# POPULATION BEHAVIOR, SOCIAL NETWORKS, TRANSPORTATIONS, INFRASTRUCTURES, INDUSTRIAL AND URBAN SIMULATION

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**ABSTRACT**
Crisis prevention and management are critical tasks for a public administration. In facts, a complex system such as a city could be difficult to keep under control, even in regular conditions, while respect emergencies it is very hard to finalize good preventive and operational plans. In order to succeed in such tasks, it is necessary to have proper support tools, capable to evaluate alternatives and predict effect of decisions in different conditions. To address such issues, the authors developed PONTUS (Population Behavior, social Networks, Transportations, Infrastructures and Industrial & Urban Simulation) which combines ability to model natural disasters with advanced human behaviors of the population.

Keywords: City Simulation, Decision Support Tool

## 1 INTRODUCTION

A modern city is a very complex System of Systems (SoS) which contains numerous types of infrastructure (e.g. transport network, water and power supply, healthcare) organizations and single individuals (Bruzzone, et al. 2017c). Hence, in order to achieve optimal efficiency, a public administration has to consider interests of numerous public and private subjects, while maintaining consensus with the inhabitants. In fact, even an optimal decision could lead to a protest in case of conflict of interests or simple miscommunications. However, the situation becomes much more complex in case of emergency; for instance, each natural disasters impact in different ways (e.g. flooding, earthquake, fires, hurricanes) and could destroy infrastructures, houses or even entire cities. Another important aspect is related to industrial areas that could ingenerate potential additional environmental damages and heavy impacts on population based on contamination and domino effect. In any case, parts of the city's infrastructures become temporary, or permanently, unavailable, while the lives of inhabitants are in danger and heavily affected by these events (Longo 2010; Longo et al.2012). In order to be ready for such situations, it is common, especially for medium and large cities, to have an emergency plan, which includes sequence of optimal actions in different crisis scenarios. Another important component of city crisis management plan is related to the analysis of high risk events, in order to prevent them or at least to reduce damages and/or probability of occurrence. For instance, this could include even simple actions such as cleaning river beds, making firebreaks in forests or enforcing earthquake resistant construction. However, it is critical to compare costs and times of preventive measures with possible damages. The present paper focuses on an urban crisis dealing with flooding, however also other disasters could be simulated by proposed simulator.

## 2 SIMULATION SOLUTIONS

In order to increase awareness regarding possible outcomes of different crisis as well as to improve preparation, it is necessary to have reliable models able to estimate quantitatively impact of events (Bruzzone, 2013). In facts, in the past years, a special interest was on development of solutions capable to recreate a situation in a virtual world and to provide quite precise results, for instance, related to flooded areas after heavy rains (Jasper et al.2002; Chen et al. 2009, Kia et al.2012). Obviously, such systems allow estimating damages of natural disasters and comparing scenarios with different boundary conditions; for instance, it is possible to simulate impact of intense rainfall, using previous weather data, respect potential actions on the stream bed, city storm drains and sewerage. Obviously, such data allows to estimate possible damages and even to decide if worth to perform certain interventions to reduce losses. However, usually such models are not devoted to study population behavior, neither to predict number of involved persons, which is critical considering the fact that depending on timing, day, meteorological conditions, as well as other factors, this number could differs by several orders of magnitude; this aspect is clear considering malls, which are crowded for instance on Saturday while almost empty during the night as well as for schools (Bruzzone et al. 2017a). Furthermore, it is critical to consider also the "status" of the involved persons, especially in term of age and physical conditions; by the way proper behavior introduce also counter flows during crises due to the fact that people is looking for friends and relatives.

In facts, it is much more dangerous to have an emergency situation in proximity of some critical infrastructures, such as hospitals or schools, industrial plants or logistic hubs dealing with explosion, fire, contamination risks or security issues. The literature review reveals how researchers are currently dealing with both theoretical frameworks and practical applications for different types of critical infrastructures (Perrow, 2011; Longo 2012, Hsu et al., 2012). Considering these elements, it is clear the importance to have a reliable data regarding population distribution during a specific crisis.

Table 1: Virtual World Characteristics Table

| Characteristic | Data Example |
|---|---|
| Transport network | Roads, highways and railways transport graph with corresponding capacities and speed limits |
| Points of interest | Schools, hospitals, cinemas, trade centers with coordinates, capacity |
| Physical map | Terrain types and orography |
| Water flows | Rivers, channels and sewerage, with depth, width and the bed's roughness |
| Scenario population | Fertility rate, medium income, religions, educational level by country |
| City population | Urban units, population and income distribution, number of workplaces in different zones |

In order to provide such information to PONTUS simulator, it was decided to recreate a population up to the level of individuals, considering age, sex and nationality distributions, medium income in different zones of the city, religion. Such detailed representation of the population is achieved by using data from various sources, such as open data provided by public administration, average rental prices and various statistical data related to different countries.

Furthermore, every generated virtual person has a list of preferences and opinions based on attributes, such as age, which allows to recreate daily behavior with higher accuracy. However, basic individual behaviors differs also based social networks and interactions, such as family, friends and colleagues. In fact, the simulator generates not only single persons, but statistically correct families, creating at the same time also a graph of social interactions considering possible friendship between individuals based on their own attributes, such as workplace, age, sex, income, nationality, religion and education level. Such approach allows to reproduce behaviors of different social groups: for example, during the simulation, a specific procedure proposes exchange of possible leisure activities; in fact, during the free time, agent driven virtual people plan collective actions as virtual persons such as going to the cinema or visiting a park. Obviously, in order to reproduce a city's life cycle correctly, it is necessary also to consider various characteristics of the scenario, as proposed by the examples of table 1.

However, it is almost impossible to collect all required information in consistent way and with a sufficient accuracy. For this reason, the simulator takes care of missing data, creating statistically proper data consistent for generating the objects and the virtual people. For example, in case of missing infrastructures, such as schools or malls, PONTUS generates them based on available data about population density as well as on other critical parameters. Furthermore, the simulator analyzes terrain types and orography in order to add missing parts of storm drain.

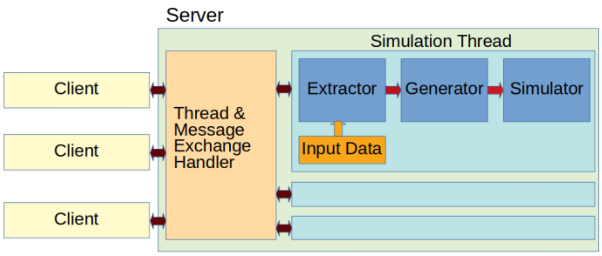


Figure 1: PONTUS Architecture

## 3 MODELING & SIMULATION AS A SERVICE

Due to big advances in cloud computing along last decade, a lot of solutions once performed locally, are now available to be addressed by solutions based on concept Software-as-a-Service (Bruzzone, 2007; Van Steen & Tanenbaum 2017). In fact, such approach allows to outsource local infrastructure to cloud providers, making the final system easier and cheaper to maintain. Obviously, same considerations are true also in the field of M&S (Modeling and Simulation), especially considering that many models require a significant computational power which would be difficult and expensive to provide. So this is an option to be evaluated and compared with traditional approach. In facts it is important to consider Modeling & Simulation as a Service (MSaaS) as well as Modeling, Interoperable Simulation and Serious Games (MS2G), a new paradigms, adopted for models devoted to multiple applications (Liu et al.2012; Bruzzone et al.2014, 2017b).

## 3 SYSTEM ARCHITECTURE

One of main benefits derived from Simulation is the ability to run scenarios multiple times in order to acquire enough statistical data to predict the situation and find optimal solutions. Furthermore in decision support tool for public authorities, it is necessary to consider potential limitations imposed by available hardware, which in most cases is not suitable for high computational workload. Based on these consideration, the authors decided to develop a web-based client-server solution, which allows to place the model in a high performance server, while leaving a relatively lightweight graphic user interface to the client. In fact, in this case, the simulator during, at start, launches a web socket server and goes in idle mode; each time a client connects, the program wakes up and starts a dedicated thread of the simulator, which extracts info from available data sources and subsequently generates the virtual world, as illustrated in the figure 1. An interesting fact is that the PONTUS architecture allows not only to perform parallel simulation, but to do it with different data sets. For instance, it is possible to launch scenarios with different transport graphs, meteorological situations and even distinct cities.

One of main advantages of such architecture is related to the implementation of the MSaaS paradigm, which imposes constraints only on the server's hardware, leaving to all clients the possibility to focus on study of scenarios of interest.

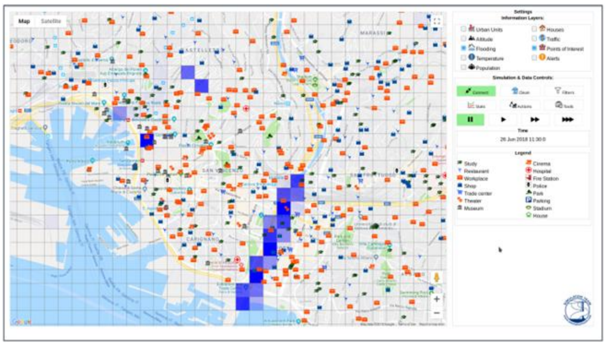

Figure 2: GUI: Points of interest (icons) and the flooded area (blue squares) on the map

As aforementioned, the graphic user interface (GUI), shown in figure 2, is created as web application, which makes it suitable for utilization in any device with sufficient screen size. The main window contains an interactive map based on Google's solution and a control panel to switch between different visualization modes as well to interact with the simulator. PONTUS is an interoperable Simulator using IA-CGF able to interact with other models by using HLA Evolved Standard (Bruzzone 2013). PONTUS allows to select different layers, such as urban units, population density distribution, points of interest, traffic intensity and weather conditions etc. Furthermore, it is possible to filter some data to be visualized: for instance, select only persons of a specific quarter, nationality or age and/or to visualize specific statistical data related to transportations, etc. While the mentioned settings are acting only on a visual part, the GUI allows also to interact with the simulator in order to modify various conditions of the generated scenario. For instance, it is possible to initiate predefined interventions, such as dike construction in a critical sections of rivers, or change 'on the fly' the road network. In order to achieve a compromise between the program's performance and required development time, the authors decided to implement PONTUS in Java. In fact, it allowed integration of various modules maintaining high simulator overall performance. The GUI is developed as a web application, it is an HTML page with formatting declared using CSS and active elements implemented in JavaScript. The proposed solution is quite lightweight and allows to integrate easily different 3rd party and auxiliary modules and extensions, such as Google map, as well as to connect it to the server using Web Socket.

## 4 CASE STUDY SCENARIO & RESULTS

PONTUS help to optimize many activities related to a city management. For instance, it is possible to estimate impact on traffic caused by road block or by construction of a new mall, or predict people presence in points of interest. However, the main scope is emergency management, with special focus on flooding. For instance in past, heavy rains caused huge damages and casualties in Genoa (Lanza 2003). For this reason, the authors tested the simulator on this context; in facts weather module of PONTUS is capable to generate rainfalls in a zone based on historical data obtained from different weather stations. In order to elaborate water transfer on the given terrain, the model create a regular mesh, with every cell characterized by multiple parameters, such as size, elevation, terrain type, its capacity to absorb water and initial saturation (Duley & Kellu 1939). During the run, the simulator calculates water flows among neighbor cells based on a average inclination and water speed on a different terrain types. At the next step, based on environmental conditions, some amount of water is evaporated and absorbed by the terrain. However, such model would not be capable to provide an acceptable precision by itself in case of the city simulation. In facts, underground rivers and channels as well as sewerage network transport a lot of water and could not be excluded from the model; for instance, in Genoa one of two big rivers goes underground for about 1 km just before the sea, which in case of utilization of only a terrain model would lead to constant flooding in such zone while in the real world this situation is very rare. Furthermore, in some cases the accessible orography is not precise enough, otherwise only a DEM (Digital Elevation Model) instead of DTM (Digital Terrain Model) is available.
In such cases provided data contains an elevation of artificial constructions, for example, buildings and bridges, instead of a "pure" terrain below them, which leads to flow calculation errors. In order to overcome these problems, the model utilizes special manually created graph which contains all major rivers, underwater channels and sewerage in the zone of interest, representing such infrastructure as nodes and links, with transfer model is based on a Manning's equation (Chanson, 2004). Such combinations of the rain, water transfer and water channel models allow to reproduce major rains of the past as well as to evaluate impact of future ones. In facts, to validate the model it is possible to compare simulated water flows in rivers as well as water levels respect the ones observed in the similar conditions in the past by using results of rain measurements, water flows, precipitations over different city areas and flooded zones. Furthermore, thanks to the human behavior model it is possible to estimate risks related to people being trapped in buildings by water, which is especially important in cases of critical infrastructures, schools and big entertainment locations. Example of this situation is presented in the figure 2, which contains overlaying layers of infrastructure and the one generated by the flooding model. In addition to this aspects the model consider objects related to industrial elements such as plants and tanks that in case are damaged by the other accidents could deal with release, in air or water, of hazardous material and create contaminated areas; obviously it could be possible also to generate explosions and fires and the simulator enables the possibility to consider domino effect

affecting progressively, along time, multiple industrial elements. This approach extends the validity of the model and allows to consider effectiveness of safety engineering solutions. In general to provide decision makers with explicit data about zones of interest, the simulator operates in a special mode to create the scenario once, and then performs multiple runs with different boundary conditions: normal, crisis and crisis after intervention. In this case the scenario is restored to the initial one after each launch using Memento pattern, which is implemented for each and every variable object. Indeed, PONTUS saves in special log files the most important data, for instance, the one related to human presence in points of interest, making it possible to perform comparison and obtain quantitative results after the finish.

## CONCLUSIONS

The proposed approach is an effective solution, capable to support decision makers in different aspects, from traffic management to emergency situation forecasting. Furthermore, the platform is open to extensions and to possibility to add further components; indeed special auxiliary tools, developed by authors, allow to define easily the scenario to run the simulator on different locations around the world. Of course, it is possible to argue that some components of this simulator is already available in other software tools, in particular the open-source ones; however PONTUS allows to combine them with population behavior and it is open to interoperate with them through HLA. Hence, it is important to highlight some of the main characteristics of PONTUS that include: capability to integrate different components in order to provide more trustworthy overall results, ability to generate secondary data in consistent way and to reduce quantity of the necessary a priori information, user-friendly interface, an effective system's architecture which implement MSaaS paradigm and it is open to HLA. Indeed these aspects support possibility to extend and keep open the simulator while the MS2G approach improve usability.

Such characteristics allow the PONTUS to be some kind of “Swiss Army Knife” in the field of M&S for urban crisis management support, hence, its comparison with more specialized tools is not yet completed and will be object of future researches. The preliminary verification of the model was performed by implementing unit tests on critical methods, as well as by using static code analysis, integration and beta tests. As anticipated, currently, the simulator development is in a validation phase, which is quite complex considering number of included components, however, preliminary results are quite promising.

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