Flood Impacts on Road Transportation Using Microscopic Traffic Modelling Technique

Contributions

Katya Pyatkova[1], Albert S. Chen[1], Slobodan Djordjević[1], David Butler[1], Zoran Vojinović[2], Yared A. Abebe[2], Michael Hammond[2];
[1] Centre for Water Systems, University of Exeter , Exeter, United Kingdom
[2] UNESCO-IHE, Institute for Water Education, Delft, The Netherlands

{K.Pyatkova, A.S.Chen, S.Djordjevic, D.Butler}@exeter.ac.uk
{Z.Vojinovic, Y.Abebe, M.Hammond}@unesco-ihe.org

1.1 Abstract

The research presented in this paper proposes a novel methodology for modelling the impacts of floods on traffic. Often flooding is a complex combination of various causes (coastal, fluvial and pluvial). Further, transportation systems are very sensitive to external disturbances. There is insufficient knowledge on the interactions in these complex and dynamic systems. This paper proposes a methodology for integrating a flood model (MIKE Flood) and a traffic model (SUMO). Traffic on inundated roads will be interrupted or delayed according to the manner of flood propagation. As a consequence, some trips will be cancelled or rerouted and other trips will be indirectly affected. A comparison between the baseline and a flood scenario yields the impacts of that flood on traffic, estimated in terms of lost business hours, additional fuel consumption, and additional CO2 emissions. The outcome suggests that the proposed methodology can help to quantify the flood impact on transportation.

Keywords: microscopic traffic modelling, flood impacts, traffic disruption, flood modelling, model integration

1.2 Introduction

In order to consider flood impacts on traffic, general aspects of flood impacts should be addressed. Floods can impact human activities in many ways and this is why it is common to categorise these impacts. The flood consequences can be grouped as direct or indirect, tangible or intangible, or a combinations of both [1].*Direct* damages occur if the asset of interest is physically exposed to flood waters (i.e., buildings, people or environment). *Indirect* damages are outside the flooded area and usually become apparent after a longer time [2]. A classic example of indirect losses is the interruption of production in a firm that might occur due to a supplier affected by flooding. Traffic disruption due to floods is another indirect flood impact, the importance of which has not been studied in detail. The main reasons are: 1) the complexity of integrating two highly dynamic and uncertain systems; 2) the need to assess flood impacts in monetary terms (for the purposes of cost-benefit ratio). Flood impacts on traffic are often intangible: loss of time, frustration, environmental degradation due to additional CO_2 emissions. However, they can also have monetary dimensions: additional operating costs and fuel consumption have market prices, and loss of time could be monetized as well. Approaches to monetize the intangibles and the emerging importance of multi-criteria analysis for hazard impact assessments create the necessary conditions for the proper evaluation of flood impacts on traffic.

To date traffic disruption due to flooding has received little attention. Comprehensive flood impact guidelines recommend carrying out traffic disruption study only if the expected traffic losses are significant, because otherwise the cost of traffic disruption is negligible compared to direct or indirect tangible costs [3]. It should also be noted that the importance of impacts on traffic (relative to other flood impacts) varies – in some cities (e.g. in Beijing) it is a major problem; but in other cities it is not so significant. So far the flood impacts on traffic have been approached using simple mathematical models [3] or macroscopic traffic models [4], [5]. None of these methods consider the dynamics of the transportation system, rerouting whilst a street is closed, or the dynamics of the flooding event. These methods represent a static system, which uses homogeneous aggregated traffic flows. The reliability of such models is not high, especially when it comes to simulating decisions in complex urban traffic networks. Microsimulation represents traffic congestion situations and bottlenecks more realistically, mainly through its algorithms incorporating drivers' responses and intermodal transportation [6], [7].

To date micro-simulation has not been used for computing flood impacts on traffic congestion and this is one of the main goals of this research. Another primary objective of this research is to introduce monetizing techniques not only for lost hours in traffic congestion, but also for the cancelled trips. Thus, the importance of flood impacts on traffic will be emphasised. From the modelling part an evident gap in the current research is the fact, that traffic models are not based on the duration and propagation of the flood. The methods introduced in this paper will address this dynamic behaviour of the system, through timely changes of the status of the links (open, closed, or with certain speed limit in accordance to the changes in flood depth).

1.3 Methodology

The proposed conceptual framework for incorporating flooding conditions into a microscopic traffic model is outlined in Figure 1. The impact of extreme hydro-meteorological events on transportation is twofold. First, the extreme weather conditions lead to reduced maximum speed limits [8], [9]. This impact will be driven by the intensity and the duration of the rainfall event and it will result in reduced road capacity before the flood has even occurred. Thus the flood impacts will start evolving in a transportation system, which already has reduced capacity due to heavy rainfall intensities.

Different combinations of intensities of rainfall and storm surges are simulated to produce the time varying flood characteristics. The consequent flood intensities in terms of flood extent, depth and propagation determine whether a street in the road network is going to be closed for traffic. This closure will affect both the overall road capacities and the trip definition components of the flood model. The trips that have an origin or destination in the flooded area will be cancelled and the routes that pass through a flooded area will be rerouted to unfavourable routes. A micro-simulation technique facilitates a better and a more detailed representation of the traffic processes, compared to macro-simulation. There are several reasons to adopt a micro-simulation technique for the assessment of flood impacts:

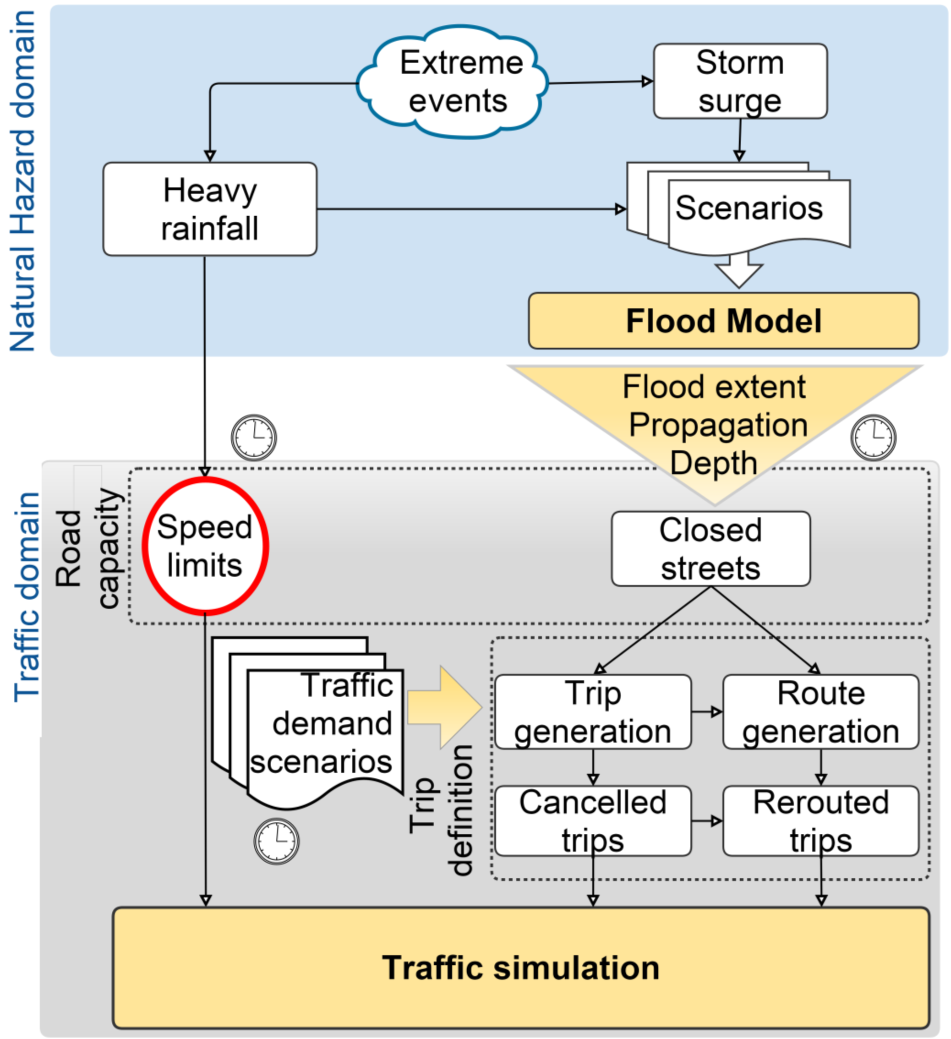

Figure 1: Flowchart of the proposed methodology

- When a street is closed due to flooding conditions, each vehicle will be rerouted individually, according to its destination. Hence, the rerouting algorithm ensures a detailed representation of the traffic condition during flooded conditions. This is particularly important if there are numerous flooded streets throughout the whole network;

- The micro-simulation technique is more reliable for the estimation of losses, related to the cancelled trips that will occur due to the flooding, because it contains a detailed description of each trip;

- The intermodal representation of different vehicle types is important for the overall consumption of fuel and greenhouse gas emissions. Different modes of transportation also indicate different cost of travel delays and will result in a more realistic representation of the flood impacts.

- Microscopic traffic models can simulate the dynamics of the flood propagation both in spatially and temporally. For instance, depending on the flood severity, it can allow closure of only one lane, whist keeping the traffic active in the other lanes;

At the end the results of the traffic simulations will be compared for scenarios with and without flooding. The whole procedure will be performed for different flooding scenarios, different times of the day (pick and off-pick times). As stated before the end results will be presented in absolute measures of lost business hours, additional fuel consumption, and additional CO_2 emissions. The lost time and the additional fuel consumption will be also represented in monetary terms, so that they can be easily compared to the other type of flood losses and damages in the studied area. Ultimately, such an approach will allow for testing the effects of both flood risk management measures and of traffic improvement systems.

The model will be applied to a case study in a Caribbean island – St Maarten. This case study is considered appropriate for the research for two reasons: first, it has been a frequent victim of tropical storms and hurricanes and second, a closed road network system of an island helps assessing indirect impacts easier.

The following sections elaborate the hydraulic model, used to simulate the flooding conditions, the translation of flooding results into SUMO environment and the SUMO modelling setup.

1.3.1 Hydraulic model

The case study area of St Maarten is prone to tropical storms and hurricanes. Even small scale floods in the past posed a serious threat to traffic [10]. The hydraulic modelling is carried out on a catchment level for the most hazardous catchments in the island of St Maarten. The flood hazard characteristics (depth and velocity) are computed using DHI software MIKE FLOOD [11]. This software makes it possible to couple MIKE 11 (1D river model) and MIKE 21 (2D model, computing the flood plain and the coastal flooding). The results from the coastal flooding model are used as boundary conditions in the MIKE FLOOD simulation. This ensures integration between surface runoff and coastal conditions at each time step. The flooding conditions are simulated for different return periods of storm events, assuming independence of the rainfall and storm surge occurrence. The results of the hydraulic model provide maps for relevant flood depth over time, depending on the flood propagation at a particular site.

1.3.2 Translation of flood model results into SUMO model input

The time varying flood maps identify the streets that will be closed and the duration of the closure. This extraction is performed in a GIS environment by overlaying the flood map with a road network (Figure 2). The roadmap is a modified version of Open Street Map (OSM), which ensures all street types and speed limits are correct. The description of the roads in OSM does not allow a precise identification of the location of the flood because streets are represented with only one line. In order to avoid conversion discrepancies, a reliable translation of the link indices is desired. This is performed first by segregating major streets into edges in a GIS environment and second, by giving unique indices of the individual edges. The resultant shapefile is saved as an OSM network and then translated to SUMO, using the netconvert application. That way, no data will be lost in conversion, i.e. space varying speed limits, or number of lanes per street. This operation also established a linkage between the ArcGIS and SUMO environments, by using the same edge IDs. Thus a list of flooded streets is identified by their IDs in GIS environment and is readily available for rerouting in SUMO. To provide consistency, the newly created road map is used for simulating traffic with and without flooding.

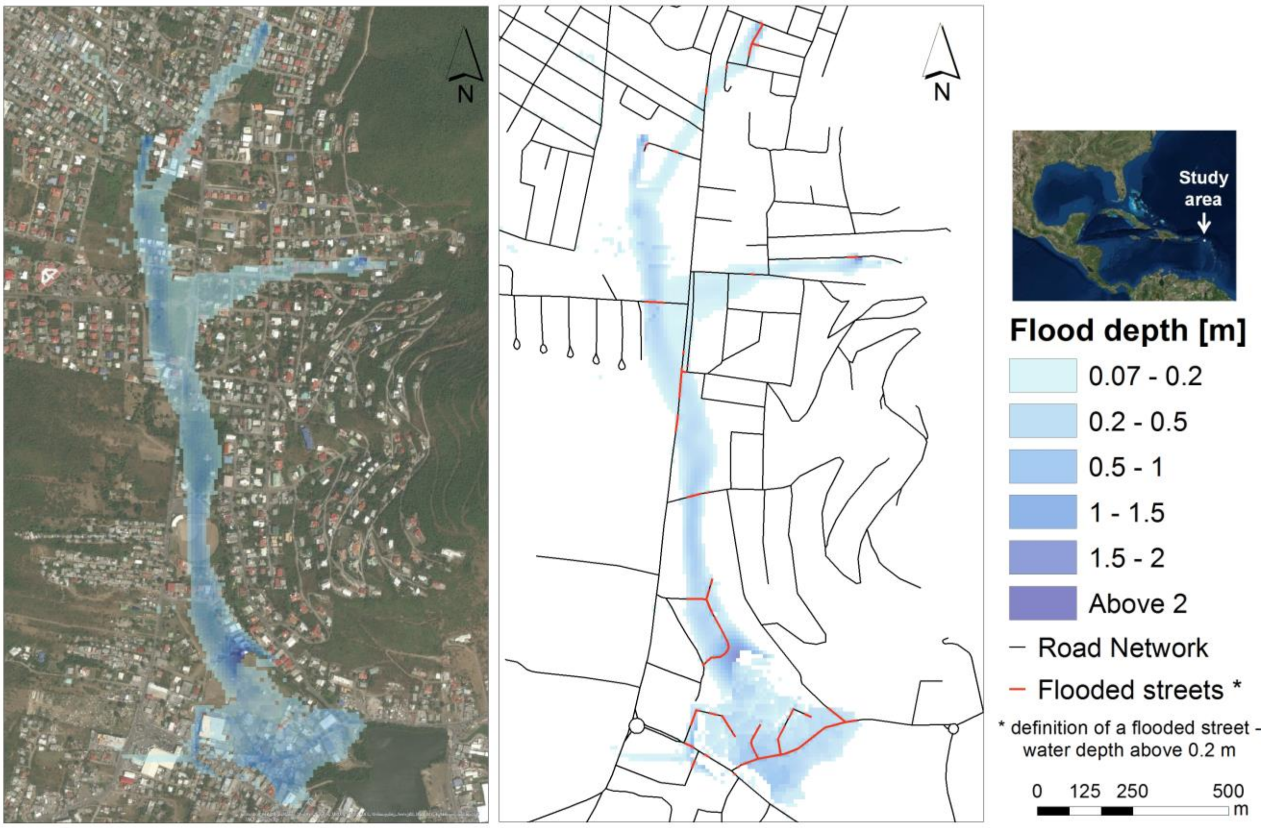

Figure 2: Flood map (left), and a road map overlaid with a flood map (right), showing in red the roads closed to traffic

1.3.3 SUMO parameters setting and traffic volume estimation

The SUMO software [12] has been used to create a basic model, so that the proposed methodology can be tested (Figure 3). The traffic model is limited by the reduced availability of transportation measurement data, but it is believed there is sufficient data with which to test the methodology. Currently the model uses the traffic network of the whole island of St Maarten, which is rather large for conventional microsimulation network (total area 34 km^2 and nearly 40 000 inhabitants).

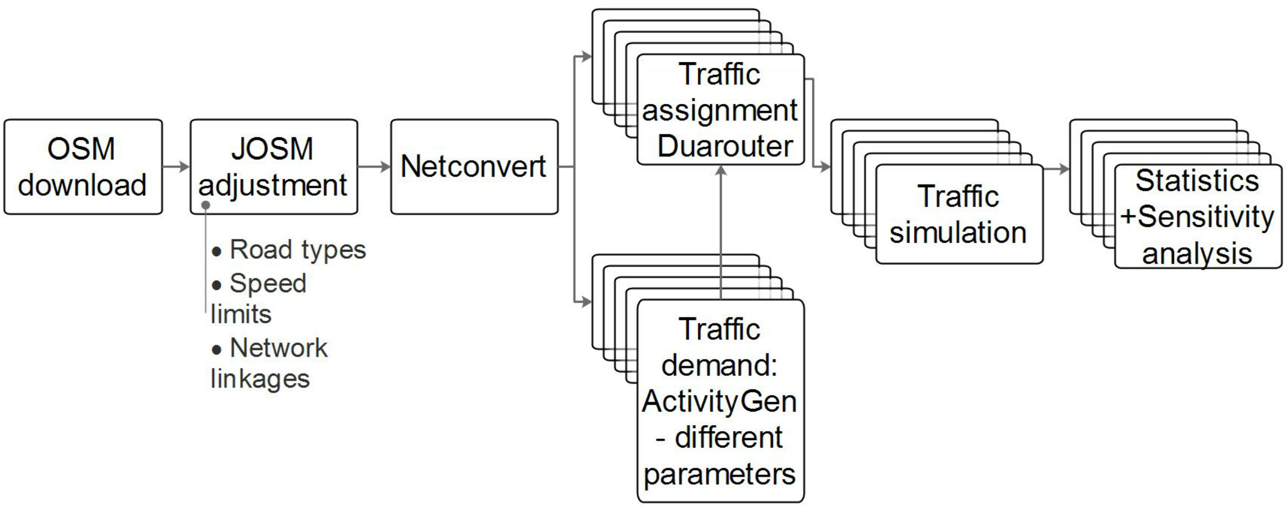

Figure 3: Flowchart of implemented traffic model

This network has been extracted from Open Street Map and later on modified for the purposes of SUMO, with special attention given to the different types of roads and their maximum speed limits. The traffic demand is based on a quasi-random route generation (ActivityGen), based on statistics about settlements, population and the location of big employers. Different parameter combinations are used to run the model and obtain statistics for each scenario. The sensitivity analysis of the different scenario results can help improve the understanding of how the system functions. This strategy for computing traffic demand is hoped to help overcome the lack of data for calibration. The large number of quasi-randomly generated data approaches the traffic demand distribution from a probabilistic standpoint.

Another objective of the research is to investigate what the environmental impact of traffic congestion during floods can be. To achieve this, the SUMO model employed a simplified HBEFA classification of vehicles and their relevant CO_2 emission levels for different engines. This model also provides a description of fuel consumption for individual trips in the simulation and thus can help monetize the impacts of floods on traffic congestion.

The actual flood impacts on traffic are estimated as a comparison between the results of a flooded and non-flooded situation for different scenarios of flooding, time of the day and traffic demand generation. The final result files provide statistics about each individual trip that has been computed. As stated before the main interest will be the difference in trip duration, fuel consumption and greenhouse gas emissions between the flooded and the baseline scenario.

1.3.4 Monetization of traffic delays

Previous studies in the field of flood impact to traffic congestion [4], [5] indicate that wasted time in traffic congestion will be the most significant flood impact to transportation. This imposes the need to monetize business hours lost in traffic, so that they can be compared to other tangible flood impacts as damage to built environment or business interruption. Value of time per individual person (driver or passenger) is defined by the purpose of the trip, mode of transportation and the type of vehicle [13]. The cost of the additional travel time can also depend on the duration of the delay. Interviews showed delays longer than 30 min have higher relative costs than shorter delays [14]. This research will employ a monetizing method which will consider a UK methodology [13] to estimate costs of travel times based on assumptions on average income.

1.4 Concluding remarks

This paper presents a novel methodology for assessing flood impacts on traffic. Micro-simulation traffic models have not been used yet to approach that problem, even though only a microsimulation model can capture the dynamics of both the natural and social-technological sphere.

The methodology presented in this paper is to be further confirmed by modelling results and supported by actual traffic measurements for calibration of the representation of traffic demand. The model for cost assessment of travel delays also needs to be adjusted to regional specifications of salaries in Saint Maarten.

The approach presented in this paper relates to off-line analysis of combined flood and traffic modelling. This methodology lends itself nicely for real-time modelling and decision making for coupled flood and traffic management systems.

ACKNOWLEDGMENT

Research on the PEARL (Preparing for Extreme And Rare events in coastaL regions) project is funded by the European Commission through Framework Programme 7, Grant Number 603663.

References

[1] E. Penning-Rowsell, J. Chatterton, and E. P. Rowsell, "Assessing benefits the of flood alleviation and land drainage schemes," *ICE Proc.*, vol. 69, no. 2, pp. 295–315, Jan. 1980.

[2] B. Merz, H. Kreibich, R. Schwarze, and A. Thieken, "Review article 'Assessment of economic flood damage,'" *Nat Hazards Earth Syst Sci*, vol. 10, no. 8, pp. 1697–1724, Aug. 2010.

[3] E. Penning-Rowsell, *The benefits of flood and coastal risk management: a manual of assessment techniques / Edmund Penning-Rowsell ... [et al.].* London: : Middlesex University Press, 2010.

[4] H. Chang, M. Lafrenz, I.-W. Jung, M. Figliozzi, D. Platman, and C. Pederson, "Potential Impacts of Climate Change on Flood-Induced Travel Disruptions: A Case Study of Portland, Oregon, USA," *Ann. Assoc. Am. Geogr.*, vol. 100, no. 4, pp. 938–952, Aug. 2010.

[5] P. Suarez, W. Anderson, V. Mahal, and T. R. Lakshmanan, "Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area," *Transp. Res. Part Transp. Environ.*, vol. 10, no. 3, pp. 231–244, May 2005.

[6] D. Helbing, A. Hennecke, V. Shvetsov, and M. Treiber, "Micro- and macro-simulation of freeway traffic," *Math. Comput. Model.*, vol. 35, no. 5–6, pp. 517–547, Mar. 2002.

[7] B. S. Kerner and S. L. Klenov, "Microscopic theory of spatial-temporal congested traffic patterns at highway bottlenecks," *Phys. Rev. E*, vol. 68, no. 3, p. 036130, Sep. 2003.

[8] D. Jaroszweski, L. Chapman, and J. Petts, "Assessing the potential impact of climate change on transportation: the need for an interdisciplinary approach," *J. Transp. Geogr.*, vol. 18, no. 2, pp. 331–335, Mar. 2010.

[9] M. J. Koetse and P. Rietveld, "The impact of climate change and weather on transport: An overview of empirical findings," *Transp. Res. Part Transp. Environ.*, vol. 14, no. 3, pp. 205–221, May 2009.

[10] UNDP, "Innovation and technology in risk mitigation and development planning in SIDS: Towards flood risk reduction in Sint Maarten. United Nations Development Programme, Barbados and the OECS," 2012.

[11] DHI, "MIKE FLOOD Modelling of Urban Flooding, A Step-by-step training guide." 2007.

[12] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, "SUMO - Simulation of Urban MObility - an Overview," presented at the SIMUL 2011, The Third International Conference on Advances in System Simulation, 2011, pp. 55–60.

[13] R. Vickerman, "Evaluation methodologies for transport projects in the United Kingdom," *Transp. Policy*, vol. 7, no. 1, pp. 7–16, Jan. 2000.

[14] N. J. Douglas, L. J. Franzmann, and T. W. Frost, "The estimation of demand parameters for primary public transport service in Brisbane attributes," in *Australasian Transport Research Forum (ATRF), 26th, 2003, Wellington, New Zealand*, 2003.