Virginia. The regional evacuation model has been developed in previous studies (Edara and Fang, 2012, Edara and Chang, 2015). A brief discussion of the regional model is presented next followed by the explanation of how a subset of the network was extracted to study the crossover and ramp closure problem.

A mesoscopic simulation model of the Hampton Roads region of Virginia was developed in earlier studies by Edara and Fang (2012) and Edara and Chang (2015). A screenshot of the model is shown in Figure 2. The model included eight cities and four counties – cities of Poquoson, Hampton, Newport News, Portsmouth, Chesapeake, Norfolk, Virginia Beach, Richmond and counties of York, Isle of Wight, and Surry. Some key aspects of the simulation model will be presented here and the reader is referred to the final project report (Edara and Fang, 2012) for additional details. The simulation model development involved coding the road network, traffic signals, defining origin and destination zones for evacuation and background traffic, and traffic control strategies. The traffic volume forecasts for different storm intensities reported in the 2008 Virginia Hurricane Evacuation Study (VHES) (PBS&J, 2008) were utilized as evacuation demand in the simulation model. Background traffic information was obtained from Virginia DOT's travel demand model for the Hampton Roads region and through continuous count stations in Richmond.

Figure 2. Screenshot of the Hampton Roads Evacuation Network (Edara and Fang, 2012)

The road network consisting of designated evacuation routes and major routes feeding into the evacuation routes were modeled. The road network was created using microscopic models developed in previous studies by Edara and McGhee (2008) and Edara *et al.*, (2010) and GIS files. The study region was divided into evacuation zones for trip generation and distribution. The zone boundaries were obtained from the VHES study's graphics reference document (PBS&J, 2008*)*. A total of 212 generation zones were created. Additional information on the evacuation model can be found in Edara and Fang (2012).Based on the results of different network treatments studied in Edara and Fang (2012) it was found that the congestion locations on I-64 typically occurred on the regular lanes, not the contraflow lanes. This was somewhat expected since the regular lanes carried more traffic than the contraflow lanes. For example, in Category 3 hurricane evacuation, the regular lanes carried 1.5 times more vehicles than contraflow lanes. Moreover, the contraflow lanes were operating under capacity for a significant amount of evacuation time. Thus, the I-64 facility was an ideal case study to study the effectiveness of additional intermediate crossovers in improving the utilization of contraflow lanes and therefore improving the overall network performance.

Since the heuristic algorithms described in the previous section rely on simulation to evaluate the objective function, the run times for each crossover configuration had to be reasonably low. The original network of the regional evacuation model (Edara and Fang,

2012) needed 72 hours to reach convergence for user equilibrium for category 3 evacuation demand. The run time was too high for using in the heuristic algorithms. Therefore, only a portion of the original network was extracted through the subarea cut process. The demand data at the boundary of the sub network was also extracted from the OD tables of the original network. The sub network still justified using DTA since there were several alternative routes connecting a given origin and destination due to the dense arterial and local street network. The mean and median number of routes connecting an origin and destination in the sub network were 107 and 11, respectively, assuming all ramps and intermediate crossovers are open. A total of 1,274 nodes, 2,474 links, 120 zones, 42 pre-timed signals and 10 actuated signals are included in the tested network. The two major evacuation routes carrying traffic out of the region were I-64 (regular and contraflow lanes) and US 60.The 73-mile I-64 segment between Hampton Roads and Richmond consists of 31 ramps and 43 intermediate crossover candidate locations. All entrance ramps for westbound I-64 (outbound direction) were included. The traffic entering I-64 at an interchange was not allowed to access the immediately downstream crossover to avoid any adverse safety and mobility impacts due to the weaving maneuvers, they can instead use the next downstream crossover. The locations of candidate intermediate crossovers are shown in Figure 3. Of the 22 locations shown in Figure 3, 21 have crossovers from regular to contraflow and contraflow lanes resulting in 42 candidate crossovers. The western most location has only one crossover from regular to contraflow lanes due to the proximity of contraflow termination point downstream.

The total evacuation volume and background volume in the model was 333,302 vehicles. The demand loading curve information can be found in Fang and Edara (2014). Figure 4 shows the size of travel demand entering from various zones in the study network. The bigger the size of the blue bubble in Figure 4, the higher is the entering demand at that location.

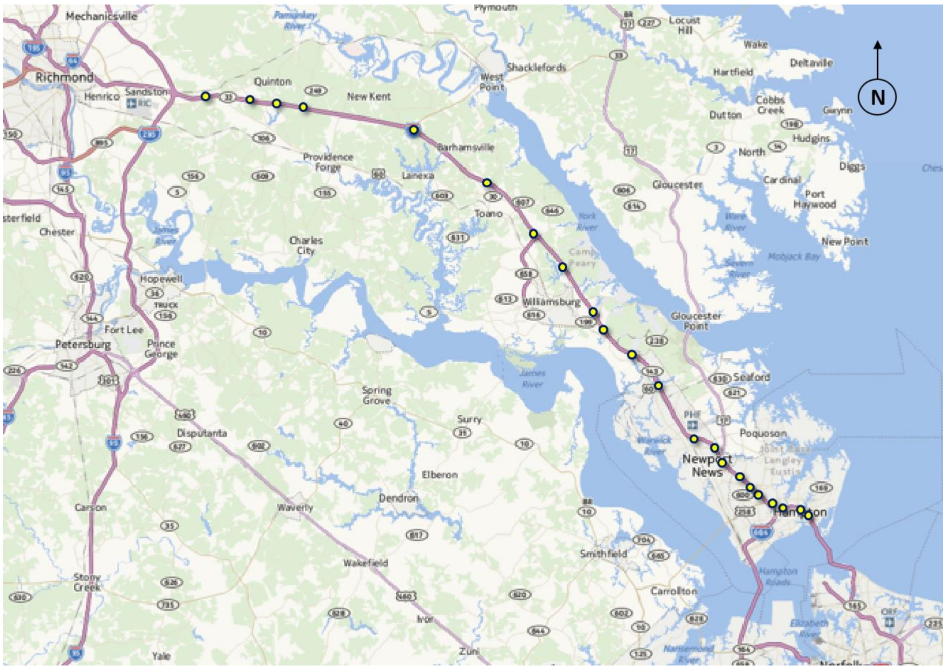


Figure 3. Candidate Crossover Locations on I-64 (Source: Nokia Maps)

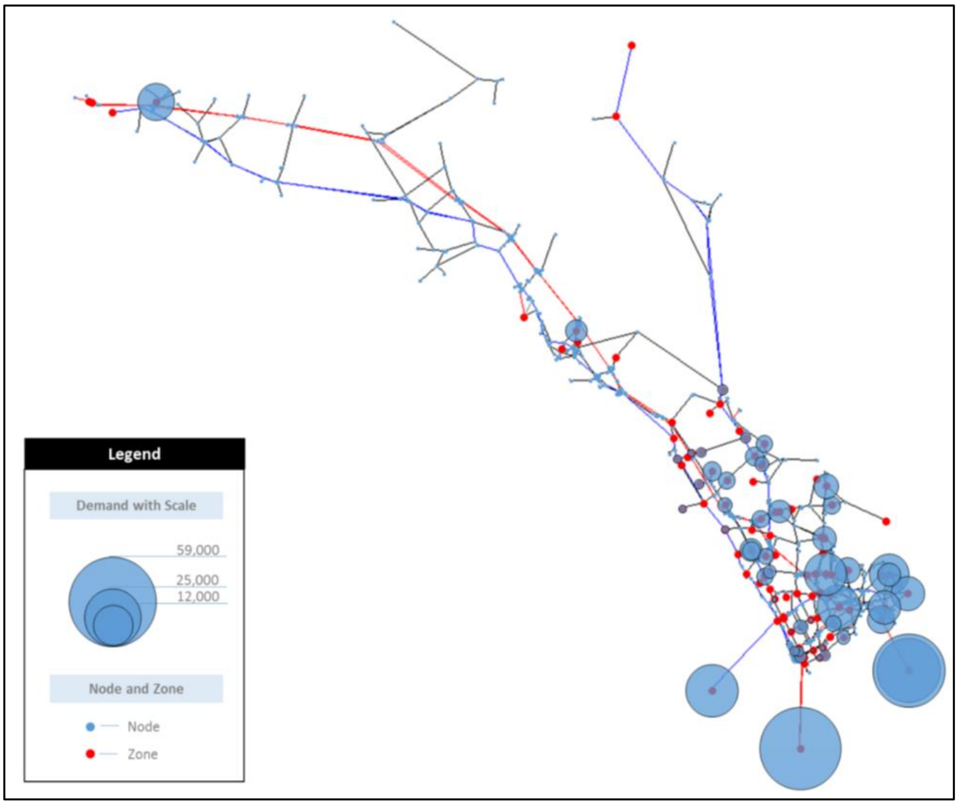


Figure 4. Origin Zones and Relative Evacuee Demand

3.2. Constraints and Algorithm Parameters

The budgetary constraint for intermediate crossovers (M) was varied from 5 to 30to investigate the network performance for different numbers and locations of intermediate crossovers. Specifically, four values of M were investigated: 5, 10, 20, and 30. For simplicity, the ramp closure constraint was not enforced in this illustrative case study i.e. ramp closures were treated as an unconstrained optimization problem. For the GA, a population size of 20 was used for each generation. Random single point crossover with a 3% mutation rate was used. The Elitist selection was applied by carrying over the top three solutions within each generation to the next generation. No special parameter assumptions were necessary for the TS algorithm. The DTA evaluation was performed using Dynasmart-P program. Dynasmart-P has been used in previous evacuation research including Kwon and Pitt, (2005), Li and Wang (2011), Sbayti and Mahmassani (2006), and Murray-Tuite and Mahmassani (2004).The DTA simulation parameters are presented in Table 1.

Table 1. DTA Simulation Parameters

Parameter type	Parameter value
Assignment technique	One-shot simulation assignment
Demand loading	Activity chain without (partial) path file
Simulation period	6000 minutes
Capacity reduction	Incident function with varying % severity

4. Results

The results of the Hampton Roads case study are presented in this section. The minimum values of average travel time (ATT) (minimizing total travel time is equivalent to minimizing ATT) for each constraint level are reported in Table 2. The number of intermediate crossovers needed and the number of ramp closures needed are shown in the rows below ATT values. Figure 5 provides a graphical comparison of the GA and TS results shown in Table 2. The GA plot shows that the minimum ATT value is attained for $M \leq 10$(when number of intermediate crossovers is 8 and the number of ramp closures is 15). Any further addition of crossovers did not provide any mobility benefit. Similarly, for TS, the minimum ATT value was attained for $M \leq 10$ (when number of intermediate crossovers is 10 and the number of ramp closures is 0). The lowest ATT value for GA (403.4 min) was 34% better than the lowest value for TS (611.27 min).

Table 2. Comparison between GA and TS

		Constraints (M)			
		M ≤ 5	**M ≤ 10**	**M ≤ 20**	**M ≤ 30**
GA	ATT (min)	493.35	403.40	403.40	403.40
	Crossovers/Ramp	2/5	8/15	8/15	8/15
TS	ATT (min)	627.22	611.27	611.27	611.27
	Crossovers/Ramp	4/0	10/0	10/0	10/0

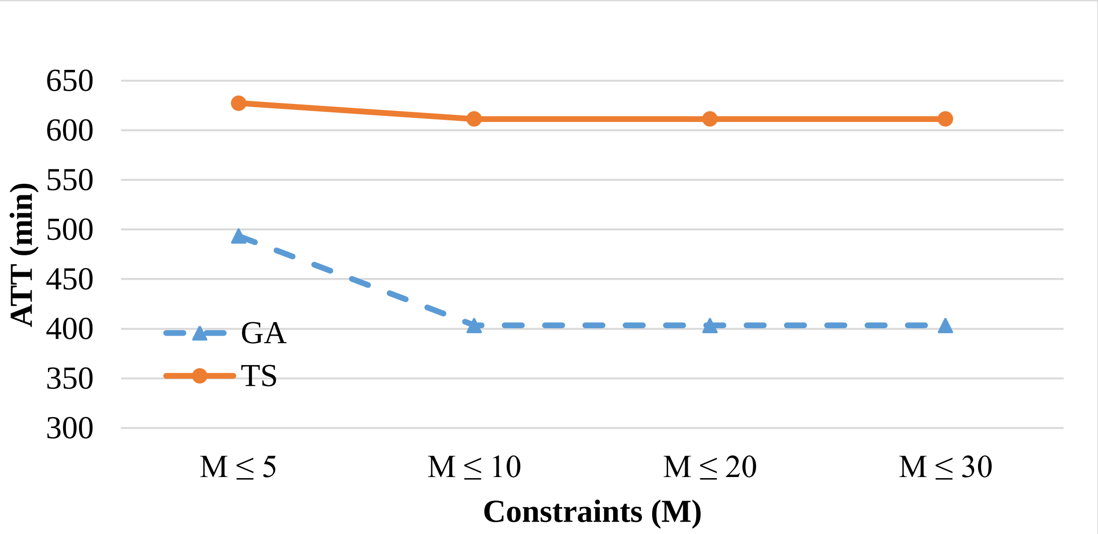


Figure 5. Comparison of GA and TS Results

A sensitivity analysis was conducted for the optimal solution (*i.e.*, 8 crossovers and 15 ramp closures) to ascertain the importance of each crossover and closure location. This was conducted by eliminating any single crossover or ramp closure location part of the optimal solution. Figures 6 and 7 show sensitivity analysis results for crossover and ramp closure locations, respectively. In these figures, X-axis shows the location of crossover (or ramp closure) that was dropped from the optimal solution to study its importance.

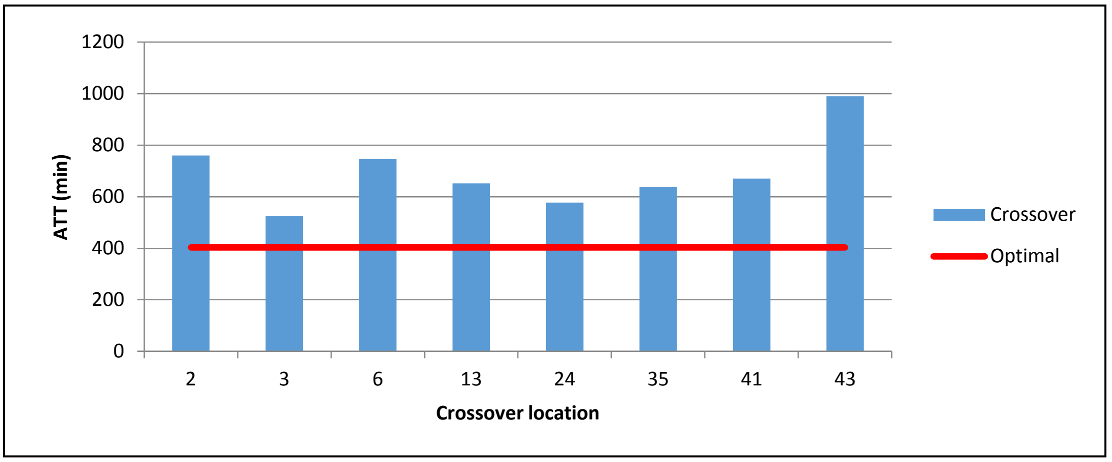


Figure 6. Importance of each Crossover Location in the Optimal Solution

From Figure 6, it can be concluded that removing the crossover from location 43 would have a more adverse impact on ATT than removing the crossover from any other single location that is part of the optimal solution. Location 43 is near the end of contraflow lanes and having an additional crossover point from contraflow lanes to regular lanes of I-64 provides significant mobility benefit. Among the different ramp closure locations shown in Figure 7, location 6 has the largest impact on ATT. The ATT value increases to over 1,100 minutes after dropping location 6 from the list of ramp closures.

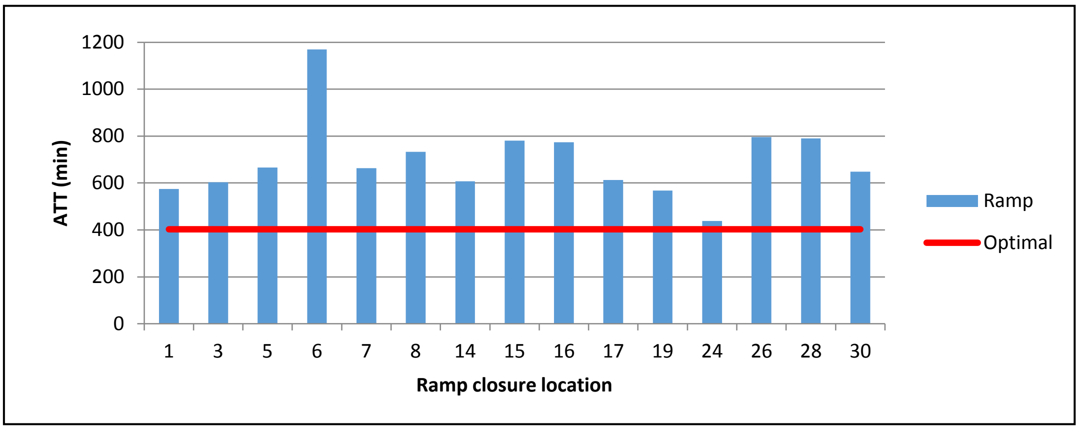


Figure 7. Importance of each Ramp Closure Location in the Optimal Solution

5. Conclusion

Traffic management strategies that can improve the efficiency of hurricane evacuation are valuable for emergency management agencies and citizens. One strategy that not been extensively studied in the past is the coordinated optimization of intermediate crossover and ramp closure locations for hurricane evacuation. A framework for accomplishing this coordinated optimization goal was presented in this paper. The proposed framework was demonstrated using a case study of Hampton Roads road network. Of the two heuristic approaches, GA outperformed TS by finding a solution with 34% lower average travel time. A sensitivity analysis was conducted to determine the importance of each crossover and ramp closure locations that were part of the optimal solution. The GA approach is recommended for optimizing the intermediate crossover and ramp closure locations. Developing a simulation model of the road network involves several steps including network creation, coding evacuation demand, selecting simulation parameters, *etc*. To expedite the simulation run times, one recommendation is to extract the portion of road network consisting of the contraflow facility and other alternative routes within its vicinity. Thus, a smaller size network can then be used to evaluate the objective function values for various intermediate crossover and ramp closure configurations.

There are a few directions for future research. First, due to the nature of heuristic optimization techniques, optimality is not guaranteed. Thus, other heuristic techniques may be explored and their performance compared with GA and TS results. Second, additional case studies from other regions are also recommended to further validate the proposed framework. Third, the proposed formulation was solved using a two-step procedure – first optimizing for intermediate crossover locations and then optimizing ramp closure locations. This approach was chosen since the costs associated with adding new crossovers involve significant construction costs, which are not factored in determining ramp closures since only existing ramps are considered. However, if both crossover and ramp closure costs must be accounted for at the same time, the solution approach must concurrently optimize the two variables. Finally, other traffic control techniques such as ramp metering, variable speed limits could also be integrated with the contraflow and ramp closure decision-making.

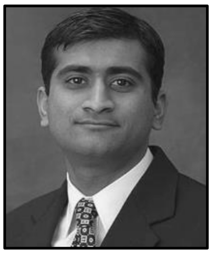
References

[1] J. Colins, “Evaluation of contraflow lanes for hurricane evacuation”, Transportation Research Record, 2041, **(2008)**, pp. 89-97.
[2] Y. C. Chiu, H. Zheng, J. Villalobos, W. Peacock and R. Henk, “Evaluating regional contra-flow and phased evacuation strategies for Texas using a large-scale dynamic traffic simulation and assignment approach”, Journal of Homeland Security and Emergency Management, vol. 5, no. 1, **(2008)**, pp. 34.
[3] E. Cox, “Fuzzy modeling and genetic algorithm for data mining and exploration”, Morgan Kaufmann Publisher, **(2005)**.
[4] Department of Transportation Federal Highway Administration. Dynasmart-P user’s guide, version 1.3.0, **(2007)**.
[5] V. V. Dixit, S. Ramasamy and E. Radwan, “Assessment of I-4 contraflow plans: microscopic versus mesoscopic simulation”, Transportation Research Record, 2041, **(2008)**, pp. 89-97.
[6] P. Edara, S. Sharma and C. McGhee, “Simulation analysis of the Hampton Roads hurricane evacuation traffic control plan”, The 88th Annual meeting of the Transportation Research Board, Washington D.C., **(2009)**.
[7] P. Edara, S. Sharma and C. McGhee, “Development of a large-scale traffic simulation model for hurricane evacuation: methodology and lessons learned”, Natural Hazard, ASCE, vol. 11, no. 4, **(2010)**, pp. 127-139.
[8] P. Edara, B. Smith, J. Guo, S. Babiceanu and C. McGhee, “A Methodology to Identify Optimal Placement of Point Detectors for Travel Time Estimation”, ASCE Journal of Transportation Engineering, vol. 137, no. 3, **(2011)**, pp. 155-173.
[9] P. Edara and L. Fang, “Hurricane evacuation modeling of the Hampton roads region – scenario analysis using mesoscopic simulation”, Virginia Center for Transportation Innovation and Research, Final Report VCTIR 12-R, **(2012)**.
[10] P. Edara and Y. Chang, “Hampton Roads Hurricane evacuation: Evaluation of Incident Effects and Network Treatments”, Virginia Center for Transportation Innovation and Research, Final Report VCTIR 15-R, **(2015)**.
[11] L. Fang and P. Edara, “Mobility benefits of intermediate crossovers on contraflow facilities during hurricane evacuation”, Transportation Research Record, vol. 2459, **(2014)**, pp. 37-46.
[12] F. Glover, “TabuSearch: ATutorial”, Interfaces, vol. 20, no. 4, **(1990)**, pp. 74-94.
[13] E. Kwon and S. Pitt, “Evaluation of emergency evacuation strategies for downtown event traffic using a dynamic network model”, Transportation Research Record, vol. 1922, no. 1, **(2005)**, pp. 149-155.
[14] C. Li and F. Wang, “Emergency evacuation study for the greater Jackson area: evacuation traffic from New Orleans”, Mississippi Department of Transportation, Final Report, vol. 210, **(2011)**.
[15] M. Mitchell, “An Introduction to genetic algorithms”, A Bradford Book, The MIT Press, **(1998)**.
[16] S. G. Machiani, P. Murray-Tuite, A. Jahangiri, S. Liu, B. Park, Y. C. Chiu and B. Wolshon, “No-notice evacuation management: ramp closures under varying budgets and demand scenarios”, 92rd Annual Meeting Transportation Research Board, Washington DC, **(2013)**.
[17] P. Murray-Tuite and H. S. Mahmassani, “Transportation network evacuation planning with household activity interactions”, Transportation Research Record, vol. 1894, **(2004)**, pp. 150-159.
[18] PBS & J. “Virginia hurricane evacuation restudy transportation analysis”, **(2008)**.

[19] T. Peoples, J. Williamson, G. Thorpe, J. Bennett and V. Barbour, "Revised median crossover guidelines", State of North Carolina Department of Transportation, **(2012)**.
[20] H. Sbayti and H. S. Mahmassani, "Optimal scheduling of evacuation operations", Transportation Research Record, vol. 1964, **(2006)**, pp. 238-246.
[21] G. Theodoulou and B. Wolshon, "Alternative methods to increase the effectiveness of freeway contraflow evacuation", Transportation Research Record, vol. 1865, **(2004)**, pp. 48-56.
[22] H. Tuydes and A. Ziliaskopoulos, "Tabu-based heuristic approach for optimization of network evacuation contraflow", Transportation Research Record, vol. 1964, **(2006)**, pp. 157-168.
[23] Y. K. Lim, "Modeling and evaluating evacuation contraflow termination point designs", Louisiana State University, **(2003)**.
[24] B. Wolshon, E. Hamilton, M. Levitan and C. Wilmot, "Review of Policies and Practices for Hurricane Evacuation II: Traffic Operations, Management, and Control", ASCE Natural Hazards Review, vol. 6, no. 3, **(2005)**, pp. 143-161.
[25] C. Xie, D. Y. Lin and S. T. Waller, "A dynamic evacuation network optimization problem with lane reversal and crossing elimination strategies", Transp. Res. Part E, vol. 46, no. 3, **(2010)**, pp. 295-316.
[26] C. Xie and M. A. Turnquist, "Lane-based evacuation network optimization: an integrated Lagrangian relaxation and Tabu search approach", Transp. Res. Part C, vol. 19, no. 1, **(2011)**, pp. 40-63.
[27] N. Zou, S. T. Yen, G. L. Chang, A. Marquess and M. Zezeski, "Simulation-based emergency evacuation system for Ocean City, Maryland, during hurricanes", Transportation Research Record, no. 1922, **(2005)**, pp. 138-148.

Authors

Yohan Chang, received his B.S. and M.S degree in civil engineering in Chonnam National University, S. Korea, in 2008, and 2010. He is currently pursuing his Ph.D. degree in civil engineering in University of Missouri-Columbia. His research interests include emergency evacuation, ITS, traffic modeling and simulation, traffic safety, machine learning, and data mining.



Praveen Edara, received his Ph.D. degree in transportation systems from Virginia Tech, Blacksburg, VA. He is an Associate Professor at the University of Missouri. His current research interests include traffic modeling, simu4lation, and ITS.

