Interactive Learning Environments for Crisis Management through a System Dynamics approach

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Abstract

In today's world flooding and bombing attacks can generate domino-effects due to the interconnected nature of Critical Infrastructures. To facilitate decision-makers take successful decisions, many scholars support a kind of learning that emphasizes active engagement. An Interactive Learning Environment (ILE) is a computer-based simulation approach, based on System Dynamics, that promotes learning on decision-makers. System Dynamics is a methodology that represents a system under study, with which the decision-maker can gain insights into the system and test policies in a safe environment. To demonstrate the capabilities of System Dynamics and ILEs, two projects (CRISADMIN and ATTACS) are described. The purpose of the projects is to help decision-makers achieve better, more informed and more effective decisions when critical infrastructures are faced with disruptive, critical events.

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1 Introduction

On October of 2014 the city of Genoa, Italy suffered from extensive flooding, when two thirds of a year's rainfall fell in less than 72 hours (Bloom, 2014). The results were traffic chaos, material damages, energy blackouts and loss of human lives (Euronews, 2014).The events in Genoa are not the only ones that showed how a critical event can disrupt a city's critical infrastructures. Moreover, disasters do not only occur by natural events, but also due to man-made acts of terror or technological failures. In today's interconnected world, such critical events are not just a distant possibility (Hinssen, 2010) and can have unwanted effects on various aspects of a country's infrastructures. Thus, it is deemed important to develop a new approach that will help appropriate authorities and policy makers-in various levels - to reach better decisions with a new kind of decision-making through modeling and simulation, which could lead to the successful management of such a crisis Mureddu et al. (2014).

In the context of this paper, a crisis is defined as an event with the following characteristics: it has high uncertainty and unfamiliarity, low probability of occurrence, it requires a rapid response, it poses a serious threat to survival and presents a dilemma, which needs a decision that will result either in a positive or a negative change (Sayegh et al., 2004). Thus, the difference between risk management and crisis management is straightforward: while the first tries to assess potential threats and to find the best ways to avoid them, the second is more concerned with dealing with effects of the same threats before, during, and after the event.

The characteristics of a crisis are magnified due to the interconnectedness and complexity of today's world. A critical event (natural or man-made) can generate domino-effects that can cripple entire regions, bringing the fundamental role of critical infrastructures to the front lines of national and transnational agendas. As a result, the need for better emergency-response techniques and resilience against critical events has become a top concern for national and international organizations.

The purpose of this paper is to present a new approach to crisis management with the development of an Interactive Learning Environment that can help decision-makers understand how Critical Infrastructures are connected, what are the types of effects that can be generated in the case of a critical event and experiment with countermeasures in a consequence-free environment.

The rest of the paper is structured as follows: Section 2 is concerned with the methodology of System Dynamics and their combination with ILEs, while in section 3 two projects that make use of System Dynamics and ILEs are presented and specifics of their models are presented. Finally, conclusions and recommendations are described in section 4.

2 Methodology

This section is focused on the methodology of System Dynamics that was used to build the simulation model, along with the definition and a literature review on Interactive Learning Environments.

2.1 System Complexity and System Dynamics

System complexity can be distinguished by several factors: the number of components of the system, the number of relationships among the components and the types of relationships among the elements (Gonzalez et al., 2005). Moreover, decision-making becomes dynamic; it requires more than one decisions, decisions are interdependent and the environment changes over time (either as a result of the decision or regardless of the decision or both) (Edwards, 1962; Qudrat-Ullah and Karakul, 2007). In this context, human subjects may have good decision rules, but they fail to apply them consistently

(Hsiao and Richardson, 1999).

Research on the reasons behind this failure is active, however several findings have emerged. Firstly, decision-makers are forced to rely on intuition to assess the situation, the likely impacts and take a decision. Second, decision-makers fail to understand the notion of feedback and how it is applied in the real world. Moreover, they fail to understand time delays and they ignore the time lag between the initiation of an action and the manifestation of its full effect. Finally, decision-makers do not understand non-linearities and how they are manifested in the real world (Sterman, 1989; Sterman et al., 2013).

To help decision-makers to understand the errors in their judgment and make more successful decisions, computer-simulation models are used. They are adequate representations of the system under study, with which the decision-maker can gain experience and test real world-like responses (Qudrat-Ullah and Karakul, 2007). System Dynamics (Forrester, 1961; Sterman, 2000) is such a computer-based modeling method that facilitates decision-makers to understand elements of complex systems over time. Its main elements are feedback loops, time delays and they are appropriate to test decisions/policies in a safe environment (Armenia et al., 2012).

To further facilitate decision-makers, many scholars support a kind of learning that emphasizes active engagement (Sterman, 2014). For that reason, Interactive Learning Environments (ILEs) or Flight Simulators - that are based on System Dynamics models - have become an important tool in decision-making.

2.2 ILEs: A small literature review

There are many definitions of ILEs (Morecroft, 1988; Warren, 1998). In the context of this paper, an ILE is a computer-based simulation approach, based on System Dynamics, that promotes learning on an individual or a a group of decision-makers (Groessler, 2006). An ILE allows the compression of time and space (Isaac and Senge, 1994), teaches the capability to manage complex systems, increases the awareness on feedback, provides insights about time delays and familiarizes the learner with the concept of non-linearities (Groessler, 2006; Morecroft et al., 1994; Sterman et al., 2012).

In the field of System Dynamics, several well-known ILEs have been used for teaching purposes. There is the Beer game (Goodman et al., 1993; Sterman and Fiddaman, 1993), which simulates the supply chain in the logistics business. The People Express Management Flight Simulator is an ILE for business management (Sterman, 1988). One of the most famous simulation games is the Fishbanks (Meadows, 1999), which simulates the fishing industry and the effect on fish resources. Lately, MIT has gathered a number of ILEs (available online) that demonstrate the capabilities of System Dynamics and ILEs (Sterman, 2014).

In conclusion, System Dynamics and Interactive Learning Environments seem an appropriate tool to help decision-makers gain insights into complex systems and take informed decisions. However, little or no attention has been paid to the use of ILEs in the field of security and crisis management.

3 ILEs in Crisis Management

To address the gap in the use of ILEs in the field of security and crisis management, two projects have been developed; CRISADMIN and ATTACS. The two projects are concerned with Critical Infrastructures and how disruptive events can affect their operations, their structure and what type of ripple effects those changes can generate in an urban environment. The ATTACS project is currently in the development phase. Thus, to demonstrate the potential of the project, the CRISADMIN project is described in detail since this is where the analysis of the transportation sector begun. The rest of the section provides the description of the projects.

3.1 The CRISADMIN ILE

The CRISADMIN project (***Cr****itical* ***I****nfrastructure* ***S****imulation of* ***Ad****vanced* ***M****odels on* ***I****nterconnected* ***N****etworks resilience*) has been aimed at using System Dynamics modeling methodology to investigate, reproduce and simulate the interdependencies between critical infrastructures while stressed by critical events. Its goal is to develop a simulation tool for the assessment and evaluation of risks and impacts due to large catastrophic events able to generate domino effects among critical infrastructures. The implemented prototype has been designed to allow decision makers to analyze the interdependencies among critical infrastructures, the modalities through which they get affected by unpredictable catastrophic events as well as to investigate the impacts of possible intervention countermeasures or prevention policies (Cavallini et al., 2014)

On the final ILE, two types of critical events are accounted for: flooding and bombing attack that can be applied in different critical infrastructures at different points in the simulation time. The focus is on the critical infrastructures of Energy, Telecommunications, Transportation and Apparatus (health services, aspects of human behavior etc.) and how they can affect and be affected by each other. The CRISADMIN simulation tool is accessible online (`http://5.249.149.78/netsims/crisadminproject/ile/index.html`)and allows the creation of custom scenarios and countermeasures/policies (more on Model Structure). Finally, the web tool will have as main beneficiaries the EU Member States stakeholders in the field of Critical Infrastructures and related services.

The CRISADMIN ILE has also a few limitations. For the time being, the ILE cannot be transformed in Decision Support System due to limitations in simulation speed, limited time scope and because it accounts for a partial view on the interconnectedness among the infrastructures. However, these limitations do not diminish its value; the tool can facilitate decision-makers to gain insights into: the dynamics of the most critical infrastructures of an urban environment, the different effects that different critical events can cause and finally, the effects and effectiveness of different countermeasures/policies [1].

3.1.1 Model Structure

The general structure of the System Dynamics model- at a high level- is depicted in the Causal Loop Diagram of Figure 1.

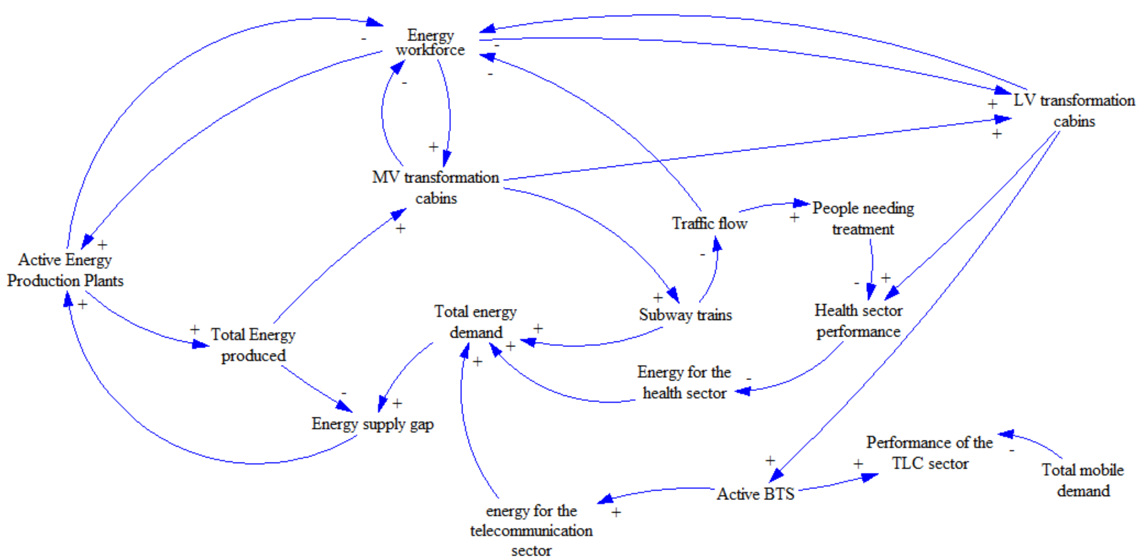

Figure 1: General Causal Loop Diagram

Energy production facilities produce High Voltage (HV), which is transferred to the distribution area. The connection between them is the Medium Voltage (MV) Transformation cabins. Consequently, the MV energy is transformed into Low Voltage and

[1] A similar effort was performed by the Los Alamos National Laboratory and was named CIPDSS: Critical Infrastructure Protection Decision Support System. The project was concerned with the protection of critical infrastructures from terrorist activities, natural disasters or accidents. For more information `http://www.lanl.gov/programs/nisac/cipdss.shtml`.

distributed to the metropolitan area. Each of the structures of the energy sector can malfunction either normally or due to a critical event and can be repaired with the appropriate allocation of the energy-sector-workforce. The energy sector determines the functionality of the rest of the Critical Infrastructures of the CRISADMIN model. More specifically, in the Telecommunication sector (TLC), the Base Transceiver Stations (BTS) that handle the mobile demand, are directly affected by the energy sector. Similarly, the subway network is connected to the Medium-Voltage part of the energy sector. A malfunction in the energy sector will affect the performance/functionality of the transportation sector, since the subway will not function properly. Thus, the passengers of the metropolitan area will seek new means of transportation. However, new means of transportation means new travel patterns (and increased traffic flow) that will affect the energy workforce ability to reach the points of damage (in the energy sector) and start the repairs. Both the energy and the transportation sector affect the health sector of the model. For a more detailed description of the CRISADMIN qualitative model check (Cavallini et al., 2014; Armenia et al., 2014).

The underlying System Dynamics model captures an urban environment (the values of which can be changed to create different urban environments, Figure 2).

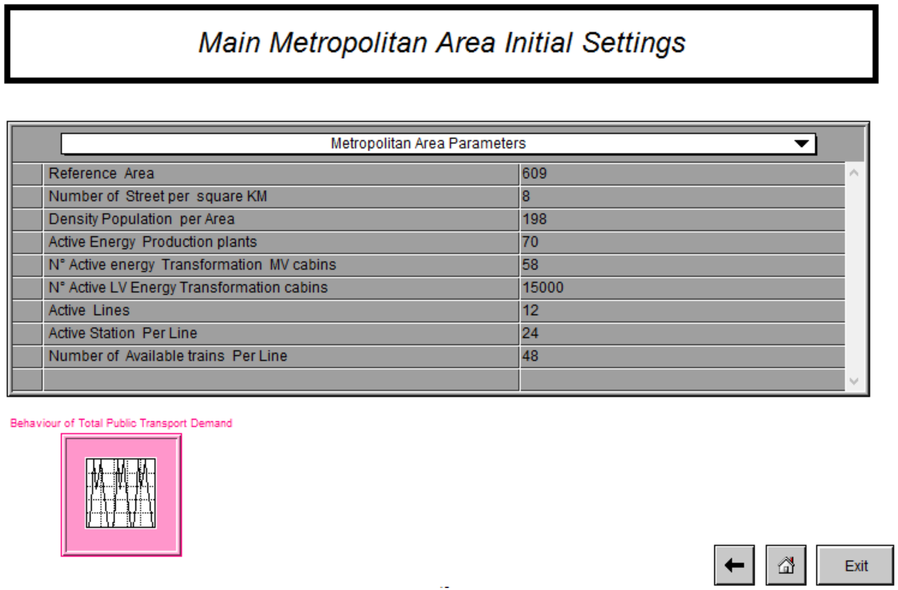

Figure 2: Urban environment ILE settings

Moreover, as it was mentioned in the previous section, four critical infrastructures are modeled: Energy, Telecommunications, Transportation and Apparatus (Armenia et al., 2014; Cavallini et al., 2014).

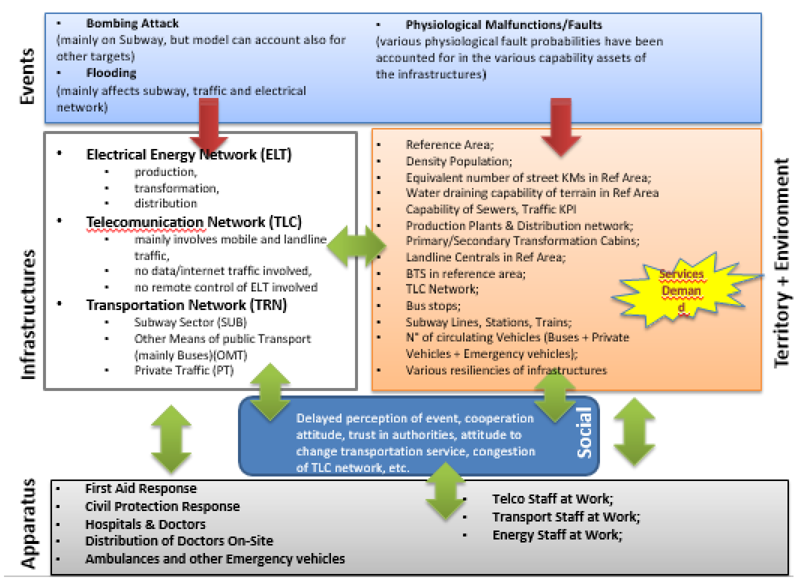

Figure 3: Theoretical relations of the main elements of the model

Energy The purpose of the energy sub-model is to describe a possible, general electrical energy infrastructure in its four fundamental parts: Production, Transportation, Distribution and Energy Workforce.

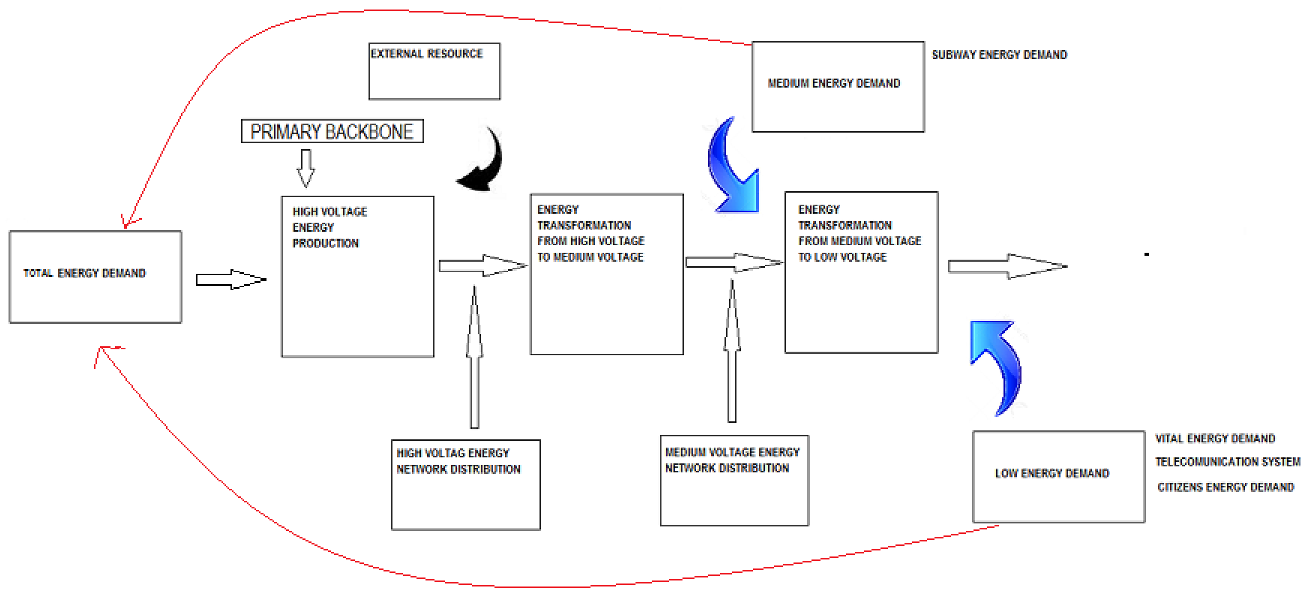

Figure 4: Electrical Energy Infrastructure main relations

Typically, energy production facilities produce High-Voltage (HV), which gets transported from the HV-lines on the national primary backbone and from the power plants up to the centers/areas where the electricity needs to be distributed.

In every part of the energy sector, the essential material can malfunction or go to maintenance normally and can be damaged due to the critical event. In those cases, the energy workforce moves dynamically to repair the damage, according to where is mostly needed.

Telecommunications The Telecommunications sector (TLC) is divided into the parts of: Mobile and Landline telecommunication, Telecommunication Network and Workforce.

Figure 5 represents a typical telecommunication data process from User A to User B. In particular, there are two main types of TLC channels: Mobile and Landline. Regarding the first one, a call starts from the mobile Phone of user A and arrives to the Base Transceiver Station (BTS) through the Mobile network. After that, the mobile signal is sent to the "TLC exchange" (TLC Centrals), which are linked with the BTS structures through the landlines. Two main capacity bottlenecks in the system were identified: the first affecting the flow of incoming calls in the BTS structures and the second affecting the flow of calls from BTS to the TLC exchange.

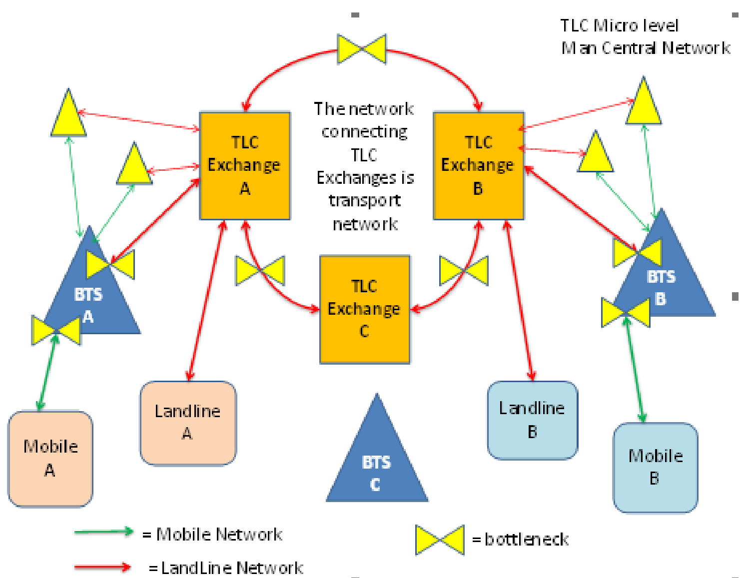

Figure 5: Schematic of Telecommunication network

Regarding the Landline source, the call starts from a landline Phone (user A) and arrive directly to the TLC exchange, through the Landline network. It is worth mentioning that "TLC exchanges" have a limited capacity in terms of the capability to manage and route calls. Once the calls from mobile and landline sources arrive to the TLC exchange, they get routed to the TLC exchange destination. Upon reaching the TLC Exchange connected to the destination, all data that had been previously unpacked, are reassembled and sent to the final user by the TLC exchange nearest to him, either through Mobile or landline channels.

Similar to the energy sector, the telecommunication workforce moves dynamically to where is mostly needed to repair damages and malfunctions.

Transportation The purpose of the Transportation sector is to describe the iterations of the main infrastructure choices represented by Subway and Other Means of Transportation (OMT) for the public transport and by private transport (PT). In order to better explain these relationship, it is useful to explain the choice mechanism implemented that allows people to choose which type of means of transport to use, in accordance with the relevant transport service level.

The reference population area must decide whether to travel by subway, by bus (OMT) or by car (PT). This choice, in the model, depends on a dynamic variable factor represented by the corresponding service level (with values ranging between 0 and 1) of the 3 sub-models contained within the transport infrastructure sector (Radzicki and Sterman, 1994).

Assuming a transport demand equal to 9999 people, in a state of equilibrium of the system, the same factor of choice for all three sub-models is assumed, which is divided as follows:

	Subway	**OMT**	**PT**	
Service Level	1	1	1	3
Partition Coefficient	1/3=33%	1/3=33%	1/3=33%	100%
Persons	3333	3333	3333	9999

Table 1: Mechanism of choice in a state of equilibrium

Let's assume now that the initial equilibrium changes, due to a malfunction in the underground network, and the subway service level drops drastically from 1 to 0.7. In this case, with this mechanism, we proceed to the dynamic distribution of the transport demand, with a weighted percentage based on the changes undergone by each service level as follows:

	Subway	**OMT**	**PT**	**Total**
Service Level	0.7	1	1	2.7
Partition Coefficient	0.7/2.7=26%	1/2.7=37%	1/2.7=37%	100%
Persons	2599	3700	3700	9999

Table 2: Mechanism of choice in a state of dis-equilibrium

Comparing the two tables, it can be seen that the people who leave the subway are equally distributed to Other Means of Transportation and Private Transportation.

Subway Transportation The main elements of the subway sector are: the dynamic subway demand, the subway behavior, the number of people who leave the subway and the subway Service Level (SL).

As explained before, the "Subway demand" is dynamically calculated from the total public demand for transport based on a percentage. The subway behavior depends on the number of lines, stations and trains that are active (and not inactive due t normal malfunctions and/or damages due to critical events) and the number of people who use the subway system. For the calculation of the Subway Service Level (SL) it had to be taken into account that a critical event (such as an explosion) is a discrete event, while the rest of the model, under the reference values\circumstances, is continuous. Therefore, two definitions for the service level had to be taken into account: the first is normal - and used for various models - is the number of people who arrived at the destination divided by the number of people who asked for a train. In order to calculate the service level it had to be taken into account that there is a need for physical time to be considered. For that reason, the service level was not calculated per time step, but after a delay. This calculation is applied before the time of the critical event and after the time it takes for the public to re-establish their trust in the subway again. Since the service level is calculated (normally) as a division, the denominator cannot be zero, although it had to be taken into account that the demand for subway could be zero (during the time the subway is closed). For that reason, during the period that the subway is under attack and the time it takes to start restoring its operation, the service level is calculated simply as the rate of damaged subway lines to the total subway lines. The changing of definitions for a notion inside the same equation, may be unconventional, but it was deemed necessary due to the restrictions that were described.

OMT and PT The other sectors of the transportation system have similar elements as the subway sector. To avoid repetition, we mention only one variable that is important not only for the transportation sector but the entire model. The variable is Key Performance Indicator of the traffic. To calculate the variable, the relationship between the Total Vehicles and the "Available Equivalent n° of street KMs in Ref Area" is taken into account. The latter variable is calculated by multiplying the kilometers in the reference area to a "n° of Street on KM". The number can be reduced by the streets involved in a critical event (flooding or bombing). A mentioned before, the "Traffic KPI" is a very important variable, whose changes affect the entire CRISADMIN model.

Finally, the workforce responsible for the repairs on the damaged materials of the sector, moves dynamically where is mostly needed.

For every critical infrastructure, the number of important elements (Figure 2) and the number of the available workforce can be altered to facilitate the needs of each user (Figure 6).

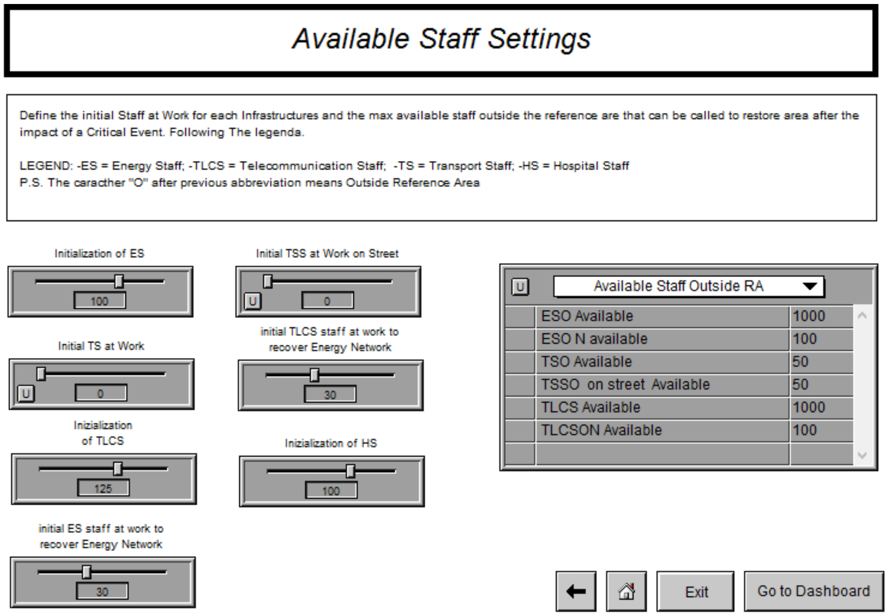

Figure 6: Available workforce ILE settings

Apparatus The Apparatus section contains the elements of the model that are the most difficult to simulate: Health services and human behavior.

Health Management The Health sector is represented as a supply chain in which patients are entered (after injury), are treated in the various stages of the chain depending on their injuries and leave the chain. Big part of the Health sub-model is the management of the ambulances and the medical personnel. Both move dynamically to where they are mostly needed and their successful operation determines the pressure under which the health management functions. The important variable of "Traffic KPI" -that was described in the transportation sector- determines how successful the functioning of the ambulances is.

Human behavior The elements of human behavior are separated into to main sub-models: the behavior of the authorities and of the citizens. These aspects of a system are represented by variables that are called "soft". Soft variables relate to attributes of human behavior or effects that variations in such behavior produce. Numerical data are often unavailable or non-existent for soft variables. However, such variables are known to be critical to decision making and, therefore should be incorporated into system dynamics models.

Authorities This section describes how information flows from the place in which the critical event has been detected to the superior hierarchical levels of command. Information is collected from local monitoring activities. Local monitoring activity refers, for example, to the personnel that sends an alarm for a bombing event in a train or subway station, or a traffic officer that alerts the major of a small town for the growing level of a river flowing in a urban center. Of course, in the case of bombing event the monitoring activity is simpler since given the higher visibility of the event. Yet, even in the case of bombing, monitoring activity is fundamental. Here, we refer, for example, to the activities such as detecting abandoned luggage and bags, or noticing suspect smoked or smells. In the case of flooding events, the monitoring activity may be more structured and may be conducted by specifically organized institutions (various local agencies that control water levels). All the mentioned monitoring activities influence the ability to locally perceive an event's entity. To be effective, the locally collected information needs to be transformed into a locally authorized and organized reaction. In our model, this process is labeled Information transferring. Information transferring converts locally collected information into a command to act. This command to act leads to on-site organization of first aid. Two mechanisms facilitates or hinder the triggering of command. First, there may be a delay in the authorization of local operation. Second, given local availability of personnel and materials, and given different socio-cultural attitudes to cooperative behaviors, the local organization of first aid may be more or less rapid.

Citizens and social variables A critical event induces behavioral changes in the people that are part of the system being in crisis as well as in those that are supposed to manage and solve such crisis. In making selections of literature for our review (Quarantelli, 1999; Tierney, 1989), our main focus was the human behavior in social systems in the response phase. We further considered the impacts of social factors connected to the individuals and organizations affected by the crisis event as well as social factors connected to organizations involved in the management of a crises event. This reflects the fact that human factors come into play at several levels of crisis management: at the individual, societal, organizational and inter-organizational level. It is therefore necessary to integrate these disparate levels and their interactions. In detail, we investigated factors that affected: individual behavior, inter-organizational cooperation, leadership and crisis communication (Figure 7).

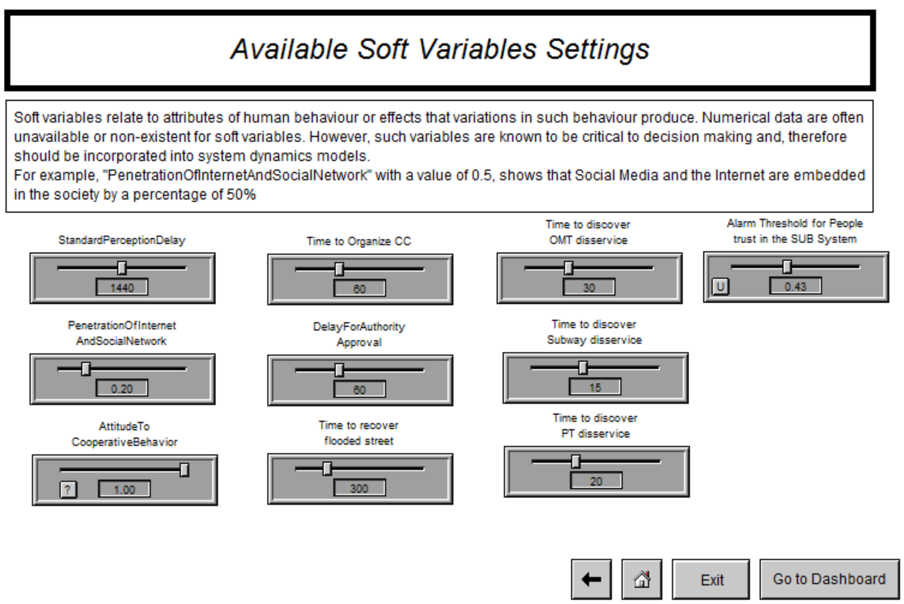

Figure 7: Social variables in the ILE

3.1.2 Critical Events

Two critical events can be accounted for in the ILE: flooding and bombing attack.

Flooding The critical event of flooding can be defined by every user independently to study different scenarios. The main variables that determine the scenarios are: th millimeters of rain per day, the water level considered as flooding, the capacity of the river banks and the weight of the monitoring that determines the prevention that increases the possibilities to intervene.

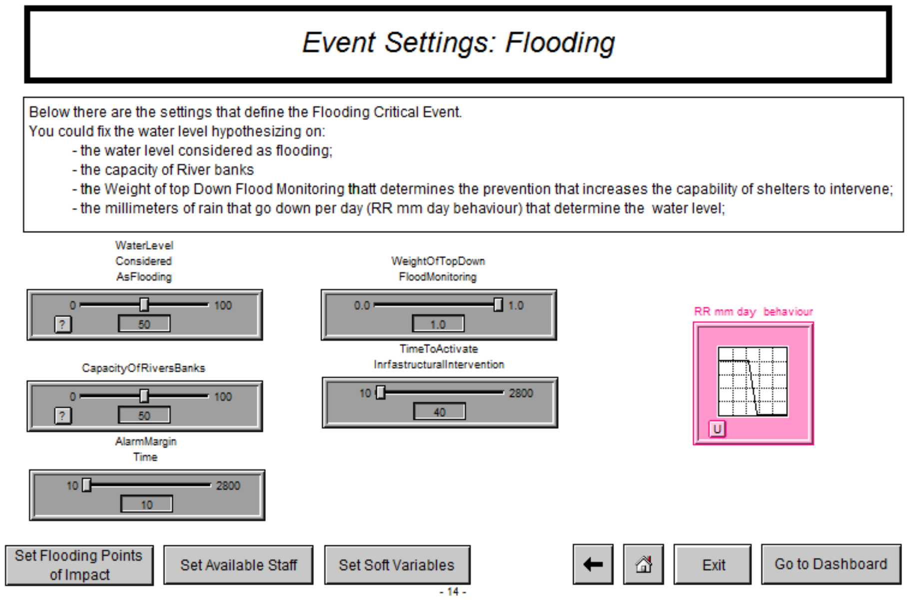

Figure 8: Flooding settings in the ILE

Bombing attack The critical event of a bombing attack can be also defined by every user independently. The main variables that determine the scenarios are: magnitude of the explosion, time of the bombing attack and Time for consecutive different attacks[2]

[2]Time for different Bombing attack is the variable that determines if the users wish another Explosive critical event, at different time after the Time of Bombing attack. For example, if the value is set at 500, an explosion will happen at Time of Bombing attack=930 [min] and then consecutive explosions each 500 minutes (at time =1430, 1930, 2430, 2930,3430,3930,4430). Remember that the simulation end - time is set to 4500 min.

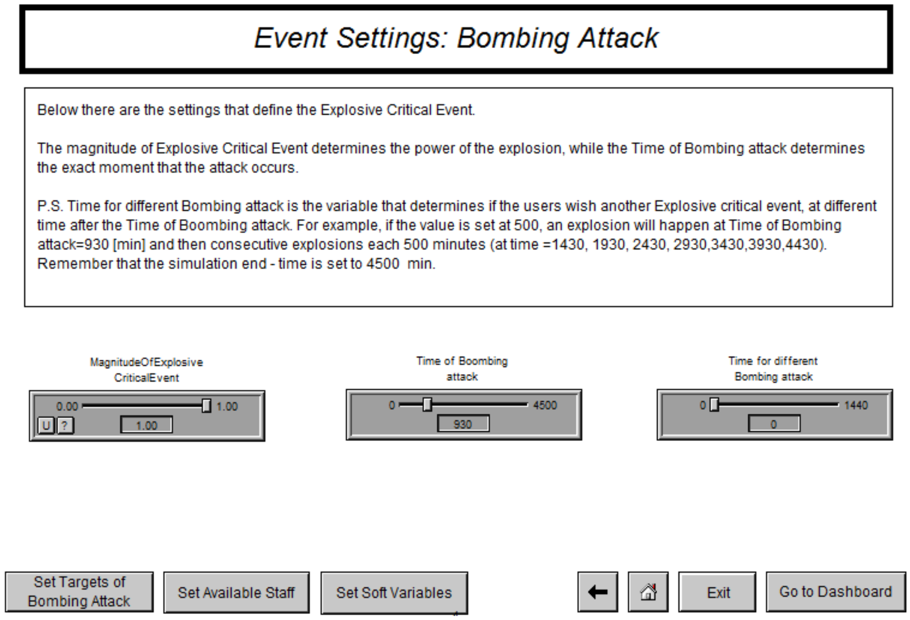

Figure 9: Bombing attack settings in the ILE

For both the critical events, different points of impact can be determined. The points of impact can be in any of the critical infrastructures, their parts or a combination of both.

3.1.3 Policies and countermeasures

Several countermeasures have been designed and created in the ILE. The policies are nothing more than variables in the model that change the value/behavior of basic variables. For CRISADMIN, five groups of variables that can influence the model output and be used as policies/interventions were identified and tested.

Policies in the energy sector These policies are focused on re-allocating the energy appropriately to the other sectors and prioritize those that are in greater need for energy. There are the options to re-allocate energy to:

- Hospitals, where it was assumed that a shortage of energy makes it more difficult to treat injured people. Thus, in cases of emergency, extra energy – taken from other non-essential sectors – is reallocated to the health organization, relieving some of the pressure

- The telecommunication sector, where the purpose is to reduce the congestion in the mobile lines

- The subway system, where it was assumed that shortage of energy diminishes the capacity for the trains to travel as fast. Thus, by re-allocating extra energy in cases of emergency, the subway can still function.

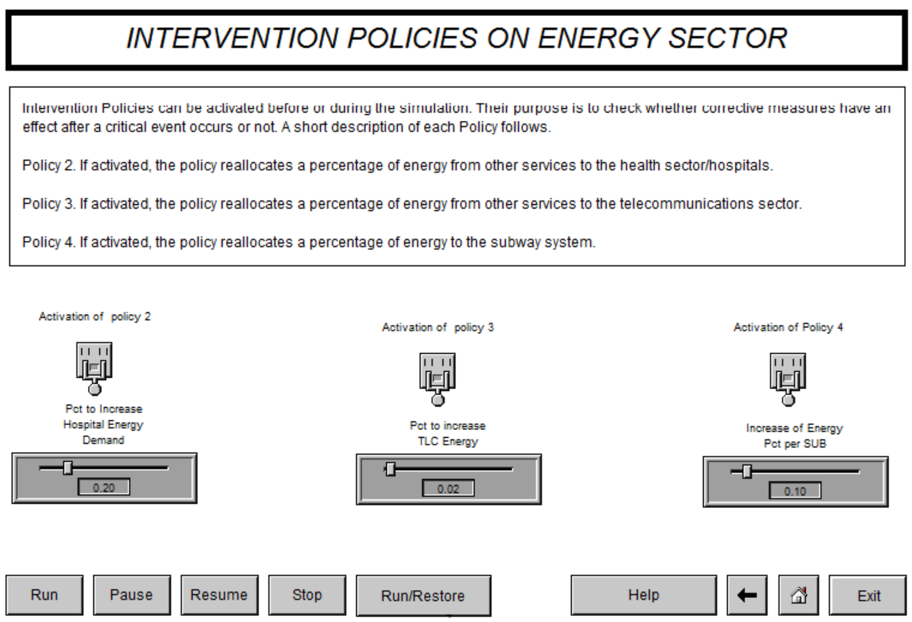

Figure 10: Policies in the energy sector in the ILE

The policies of the energy sector are extremely effective, because they are applied to the problematic point directly. However, this is also one of their weaknesses; they are designed with a specific purpose in mind ("cure the symptom…") and they cannot affect the entire behavior of the model ("…but the cause remains untreated"). Finally, the policies are meaningful only when a critical event is applied in the energy sector and is meaningful to discuss about the appropriate allocation of the remaining energy.

In that case, though giving extra energy to the hospitals means that the energy has to be taken from somewhere else and the effects of that decision can be undesired.

Policies in the transportation sector These policies are designed to help the transportation sector operate as smoothly as possible after a critical event. They are:

- Reduction of the traffic KPI. The rationale behind the specific policy is that the authorities can deploy extra (police) forces after a critical event to secure that the traffic congestion can be reduced. The policy is very effective because the traffic KPI affects a lot of aspects of the model. However, the policy is extremely uncertain and difficult to materialize; it could be said that more police officers can regulate the traffic, but the reduction of the percentage of the traffic is not certain

- Mechanisms to reduce the crowding in the subway system. Like with the reduction of the traffic KPI, this policy is extremely powerful (less crowding less people injured less pressure on the health organization), but once again (and for the same reasons) uncertain and difficult to materialize/parametarize.

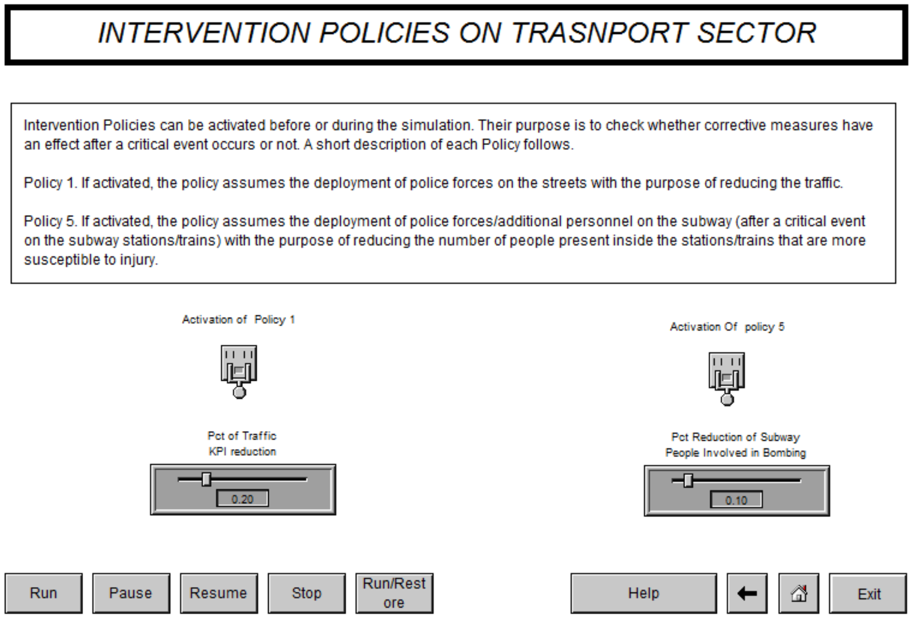

Figure 11: Policies in the transportation sector in the ILE

Policies for the availability of resources The rationale behind those interventions is that in cases of emergencies, more resources (either human or material) are usually necessary.

- More materials. This intervention is focused on the number of ambulances available. In the case of a critical event, the number of injured people may not be covered by the existing ambulances. Thus, it could be useful to increase that number. However, more ambulances might means more vehicles on the streets, thus increasing the traffic KPI and making the policy to fail

- More human workforce. The model is designed to dynamically allocate the personnel of each sector, where it is most needed. Thus, similar to the ambulances, more people to repair damages could be useful. However, once again this policy can fail because for the extra people to reach the point of need/repair, they have to cross the congested streets. Consequently, extra manpower may not help because they arrive where they are needed too late.

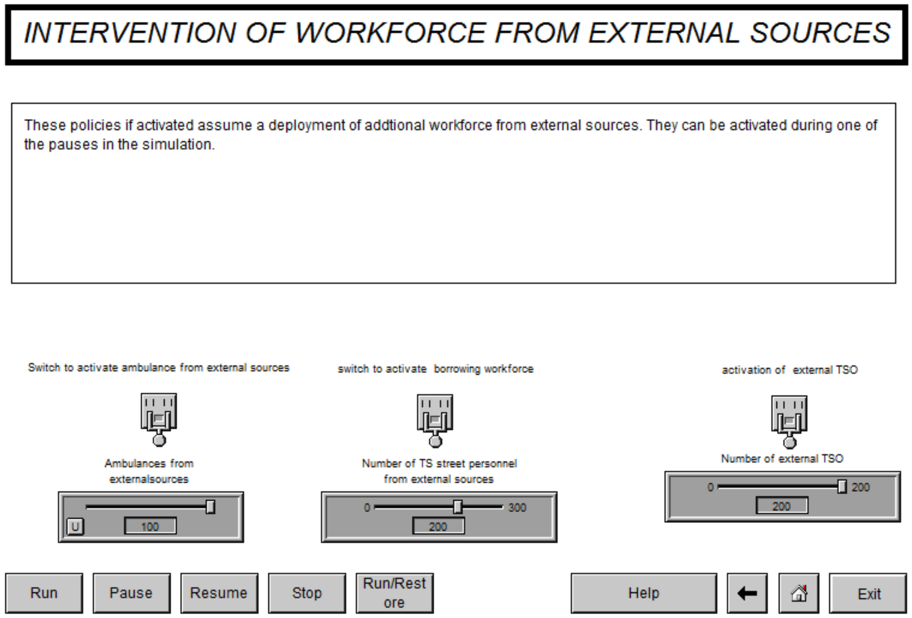

Figure 12: Policies for the availability of resources in the ILE

Policies on people's behavior The rationale behind those policies is to try and control people's behavior after a critical event. For example, if people start behaving "normally" sooner, then chaos might be contained, thus ensuring that less people are injured and the pressure in the health organization remains manageable. However, these policies are extremely difficult to materialize (how can someone control effectively people's behavior after a critical event?) and extremely uncertain (how can a "real" value be assigned to the intervention?).

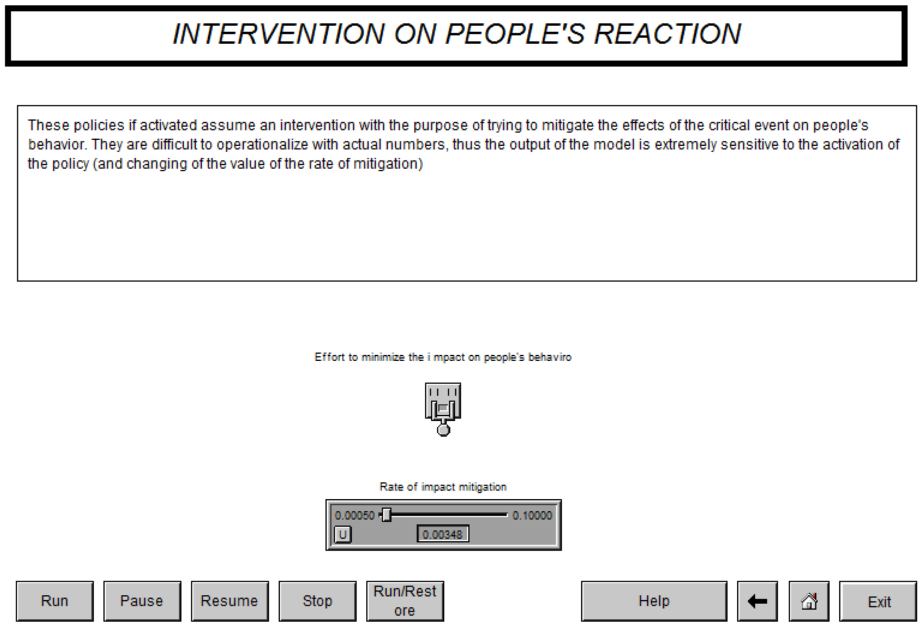

Figure 13: Policies on people's behavior in the ILE

Policies on the authorities' behavior These policies/interventions are focused on how the authorities can be organized faster to avoid the most severe/crippling effects of a critical event. Similar to the previous type of policies, they are difficult to materialize and uncertain. However, they can be very effective, especially if they are applied before a critical event (Figure 7).

In conclusion, several policies were designed and tested across the different sectors of the model. The policies could be sector-specific and if used appropriately could solve important problems in the sector. Moreover, there were policies that were easier to fail, if they were not used appropriately (for example bringing in more ambulances). Finally, there were policies that had an effect throughout the model and those were focused on people's behavior (either the general population or the authorities). These interventions proved extremely effective and produced interesting results, however, they cannot be easily materialized in "real-life" terms and they are extremely uncertain.

3.1.4 Main Dashboard

Figure 14 shows the main dashboard of the ILE, in which the user can run the various simulations. In default, the model will stop the simulation every 1000 minutes to give the user the possibility to study the effects, understand the dynamics of the various sectors and decide whether to apply a countermeasure or not.

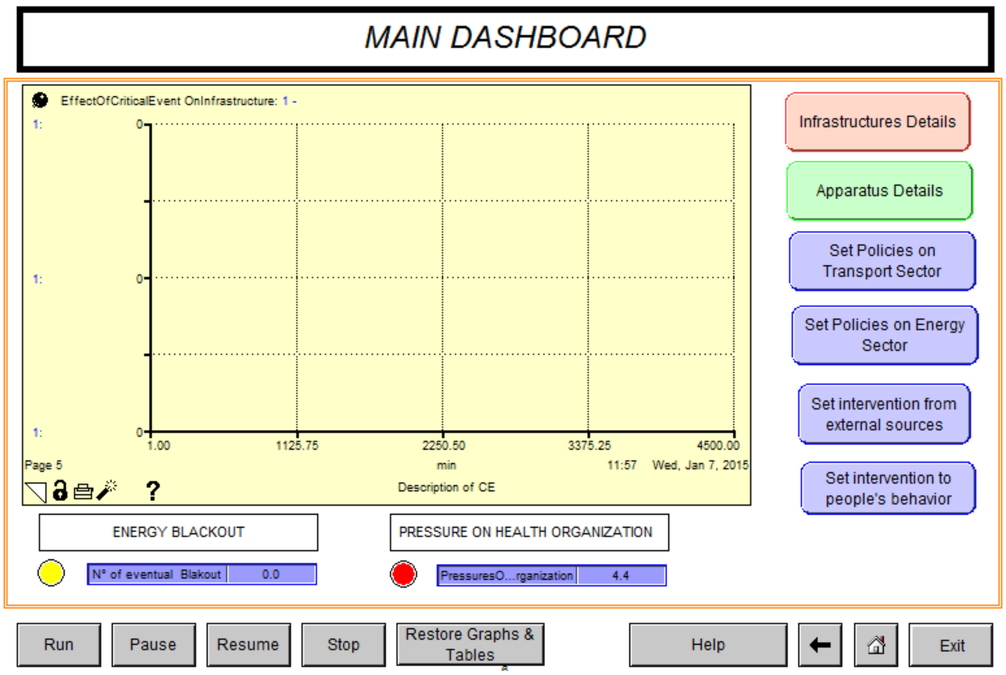

Figure 14: Main ILE dashboard

In conclusion, the underlying model represents several critical infrastructures and how they interact with each other. Furthermore, aspects of human behavior- which is difficult to parametarize and simulate- were created to study the effects of a critical event not only on materials but also on people, their behavior and how that behavior can in return affect the entire system. Several policies were designed and tested, across the different infrastructures. The policies can be sector-specific or try to mitigate the effects of a critical event for the entire system/model. Finally, everything can be accessed through the main dashboard of the ILE.

3.1.5 Results

To fully illustrate the function and the capabilities of the ILE and demonstrate some results, the case of Genoa will be described. The real amount of accumulated rain that was observed was used as an input and when the model was simulated with the above data it produced an amount of water that corresponded to the levels that were observed in the city of Genoa (Figure 15).

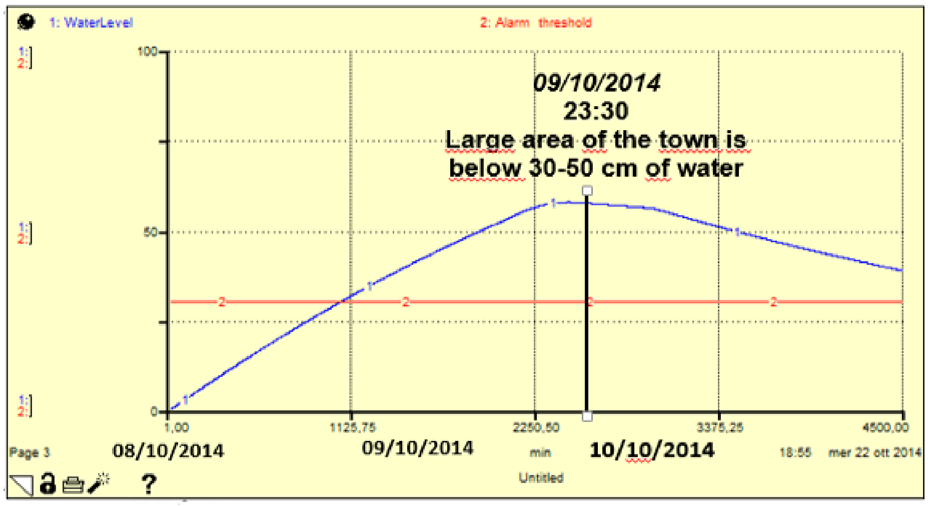

Figure 15: Water level produced from the simulation and the actual level observed

Similarly, the flooding of the (simulated) river reaches its maximum the same period that the actual event took place (Figure 16). However, the value that was observed was higher than the one produced by the model and occurred at a time slightly different than the model's.

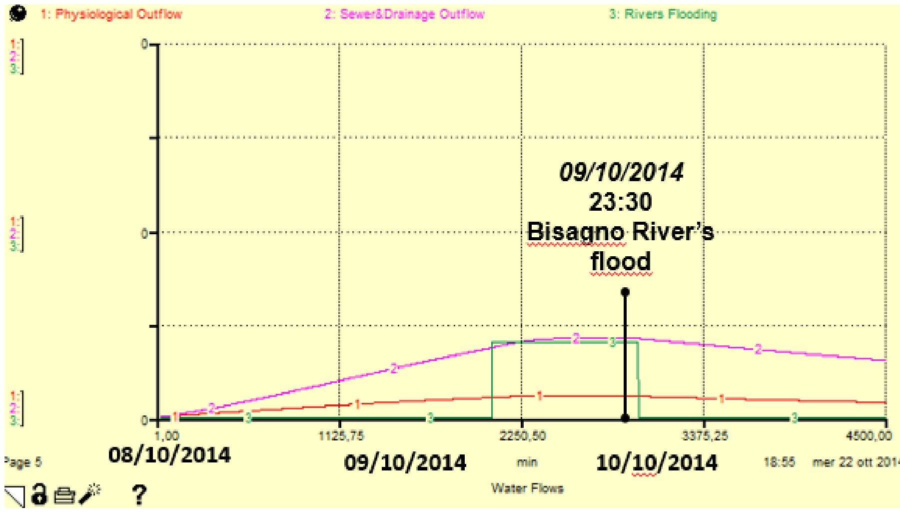

Figure 16: Simulated River behavior

Furthermore, the city of Genoa suffered from several blackouts that occurred at the second and third day that can be observed in Figure 17, where the number of active energy production plants is reduced due to the malfunctions caused by the flooding.

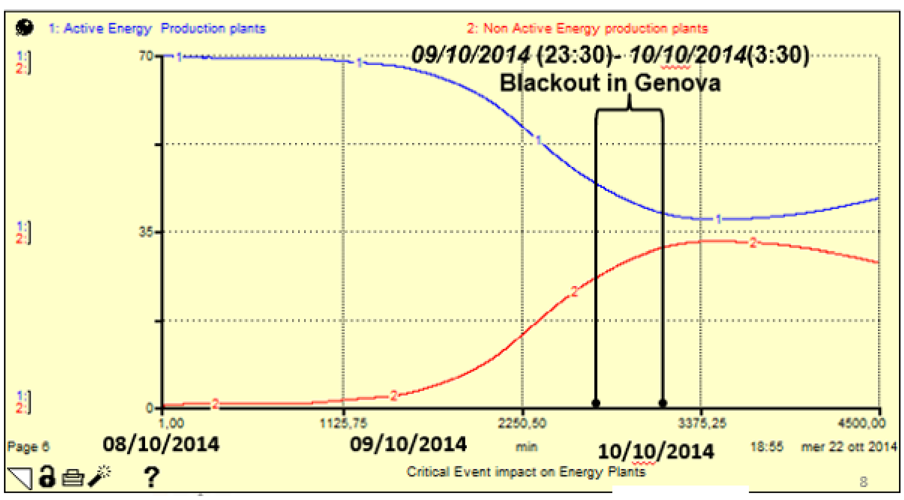

Figure 17: Simulated Blackouts in Genoa

Finally, to test some of the policies, we re-run the simulation, but with different values on the variables that determine the authorities' behavior (Figure 18).

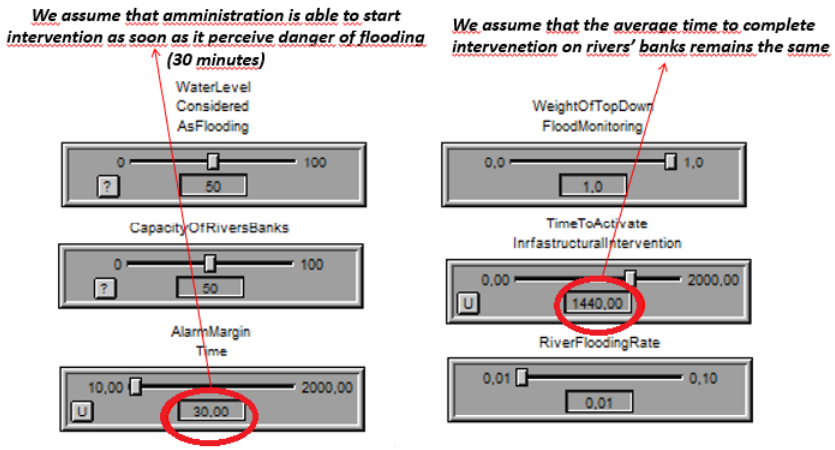

Figure 18: Policies on the authorities' behavior

By anticipating the critical event of flooding and reducing the alarm time by 30 minutes, the water level comes back to its original levels faster (Figure 19).

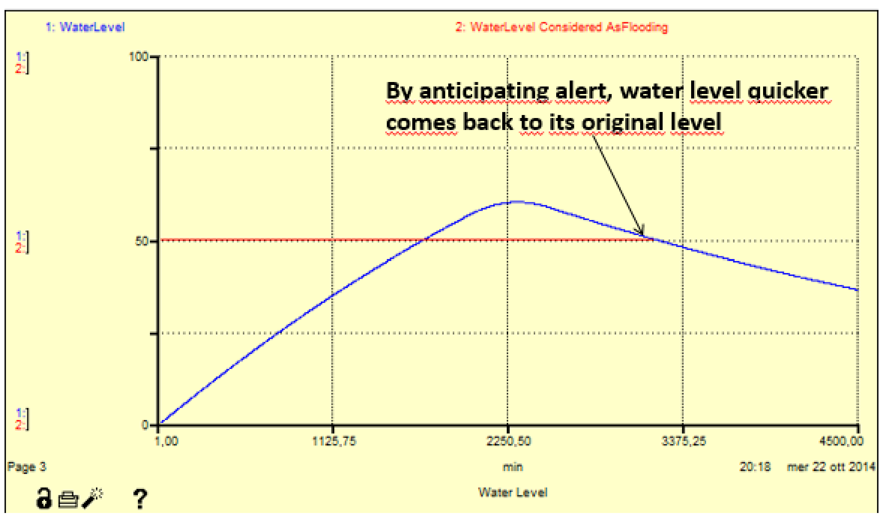

Figure 19: Results of the simulated intervention policy

To conclude, we evidenced that our model is able to capture the overall dynamics (though obviously not in every detail) of the flooding behavior in Genova. As expected, some differences are observed due to two main reasons: 1) models cannot depict accurately the full complexity of reality ("All Models Are Wrong", (Sterman, 2002)) , and 2) our model has the limitations that we have evidenced in previous paragraphs, and mainly due to the fact that we are only considering (due to manageable complexity issues) just for the 3 previously described infrastructures (thus neglecting possibly any other feedback passing through other infrastructures not in the model) and, inside such CIs, we are accounting for a limited set of variables. However, the inclusion in our model of several relevant "soft" variables (such as the *Alarm Margin Time* or *Perceived Impact on People's Behaviour*) – that capture aspects of human behavior – offers some interesting insights that can be extremely helpful to decision makers (for example, a smaller *Alarm Margin Time* in a flooding reduces its impact on the critical infrastructures). It must also be stated, that correctly using the model is also an important factor in confirming hypotheses: if the model is used for gaining "insights" into the general dynamics of Critical Infrastructures (CIs) interdependencies, how CIs might be affected by a critical event and by analysing impacts propagation, then the model can prove extremely useful; otherwise-if used for "predictive purposes"- its value is diminished. With reference to the results obtained from the simulations and the effectiveness of the simulated countermeasures, it appears that a correct allocation of resources (mainly workforce) to damaged areas, can provide to be more effective (and helpful) than increasing such intervention workforce by large numbers of personnel. Finally, those characteristics that are the most important to simulate – and are depicted in the model by "soft" variables – seem to be the ones that really affect the outcome of a crisis.

3.2 ATTACS

The ATTACS project (***A****ssessing the economic impacts of* ***T****errorist* ***T****hreats or* ***A****ttacks following the* ***C****lose down of public transportation* ***S****ystems*) aims to create a simulation tool that will facilitate decision-makers to evaluate the effects (direct and indirect and under economic terms) of a public transportation system closedown. The CRISAD-

MIN project demonstrated that the transportation system is extremely important for the other critical infrastructures. As such, ATTACS is a continuation of CRISADMIN, with a focus on urban transportation systems and the economic effects that a closedown (due to a threat of or a terrorist attack) would generate in the urban environment.

The ATTACS project is currently in the phase of developing the simulation model, however an original analysis has been conducted to map the potential economic effects due to a transportation system closedown. The mapping of the effects is summarized in the Causal Loop Diagram that follows.

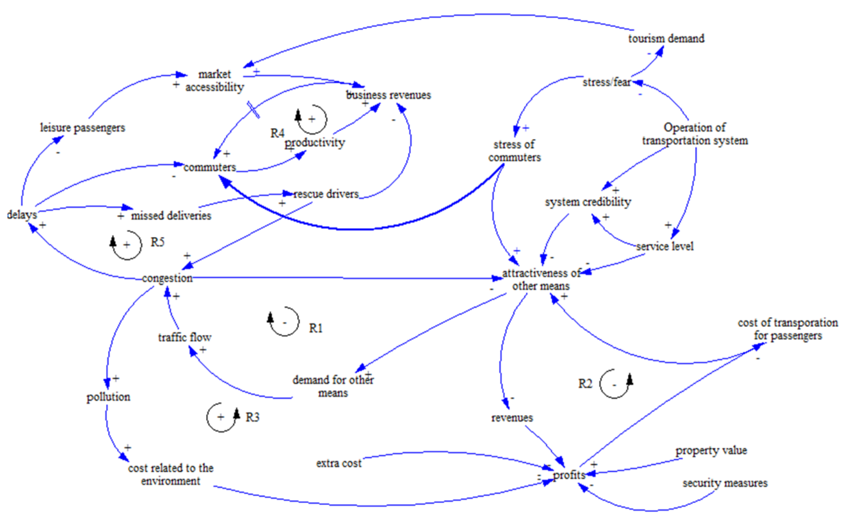

Figure 20: Causal Loop Diagram for the ATTACS project

The two projects will serve as a comprehensive study of the Critical Infrastructures –with a focus on the transportation sector- their interdependencies and their interactions with the urban environment. Thus, decision-makers can utilize the two projects in order to reach better decisions in the face of complexity, uncertainty and unintended consequences.

4 Conclusions

Critical events- such as flooding and bombing attacks- have become a real and possible danger in today's world. As a result, the protection of critical infrastructures against such events has moved to the front lines of the discussion for national and international organizations. Decision-makers need to gain better understanding on the complexity and interconnectedness of the critical infrastructures, in order to make more informed and hopefully more successful decisions in cases of crisis.

System Dynamics is a simulation methodology that can facilitate decision-makers to gain that insights, better understand the dynamics among complex systems and test policies in a safe environment. To facilitate that learning, Interactive Learning Environments have been created that make this task easier. There are many ILEs that are based on System Dynamics models and explore a wide range of systems.

Two projects have been and are currently being developed; CRISADMIN and ATTACS. The two projects are concerned with Critical Infrastructures and how disruptive events can affect their operations, their structure and the what the ripple effects that those changes generate in an urban environment

The CRISADMIN ILE is based on a System Dynamics model that captures the interdependencies of the critical infrastructures of Energy, Telecommunications, Transportation and Apparatus (health sector and aspects of human behavior). The CRISADMIN model recognizes two types of critical events (flooding and bombing attack) that can be applied in different infrastructures, at different points in time and with a different magnitude. Moreover, several custom policies/countermeasures have been designed and tested that can be sector-specific or try to mitigate the effects of a critical event for the entire system/model.

The recent flooding in Genoa, Italy provided an opportunity to test the appropriateness of the ILE and determine its value. Real data were collected and used as an input in the ILE. The simulation reproduced the behavior that was observed in Genoa, though not in every detail. Differences were observed (and expected), but the overall performance of the ILE was deemed satisfactory.

Finally, it should be stated that the CRISADMIN Interactive Learning Environment should neither be used as a Decision Support System nor as prediction tool. Its real value is that it provides insights into the dynamics of infrastructures and how they might be affected by an uncertain and unpredictable critical event.

The ATTACS project is a continuation of CRISDMIN with a focus on the transportation sector. Its aim is to investigate the economic effects a transportation system closedown would generate in an urban environment.

Both projects serve as a systemic study of Critical Infrastructures with a special focus on transportation. The final objective of the projects is to help decision-makers reach better decisions in the face of disruptive events, complexity, uncertainty and unintended consequences.

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