A DECISION SUPPORT SYSTEM FOR DISASTER PREVENTION IN URBAN AREAS

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ABSTRACT

This paper proposes an overview of floods simulation models linked to Decision Support Systems focused on disaster prevention in urban areas. The preliminary solution proposed consists of a system of models simulating different layers. The authors developed human behavior models able to reproduce the reactions of the population in this context.

Keywords: Flood Simulation, Mega-Cities, Smart Government, Intelligent Agents, Decision Support Systems

1. INTRODUCTION

Prevention from risks is one of the biggest challenges for modern societies indeed politicians and decision makers constantly need to face strategic decisions to ensure a good quality of life and a high level of safety and security to their citizens.

Disasters are frequent and may happen for natural causes (i.e. extreme natural events such as heart quakes, Tornadoes, Tsunami, Floods) or can be provoked by men (i.e. chemical or nuclear accidents, terroristic attacks etc..). These events happen in rural areas or in high density populated zones and they usually create humanitarian emergencies even with critical logistics problems (Diaz et al. 2013-a). Obviously when they happen inside a high populated city the magnitude of the disaster increases exponentially and nowadays there is the rise of the urbanization process.

It is important to note that urbanization is changing the world and a growing number of people is moving from the countryside to the city: it has been calculated that in 2014 for the first time more than 50% of global world population was living in urban areas and this trend is expected to grow and to overcome the 60% within the 2050. (World Urbanization Prospects, 2014).

In Fig. 1 is reported the percentage of population living in urban area: North America and Latin America have the higher value with, respectively, 81,8% and 80%while Europe the urban population is 73 %. Only Africa and Asia are now below the 50% (with 40,8% and 48,8%), but there is the perspective to overcome this quota in the next years.

Table 1: Percentage of Urban Population Data, elaborated from UN "Department of Economic and Social Affairs"

Percentage of Urban population	2016	2020	2030	2040	2050
WORLD	54,48%	56,22%	60,04%	63,23%	66,37%
AFRICA	40,87%	42,64%	47,12%	51,48%	55,93%
ASIA	48,83%	51,24%	56,32%	60,34%	64,16%
EUROPE	73,82%	74,65%	77,00%	79,55%	81,95%
LATIN AMERICA AND THE CARIBBEAN	80,05%	81,01%	83,04%	84,68%	86,19%
NORTHERN AMERICA	81,81%	82,50%	84,24%	85,90%	87,42%
OCEANIA	70,78%	70,88%	71,32%	72,18%	73,51%

The rise of urban population also directly associated to an other global phenomena: the proliferation of the megacities, that are usually defined as *"cities with more than 10 Millions of inhabitants"*. The number of such mega urban centers is growing: in 1990 there were only 10 megacities worldwide and in 2014 such cities were already 28 with a population living there of 453 Million. Such number represent the 12% of the total world's urban population. (Un, D. E. S. A., 2015). By 2030, the world is projected to have 41 mega cities (Cohen, 2006).

In this context, one of the big challenges for the future generations is to preserve the harmonized growth of urban centers, guaranteeing a good balance between urbanization, development, and welfare and healthcare (Fujita et al.1999; Hoornweg, 2011, Diaz et al. 2013-b). The high density of people living and consuming energy in the same area lead to several challenges such as guaranteeing a sustainable growth preserving Safety & Security and the Environment.

Indeed it is important to underline that the cities and urbanized areas have more than 50% of total global population, use 75% of global resources (Bugliarello, 1999), but represent only 2% of earth's surface.

Mayors and decision makers constantly need to face with strategic decisions, but making the "right" choice is more related to "art" than to quantitative optimization; indeed, even this process cannot be the pure result of a mathematical computation, it is evident that the use of simulation model provide an opportunity for a more reliable decision making. It is also possible t consider to use these models for supporting the crowdsourcing approach and to engage in the process directly the population.

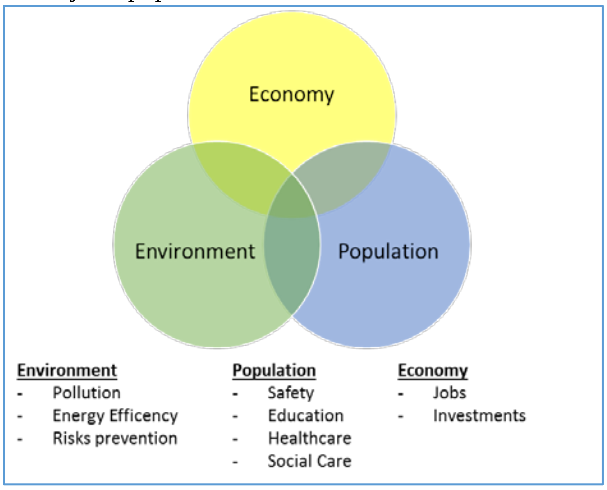

Figure 1: Main driver for decision makers

Obviously this requires also a cultural evolution of political decision makers and public opinion .

In this context the possible sources of complexity includes among the others:

a) Correlation between different Goals: different priorities are often in contrast:

- **Economy:** keeping high the number of jobs, and the income of the citizens, increasing the economic development, increasing the number of industries etc..
- **Environment**: keep low the pollution, increase the energy efficiency and prevent natural risks
- **Population and Welfare :** improve the welfare, increase the education level, improve safety and security, improve social care

b) Limited Resources: decision making process for public authorities is an hard task since it is necessary to balance the limited resources available (for example in terms of money, people and time).

c) Political constraints: decision makers need also to keep high the political consensus among their citizens.

For example the pedestrization of a road can appear a wrong choice and it can receive several negative opinions, but after a certain time people is happy and will never change such choice.

d) "Chicken and Egg" Problem

Defining some priorities to certain projects or certain activities and operas imply the exclusion or the procrastination of other actions.

It is important to note that decision makers often need to take also unpopular decision that can be "right" or decisions that can be "costly", but with no direct impact on popularity: for example cleaning a river is a costly action, it require time and it can also lead disturbance to commercial activities and lead disturbance to the traffic

Indeed there are some decision that require time for being effective and others that are more appealing and can provide immediate results with less effort. An example is a wrong urban planning and land use, with an uncontrolled urban growth.

Indeed each choice have a potential impact on the future of the city on different time scales: sometimes a choice may be unpopular, but extremely useful for the future and it may require time for being accepted and appreciated by the population.

e) Complexity in Predicting the Behaviour of the System

The decision making process is often the result of an intuitive solutions based on a qualitative estimation. Indeed considering and predicting all the possible effects of each set of possible choices in a quantitative way is not possible for human brain if the number of variables becomes high.

In addition it is important to note that many variables and process are stochastic and the secondary effects generated among the different entities and events may have a high impact on the final result. (Bruzzone et al, 2015a).

Historically, the pioneer in simulating complex system was Jay W. Forrester, that introduced the concept of System Dynamic and Urban Dynamics (Forrester 1961; Forrester,1969). Urban systems are described as *"complex systems"* and the governance of these systems is obviously extremely challenging. In this sense simulation provides a strong support in this area providing numerical results derived from an analytic analysis. Such analytical results may be available only by using a computer simulation, that is a fundamental instrument to study complex systems (McLeod 1982; Gould et al, 1988; Bar-Yam, 1997).

2. FLOODS OVERVIEW

In this paragraph the authors focus the attention on floods that are one of the most common natural disasters and one of the most dangerous.

Floods have strong impact in safety and economy; in literature it is possible to find several studies related to human losses (Neumayer et Barthel,2011;Doocy et al., 2013) and quantification of economical ones. (Cochrane,2004). Looking for a possible definition of flood the authors decide to use *"a situation in which water temporarily covers land where it normally doesn't"* (Martini, & Loat, 2010). Rainfall rate is generally the direct responsible of the rise in water level; a possible classification of rains is provided by Spanish National Meteorological institute, see Table 2.

Table 2: Rain Classification

Type of Rain	***mm/h***
Light Rain	< 2.0
Moderate Rain	2 – 15
Heavy Rain	15 - 30
Very Heavy Rain	30-60
Torrential Rain	> 60

After a first analysis, such values seems to be slightly different in Europe among different Nations and Institutes and the authors were not able to find a common standard for them.

Before focusing on simulation techniques and achievements of the previous researches it is important to understand the flood phenomena and clarify what are the different type of floods and understand their causes and their effects. In the Table 3 the different types of floods are described and summarized. Floods can be divided into five different typologies: Flash Floods, Coastal Floods, Urban Floods, River or Fluvial Floods and Ponding (or Pluvial) Floods based also on previous works on this topic (Jha, et. al., 2012) and (Anonymus, A. 2007). The main differences are summarized in Table 3.

- **Flash flood**

Flash floods are distinguished by the rapid rate of rise in the water level, they provide a short warning lead time, resulting in very little time to respond to the threat. (Davis, 2001).

It is a direct response to rainfalls; it has a really high intensity, but it is normally concentrated in a small area. The amount of water involved can be lower compared to other types of floods, but the energy of the flow drags big objects like trees and cars. A flash flood occurs usually in conjunction with heavy rains, with a minimum average value of 20mm/h (Bluestein, 1993) and such phenomena normally covers a period of less than 6 hours.(Gaume et al., 2009).

The short notice, huge flows and high velocities of flash floods make these types of floods particularly dangerous. Examples of flash floods in the recent year are documented in several papers, for example in Italy by Faccini et al. (2015) and Borga et al. (2007) and in France by Delrieu et. al, (2005).

- **Coastal floods:** a coastal flood, or tsunami-like phenomenon, happens when the coast is flooded by the sea, this could be caused by an intense storm or a big
- natural event such as a hearth-quake or a hurricane that creates high waves in the sea.
- **Urban floods**

Urban floods are a growing issue both for developing and developed countries. They are frequent in particular in rapidly expanding towns that often are characterized by a wrong land use that usually is correlated to a lack of urban drainage of the water.

The speed of the water depend on the orography of the city.

- **River (or fluvial) floods**

Such phenomena are caused by rainfall over extended period. In this case the river could overflow its banks and create flooding. This kind of flooding involve huge quantities of water.

- **Ponding (or pluvial flooding)**

Such type of floods happens in quite flat areas: when the rain water falling that is normally stored and absorbed by the ground cannot be more absorbed; in these case the flooding occurs. This event is similar to an urban flooding, but it happen in rural areas.

*Table 3: Floods Classification * data elaborated from (Jha, et. al., 2012), (Anonymus, A. 2007).*

Type	Natural causes	Human induced	Area Covered	Lead time	Capability to predict the area involved	People potentially involved	Duration	Intensity of water	Relevant Parameters
Flash floods	- Fluvial - Cost - River - Pluvial	Insufficient drainage system	Low	Short	Low	Low	Few hours	High	Intensity duration of rainfalls and prediction of the most affected area
Coastal floods	Storm Tsunami Volcanic eruptions	Development of coastal zone Destruction of natural flora	Medium/ high depending on local topography	Medium	High	Medium	Long	Medium	Strength, intensity, direction and speed of the hurricane or storm.
Urban floods	Rainfalls Coastal Fluvial	Saturation of drainage Lack of permeability due wrong land use planning Lack of management	Medium	Medium	Low/Medium	High	Few hours to days	Low	Intensity of rainfalls, Elevation profile, Urban drainage system condition
River (or fluvial) floods	Intensive rainfall Ice jam clogging Collapse of dikes	Lack of river manteinance Wrong Urbanization	Depending on terrain elevation	Medium/High	Medium/High	Medium/High	days/weeks	High	Water level prediction
Ponding (or pluvial flooding)	Rainfalls	Terrain saturation	High	High	High	Long	Varies	Medium	Intensity of rainfalls, Elevation profile, Urban drainage system condition

As it possible to see in Table 3, each type of flood have different characteristics and it is clear that facing with these different phenomena require different strategies and different countermeasures. For example, if we compare pluvial floods with flash floods it is evident that they need different preventive actions: the flash floods are faster and have a low lead time while the pluvial flood are slower but they involve a higher territory. Indeed, it is obvious that the model required for the analysis should be different according to the different flood risk type and, consequently there is a need for different type of simulators.

3. FLOODS SIMULATION AND ITS POTENTIAL

The number of mobile phones, sensors, cameras and other devices that are present in urban area is huge. Potentially these data can be used for several applications in real time; tweets and post contents in the web, variation of data traffic etc. are already used for several application such as traffic jams monitoring or emergency detections.

E-government is also correlated to new ways of taking measures, for example river level with telemetry cameras or the use of drones for acquiring real time information and measures (Changchun et al. 2010). Real time Decision Support Systems is a potential instrument for the future, but if we consider floods, it is important to note that the hydrological models that are needed to calculate the level of water are often really computational heavy since they are based on Saint Venant equation and finite element techniques. That's why many existing models and simulators cannot be used in real time and they need a pre-simulated scenario. Hereafter it is described a possible classification of real time flood forecasting systems into three main categories (Henonin et. al., 2013):

- **Empirical Scenario Based**: it is based on real time flood forecasting without any hydraulic-hydrogeological model. Such tool is based on historical data and past events, which are tested by Subject Matter Experts. The warning is attributed based on the past data, the current level of rainfalls, and the predicted one. It can be extended with an automatic system of alerts to key people and citizens by mail/SMS/website and can be completed with a specific web page where citizens can connect and take information on the appropriate measures to avoid the damage.
- **Pre-simulated scenario**: it is a real time flood forecasting system based on previous hydraulic simulation. In this case, the input of the system is still the rainfall intensity prediction and its actual value; the system will match the pre-simulated scenario that is closer to such values.
- **Real time simulation;** it is a flood forecasting model with a real time hydraulic simulation. In this case it is important to balance the model complexity with the computational power that is needed.

Obviously the complexity of the simulation that is needed for a comprehensive reproduction of the phenomena should be different according each type of floods. The floods happening in rural areas are "easier" to be analysed, in a certain way, because the presence of human is lower than in the city and men made structures are not intensively present within the area; for example the "artificial" drainage system is often not present, and urban structures are rare; such situation make the hydraulic model simpler. On the contrary, modelling floods inside a city, such as urban flash floods is particularly difficult due to the absence of natural flow paths and the presence of man-made structures. (Snell & Gregory, 2002; Hapuarachchi et al. 2011); in these cases the errors are inherent both the process of estimating rainfall from radar and the modelling of the rainfall–runoff transformation (Hossain et al., 2004). In addition the dataset available to calibrate the model comes from cities that are different. (Viglione et.al., 2010) For this reason in the past years have been developed the HYDRATE Project, founded by European Commission, to develop a harmonized dataset of European flash food data (www.hydrate.tesaf.unipd.it) that represents a valuable source.

4. HUMAN BEHAVIOUR MODELLING

Human Behavior Modelling (HBM) is a challenging task and it is the subject of ongoing researches even because of the emergent behaviors and properties due to the presence of multiple complex interactions among humans (Oren and Longo, 2008). Indeed it has a great potential in different contexts such as military, economic, political, and emergency or evacuation. The continuous evolution of interoperable simulation reinforce the opportunity to combine different models to create federation based on Modelling & Simulation in new areas; an example is the possibility to support strategic decision making and to face complex humanitarian scenario (Simulation Team and NATO M&S COE, 2013). In facts the Simulation Team have developed different solutions based on Intelligent Agents to address in this context the HBM (Bruzzone et.al.,2015a; Bruzzone et. al.,2014); a good example are the Intelligent Agent Computer Generated Forces (IA-CGF) for simulating intelligent behavior in defence and humanitarian crisis.

HBM is often based on micro-simulation, that means that each different human correspond to a single entity; in some other case the HBM are based on social and economic group interactions; currently IA-CGF operates on these different layers concurrently; indeed in reproducing human factor for computer simulation, it is quite common the necessity to address different layers such as:

- Individual layer including Rational Decision making and Emotional and Irrational;
- Social layer including Crowd Behavior, Social Networks and Families.

For instance these two layers could be simulated by means of Intelligent Agents (IA) able to reproduce the following different aspects (Wooldrige & Jennings, 1995):

- Autonomy: ability to operate without external control
- Reactivity: capability to respond to any stimulus
- Social Ability: Capability to interact with other agents
- Proactivity: capability to take the initiative

Focusing the attention on urban context, the simulation of the population behavior results a powerful instrument for decision makers. Indeed it provides a quantitative feedback of the reaction of the citizens to the different political choices on different time-scales:

- **short term behavior** (i.e. pedestrian evacuation swarm behavior etc.)
- **long term reactions** (i.e. simulation of political consensus, trustiness level

5. TRAFFIC SIMULATION DURING EMERGENCY SITUATION

There are interesting studies carried out on the impact of flooding on road transportation systems; for instance simulations have been carried on by integrating a flood simulator, (MIKE) with a traffic model (SUMO) by means of a microscopic simulation: in case of a flood the trips that have an origin or destination in the flooded area are cancelled and the routes that pass through a flooded area are rerouted to unfavourable routes; furthermore, the speed of the vehicles is reduced in function of the intensity of the rainfalls.(Pyatkova, 2015). Another example, have been developer for quantifying and spatially map the flood characteristics by integrating GIS data. The estimated flood volume is used to estimate a hazard factor of each road (Dawod et. al., 2012). The authors developed in the past a demonstration based on IA-CGF and interoperable simulation to reproduce flooding covering an entire State respect the transportation layer; the case was inspired to Katrina and demonstrated the effectiveness of this context (Bruzzone & Massei 2006).

6. SIMULATION MODEL DESCRIPTION

Based on the above mentioned consideration it is evident that Modeling & Simulation is fundamental to test the feasibility of complex systems such as a decision support system for flooding in urban areas; indeed this approach support the adoption of an holistic view of the system and the assessment of the scenario awareness before making important choices; this allows to evaluate risks of alternative decision and it is fundamental to prevent problems and errors. The adoption of an interoperable simulation framework is the key to support decision making, in facts the adoption of HLA (High Level Architecture) allows to interoperate also with external systems to guarantee dynamical update on the situation.
Indeed this framework could be dynamically connected through the High Level Architecture supported by the RTI (Run Time Infrastructure) with real systems such as C2 (Command and Control systems), Sensor Networks, web mining to update the situation and provide a real time representation of the scenario (Srivastava et al.2000). Another important aspect is related to the necessity to integrated Dbase covering the complex description of the urban area and providing all the boundary conditions necessary for processing the flooding dynamic evolution.
In the following, the overall architecture and nature of the proposed system is summarized:

- **Meteo forecasting Model**: this model simulates the weather forecasting. The output of such model provide the probability of rain that is associated to each zone of the city and the dynamic evolution of it along time as well as other boundary conditions that influence the situation (e.g. wind, luminosity, ect.).
- **Catchment Model:** this model simulate the water catchment by the soil. The model is quite complex because it need to consider the actual drainage network in the city and the different composition of the soil (green areas, building etc.).
- **Hydrological Model:** this model is strictly correlated to the catchment model, it determines the water level inside the city; the simulation of the rivers could be based on this model or it could be incorporated in the catchment model depending on the resolution applied; in general this model address simulation of water streams and flooding flows.
- **Town Model:** this model reproduce the rainfall on the urban area**;** for instance the falling on the roofs is conveyed in drainage system, therefore the different buildings are characterized by pumping systems located in different part that could be subjected to block in different ways during the flooding (e.g. hospitals with pumps in the basement and hospital with pumps on the roof).
- **Human Behavior Model:** this model simulate the human behavior of individuals and groups that compose the city. The model allows to consider multi resolution entities corresponding to aggregated people objects allowing to reproduce individuals as well as groups. This model provides as output the feelings of the population and of different aggregations such as consensus level, fear, trustiness to a political group in charge of the government of the city. This mode reproduces also the entities and units devoted to apply countermeasures to the flooding.
- **Environmental Framework:** this model provide access to the Dbases representing the different elements; indeed in large urban areas the size of this Dbase suggests to create a scalable access potentially distributed, therefore the computational aspects shoul drive the specific implementation to guarantee quick access to the information required by the different simulators; the Dbases include the different urban layers and data of the town, the population demographics as well as terrain characteristics and digital elevation mapping.

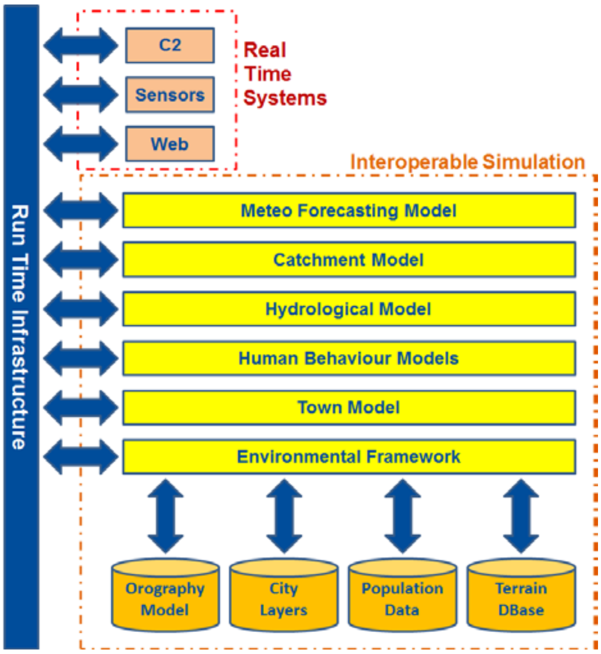

Figure 2:General Architecture

The simulator proposed in this case is designed to adopt the HLA IEEE1516 (High Level Architecture) standards and guarantees interoperability; the Federates could be based on stochastic models adopting combined simulation continuous and discrete events combined together.

7. CONCLUSIONS

In this paper the general architecture of a Decision Support System for urban disaster prevention is presented with special attention to flooding; the analysis outline the complexity to reproduce the dynamics of both physical and social phenomena in this context, but also the potential of adopting innovative approaches (e.g. HLA, IA) to address these issues. The analysis on the experimental results of previous researches confirms the feasibility of the approach and it is used to support the design of the general architecture of the simulator to be used. The authors provides here a synthetic proposal for the structure of an interoperable simulator devoted to address this issue and, currently, further development are on-going for the implementation and the Verification and Validation of the model.

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