SIMULATION OF CRITICAL INFRASTRUCTURES

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Abstract: The paper presents a set of model prototypes developed to simulate the most critical areas of a highly-developed region in social, economic, technical and informational terms. The models were developed inspired by the fact that the highly integrated information infrastructure creates risks of failure and intrusions with a possible consequence of total loss of vital resources, such as energy or traffic. The models are seen on three levels of abstraction and are programmed and executed with tools from System Dynamics. On the highest level of abstraction, the modelled region is described and calculated using system attributes and variables like productivity, social pressure, satisfaction, etc. Different layers of social, informational and physical realities are defined. On the medium level of abstraction, critical areas of an advanced society are identified and calculated using variables that represent an entity in the reality and that, in general, have an empirical context. Identified critical areas for the first experiments with the model were the sectors of energy, communications, traffic, security, government, and defence. Applying a methodology to identify value drivers and to visualise the interrelations of components in complex systems helped in developing the model inputs and descriptive factors. This approach was used together with a group of experts in each area. On a low level of abstraction, a model prototype was developed using variables that in general can be measured and quantified based on real-life empirical sources. The latter approach is very complex and resource-intensive and requires detailed insight and knowledge. The first application of the models was related to an exercise that demonstrates the risks of software attacks in information networks and the possible consequences for other sensitive areas. Sensitivity analyses with the models showed that the threat of intrusion into the information networks with the consequence of loss of vital resources is likely to be overestimated in comparison to the threat of a direct attack on the relevant vital sectors.

Keywords: Modelling and Simulation, Critical Infrastructure, Gamma Methodology, System Dynamics, Powersim.

Background

Information Networks

The initially defined task has been inspired by fears that cleverly developed, although destructive, software (viruses, worms, etc.) possibly spreads on the Internet, as well as on various operating systems and computer applications with the possible consequence that, at least for a certain time, the operation of software-dependent systems is interrupted.

In 1999, together with the fear that the change of the millennium would bring considerable problems in the information sector, another concern had originated – the growing network of many important industries of the social economy generates a dependence that is intense and increasingly vulnerable.

All these facts brought up the idea that the development and application of a simulation exercise that supports this hypothesis could show the vulnerabilities to the decision makers and could offer the possibility to look into potential improvements.

Essentially, the initial problem area and system of interest consist of information-networks that provide high variety of communication, control, data and other traffic between the numerous points of a highly developed socio-economic society. In the physical domain, these information networks are classic cable-based or radio networks. In addition, the information networks are characterized by the logical virtual networks installed in several layers on the physical networks with the help of the digital information technology. Meanwhile, the information networks penetrate all public areas and industries more or less intensively.

The high accessibility of the information networks, in particular the Internet, creates opportunities for the destructive software to intrude sensitive functional areas and to potentially cause considerable damage. We are afraid that the vulnerability increases with the intense network interconnectedness with the consequence of high economic losses.[1]

Although information networks were the essential element of the analyses, effects are measured only on the basis of productivity and performance of production and service industries. However, both the information networks and the production and service industries share a common user. The user is the individual human being and collectively – the social system of the society.

Socio-Economic Systems

The problem of vulnerability of modern socio-economic systems is considered extremely important. The critical conditions of modern, technologically-based economies are not enough explored and researched from the holistic point of view of the whole system. Although natural, man-made or system-inherent crises and catastrophes appear regularly, systematic examinations with the goal to forecast, to possibly prevent or to control the consequences are comparatively low or are not taken seriously. Most recent events provide evidence for this fundamental problem. If something happens, activities and planning are organized to a great extent only around the most recent catastrophic event.[2]

Crisis Team

In a crisis or catastrophe, the crisis team is the crucial group of people that can prevent possible chaotic development and disorganisation and can act to avoid disastrous consequences. These are people that come from various organisations, administrations and industries and have to get organised for the required purpose. Due to the fact that different organizations often work in normal circumstances in conditions of competition, it cannot be assumed that the designated people in the crisis team immediately find a harmonic basis for cooperative work. It is, therefore, necessary to establish methods and mechanisms for the formation of a crisis team to compensate these negative effects.

In addition, it has to be assumed that the members of the crisis team originate from very diverse knowledge areas. Although this is an essential element of crisis management, this substantial problem has to be taken into consideration in the internal communication since the different knowledge areas have developed their own, very specific languages that hinder the communication within the crisis team.

An essential attribute of crises and catastrophes is their sudden, partially very surprising emergence. Since crises are characterized by a series of unexpected and quick events, a requirement exists for the crisis team to react under very high time pressure. Since only a few people are able to act in these circumstances and since there are psychological group-dynamic effects in addition, a relevant and rational work is possible only within a very rigid configuration. For the successful work of the group, a crucial prerequisite is the structure of the team and accordingly trained personnel to fill the positions.

For the purposes of the consequent analysis, the decisions and actions of the crisis group necessitate a maximum transparency. The analysis of a crisis is required in all related areas in order to systematically gain experience. In addition, the actions of the members of the crisis team often have legal, ethical or moral consequences that are justified only with a complete set of well-documented underlying principles, causes, and effects.

Usually, the crisis team has high authority and responsibilities in order to be able to act if risk exists. Compulsory orders from higher levels in the hierarchy lead to considerable loss of time and generate worse results. The higher decision-making level or echelons do not necessarily possess better knowledge or a higher competence. Here, the constructive and very efficient principle of the task-oriented tactic used in the military has shown many positive results. This delegation of authorities has a high value; the staff must be able to exercise these authorities and it has to recognise the related responsibilities. This also requires an excellent preparation and training of the crisis team.

Wrong decisions of the crisis team could lead to serious consequences. Decisions may even intensify a crisis; they could cause the exactly opposite of that intended or consequences with similarly negative effects as the crisis itself may occur. Since many actions are already clear and fixed during the preparation phase, a failure of a crisis team in a real crisis situation can only be sought in the intellectual and organizational preparation of the crisis team.

Therefore, exercising of the crisis team is mandatory in all organisations.

Exercises

The methods of model-assisted exercises and simulation are very suitable to clarify, recognize and practise system contexts. And, once more, it has been confirmed in such applications, especially in the military domain, that crisis teams act successfully in real crises if they have previously practised and exercised intensively. Without exercising, a crisis team is condemned to failure. Only real practice with tools that enable simulation of crisis situations and that show the consequences of making wrong decisions, can make possible the formation of capable and successful crisis teams.

It is assumed that a crisis in the functionality of an information network occurs starting from equilibrium or a stable situation of the socio-economic system. If a disruption, damage or any attack on the net occurs, it needs first to be recognised, second, a crisis team has to be established, which in turn has to find suitable counter-measures. Within the crisis team, the task is to get organised, e.g. to find a common language, to look for realistic solutions and to put them into operation.

The setup of an exercise consists of the crisis team and the exercise control. The crisis team involves representatives from industries and involved groups, organisations, governmental administration, etc. Peripheral groups are represented through the control team. The control team operates the script and/or the simulation model in order to provide a common picture of the development of the scenario. The simulation model has to represent the scenario in real measurement categories and elements of the reality, which are assigned to virtual entities of the model world.

The course of events within an exercise is a change between phases with lectures and/or discussions of the problem and phases of simulation in a logical sequence of events. The simulation is accompanied and assisted through quantitative evaluation of the model with a partially automated generation of events (see Figure 1). This setup can be called a Model-Assisted Exercise (MAX).

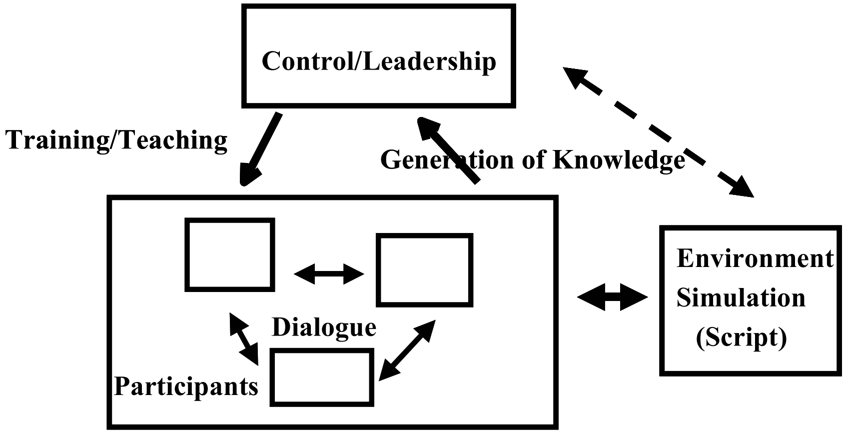

Figure 1: Model-Assisted Exercise (MAX).

The purpose of a model-assisted exercise could be: a dialogue between the participants in order to improve the communication among the experts on a peer-to-peer basis, negotiation related to the problem or simply working together towards a common objective. The control team, or the leadership, could perceive the exercise as a teaching or training device for the participants and at the same time can collect knowledge on the crisis team in terms of system analysis, testing of hypotheses, getting behavioural data, etc.

The attacker or the opponent in the exercise is usually represented as a subgroup of the control team. It represents the functions of motivation of the attacker, reconnaissance of weak elements of the system, planning and preparation of the attack, execution of the attack, eventual negotiations, and trying to ensure success.

The crisis team has to take precautionary measures, recognise the intention and perform reconnaissance of the attack, prepare for counteractions and safeguarding; once recognizing the attack, it should prevent collateral effects, counter the attack and defend, negotiate, recover and reconstitute to normal conditions.

In trying to create a reasonable model as a support tool for an exercise, many questions need to be answered during the initial phases of the project work. In particular, the dimensions of the scenario, the system under investigation, the required effort for model development, the level of abstraction of the model, the degree of detail of the model, and many other issues need to be determined.

Methodology

In a set of brainstorming sessions, a small group of analysts created and agreed on assumptions that lead to the approach summarised below.[3]

Essentially, a top-down approach of system analysis and related modelling is pursued in the presented work. Starting from a holistic point of view, the socio-economic system of a highly-developed region is identifiable by very general element areas or object classes. On this high level of abstraction, variables and objects are postulated that can be programmed in the model. This model on high abstraction level is seen as a first and rapid procedure for testing only some of the relationships and for preparation to get improved insights into system behaviour. Since almost no experience is available, such as the interactions of the information networks with the physical and social systems in mathematical-logical form, assumptions and hypotheses are made that appear plausible, but an intensive examination and verification is required.

There is a small amount of systematic and useful research and practical results available for development of such models. Nevertheless, a model of high abstraction has been chosen as a first design and quick prototype for generation of initial guess for the system structure.

In a second step, a relatively low abstraction-level model has been developed. Here, the reference to real objects is much better; however, there are also major problems regarding data collection and modelling of system structure. In addition, a much bigger effort is required for model development. Due to this reason, only a model of the traffic sector has been developed, which required considerably more time and effort for development compared to the high abstraction level model. Nevertheless, this approach should still be pursued in order to find better solutions.

As a compromise, a model has been developed that can be represented as a model of medium abstraction level. In order to collect the required input data and to generate an acceptable model of the system structure, a series of seminars and brainstorming sessions were conducted.[4] The seminars were supported intensively by the methodology "Gamma." This effort led to the development of a model that can serve as a driving force for exercises and follow-on research.

Gamma

For initial structuring, generation of assumptions, and estimation of factors and parameters, a brainstorming approach supported by computer software called *Gamma* was used. *Gamma* provides tools for interactive visualisation and analysis of complex interrelationships of systems and from the beginning it generates a holistic view.[5]

The graphical toolset generates a net diagram as a result of the thinking process of session participants and captures parameters and values of identified links between system elements. Understanding relationships of type cause and effect becomes possible. This provides a good ground for mutual acceptance and a common view of system interrelations. The generated values are available for subsequent analysis.

Gamma is not a rigid methodology providing decision optimisation with a guarantee to find the best solution. It rather belongs to the group of the so-called heuristic approaches that improve the likelihood of locating a good solution.

In an initial step, relevant influential factors and elements of the system under consideration are drafted. This is followed by the creation of a graphical network of interrelationships. Direction, type, intensity and frequency determine the relationships between the elements. The objective is to get knowledge about the structure and dynamics of the essential processes in the system.

System Dynamics

For simulation, the method of *System Dynamics* has been chosen due to the fact that it is very well suited for quick prototyping.[6,7]

This method has been applied to a wide variety of problems in both the public and private sectors. Large corporations and governmental agencies make use of the insights gained from building *System Dynamics* models while designing policies and strategies and in tactical and operational decision making.

Within the *System Dynamics* paradigm, emphasis is placed on model conceptualisation and on the utilization of a wide spectrum of criteria for model validation that help to ensure that the resulting models correspond to real systems structurally as well as behaviourally.

In particular, there are four types of structural properties that humans find cognitively challenging in dynamic systems.

First, there is the origin of dynamic behaviour itself, the relationship between flows and levels. Levels accumulate flows and flows cause the levels of levels to change over time. Although simple in principle, humans often find it difficult to distinguish between real levels and flows and to identify the behavioural consequences of flows acting on levels.

Second, there are delays or lags in actual systems. Delays distribute the effects of changes in variables throughout a system over time and often cause information to arrive at its destination in an untimely, and hence harmful, manner. Delays and lags lead humans to discover and give priority to short-run gains and to ignore and postpone actions against future losses. Delayed reactions typically cause systems to over- and undershoot and thus to exhibit oscillatory behaviour.

Third, there is a feedback. Real-world systems are usually characterised by circular causality. Their structures contain feedback loops that transmit the dynamic behaviour of one attribute to the next until the circle is closed and the signal, in a modified form, is fed back to its origin. Such loops have a tendency to stabilise or to destabilise a system. When humans try to control a feedback system, their actions are typically amplified or counteracted, depending on which feedback structure is dominating the system at the time.

Finally, there are nonlinear relationships. Nonlinearity implies that system attributes influence each other in a non-proportional way and that they interact so that their partial effects, calculated over time, cannot easily be distinguished. Such interactions may cause shifts in the structural dominance of a system over time. That is, substructures that have dominated a system's behaviour for some time may, suddenly or gradually, loose their influence while other substructures gain influence. This typically causes a dramatic modification of the system's dynamic behaviour.

Powersim

The availability of easy-to-use software engineering tools such as *Powersim* enabled a fast model development process.

Powersim is a software package that facilitates the study of dynamic systems. It makes possible the formulation of simulation models in the graphical notation as defined in the *System Dynamics* methodology.[8]

Powersim is particularly convenient for use of generic models. These models can be stored in a library, from which they can be copied, modified, and incorporated as co-models or integrated (pasted) as sub-models in a larger "main" model.

The ability of *Powersim* to describe and solve problems, however, suggests that its real benefit comes from its application in the model-building process itself, rather than from its ability to simulate a particular model. As a result, the people who both know the system experiencing the problem and are charged with implementing model-based results should participate fully in the modelling process. Their participation increases the probability that they will trust the model they helped to create and will implement its results. *Powersim*'s graphical user interface greatly reduces the barriers to the participation of policy makers in the modelling process. In addition, the graphical notation and the user-friendly interface make possible the fast development and rapid prototyping of simulation models.

High Abstraction-Level Model

On a high abstraction level, the system to be simulated is determined by variables that are defined in relation to a maximum possible value. In this way, it is not necessary to introduce absolute values since the variables are defined without a physical dimension and can only take values between 0 and 1. Relative variables of this type make possible the quantitative calculations with freely chosen, normally only qualitatively describable, parameters such as, for example, "satisfaction" or "alteration pressure," especially in areas where no or only restricted empirical data is available. Quickly-developed abstract models can be generated with relative variables although with the disadvantage of being highly speculative.[9]

In the high abstraction-level model, the elements are subdivided into three areas: the physical area, the information area and the social area. The physical area contains all the components that are physically defined, and can be physically measured and described. The information area contains all the components that can be assigned to an information network: the logical and virtual elements, the procedures, programs, data, or, in other words, the software and the databases. Computers, cable, storage mediums, electronic devices, etc., or the hardware, are physical components. The social area consists of humans, groups, hierarchies, organizations, etc. The elements of the social area could be allotted to the physical and information area. However, since this area contains important feedbacks, the social area is identified explicitly (Figure 2).

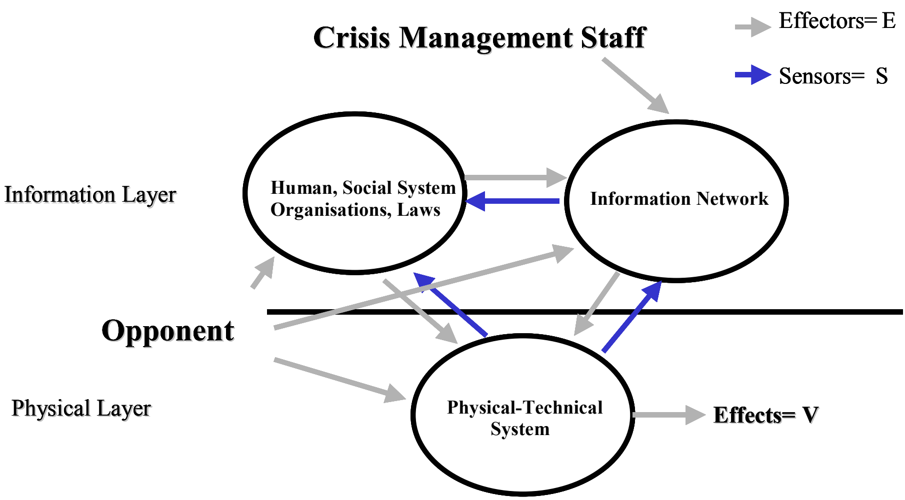

Figure 2: Layers of a Socio-Economic System.

Table 1: Objects of a Socio-Economic System.

Sectors	*Physical area*	*Information area*	*Social area*
energy	power plants, refineries, pipelines, gas stations, power lines	accounting, control of electricity	share holder, consumer
information industry	media, TV, newspapers, Radio stations, satellites, cable networks, computers	virtual nets, operating systems, software, databases, internet, applications, news	end user, consumer, opinion maker
civil service	work time, productivity	laws, regulations, orders	public opinion
security	police, armed forces, supporting forces	command, control, safety	public opinion
traffic and transport	road and rail net, links, airports, sea ports, stations	plans, nets, control	traffic participants, consumer
financial	banks, insurance companies, money	accounts	consumer

For each area, one can identify and describe sectors of industries, administration, security area, etc. The following six sectors were defined in the initial research phase: energy sector, information industry, civil service, security, traffic and transportation, and finance. Table 1 presents some of the real objects and elements that were assigned to these sectors and outlines the areas for further explanation and development.

Figure 3 illustrates the physical area. Some important interrelations are defined that already describe the structure of the simulation model in the graphical notation used by the *Powersim* simulation software. The variable physical *performance* as relative value describes the contribution of each element to the total productivity of the viewed system considering all sectors. The total productivity or the success of the system has an effect on the *satisfaction* of the social system in the social area in consequence. At the same time, the *performance* of a given sector is influenced by the performance of other sectors. Furthermore, the *performance* is diminished by random disturbances from the environment.

Each system has internal forces that keep the processes running and produce the *performance*. These forces are controlled by a feedback loop that tries to keep the

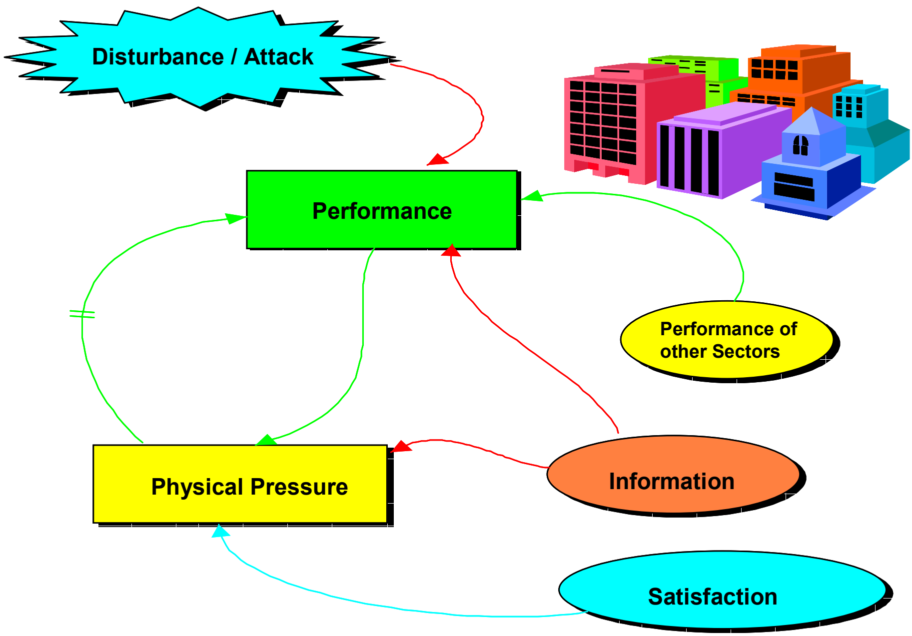

Figure 3: Physical Area.

performance level close to a desired value; in other words, the system tries to maintain equilibrium or a stable state. The role of feedback is played by the size of the variable *physical pressure*. By definition, the influence of the *physical pressure* is delayed in time and depends on *performance*. In addition, the *physical pressure* is influenced by *satisfaction* in the social area and *information* in the information area.

Figure 4 illustrates the information area. Similarly to the physical area, analogous interrelations and variables are defined. The variable *information* describes in relative terms the total result of each element of the considered system in all sectors. Again, the success of the system has in consequence an effect on *satisfaction* of the social system in the social area. The *information* of a sector is influenced by the *information* of other sectors. Furthermore, the *information* is reduced by disturbances from the environment. In addition, the *information* depends on the *performance* in the physical area.

Analogously to the physical area, a feedback loop tries to maintain the inner stability of the system, expressed via the variable *information pressure*. Again, by definition, this *information pressure* only works delayed in time and depends on the variable *information*, as well as on *satisfaction* in the social area.