

Real-time Information Driven Decision Support System for Evacuation Planning

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Abstract -- Mass traffic evacuations during Hurricanes Rita and Katrina demonstrated limitations of static planning-based evacuation models based on data from historical events. Evacuation dynamics are complex due to the number of people and vehicles, road networks, the uncertainty and perception of the event, public safety advisories, and human decisions regarding evacuation routes and behaviors. We describe a system under development for real-time information driven decision support system for evacuation planning and response. This system consists of an evacuation traffic prediction model injected with situational information extracted from traffic sensors and social networking sites. The situational awareness information obtained from multiple sources is fused with historic stated-preferences behavior data. Our model is novel because it augments standard evacuation models with evacuee sentiment via social media networks.

1. INTRODUCTION

Recent evacuations have highlighted the limitations of existing evacuation management systems. Hurricanes Floyd in 1999, Katrina and Rita in 2005, and more recently Gustav and Ike in 2008, necessitated large-scale evacuations, demonstrating significant shortcomings in the current state-of-practice in mass-evacuations during disasters. Traffic jams that thousands of motorists experienced in South Carolina while fleeing Hurricane Floyd, and in Texas while fleeing Hurricane Rita exemplify the frustration of people trying to evacuate. In the largest evacuation in U.S. history, more than three million residents of Texas tried to evacuate in advance of Rita, with memories of the devastation of Hurricane Katrina fresh on their minds. These events highlight the limitations of general evacuation management.

Several tools were developed to improve evacuation management process. Local and county level emergency managers use HURREVAC [8] to estimate hurricane evacuation traffic based on the potential threat of the event, weather conditions and historical patterns. Several DOTD state agencies have deployed Intelligent Transportation Systems (ITS) for traffic surveillance and monitoring. Real-time traffic for prediction is currently used for normal daily traffic prediction and transportation planning, rather than evacuation planning. Traffic maps provided by Google Maps, Bing Maps and Yahoo Maps provide traffic predictions based on normal daily traffic patterns, rather than evacuation traffic patterns.

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Evacuation based transportation modeling tools such as TRANSCAD [4], OREMS [2], DYNASMART [7] and ETIS [9] have limited capability to integrate situational awareness knowledge on real-time traffic conditions and evacuee behavior. Given the uncertainty associated with the impact of an event, the dynamics of evacuee behavior and availability of resources, developing an effective evacuation strategy is a challenge. While creating a perfect evacuation plan may seem impossible, we can dramatically reduce the risk of evacuation related disasters. Having reliable situational awareness will enable emergency managers to mobilize necessary resources in a timely manner to coordinate an effective emergency response. Recent studies on TwitterTM content from the Japanese earthquake [17] Red River flooding [20] highlight the potential of using social media as an effective tool to obtain situational awareness.

2. EVACUATION TRAFFIC AND FUEL DEMAND ESTIMATION TOOL

The NIMSAT Institute developed Evacuation Traffic and Fuel Demand Estimation tool for regional hurricane evacuation for the Louisiana's Department of Natural Resources (shown in Figure 1). This tool helps emergency managers to inform gas station owners ahead of time on expected demand and also coordinate emergency fuel distribution to areas that are likely to have fuel outages. This tool uses historical evacuee behavior, historical evacuation traffic patterns and a transportation model to predict evacuation traffic. The traffic predictions and fuel demand predictions can be viewed over different time intervals over a 3 day period prior to landfall on Geographical Information System (GIS) interface. Users can also configure the network reflecting evacuation orders and contra flow orders to

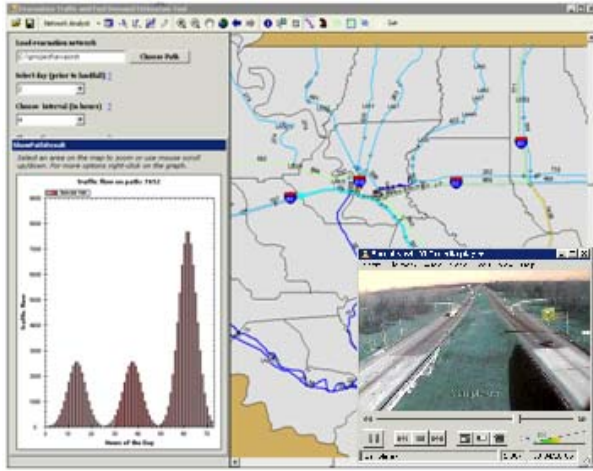


Figure 1 Evacuation traffic and Fuel Demand Estimation Tool

run traffic simulations. This tool also has the capability to stream real-time traffic from various sources such as video cameras, ATR's and gas station tank monitoring sensors to inform the decision of the current situation. While this tool provides some situational awareness visibility for the users, it does not use the situational awareness knowledge for evacuation traffic predictions. We are leveraging this existing tool that was built using ESRI's ArcObjects APITM to build our proposed real-time information based evacuation decision support system.

3. REAL-TIME INFORMATION BASED EVACUATION DECISION SUPPORT SYSTEM

Figure 2 shows a detailed description of system architecture. The information processing and synthesis component extracts data from various heterogeneous sources into origin-destination matrices and evacuation network configuration. The origin destination matrix represents the number of people evacuating from each origin to multiple destinations. The evacuation network configuration represents the state of evacuation highway network in terms of their most recent capacities, taking into consideration the contraflow lanes, road closures and recent traffic conditions. Both the origin-destination matrices and current evacuation network configuration serve as inputs to the evacuation traffic estimation model. The evacuation traffic prediction and simulation module uses the origin destination matrices, and network configuration generated from real-time data sources and any configuration parameters set by the user to generate traffic predictions. A GIS interface is provided to view the current traffic conditions and future traffic conditions based on the current situational awareness

knowledge. A configuration screen will enable users to review the input parameters such as the percentage of population that will evacuate the destination choices, the distribution of number of people vs. time, the network capacities and rerouting options to adjust these parameters to run what-if-scenario analysis.

The existing Evacuation Traffic and Fuel Demand Estimation tool is developed using ESRI ArcObjects APITM, along with Network Analyst extension. The proposed Real-time Information Based Evacuation Decision Support System will leverage this tool. Data from Twitter streams would be obtained from the TwitterTM streaming API through keyword based retrieval.

A. Extracting evacuee behavior from social media

Social information about evacuee behaviors during an event would make current evacuation modeling methods based on historical patterns of evacuee behaviors more useful to emergency management and transportation planners. These stakeholders must make critical decisions about locations, timing, and volumes of evacuees, but most tools are based on static network-planning models. We posit that real-time social media sources, such as TwitterTM, can be utilized to augment these models with behavior information during an event.

Previous research on social media content analysis focused on analyzing specific behavior elements or patterns of evacuees during previous events [1][6][10]. The co-authors of this paper developed an evacuation study along Louisiana's twelve coastal parishes [12]. The resulting "Evacuee Behavior Model" provides an understanding of the origin and preferred destinations of evacuating populations as well as timing of evacuations based on a set of parameters associated with the storm threat, physical infrastructure, fuel supply chain, and desired destination of evacuees.

Past evacuation behaviors have utility in developing evacuation plans, but they are poor predictors of future evacuation performance. We are developing novel methods to incorporate social media information about evacuation behaviors to refined and inform existing evacuation models. This approach utilizes hashtags from TwitterTM messages for inference modeling of evacuee behaviors. The advantages of this approach are the simplicity with which hashtags can be extracted and the popularity of hashtag adoption on TwitterTM. The drawbacks of hashtags as a primary concept extraction method are usage is optional, inconsistent, and specific to TwitterTM. Despite these drawbacks, hashtags are a primary mechanism for concept diffusion across TwitterTM. Romeo, Meeder,

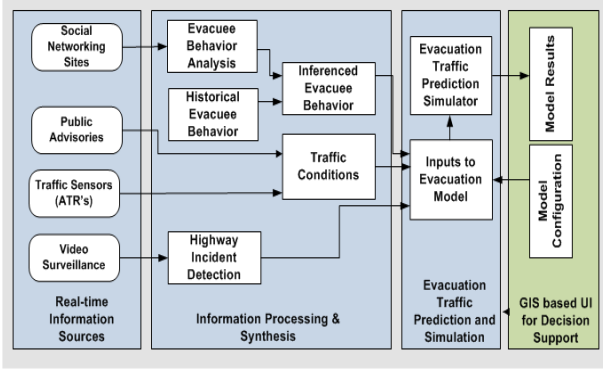


Figure 2 System architecture for real-time evacuation decision support system

and Kleinberg [16] characterize the spread of hashtags within user population using two properties: *stickiness* and *persistence*. *Stickiness* is the “probability of adoption of a hashtag based on one or more exposures”, and *persistence* is the “relative extent to which repeated exposures to a hashtag continue to have significant marginal effects on its adoption”. We are developing a hashtag schema for efficiently extracting and classifying evacuee behavior concepts from the Twitter stream before, during, and after a major event. This information will be integrated into our “Evacuee Behavior Model” to allow adaptation of the static model component to new behavior information.

B. Estimating current evacuation traffic conditions

Traffic information such as the current traffic along various evacuation routes, the traffic outflow from various origins that has occurred since evacuation are required to estimate the future evacuee traffic. The traffic counts along various highways can be recorded over time to obtain this information. However, traffic counting sensors are typically available along critical evacuation highway segments. We are investigating standard spatiotemporal interpolation techniques [3] to estimate missing traffic counts along various evacuation highways. Video cameras are a cheaper alternative for traffic surveillance and monitoring. Video content can be analyzed to estimate the traffic density and congestion at various evacuation highway segments [15]. The traffic information from traffic sensors and video will be combined to provide better estimates of evacuation traffic conditions.

C. Evacuation traffic prediction

Evacuation is typically modeled as a network optimization problem, where the goal is to select optimal routes from a set of candidate nodes within an existing evacuation network. The selection of optimal routes involves determining the potential evacuation

routes based on the location of origin and destination points, the capacity of highways, and the evacuee traffic patterns, that is, how, when, and where people would evacuate. The objective will be to minimize the maximum of the individual remaining times to the destinations, given the evacuee configuration and times to destination at the present time step. The constraints will be on fuel availability at the nodes at the next time step, traffic capacities along the edges, and the condition that no time to destination increases. Since this is a local-in-time model with re-initialization at each time step, it can be relatively simple, with robustness supplied by the constant data input. The model will compute traffic, fuel, and route capacities (adjusted e.g. through contra flow) for the next time step. The model would be adjusted with the most recently available data before the next time step. An example objective constructed with these considerations is of the form

$$\min(\phi(f)) = \max \{T_i^{t+\Delta t}\}$$

Where, $T_i^{t+\Delta t}$ is the sum of total remaining travel times of all population at node i to reach their destination at time t . This objective and the constraints will be computed in terms of variables $x_{i,j,l}^t$, representing the number of people to be traveling from location i to location j , with the ultimate final destination l in the next time step. Since, the $x_{i,j,l}$ can be pre-identified to equal zero at a given time step, the resulting linear program is extremely sparse, reducing the computational time. Existing evacuation models such as [13] are utilized for planning purposes to develop an optimal evacuation network configuration to minimize the overall evacuation time. In contrast to these models [13], our optimization model will not be done before the evacuation and over the entire evacuation period (that is, over multiple time steps), but during the evacuation, over a single time step, leading to a much smaller problem. The idea is that we are not optimizing the total evacuation event, but are minimizing the maximum delay in reaching the goal over each individual period of time, with adjustment from new observational data at each new time period.

4. CONCLUSION AND FUTURE RESEARCH

We described a system architecture for evacuation traffic prediction and management that leverages situational awareness knowledge from multiple real-time information sources such as traffic sensors, video cameras and social media. This system is being developed as a next-phase to the existing evacuation traffic and fuel demand estimation tool we developed for regional hurricane evacuation

The authors plan to investigate various research problems. First, we will identify ways to improve the quality of hashtags, given that hashtags in raw form may be incorrectly formatted or have spelling errors. Second, we will investigate content analysis techniques to mine situational awareness knowledge from raw tweets, since all Twitter users may not opt to use predefined hashtags. For example, the location information can be extracted from both the user profile and tweets. The evacuee sentiment [17] on decision to evacuate, data on destination choice and evacuation time can be extracted from raw tweet information and combined with historical evacuee behavior. We will also compare the performance of the proposed real-time information based evacuation model with existing evacuation models that are based on past behaviors.

5. REFERENCES

- [1] Baker, E. J. (1991). "Hurricane evacuation behavior." *Int. J. Mass Erg. Disasters*, 9(2), 287–310.
- [2] Bhaduri, B. and Liu, C. and Franzese, O., Oak Ridge evacuation modeling system (OREMS): A PC-based computer tool for emergency evacuation planning
- [3] Burnham, K. P., & Anderson, D. R. (1998). *Model Selection and Inference: A Practical Information-Theoretic Approach*. New York Springer (p. 353). Springer-Verlag.
- [4] Caliper Corp. "TransCAD Manual." *Travel Demand Modeling with TransCAD*. No. Version 5.0. 2007.
- [5] Chew C, Eysenbach G, 2010 Pandemics in the Age of Twitter: Content Analysis of Tweets during the 2009 H1N1 Outbreak. *PLoS ONE* 5(11):
- [6] Dash, N. and H.Gladwin. "Evacuation Decision Making and Behavioral Responses: Individual and Household", *Natural Hazards Review* 8, 69-77,
- [7] Mahmassani, HS and Hu, T. and Jayakrishnan, R. Dynamic traffic assignment and simulation for advanced network informatics (DYNASMART)
- [8] FEMA (2011): Retrieved Oct, 2011, available at <http://www.fema.gov/plan/prevent/nhp/hurrevac>
- [9] Evacuation Traffic Information System , available at <http://www.fhwaetis.com/>
- [10] Kang, J. E., Lindell, M. K., & Prater, C. S. (2007). Hurricane Evacuation Expectations and Actual Behavior in Hurricane Lili. *Journal of Applied Social Psychology*, 37(4), 887-903
- [11] Louisiana DOTD: traffic counts available at <http://www.dotd.la.gov/highways/tatv/default.asp>
- [12] Gottumukkala, N.R., R.Kolluru, X. Sun, Mark Smith, Bob Grambling, Haochun Zhang, "Fuel Demand Estimation for Regional Hurricane Evacuation", *The National Evacuation Conference*, Feb 3-5, 2010, New Orleans, LA.
- [13] Lu, Q., George, B., & Shekhar, S. (2005). Capacity constrained routing algorithms for evacuation planning: A summary of results. *Advances in Spatial and Temporal Databases*, 3633(81655), 291-307.
- [14] Mendoza, M., B. Poblete, and C.Castillo. 2010. Twitter under crisis: can we trust what we RT?. In *Proceedings of the First Workshop on Social Media Analytics, SOMA '10*
- [15] Porikli, F. and X. Li, "Traffic congestion estimation using HMM models without tracking", *IEEE Proc. Intelligent Vehicles*, 2004
- [16] Romero, D. B. Meeder, and J. Kleinberg. "Differences in the Mechanics of Information Diffusion Across Topics: Idioms, Political Hashtags, and Complex Contagion on Twitter", In *Proc.s of the Intl. WWW Conf*, March 2011, Hyderabad, India.
- [17] Sakaki, T., M. Okazaki, and Y. Matsuo. 2010. Earthquake shakes Twitter users: real-time event detection by social sensors. In *Proceedings of the 19th international conference on WWW '10*. ACM, New York, NY, USA, 851-860.
- [18] Signorini A, Segre AM, Polgreen PM, 2011 The Use of Twitter to Track Levels of Disease Activity and Public Concern in the U.S. during the Influenza A H1N1 Pandemic. *PLoS ONE* 6(5)
- [19] Smith, A. Twitter Update 2011. Pew Internet & American Life Project. Retrieved from <http://pewinternet.org/Reports/2011/Twitter-Update-2011/Main-Report.aspx>.
- [20] Starbird, K, L. Palen, Amanda L. Hughes, and Sarah Vieweg. 2010. Chatter on the red: what hazards threat reveals about the social life of microblogged information. In *Proceedings of the 2010 ACM conference CSCW '10*. ACM, NY
- [21] Wilmot, C. G., and Mei, B. 2004. "Comparison of alternative trip generation models for hurricane evacuation." *Nat. Hazards Rev.*, 54,170–17