MODELING CONGESTION IN EMERGENCY EVACUATION MODELS

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ABSTRACT

We have been developing a PC based emergency hurricane evacuation planning module, Regional Evacuation Modeling System (REMS), at the University of Florida since 1990 as part of a comprehensive hurricane emergency management decision support system. The software uses simulation as well as several network optimization models in estimating the evacuation time and the traffic flow on a given transportation road network. The system is very robust and user friendly. One of the important features of REMS is its ability to be used in real time. The simulation and optimization models implemented in REMS use different traffic congestion models into the estimation of evacuation times. As part of our ongoing integrated emergency management system development, we are refining and continuously testing congestion models used in REMS. We report some new experimental results that are currently available on REMS for congestion modeling.

1. INTRODUCTION

An ongoing issue in hurricane evacuation modeling is to the following: how does congestion affect the evacuation times?

Quick and accurate answer to this question is very important for the safety of the people being evacuated. In the past, many geographical areas have been ordered to evacuate to find out later that the hurricane did not hit their community. Usually, the hurricane tracking models are more accurate in determining the point of landfall as the storm gets closer to land. Therefore, an accurate estimate of evacuation times provides the needed few extra hours for the storm tracking models to be more accurate in their estimation. However, one should always keep in mind that an under-estimation of the evacuation time will have serious consequences since a good number of people will still be on the road as the pre-landfall hazards start to make travel difficult.

In managing evacuation during a hurricane, it is of paramount importance to estimate the evacuating population and the shelters that will hold the evacuating population accurately. It makes a great sense to establish safe shelters for the evacuating population within the county instead of sending several hundred thousand people on the roads for many miles to travel inland. A good hurricane emergency management system must consider establishing many new safe shelters before resorting to mass evacuation of the population. Providing many safe shelters for the evacuating population will have a dual advantage. Firstly, it will allow people which will be affected by the storm to move to their closest shelter without putting too much burden on the transportation network. Secondly, because of lesser traffic on the roads mostly generated by the transients and some background traffic, the evacuation time for the entire county will be reduced dramatically. This in turn will allow the decision makers to track the storm more accurately and minimize false alarms which is usually common in hurricane evacuation. It is well known that the accuracy of track estimation of a hurricane gets more accurate as the storm gets closer to land. Therefore, this management philosophy of establishing many evacuation shelters and opening them immediately as the storm approaches will have a profound effect in mitigating the dangers and hazards due to hurricanes. This suggested philosophy is in contrast to the existing practices in Florida. Some shelters stay closed during a hurricane if the intensity of the approaching hurricane is below 3 in Saphir-Simpson scale. Due to limited shelter capacity many evacuees naturally travel out of county to find hotels and motels in the neighboring counties inland. This puts undue burden on the transportation network. Excessive load on the roadways make it very difficult to travel and it takes many hours to travel distances normally can be travel in a matter of few minutes.

The accurate estimation of these road delays is of paramount importance to effective hurricane warning and evacuation ordering process. Over-estimation of evacuation times may evacuate an entire coastal community when not needed due to earlier evacuation order and under estimation may leave many evacuees struggling to flee when the wrath of a hurricane such as Andrew or Iniki is upon them.

With the help of REMS one can select among the candidate sites the ones that will serve the purpose of minimizing the total hurricane evacuation time. Furthermore, the software will also provide information as to which road segments will be heavily traveled and potentially become bottlenecks. This will also help planners to be proactive to oncoming storm and allocate necessary resources for managing and controlling appropriate roads and intersections. REMS will also have the ability to update the input data based on the current prevailing traffic conditions. With the help of continuous monitoring of roadways, emerging road conditions may be fed into REMS for analyzing the effects of these conditions on the bottleneck roads and the evacuation times.

REMS is an important component of an integrated proactive emergency management system we are currently developing at the University of Florida.

The current evacuation plans widely used in the State of Florida today are the evacuation studies of a number of different hurricane scenarios evaluated under the population and road traffic conditions of usually 3-8 years old. These studies are usually outdated either due to significant changes in the underlying traffic network and/or due to dramatic changes in the population mix and distribution. Furthermore, most of the traffic flow models used in those studies are not state of the art technology in modeling congestion that exists today. It is very likely that many of the existing evacuation studies which have been conducted several years ago are not valid representation of the reality which exists today.

3. MODELING AREA EVACUATION PROBLEMS

We have presented the process of developing data bases and the evacuation roadway networks in our earlier presentations. For further information of network modeling of area evacuations we refer our readers to [17].

The existing optimization and simulation models (Dafermos and Sparrow 1969, Gibson and Ross 1977, Hobeika and Bahram 1985, KLD Associates Inc. 1990, Sheffi, Mahmassani, and Powell 1981, Sheffi 1985, Sherali, Carter and Hobeika 1991) use one of the two fundamental approaches to allocate the people onto the road network. In one method, the people who reside at a particular origin (centroid) are matched (allocated) with a particular destination (shelter). This allocation process is accomplished by using what is known as the "gravity model" (Sheffi 1985). This model pre-assigns people from an origin to a destination before the actual traffic is loaded onto the road network. It uses the logic that the interchange volume between an origin and a destination is directly proportional to the magnitude of the evacuating people at that origin and the attractiveness of the shelter and inversely proportional to the impedance (distance) between the origin and the destination(see Sheffi (1985) for more details). This is the model used in many hurricane evacuation studies in the State of Florida (Tri-State Hurricane Study Tech. Data Report, and Appendix C 1986, Withlachoochee Hurricane Evacuation Study 1989),and also in some of the software developed for evacuation modeling (Hobeika and Bahram 1985, KLD Associates Inc 1990, Sheffi, Mahmassani, and Powell 1981, Sheffi 1985). The models then proceed to solve the allocation of traffic on the links of the network by using an appropriate model. The models used in this respect are usually either a simulation model or a user equilibrium models as discussed in Sheffi (1985). We call the resultant problem "The Specific Origin-Destination Problem".

Although this method of generating productions, attractions and subsequent trip distribution calculations may be appropriate in regular urban transportation analysis, it usually fails to apply in the case of emergency evacuations. First of all, many of the evacuees do not have any preference as to which particular shelter to go to other than a specific shelter type. Therefore, it is reasonable to assume that they will try to reach to the closest shelter of the type they prefer and settle in the first one with a vacancy. Pre-assigning people to shelters before the analysis seems to defeat the purpose of finding the optimal evacuation pattern which evacuates the people in the shortest possible time. Therefore, models which do not require the pre-assignment of trip tables may yield better evacuation results. In addition, as we shall see later, not restricting the movement of people between a specific origin-destination pair may help reduce the dimension of the problem.

The second group of models do not use any pre-assignment. In contrast, they assign people to their destination as part of the optimal allocation of the entire population on the transportation network. These models are said to combine the trip distribution and traffic assignment simultaneously. There have been a good number of user equilibrium models which combine the trip distribution and traffic assignment simultaneously. One particular network model which has been proposed by Sheffi (1985) also uses user equilibrium in allocating people on the roadways. In this model the transportation network is first augmented with some dummy destination nodes. The number of these dummy nodes equal to the number of types of shelters in the hurricane evacuation study. Each one of these dummy nodes corresponds to a particular type of shelter. Each shelter node in the original traffic network is then connected to its corresponding dummy shelter node via a dummy arc. Assuming O_{rk} represent the number of people who prefer to go to a shelter type k from origin r, this amount now will be assumed to be the origin-destination allocation between origin node r and the dummy destination node corresponding to shelter type k. Once the origin-destination allocations are complete the resulting problem can be solved by using any user equilibrium traffic assignment model. Note that this will produce an origin destination matrix of |O|x4 since there are only four different shelter types in a hurricane evacuation model. For further details on this model see Sheffi (1985).

Sherali and Hobeika (1991) propose another model for handling the trip distribution and traffic assignment simultaneously. In their model they make the number of shelter locations to be opened a decision variable. The resultant mixed integer programming model is then solved by Generalized Bender's Decomposition.

In the specific origin-destination models each origin-destination pair must be handled as a distinct commodity, requiring |O|x|D| many commodities in the corresponding network flow formulation, where |O| represents the number of origins and |D| represents the number of destinations (shelters) , respectively. If, on the other hand, the evacuees are allowed to go to any shelter of their choice, this will produce fewer commodities since there are only four different shelter types in an evacuation study (e.g. hotels/motels, public shelters, neighboring states, relatives' homes). In this case, we will call the corresponding problem as the nonspecific origin-destination evacuation problem.

The final possible modeling technique is when each evacuee is allowed to go to the closest and most convenient shelter. This certainly is the case in building evacuations and may be used for obtaining lower bounds on the area evacuation problems. This approach reduces the problem into a single commodity network flow problem. The problem dimensions get further reduced dramatically in this formulation.

In [17] we discussed extensively the static and dynamic network flow models and their use in congestion modeling. The following table provides the results of 3 Florida counties network clearing times based on arc-LP, arc-NLP, user equilibrium, path-LP and simulation solutions. In this paper we continue reporting further experimental results on these models. For details on these models we refer our readers to [17].

Following each static solution we used our dynamic simulation model to find out how the queues actually will form and what will be the actual evacuation times if we impose the static model solutions on the dynamic network. This is accomplished as follows: given that a static model assigned a flow of x_{ij}^* units on a road segment (i,j) we imposed the additional constraints on the dynamic model which required that the flow on all the time copies of that road segment should be exactly equal to x_{ij}^*

County/Model	Arc LP	Dyn. Sim.	Arc NLP	Dyn. Sim.	User Eql.	Dyn. Sim.	Path LP	Dyn. Sim.
Santa Rosa	4.22	4.43	4.36	4.33	5.60	5.36	4.44	5.4
Wakulla	1.46	1.67	1.51	1.83	1.95	1.83	1.60	1.88
Walton	12.98	12.7	13.08	12.8	12.99	12.7	13.01	12.75

TABLE 1. Results of specific OD models.

County/Model	Arc LP	Dynamic Sim.	Arc NLP	Dynamic Sim.
Jackson	18.56	18.50	18.67	18.5
Hancock	10.29	10.2	10.33	10.2
Santa Rosa	4.43	5.1	4.44	5.36
Wakulla	1.52	1.67	1.61	1.83
Harrison	37.16	36.83	37.23	36.83
Okaloosa	7.91	8.6	8.45	8.7
Walton	13.82	13.4	13.87	13.5

TABLE 2. Results of nonspecific OD models.

We have tested two versions of our models. In one version we assumed the people will select the closest shelter for their travel. We called these model the nonspecific OD models. In the second group we allocated each person to a specific destination and then solved for the best time and route to reach there. We called the corresponding models the specific OD models. The results of our test runs are given in Tables 1 and 2 below.

As we can conclude from these tables, the arc-LP and arc-NLP results are robust and yield very close evacuation times as compared with actual dynamic simulation results. Since the path LP does not utilize the entire transportation network (only those roads on the K shortest paths), its results are more on the conservative side when compared to arc-LP and arc-NLP results. This result was expected. However, the differences were dramatically small and thus making the path LP also a good model in estimating network evacuation times.

6. CONCLUSIONS

We have presented several network optimization and simulation models for the emergency evacuation problem. Results of comparison indicate that all models compare favorably with the established evacuation results taken from the county evacuation reports. The arc-LP and path-LP models are good models for obtaining quick approximations about the evacuation times and establishing bottleneck links. The arc-NLP model turned out to be a nice model to use in estimating evacuation times and establishing bottleneck links. One advantage of this model over the path-LP and arc-LP is its ability to allocate people on more links of the transportation network. Such a solution is much easier to communicate to an emergency manager than the one that predicts only a few roads carrying flow during evacuation. Dynamic network flow model is the most accurate of the models presented. however, due to excessive time requirements of the underlying optimization problem it can not be used very successfully on a PC platform. This is why we use an approximate dynamic model which uses only a small portion of the entire dynamic network and also uses a flow augmentation heuristic in assigning flows to paths instead of attempting to solve a very large size LP problem.

In many emergency evacuation problems the simpler models such as path allocation with linear objective may yield solutions accurate enough to compare favorably with more sophisticated nonlinear multicommodity specific O-D models.

In our follow up study, we will use these models in estimating network clearing times of other counties in the State of Florida. The results from our models will be compared with the current available evacuation result available in Regional Evacuation Reports which use gravity models followed by path allocation techniques of various complexities.

7. REFERENCES

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