TRAFFIC MANAGEMENT MODEL TO FLOODED REGIONS

Leise Kelli de Oliveira – Departamento de Engenharia de Transportes e Geotecnia, Universidade Federal de Minas Gerais – leise@etg.ufmg.br

Nilo de Oliveira Nascimento – Departamento de Engenharia Hidráulica e Recursos Hídricos, Universidade Federal de Minas Gerais – niloon@ehr.ufmg.br

Farney Aurélio Alcantara - Departamento de Engenharia de Transportes e Geotecnia, Universidade Federal de Minas Gerais – farney@ufmg.br

Rodrigo Amaral Bonatti – Departamento de Engenharia Hidráulica e Recursos Hídricos, Universidade Federal de Minas Gerais – rodrigo.bonatti@gmail.com

ABSTRACT

During the months from November to March, heavy and located rains occur in the Metropolitan Region of Belo Horizonte. Due to the sinuous topography of this region and the high rate of soil sealing, the watercourse of the city often does not include the rapid rise in the volume of water transported, coming to overflow and flood their respective flood plains, usually occupied by men. When floods occur, the traffic of this region is directly affected, causing major traffic jams due to the interruption of roads. This paper presents a traffic management model that allows to quantify the impact of traffic disruption due to flooding on roads, estimating the diseconomy caused by increase in travel time, fuel consumption, among others. Moreover, alternative routes will be research when a particular road is flooded or in imminent risk of flooding. The methodology includes research on traffic conditions in this region in normal weather. Subsequently, a virtual model will be developed to simulate the traffic in this region. In this model, knowing the spots of flooding in the region, scenarios will be simulated with disruption due to flooding, to analyze the new traffic conditions and the operation of the alternative routes suggested by the model. Moreover, the increments are calculated in travel time, fuel consumption, environmental impacts, and, consequently, economic impacts.

INTRODUCTION

It is well known that the urban transportation sector contribute to climate change through emissions, but much less attention has been given to the potential impacts of climate change on urban transportation system. In addition to a gradual warming of ambient temperatures, climate change is expected to include increases in the frequency and severity of storms (SUAREZ *et al.,* 2005).

Flooding is on the rise not only due to climate change. The relentless canalisation of streams and waterways of the last 100 years has combined with urban exploitation of natural flood plains and marshlands to raise the stakes. Ground-absorption rates have declined, while run-off from precipitation finds fewer and fewer natural channels. The result is increasing incidence of flash flooding at the local level and catastrophic-sized flooding regionally.

A flood is an overflow or accumulation of an expanse of water that submerges land. Floods can also occur in rivers, when the strength of the river is so high it flows out of the river channel, particularly at bends or meanders and causes damage to homes and businesses along such rivers. While flood damage can be virtually eliminated by moving away from rivers and other bodies of water, since time out of mind, people have lived and worked by water to seek sustenance and capitalize on the gains of cheap and easy travel and commerce by being near water. That humans continue to inhabit areas threatened by flood damage is evidence that the perceived value of living near water exceeds the cost of repeated periodic flooding.

It is recognized that urban infrastructure is vulnerable to flooding (SCHREIDER *et al., 2000*), but little is known about how flooding events affect the performance of urban transportation networks as integrated systems (SUAREZ *et al*., 2005). For this, it is important to know how traffic disruption in urban travel results from the intense rainfall flooding events that are expected to become more common over the 21st century.

In the transportation sector, floods cause traffic disruption, traffic jams and associated damage such as increasing emission of pollutants and consumption of gas, increasing travel time, as well as other disruptions on the economic activity. Casualties and deaths may result of people being stuck in their cars or in buses during floods. In Brazil, some cities such as Belo Horizonte, São Paulo, Recife, Rio de Janeiro, and others, frequently suffer from floods leading to different types of losses, including direct and indirect losses associated to traffic disruption. Figure 01 illustrates a flood occurrence in December 2008, in the Arrudas river valley in Belo Horizonte (BR). The Arrudas catchment is one of the largest in the city area, with a total surface of 250 km^2, and about 170 km^2 in the municipal area. The Arrudas river length in the municipal territory is 37 km. Some of Arrudas floods caused death, as in the case of floods in 1977, with 17 deaths, and 2002 with 16 deaths. 1977 floods lead to the proposal and set up of a major structural project focusing on flood control and based on channelization. Although the flood risk has indeed been reduced in downtown Belo Horizonte, the upper parts of the catchment still are subject to high flood risk levels in spite of the channelization of the Arrudas river.

This paper presents a model to assess economical impacts on urban traffic caused by floods. The study was developed using traffic simulation to compute the levels of congestion caused by a road interrupted by typical floods. Through simulation it was possible to determine the fuel consumption, emissions, and delays in travel time. With this information, it was possible to estimate the economic impacts caused by floods according to the methodology proposed by Cançado (2009). Modelling of floods, using models CABC and HEC-RAS (COBRAPE, 2008; PBH, 2009) and of traffic, using traffic simulation, were applied in a catchment located in the north area of Belo Horizonte.

DEFINING FLOODS

Floods can be defined as a temporary covering of land by water outside its normal confines. They happen in small and large river basins, in estuaries, at coasts and locally. Beside these general conditions, floods can be systematized according to the genesis of events, such as winter rainfall floods, summer convectional storms provoking floods, surge CABCs and tidal floods, urban sewer floods, dam break or floods caused by the operation of reservoirs. Each event can be characterized by features such as water depth, flow velocity, matter fluxes, and temporal and spatial dynamics (SCHANZE *et al.,* 2006)

Yevjevich (1994) defines the three main types of flooding as:

- Natural floods: any flooding that occurs in natural catchments non occupied by human activities;
- Modified Natural Floods: like the first, but in this case floods are modified by human intervention, such as for instance by flood attenuation measures; Disaster generated entirely by men, including the group of flooding caused by the collapse of structures, such as dam breaks.

The probability of occurrence of potentially damaging flood events is called flood hazard. Potential damage means that there are elements exposed to floods which could, but not necessarily, be harmed. For example, a building in a floodplain can be threatened by 50-year return period flood event, with a water level of a 1 meter and by a 100-year flood, with a water level of 1,5 meters, leading to different issues in terms of flood damages. Moreover, these events may be associated with different transport capabilities regarding debris, sediment and other substances with varying impacts on human beings and on the environment (SCHANZE *et al.*, 2006).

Damage caused by floods depends on the vulnerability of exposed elements. The term vulnerability refers to inherent characteristics of these elements which determine their potential to be harmed. It can be understood as a combination of susceptibility and societal value and be expressed by direct and indirect effects which are tangible and intangible (SCHANZE *et al.*, 2006; SCHIMTT *et al.*, 2004). Based on the technical literature in this domain (e.g. HUBERT and LEDOUX, 1999; DUTTA *et al.,* 2003; and PENNING-ROWSELL and CHATTERTON, 1977) Nascimento et al. (2005) suggested the classification of flood damage described by Table 1.

Table 1: Typology of damage caused by floods in urban areas (NASCIMENTO et al, 2005)

Sector	Tangible Damage		Intangible Damage	
	Direct	Indirect	Direct	Indirect
Dwelling	Physical damage to the building, structure and its content	Cleaning costs, household, medicines	Human lives losses	Psychological stress and anxiety state; long term health damage
Commerce and services	Physical damage to the building, structure and its content Loss or harm to stock goods	Cleaning costs Loss of trading profits Unemployment Data base loss	Human lives losses	Psychological stress and anxiety state; long term health damage
Industrial	Physical damage to the building, structure and its content Loss or harm to stock of raw material and finished goods	Cleaning costs Loss of trading profits Unemployment Data base loss	Human lives losses	Psychological stress and anxiety state; long term health damage
Public equipment and services	Physical damage to the building, structure and its content	Cleaning and service interruption costs Emergency services costs	Human lives losses	Psychological stress and anxiety state and lack of motivation; long term health damage Inconveniences due to services interruption
Infra-structure	Physical damage to the patrimony	Cleaning and service interruption costs	Human lives losses	Inconveniences due to services interruption
Historical and cultural patrimony	Physical damage to the patrimony	Cleaning and service interruption costs	Human lives losses	Inconveniences due to services interruption

When a flood occurs, the local traffic is hit directly by the event and the consequences are of direct and indirect nature, with tangible and intangible damage. For instance, cars may be directly touched by flood waters and there is an obvious impact on traffic resulting in traffic jams. Also frequently, the road infrastructure needs to be repaired, leading to longer time period required to recover former traffic conditions in the damaged area.

Floods in Belo Horizonte

The occurrence of floods in Belo Horizonte, and throughout its metropolitan area, is frequent. The topography of the city is characterized by narrow valleys and steep slopes which make the area prone to flash flooding. The land use of the area is typically of high population density implying a general spread of impervious surfaces, preventing good infiltration conditions, increasing runoff volume and velocity. These are factors that explain the high flood risk observed in different area of the municipality. Due to the topographic and land use characteristics of the area, it is more sensitive to rainfall events of convective origin. Figure 1 illustrates a typical channel built in Belo Horizonte for flood control (Arrudas stream) and a failure of this structure, leading to floods. The flood event shown in the picture occurred 31st December 2008 and was caused by a rainfall event which lasted of 1 hour with average rainfall depth of 70 mm on the catchment area.

Figure 1 –Arrudas River

FLOODS AND ROAD TRAFFIC

Floods can damage any transportation system. When a segment of a network is closed by floodwater, various flood impacts can be observed on the characteristics of traffic flow, including the traffic congestion, increased traffic volume, decreased speed limit and increased travel time. For this reason, any effect on the network can be seen as a potential threat to the characteristics of traffic flow (HOSSAIN and DAVIES, 2004).
Networks consist in nodes and links. In nodes, a service is produced, generated or consumed. In links are transported discrete units such as cars, buses or trucks. Travelers are consumers who receive the benefits of networking to reach their destination. Floods can cause damage in two different ways: additional costs (marginal) transportation and the damage caused by the monetary value of time. Transport costs comprise fuel, oil and depreciation costs. Flood losses represent lost opportunities which can never be recovered because we cannot go back in time. Time wasted because of a flood can never be recovered

and represents a lost resource or opportunity. Valuing losses due to traffic delays at either the origin or destination of the disrupted travelers is complex (BRUZELIUS, 1979).

It is important to evaluate the flood impacts on the transportation system because (SUAREZ *et al., 2005)*:

- Some trips will be cancelled because the origin location or the destination location is flooded. For example, some work trips or shopping trips will not occur because the homes, work or shopping places are flooded;
- The travel time will be much higher due to flooding. This may occur because travelers are forced to take different routes from origin to destination to avoid impassable links, or as a result of traffic congestion.

These disruptions have economic costs and it may be expressed in terms of lost work-days, lost sales, or lost production. Travel time also has value and, thus, lost time due to traffic congestion has a significant cost (SUAREZ *et al.,* 2005).

Dutta *et al.* (2003) developed a model for flood loss estimation in a river. The loss estimation model is formulated based on relationships between different flood parameters and land use features. It calculates economic loss to different land use based on the simulated flood parameters obtained from the hydrologic model for any flood event. The transportation interruption was evaluated considering traffic volume in each road in temporal scale, average velocity and maximum traffic capacity in each road and delay cost per unit time. This model was applied in Chiba (Japan), in a medium-size and frequently flood affected Japanese river. For the application, a major flood event in 1996 was selected. The results for transportation indicated that traffic losses are of two kinds, marginal costs and delays. The delay costs (552.11 damage in million yen) are much higher than the marginal costs (1.05 damage in million yen). Overall traffic interruption loss was much less in this flood event compared to urban flood damage, which is about 4%, as the duration of flood was very short and only a few major roads were inundated.

Suarez *et al.* (2005) assess the potential impact of climate change on the system performance of transportation networks using the Boston Metro Area as a case study. The methodology integrates projected changes in land use, demographic and climatic conditions into the urban transportation modelling system in order to explore the relative impacts of global warming on the system performance due to floods. Results indicate almost a doubling in delays and lost trips. The authors indicate that these impacts are significant, but probably not large enough to justify a major effort for adapting the physical infrastructure, except for some key links.

Hossain and Davies (2004) develop a system in GIS, because the flood and road transportation have a strong spatial existence. This system can classify the levels of flood impact on the network and this enable a qualitative evaluation of the impact. Besides this, the system can visualise the flood impact on the characteristics of traffic flow as consequences of inundation.

METHODOLOGY PROPOSED

When a region suffers a flood, the disturbance reflected in the road traffic is directly related to the urban characteristics of the location that makes the use of standardized methodologies difficult. Therefore, local characteristics of the flood prone area must be considered such as road maps, flood maps and information about local road traffic, to evaluate the cost of a disturbance (CANÇADO, 2008).

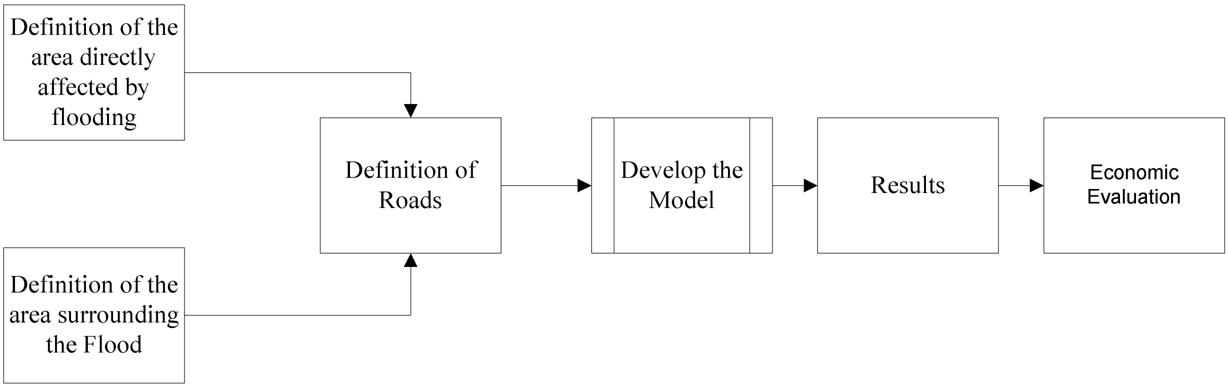

Figure 2 – Development of the Traffic Management Model for Floods

Figure 2 shows the flow modelling to evaluate losses due to traffic disruption by floods. The flood information required to apply this approach are: area directly affected by flooding, flood depth distribution on the flooded area, and flood duration. Other relevant information is the time required to recover the road system after flooding, in order to re-establish safe traffic conditions. Actually, floods almost always produce the settlement of sediments, solid wastes and other materials in the flooded area, particularly in the case of Brazilian cities, due to intense urban erosion processes and lack of adequate solid waste management. A time is therefore required to remove those settled materials before allowing traffic in the area. Also, depending on flow velocity and duration, part of the pavement may be damaged and therefore must be rebuilt.

The hydrologic and hydraulic modelling requires detailed information on the catchment morphology, topography, soil types, vegetation cover, land use, road system, and the characteristics of the drainage infrastructure (e.g.: drainage network, source control devices, detention structures, pipe characteristics, and others). Local climate information as well as rainfall and flow time series are also required information for the modelling process. Registered information on major historic floods is also important to constitute a scenario base on floods and for assessing flood risk in the area. It also provides information on flood chronology (flood starting and ending times) with can then be combined with the time distribution of traffic flow, allowing a more precise modelling of flood impacts on traffic. Flood risk may also be estimated with the help of local design storms, an approach which is complementary to the use of historical information and may be the sole possibility when historical information is lacking. Nevertheless, usually no information is available on when rainfall events and associated floods happen.

A process of modelling validation and model uncertainty assessment must be performed before using modelled flood information in the next step of simulation, i.e. the traffic disruption simulation. In the case of Brazilian cities this simulation quality assessment is frequently difficult to be implemented due to the lack of discharge information on urban creeks and rivers. In spite of this important drawback for the modelling process, some historical information may exist on flooded areas and on flood depths that may contribute to improve the model calibration process. After calibration, some modelling sensitivity analysis may be performed so that estimation on modelling uncertainties, although very simplified, can be performed.

The hydrological and hydraulic modeling is of fundamental importance in the creation of various flood scenarios, using rainfall events of different intensity and duration, thus defining the urban roads that may be affected by floods and the way they will be affected according to flooding characteristics.
With the information produced by the hydrologic-hydraulic modeling process it is then possible to develop the traffic model for assessing economic losses due to traffic disruption by floods. Figure 3 summarizes the main steps of this modeling process.

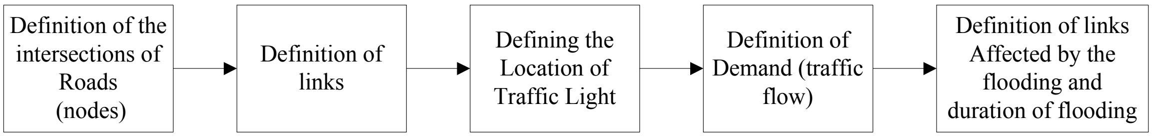

Figure 3 – Development of the Traffic Management Model taking into account flood information

Obviously, adopting the procedures illustrated by Figure 3 requires to previously having the traffic model developed of the area of interest under normal conditions, i.e. as a non-flooded area. The basic procedure for creating a road traffic model requires the construction of a diagram containing the road network, with connecting lines, the intersections, the length of the lanes, the number of vehicles passing per hour and their average speed. Other required information is the location and cycle of traffic lights in the area. Most of that information is usually available at municipal or regional traffic management organisations that usually perform surveys on these topics. That is the case for Belo Horizonte, where the traffic planning and management company, BHTrans, has a detailed data base about the traffic covering all the municipal urban area, with time series on traffic flow at an hourly time base and other relevant information for traffic modelling.
When these data are not available, it is necessary to perform surveys focusing on traffic volume count, which are conducted to determine the number, movements, and classifications of roadway vehicles at a given location. These data can help to identify critical flow time periods, to determine the influence of large vehicles or pedestrians on vehicular traffic flow, or to document traffic volume trends. The length of the sampling period depends on the type of counting being adopted and the survey purpose. Two methods are available for conducting traffic volume counts: manual and automatic. Manual counts are typically used to gather data for assessing vehicle classification, turning movements, direction of travel, pedestrian movements, or vehicle occupancy. Automatic counts are typically used to gather data for assessing vehicle hourly patterns, daily or season variations and growth trends, or annual traffic estimates.
After, the information about intersection, road, traffic light and demand is represented in traffic model, typical model validation approaches can be adopted to assess model performance and uncertainties. After assessing the quality of modeling then flood information may be entered in the model in order to simulate flood effects on traffic.

The main issues of this complex modeling process are the information that allows the assessment of main economic impacts of floods on the traffic system: travel time, fuel consumption, pollutant emissions such as CO, HC and NOx.

Environmental and Economic Impacts

Information on travel time, fuel consumption, pollutant emissions are available by links, vehicles and roads, through the traffic modelling approach from a definition of origin and destination.

The economic assessment of flood impacts on traffic requires the translation of traffic information obtained by simulation in monetary values. In the present paper this is performed adopting the approach proposed by Cançado (2009).

The additional cost of fuel due to traffic jam caused by flooding can be estimated through Equation 01:

$$C^C = y^C \times p^C \times 0{,}718 \qquad 01$$

where:

- C^C = Fuel Total Cost per vehicle (in real[1]);
- y^C = Total consumption per vehicle (l/km);
- p^C= Gasoline Prices (in reais);
- 0,718 = factor proposed in Nagem (2008) to make up for the difference in fuel used by vehicles.

Perhaps the definition of monetary values for pollutants is conceptually more difficult than for time. In estimating the value of time it is possible to take as a reference the "economic utility" of the individual. Since the monetization of pollutants involves studies on the effects of pollution on humans, which can show high variability according to local environmental conditions (climate, elevation in respect to sea level, pollutant dispersion, wind patterns, topography, etc.), and the consideration of the effects obtained by the combined action of pollutants. IPEA/ANTP (1997) proposed unitary values for major traffic emissions (air pollutants) for the Brazilian context from similar studies developed for the USA and European countries. These unitary values were updated from 1997 to the year 2010 (Equations 02, 03 and 04):

$$CO = R\$\ 0{,}45/kg \qquad 02$$
$$HC = R\$\ 3{,}17/kg \qquad 03$$
$$NOx = R\$\ 3{,}12/kg \qquad 04$$

It is worthwhile to point out that direct fuel costs are supported by travellers and by the public transport system, while costs due to pollutant emissions are shared by a much larger number of people, travellers or not. Costs associated to time are more complex to evaluate, in this sense, due to opportunity cost aspects, the regulation of work contracts between employees and employers, and the diversity of occupations of travellers (employees, employers, liberal professionals, and other). The cost of travel time due to traffic jam caused by flooding can be estimated through Equation 05:

[1] Real (R$) is the Brazilian Currency (R$ 2.50 = 1.00 Euro in April 2010)

$$CT = \left(\frac{w \times EX \times FA \times HP}{y_w} \right) \times tv \qquad 05$$

where:

CT = Cost of travel time (in reais);
w = income (in reais);
ES = social charge in Brazil (0,9502);
FA = Possibility alternative use of time (0,3);
HP = Percentage of the productive use of time (% work travel + % house/work travel x 0,75). If unavailable, use 0,5;
Y_w = number of hours worked per month. If unavailable, use 168 hours;
tv = travel time.

APPLICATION: CASE STUDY IN VENDA NOVA REGION, BELO HORIZONTE (MG)

Venda Nova is a region northwest of Belo Horizonte (Figure 4), with a 27,80 km² area and, 242.341 habitants. The IDH (human development index) of this neighborhood is 0,788 and monthly income average is R$ 558,82 (PNUD Brazil, 2000 update to 2010), it is therefore a poor neighborhood in the city. In comparison to Belo Horizonte city, the IDH is 0,839 and monthly income average is R$1.939,00 .

Figure 4 – Venda Nova Region in Belo Horizonte

In this region, there are 39 neighbourhoods and two important roads: Vilarinho Avenue and Padre Pedro Pinto Street. The access to this region is from Dom Pedro I Avenue, Cristiano Machado Avenue and MG-10 freeway. The Vilarinho creek was lined and the Vilarinho Avenue was then implanted in its narrow valley as part of the urbanisation project of this region. The region is prone to floods, particularly the Vilarinho Avenue. Figure 5 illustrates the estimated flooded area for the 25-year return period rainfall event in the Vilarinho Avenue (PBH, 2009). This event here is used in order to estimate losses caused by floods to the traffic disruption in this area.

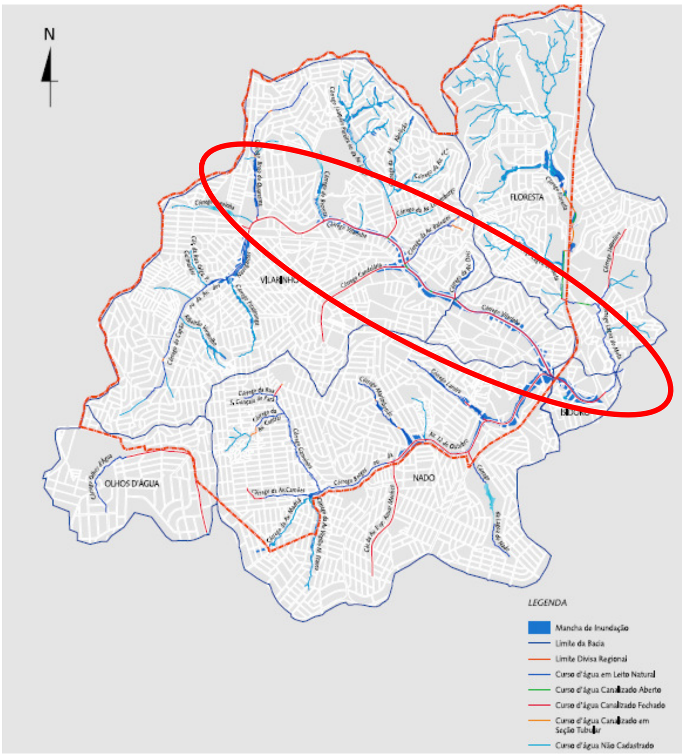

Figure 5 – Flood map of the Venda Nova area – Vilarinho Avenue is highlighted

Input Parameters

As defined in methodology, for this modeling were considered the main roads of the region in terms of flow of vehicles and alternative diversion of traffic before the occurrence of flooding (Figure 6).
Information about traffic count was obtained from the BHTrans and was applied the growth of the fleet of Belo Horizonte, to update the values to 2010. Figure 7 and figure 8 show the temporal distribution of the flow of vehicles in a specific junction in Venda Nova Region, where it is evident the morning peak, the peak banking and the highest peak during a work day. This information was necessary to estimating travel demand. For this model, the accuracy was of 93%.

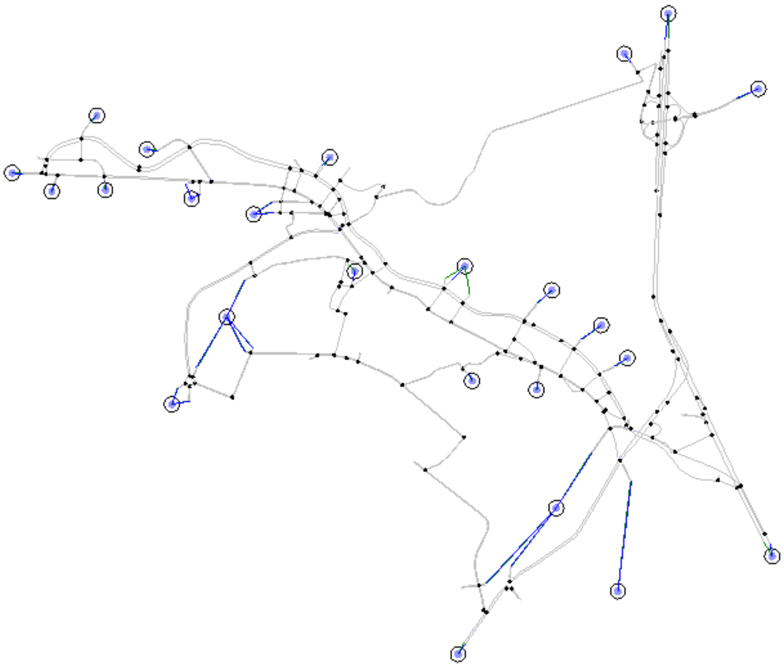

Figure 6 - Region Modeled

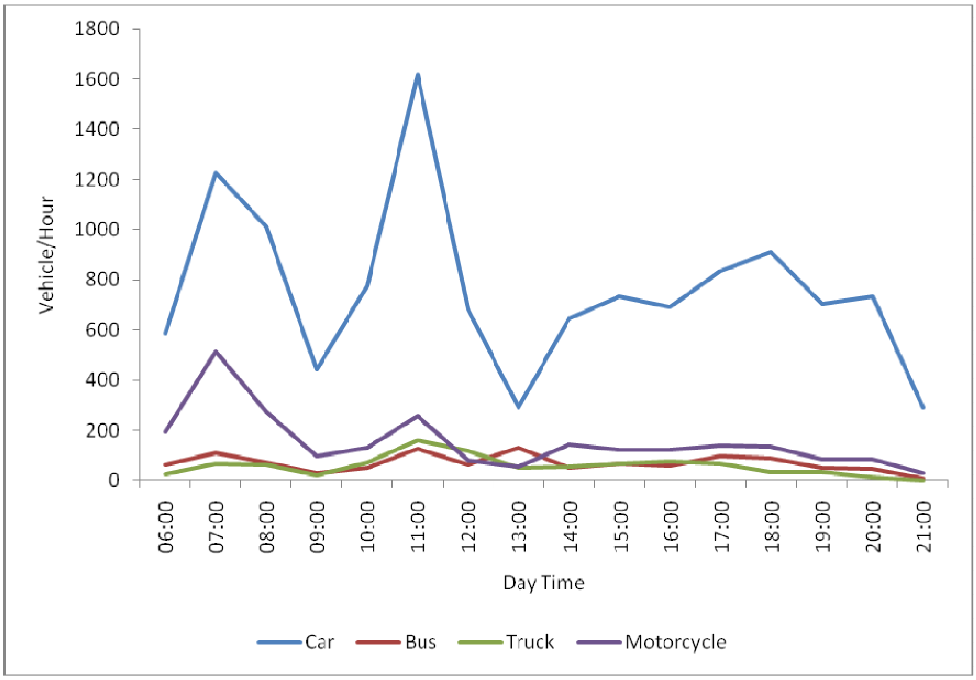

Figure 7 - Distribution of the flow of vehicles throughout the day for a specific junction in Venda Nova Region – From Neighbourhoods to Downtown

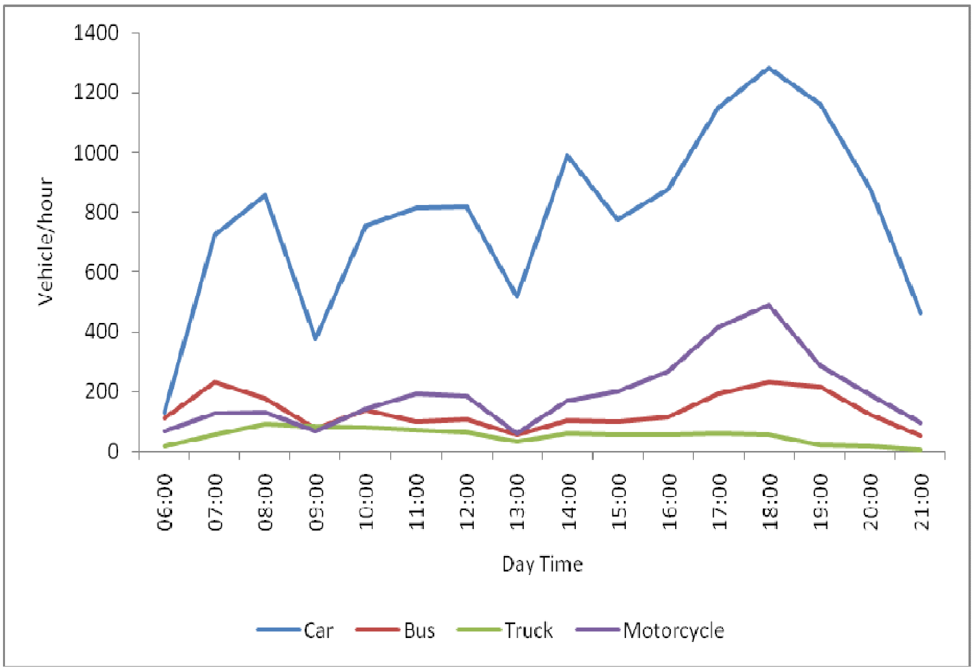

Figure 8 - Distribution of the flow of vehicles throughout the day for a specific junction in Venda Nova Region – From Downtown to Neighbourhoods

The capacity and speed parameters of the model were based on the recommendation of the Highway Capacity Manual - HCM (TRB, 2000), a reference which is used worldwide in studies of traffic engineering. For lane capability, we defined the flow as 700 vehicles per hour for each lane. The speed used is 60km/h for the arterial Street and 40k/h for the collector Street, and 80 km/h for freeway. If there is congestion, the speed is reduced by half. In places where a very high flow of vehicles was found, traffic lights were placed to avoid collisions.

Scenarios

Analysis in the road system is made according to two scenarios: with and without flood. When a region is flooded, the model verifies the existence of alternative paths that can be chosen by the driver, diverting the traffic flow. The use of alternative routes also increases travel time, and consequently associated costs such as fuel consumption. Yet, due to interruption of the road and the increase in the distance, emission of pollutants emitted by vehicles and travel time increase, implying, consequently, environmental and economical impacts.

The simulations involved two scenarios: one without flooding and the other with flooding with a time of return of 25 years. In this scenario, the flood starts at 7 a.m and, lasts 3 hours. Also, it was considered one scenario with intervention using variable message signs.

RESULTS

The scenarios were simulated starting at 6 a.m. and finished at 10 p.m. Table 2 shows the principal outputs in each scenario.

Table 2: Principals Outputs

Scenario	Travel Time (min)	Emissions (t)		Fuel Consumption (l)
		CO	NOx	
No Flooding	43	14.286	6,49	10.227
Flooding at 7 a.m	137	84.172	69,86	20.739
Flooding at 7 a.m with interventions	106	59.168	44,27	19.776

With this information was possible to calculate the damage in travel time, fuel cost and emissions cost. This travel time cost indicates the monetary value that the population, that lives or works in Venda Nova Region, lost when a flooding with a time of return of the 25 years occurs (table 3). Still, the creation of policy interventions to reduce these impacts is important, such as the use of variable message signs. This scenario was simulated and the results indicate that this policy is important to avoid serious catastrophes.
However, it is important to observe that the intervention decrease only 23% the travel time. Therefore, it is necessary to do more than intervention to reduce the floods damages in traffic.

Table 3: Monetary Damage

Scenario	Travel Time Cost (R$ mil)	Emissions Cost (R$ mil)		Fuel Cost (R$ mil)
		CO	NOx	
No Flooding	7,03	6.428,84	20,24	16,89
Flooding at 7h	22,26	37.877,67	217,96	34,25
Flooding at 7h with interventions	17,21	26.625,72	138,13	32,66

CONCLUSIONS

In Brazil, risk of flooding and associated impacts have increased with urbanisation from the 1940´s up to present time. The country faced very high taxes of urbanisation in this period due to intense migration from the countryside to big cities associated to general population growth. The lack of appropriate urban planning and of land use regulation has lead to the mentioned increase in the frequency of flooding and its impacts. Although emergency planning for flood fighting exists, those plans do not incorporate appropriate traffic management. There is therefore a significant interest in combining meteorological, hydrologic and traffic information in order to improve flood fighting measures so that flood impacts on traffic may be reduced as well as casualty and death risks.

This paper proposes a methodology for combining hydrologic and traffic information through rainfall-runoff and traffic simulation, with application to a small urban catchment in the city of Belo Horizonte in Brazil. The 25-year return period rainfall event was taken as reference for the hydrologic risk. Traffic flows were simulated based on hourly data classified by vehicles types obtained by surveys in this area in 2009.
Results of the traffic model calibration suggest that the model is able to explain 93% of the variability observed on the traffic data. Hydrologic and hydraulic modeling cannot be calibrated on observed flow data due to the lack of monitoring discharges in the Belo Horizonte streams. Notwithstanding, PBH (2009) conducted verification studies of typical flood depths in all the flood prone areas in Belo Horizonte, verifying a good agreement between flood depth simulations an historic registers of floods.
Results of these combined hydrologic–traffic simulations suggest that a real time management of traffic considering the implementation of a flood forecast and flood warning system can provide a significant reduction on the flood impacts for the event simulated. For instance, when considering a flood event starting at 7 a.m., average travel time with traffic management is estimated to 106 minutes. Without considering traffic management for the same scenario, the average traffic speed increases to 137 minutes.
Regarding cost of flooding estimations on the traffic system, figures suggest R$ 31,68MM of total damages in monetary terms for the event simulated. This figure suggests the interest of investments on the traffic management alternative although a formal cost-benefit analysis has not been done so far. It is important that CO2 emission cost is very high, however, it is real and it occurs every day, with or without flooding. This cost can be converted into investments such as containment of floods and improving of roads, thus reducing the emissions of pollutants.
The paper presents preliminary results of a research project that will include not only simulation of rainfall design events but also major floods observed in the area. Improvements on the hydrologic and hydraulic modeling are also required to improve information on flood relevant variables (depth, duration, area). The exploratory research performed so far suggests its interest in terms of potential contribution to improving emergence actions during floods with leading to the reducing flood consequences in the urban environment.

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BIBLIOGRAPHY

Bruzelius, N. (1979) The Value of Travel Time, Theory and Measurement, Croom Helm, London

Cançado, V. L.(2009) Consequências Econômicas das Inundações e Vulnerabilidade: Desenvolvimento de metodologia para a avaliação do impacto nas famílias e na cidade. Tese de Doutorado, Universidade Federal de Minas Gerais, Belo Horizonte.

Canholi, A. P. (2005) Drenagem Urbana: Controle de Enchentes. São Paulo: Oficina de Textos.

Dutta, D.; Herath, S.; Musiake, K. A mathematical model for flood loss estimation. Journal of Hydrology, v. 277, n.1-2, p. 24-29.

FECM-BH (2009). Solo impermeável, população vulnerável: Políticas de saneamento. Available at : http://www.metro.org.br/andre_samuel/solo-impermeavel-populacao-vulneravel, in November 2009

Fleming, G.; Frost, L. (2002) Flooding and Flood Estimation. In: FLEMING, G. Flood Risk Management, Thomas Telford Ltd, 280 p.

Frank, B. (1987) Projeto Crise: Estratégias e Ações Frente a Desastres Naturais. Salvador, n. 4, p. 29-46.

Gastal, A. (1987) Efeitos sociais e econômicos dos recentes grandes desastres naturais na América Latina e a necessidade de preveni-los. Estratégias e Ações Frente a Desastres Naturais, Salvador, n. 2, p. 12-16.

Hossain, M. S.; Davies, C. G. (2004) A GIS to Reduce Flood Impact on Road Transportation Systems. In: ESRI International User Conference 2004, San Diego, California.

IPEA/ANTP (1997). Redução das Deseconomias Urbanas pela Melhoria do Transporte Público, Rio de Janeiro.

Lieberman, E., Ratgi, A. J. (1997). Traffic Simulation Traffic Flow Theory, A State of the Art Report of Turner Fairbank Highway Research Ceter, Federal Highway Administration, U. S. Department of Transport, p.10-1 – 10-23.

Lira, V. (2009) Desenvolvimento de Tecnologia de Manejo de Águas Pluviais: Modelagem hidrológica da Bacia do Vilarinho, Belo Horizonte, MG. Relatório CNPQ – Escola de Engenharia, Universidade Federal de Minas Gerais.

Machado, M. L. (2005) Curvas de Inundação versus Profundidade de Submersão: Desenvolvimento de Metodologia: Estudo de Caso da Bacia do Rio Sapucaí, Itajubá (MG). Tese de Doutorado, Universidade Federal de Minas Gerais, Belo Horizonte.

Marco, J. B. (1994) Flood risk mapping. In: ROSSI, G.; HARMANCIOGLU, N.; YEVJEVICH, V. Coping with Floods. Colorado State University, Civil Engineering Department.

Nagem, F. (2008) Avaliação Econômica dos Prejuízos Causados pelas Cheias Urbanas. Dissertação de Mestrado. Universidade Federal de Minas Gerais, Rio de Janeiro.

Nascimento, N. O. ; Baptista, M. B.; Silva, A.; Machado, M. L.; Lima, J. C.; Demian, M.; Dias, R.; Machado, E. (2005) Flood-damage curves: methodological development for the Brazilian context. In: 10th International Conference on Urban Drainage, 2005, Copenhague.

Parker, D. J.; Green, C.H.; Thompson, P.M. (1987). Urban Flood Protection Benefits: a Project Appraisal Guide. Gower Technical Press Ltda, England

Parker, D. J.; Thompson, P.; Thompson, P. M.; Green, C. H. (1987) Urban Flood Protection Benefits: a project appraisal guide. Hants, England: Gower Technical Press Ltd.

Parker, R. (1998) Reducing Flood Hazards and Traffic Congestion in Tunisia. World Bank Operations Evaluation Department, n. 157, p. 1-4.

PBH (2009) Carta de Inundações de Belo Horizonte – Identificação de áreas potencialmente suscetíveis.

PNUD Brasil (2000) Atlas de Desenvolvimento Humano da Região Metropolitana de Belo Horizonte. Available in: http://www.pnud.org.br/publicacoes/atlas_bh/index.php. Access in abr/2010.

Rakha H.; Kang Y.; Dion F. Estimating Vehicle Stops at Under-Saturated and Over-Saturated Fixed-Time Signalized Intersections – Transportation Research Record, 2001, No. 1776, pp. 128-137.

Schanze, J.; Zeman, E.; Marsalek, J. (2006) Flood Risk Management: Hazards, Vulnerability and Mitigation Measures. NATO Science Series, v. 67.

Schmitt, T. G.; Thomas, M.; Ettrich, N. (2004) Analysis and modelling of flooding in urban drainage systems. Journal of Hydrology, v. 299, n.3-4, p. 300-311.

Schreider, S. Y.; Smith, D. I.; Jakeman, A. J. Climate Changes Impacts on Urban Flooding. Climate Changes, v. 47, p. 91-115.

Simonovic, S. P. (2009). Managing flood risk, reability and vulnerability. Journal of Flood Risk Management, 230-231.

Suarez, P.; Anderson, W.; Mahal, V.; Lakshmanan, T. R. (2005) Impacts of flooding and climate change on urban transportation: A systemwide performance assessment of the Boston Metro Area. Transportation Research Part D, v. 10, p.231-244.

TRB (2000). . Highway Capacity Manual. Transportation Research Board, Nacional Research Council, 2000. Washington, D.C.

TRB (2008). Potential Impacts of Climate Change On U.S Transportation. Report on Brief. Available at http://onlinepubs.trb.org/onlinepubs/sr/sr290summary.pdf, in November 2009.

Yang, Q., Slavin, H., Stefansson, K., Rabinowicz, A., Olsberg, S., LaClair, M., Brandon, J. (2002). Traffic data management and simulation system, Word Intellectual Property Organization, Boston

Yevjevich, V. (1994) Floods and Society. In: ROSSI, G.; HARMANCIOGLU, N.; YEVJEVICH, V. Coping With Floods – Colorado State University, Civil Engineering Department, 776 p.