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).

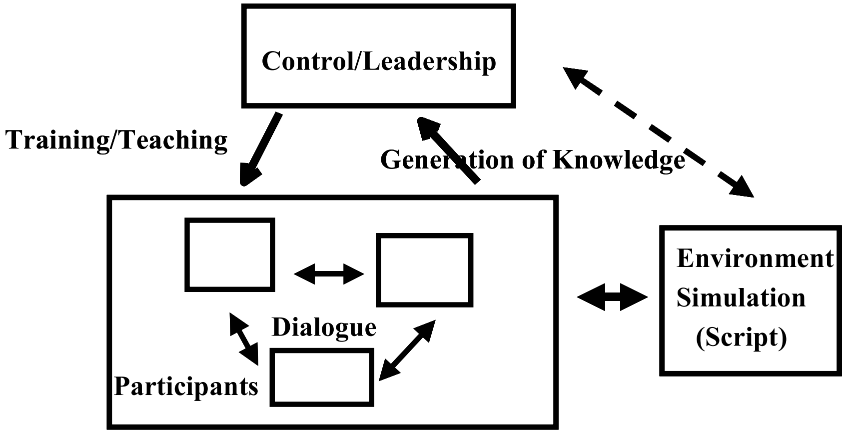

Figure 1: Model-Assisted Exercise (MAX).

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).

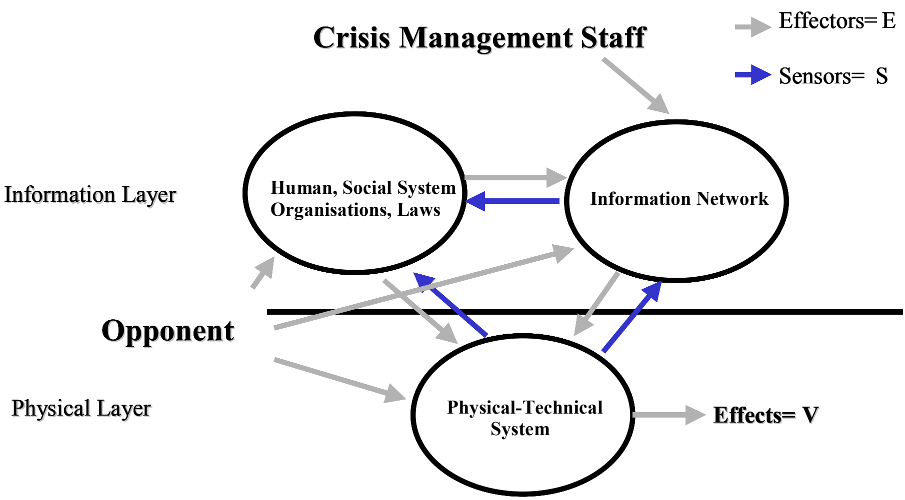

Figure 2: Layers of a Socio-Economic System.

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

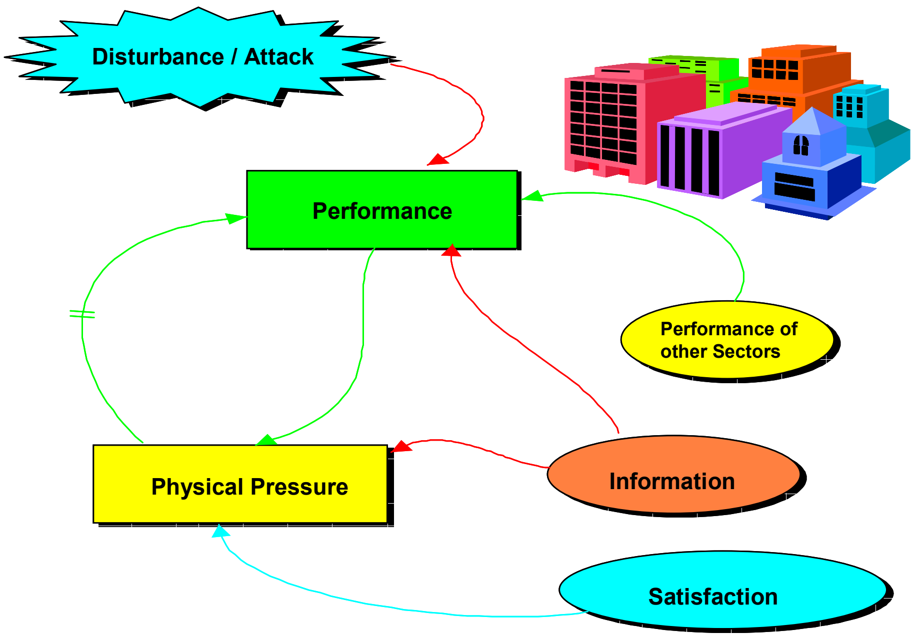

Figure 3: Physical Area.

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.

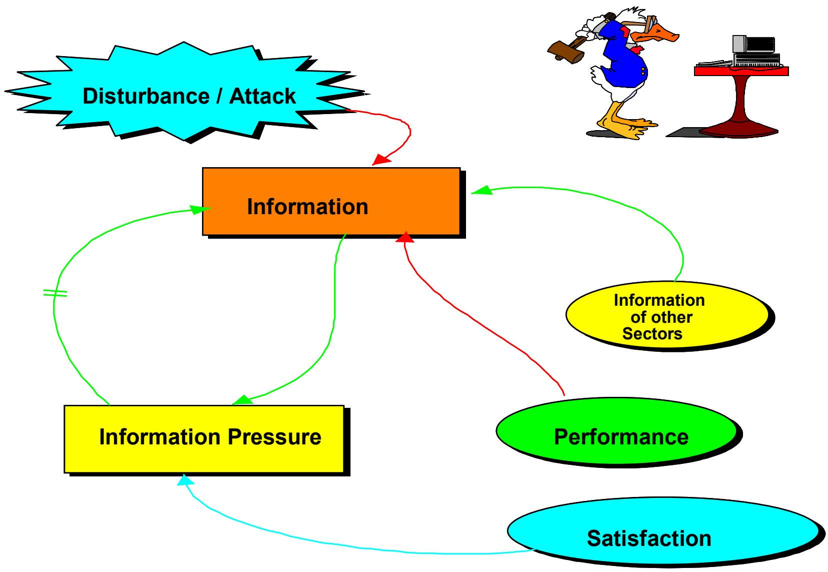

Figure 4: Information Area.

Figure 5 defines the social area. The variable *satisfaction* describes in relative terms the general status of the social part of the considered system for each element in all sectors. The *satisfaction* of a sector depends on the *performance* and the *information*

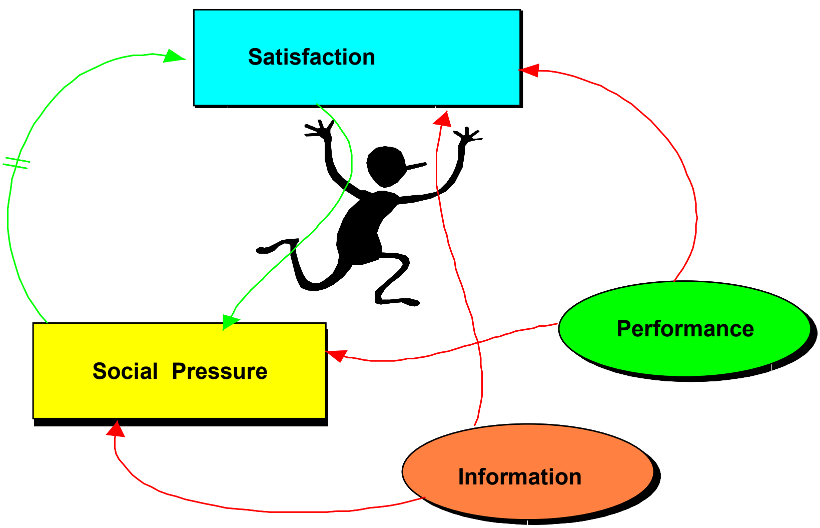

Figure 5: Social Area.

from the other areas. Again, a feedback loop is considered to cover the inner forces for maintaining a stable state. Here, the variable *social pressure* that also depends on performance and information plays the role of a feedback.

Figure 5 presents a typical diagram of the model in *System Dynamics* notation as realized in *Powersim*. Most of the variables are defined as vectors, where the index represents the sectors under consideration. The detailed description of the model is part of *Powersim*'s code. The code and the interpretation of the variables can only be seen in the context while the model is executed and calculation experiments are performed.

Low Abstraction-Level Model

Essentially, the system under consideration consists of the various types of transportation: road, rail, air and sea (water), split into transportation of goods and transportation of people. The traffic elements or the vehicles depend on the existence of a transportation network. The transportation network is simplified according to the traffic elements. For road and rail transportation, the traffic within the region and traffic in the outside world are separately modelled. For the model of the traffic within the region, the traffic is considered as a sort of container with a corresponding descriptive size; for the traffic in the outside world the region is viewed as a node of a network. For air and water transport, the region represents only one node, i.e. an airport or seaport.[10]

Although the information networks are the essential element of research in the intended application of simulation of disturbances as a training ground for exercises of crisis teams, the effects are rated only on the basis of indirect effects in the physical area. In the transportation sector, disturbances may occur due to lack of traffic control that under normal conditions optimises the flow of traffic elements and vehicles. Power outages, in particular the electric power ones, would cause major disturbances. Further direct disturbances are expected owing to physical effects, for example the cancellation of an air traffic node.

In the considered simulation of the transportation system of a region, the elements represented in Table 2 are taken into account. The abbreviation of the individual elements has the following meaning:

- Letters *F* = Long-distance traffic out of the region, *N* = Short-distance traffic within the region;
- Letters *L* = Air, *B* = Rail, *S* = Road, *W* = Water;
- Letters *P* = Passenger, *F* = Freight.

Table 2: Objects of a Traffic System.

Type	*Transport*	*Abbreviation*	*Object*	*Units of measurement*
Air (L)	Passenger (P)	FLP	Airport	Flgz, Pax
Air(L)	Freight(F)	FLF	Airport freight	Flgz, TEU
Railroad (B)	Passenger (P)	FBP	Rail station	Zug, Pax
Railroad (B)	Freight (F)	FBF	Rail station freight	Zug, TEU
Road (S)	Passenger (P)	FSP	Long-distance road net	Pkw, Pax
Road (S)	Freight (F)	FSF	Long-distance road net	Lkw, TEU
Water (W)	Freight (F)	FWF	Harbour	S, TEU
Railroad (B)	Passenger (P)	NBP	Regional railroad net	Zug, Pax
Road (S)	Passenger (P)	NSP	Short-distance road net	Pkw, Pax
Road (S)	Freight (F)	NSF	Short-distance road net	Lkw, TEU

All combinations considered realistic are given in the table. Certain combinations, for example, air traffic locally within the region, railroad freight within the region or water transport within the region, are not considered.

The objects / elements of the traffic system are empirically determined and described by means of units of measurement. The unit TEU, a standard twenty foot equivalent container unit, describes the freight. The number of *Passengers* is quantitatively described by the unit *Pax*. *Airplanes* are a quantity with measurement unit *Flgz*. For all aircraft types a common unit with an average capacity is assumed. The same is applied to trains with the unit *Zug*. For the road transport, the number of cars with an average capacity is measured with the unit *Pkw* and the number of trucks is measured with the unit *Lkw*. Similarly, the number of ships is defined with the unit *S*. For the objects in the table, the combinations of the units are important, as represented in column 5.

For the considered objects, average values can be assumed for typical sizes or can be derived from existing statistics. Some example values are given in Table 3.

The principal flow of passengers (P) and the flow of freight (F) are shown in Figure 6. It is assumed that the long-distance traffic areas are essentially connected via the local traffic areas. Furthermore, passengers and freight use the same infra-

Table 3: Some Maximum Values.

Object	*Speed*	*Average Length*	*Maximum Volume*
FLP	1000 m/h	1000 m	50 kPax
FLF	300 m/h	1000 m	500 TEU
FBP	3000 m/h	500 m	20 kPax
FBF	200 m/h	500 m	1000 TEU
FSP	120 km/h	50 km	20000 PKW
FSF	100 km/h	50 km	20000 PKW
FWF	100 m/h	25 km	10000 TEU
NBP	30 km/h	25 km	30 kPax
NSP	50 km/h	25 km	30000 PKW
NSF	50 km/h	25 km	30000 PKW

structure, such as for example railway stations, roads, and airports. In any case, the infrastructure is systematically subdivided into infrastructure of railway stations, rail network, long-distance traffic network, local traffic network, harbours, airports, vehicles, ships, airplanes, trains, trucks, cars, and freight as well as passengers. Each infrastructure object contains sources and sinks for the transportation goods that enter

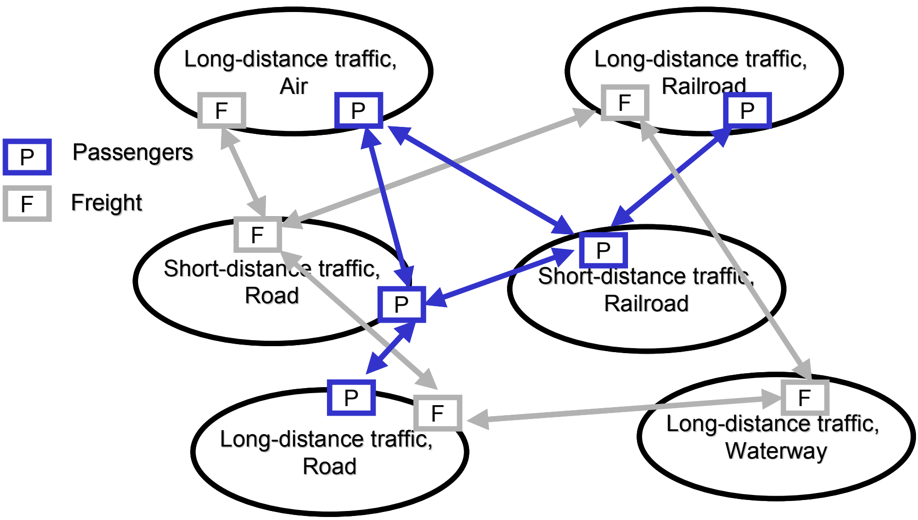

Figure 6: Flow of Passengers and Freight.

and leave the system. Within the system, the transportation goods are contained either in the infrastructure, the storages or in the transportation vehicles.

In the diagram, each node is individually modelled as a *System Dynamics* model in *Powersim*. All models are linked in a main program that controls the overall flow of processes and events. The detailed model description, definition of parameters, etc., is again part of *Powersim*'s code and can only be interpreted in context with the diagrams and the equations.

Medium Abstraction-Level Model

Experiments with the high abstraction-level model revealed the difficulty to establish a relationship between realistic absolute values and the generic variables as postulated. On the other hand, this is a prerequisite for application of models in exercises.[11]

For this reason, a series of brainstorming seminars were organised with the objective to generate real objects, entities, variables of the system and the sectors, as well as to quantitatively define their relationships.[12]

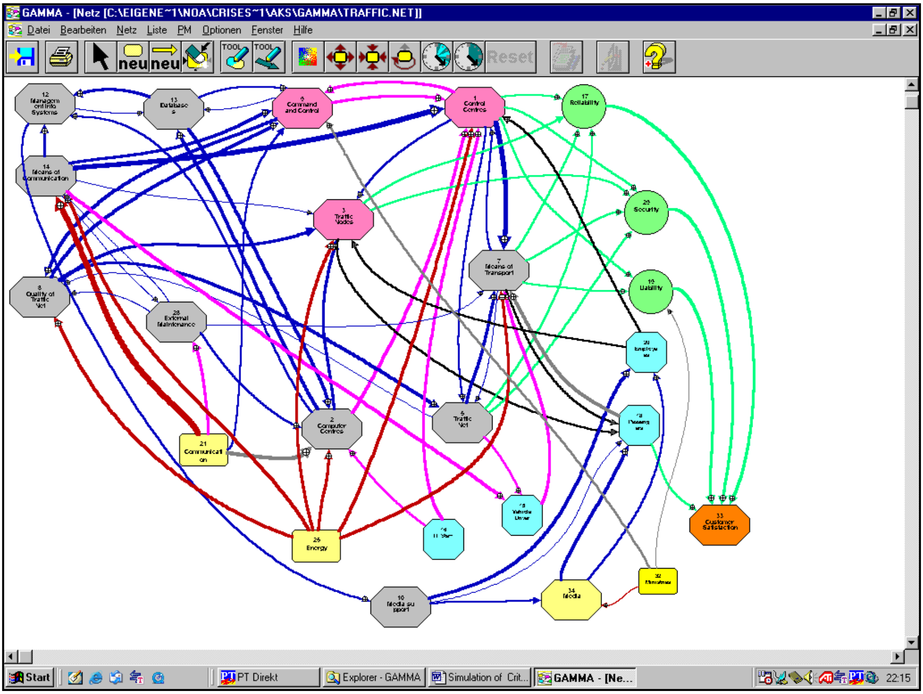

Figure 7: *Gamma* Network Diagram.

A list of elements was used as a basis for creation of cause-and-effect network in *Gamma*. With the help of *Gamma*’s graphical tools it was possible to arrange the elements as components of a network on the screen. Simultaneously, values for the influences were defined with the help of lines and arrows and their strength estimated. All the models were executed during the brainstorming sessions and corrections were made in multiple iterations, considering the different points of view of the participating experts.

A typical *Gamma* diagram for the transportation case study was created during these sessions as shown in Figure 7.

In a later phase, delay times of the influences of one element on another were defined. These delay times and the effects are direct results of the *Gamma* sessions; they are collected in tables and serve as input to the *System Dynamics* model of medium-abstraction level.

The diagram also indicates by means of lines and arrows how strong is the influence of each entity on other entities in the postulated system, which can be transformed easily into a matrix of influences. A different view at these dependencies for the en-

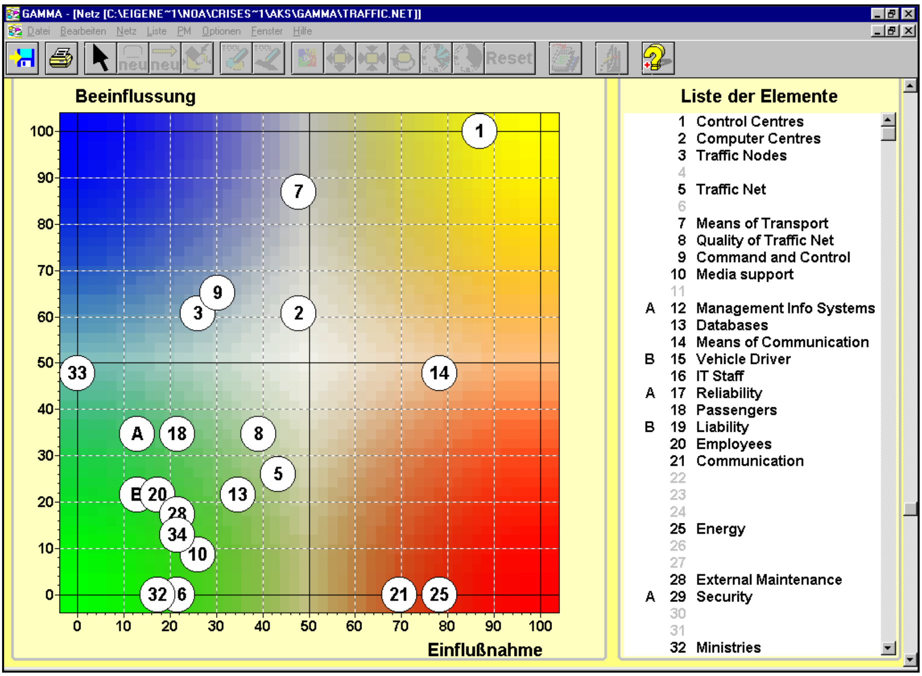

Figure 8: *Gamma* Sensitivity Diagram.

ergy sector is demonstrated in Figure 8. The horizontal axis represents on a scale between 0 and 1 the relative strength of the influence of an entity on other entities in the system, while the vertical axis represents on a scale between 0 and 1 the relative strength by which an entity is influenced by other entities in the system. Each entity has a well-defined position on the diagram. The distribution of positions demonstrates which entities are highly sensitive and require further specific attention in a straightforward manner.

Modelling and simulation of critical business and public sectors of a highly developed technical society is based on the entities, relationships and sensitive parameters as developed in brainstorming sessions by sector experts utilising the *Gamma* methodology. These relations are then transformed into a logical structure based on the *System Dynamics* methodology using *Powersim*.

On this medium level of abstraction the system to be simulated is determined and described by parameters and values, which are again defined relatively to a maximum possible absolute value. In this way, setting absolute values is not necessary since the parameters are defined without a measurement dimension and can take only values between 0 and 1. Relative parameters of this type make also possible quantitative calculations with freely-chosen, normally only qualitatively describable, parameters as defined in the expert sessions with the *Gamma* methodology.

For each industry and sector, the set of defined parameters describes the system under consideration and represents its state at any point in time if the parameter values are available quantitatively. The relative value describes the actual absolute value in relation to a maximum possible value and can formally be treated as value without a unit or measurement dimension. If the relative value is multiplied by the maximum possible value, the value emerges as value with the corresponding measurement unit.

In addition, in normal conditions the system of each sector is in a stable state or in equilibrium, i.e. the parameters do not change with time. These changes only occur if disturbances from outside act on the system. And this is the case in reality, although disturbances are continuously balanced by system internal regulations and control mechanisms. The system state becomes stable and eventually fluctuates only around the equilibrium. Only unusual disturbances are able to generate unstable behaviour, however, leading to stable state again although at different level. Theoretically, the set of relationships among the elements, as defined with the *Gamma* methodology, should cover this stabilisation effect. Unfortunately, this was not the case; all relationships were defined as positive feedbacks in the *System Dynamics* notation. In any system, for stabilising control mechanisms negative feedbacks have to be available in order to create a stable equilibrium.

Due to the fact that it is not obvious which parameters will have the stabilisation effect in the sense of a negative feedback, it has been assumed that the change of a parameter value depends on the change of all other parameter values, although delayed in time and with the effect according to the *Gamma* analyses. In principle, the state of a system is described by a state equation. However, in general this equation is not known; each parameter is a function of all other parameters. Since the values of the parameters, as determined in *Gamma*, are only positively defined, the system is unstable. All values would approach zero as soon as a disturbance occurs. Since this development does not correspond to the real behaviour of any system, it has been assumed that some inner forces of the system create an effect that stabilises each parameter after a certain time. If the disturbance remains, the system should move to a new equilibrium. If the disturbance disappears, the system should approach the original equilibrium again.

The parameters and relationships in the *System Dynamics* model follow the described assumptions. They are documented in great detail in the diagrams, equations and accompanied descriptions of the individual parameters within the *Powersim*'s code. It is recommended to perform further extensive tests with the model and adaptation of the parameters and values on this ground, respectively. Whether the model is acceptable enough for representing a scenario or a real system for use in a given exercise has to be judged by the operator.

Figure 9 presents the general picture of the areas considered in the simulation. In addition, the lines indicate the numerous many-fold interactive processes between the areas. Potential incidents resulting from terrorist acts, natural disasters or other major accidents will cause operational problems in these areas. In the simulation, the variables react on these intrusions in a manner similar to that of their real-life counterparts.

In order to develop appropriate actions and counteractions to such catastrophic events, the simulation models are used in an exercise to represent the reaction of the real world to the actions of the crisis team. Model of this form of application together with the control team of the exercise setup are the virtual environment for the participants that represent real crisis teams within the areas considered.

Presently, the following sectors have been considered: Traffic / Transportation (Air, Land, Sea), Banks and Finance, Energy, Vital Human Services, Government and Telecommunications (see Figure 9).

In the beginning of the simulation, the tabs *Causality*, *Model*, *Entities* and *Times* switch between several functional areas.

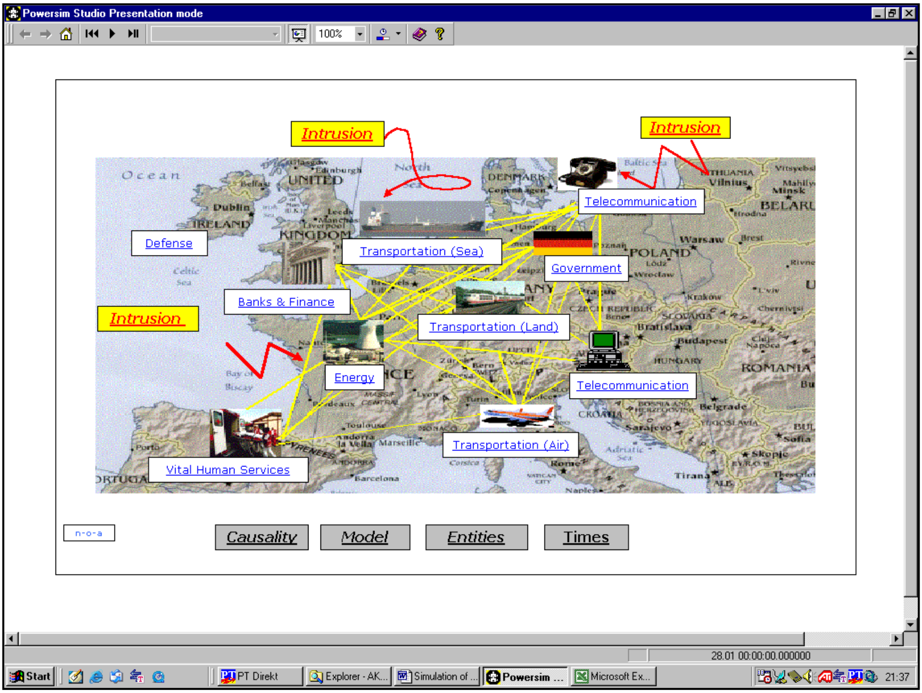

Figure 9: Sectors in the *Powersim* Model.

The tab *Times* is used to control the time periods in the gaming setup and to input intrusions and other parameters. Sliders permit simple and intuitive time setting for stop events in the course of the simulation.

The control tabs labelled *Intrusion* in this diagram provide pointers to control diagrams that enable the input of actions by the control team causing considerable changes to certain sensitive entities of several sectors, in the considered example energy, transportation and telecommunications.

The Causality Diagram in Figure 10 shows the two principal feedback loops in the model. It is assumed that these loops are valid for all sectors and entities represented in the model. Two variables are defined as levels in the *System Dynamics* notation: *Productivity* of the entities and *Internal Pressure*. Both variables / levels are defined in relative dimensions: the absolute value of any represented property of any entity is defined in relation to its maximum possible value within the system under investigation. The first feedback loop is positive. The productivity of each entity increases in the same direction as the influence or change of all other productivity levels based on the findings from the *Gamma* evaluations, considered with some time delays.

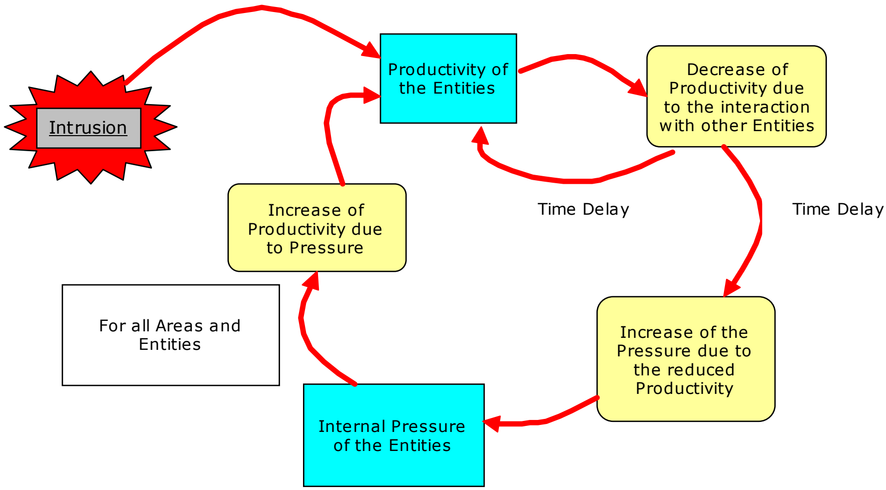

Figure 10: Causality Diagram in Powersim.

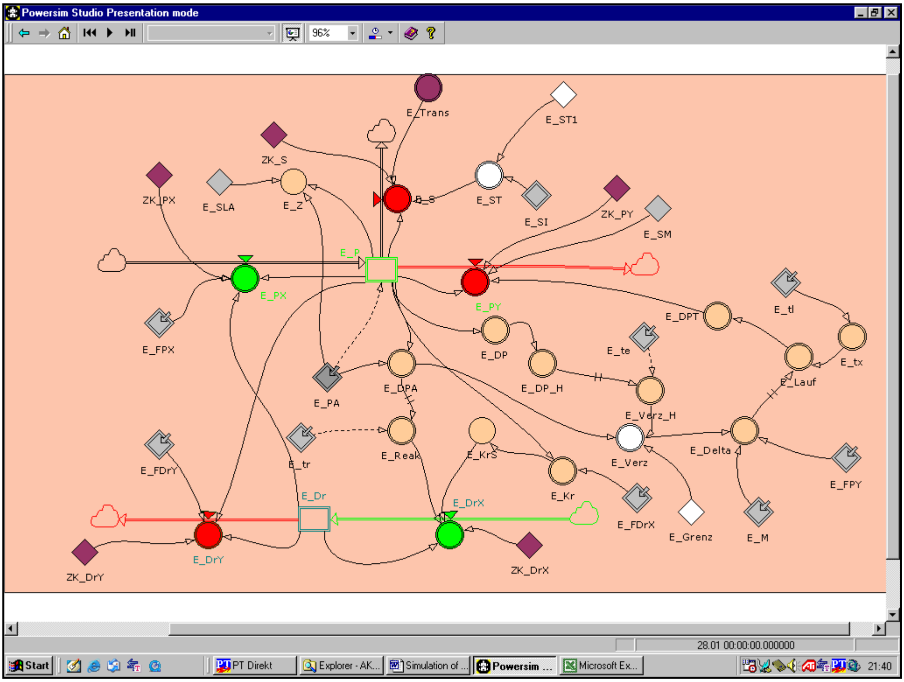

Figure 11: System Dynamics Notation in *Powersim*.

The second feedback loop is a negative one. It represents an internal build-up of counter forces of the system with the trend to stabilise the present state. This is measured by means of the assumed value of a pressure.

The model diagram in Figure 11 shows in greater detail the elements and interactions of the model for all areas, entities, levels, rates, and properties. This diagram illustrates the multiple interdependencies and it is described and integrated into the *Powersim*'s code in more detail. This diagram is the typical graphical structure used in *System Dynamics* notation and is automatically transferred to the executable computer program that simulates the dynamical system under study.

Notes:

[1] However, the anti-thesis says that increasing network connectivity creates an increased redundancy with the consequence of an increased reliability. The big success of the Internet is based on its ability to self-organise and to automatically produce new connections, if nodes or routes are cancelled or due to other reasons. Each additional computer, router or link to the Internet is an additional connection possibility, which increases the reliability. In practice, computers are constatntly switched off, completely decentralized for diverse reasons, and switched on again, without users of the network noticing this events. James A. Lewis, *Assessing the Risks of Cyber Terrorism, Cyber War and other Cyber Threats* (Washington, DC: Center for Strategic and International Studies, December 2002), <http://www.csis.org/tech/0211_lewis.pdf> (4 July 2005).

[2] Wolf R. Dombrowsky and Christian Brauner, "Defizite der Katastrophenvorsorge in Industriegesellschaften am Beispiel Deutschlands. Untersuchungen und Empfehlungen zu methodischen und inhaltlichen Grundsatzfragen," Gutachten im Auftrag des Deutschen IDNDR-Komitees für Katastrophenvorbeugung e.V. (Kurzfassung) (Bonn: INDR, Deutsche

IDNDR Reihe Nr. 3a, 1996); Klaus Niemeyer, *Interaktive Simulationen zum Krisenmanagement* (NOA-TB-5, 2001, Krisenproblematik).

[3] Analysts from IABG and NOA. IABG (Industrieanlagen Betriebsgesellschaft mbH) is an agency providing system analysis support, <www.iabg.de> (4 July 2005); NOA is a network of freelance operation analysts, <www.n-o-a.de> (4 July 2005).

[4] These seminars were conducted in 2001 together with IABG and showed that no methodology or models seemed to exist in the sense and for use for the present purposes to simulate disturbances in a network of several industries and sectors.

[5] The tool “Gamma” is based on the ideas and the research of Frederic Vester and is developed and distributed by Unicon GmbH, Meersburg, Germany. Frederic Vester, *Das kybernetische Zeitalter* (Frankfurt/M, Germany: S. Fischer Verlag, 1982); Frederic Vester, *Leitmotiv vernetztes Denken* (München, Germany: Heyne, 1990); *GAMMA 3.0* (Unicon Management Development GmbH, 2000); <www.unicon.de> (4 July 2005).

[6] In the late 1950s, Jay W. Forrester of the Sloan School of Management at the Massachusetts Institute of Technology developed the System Dynamics method. This methodology became known from the famous study “The Limits to Growth” published in the 1970s by the “Club of Rome.” Jay W. Forrester, *Industrial Dynamics* (Productivity Press, 1961); Jay W. Forrester, *Principles of Systems* (Productivity Press, 1968); Donella H. Meadows, Dennis L. Meadows, Jorgen Randers, and William W. Behrens III, *The Limits to Growth: A Report for the Club of Rome’s Project on the Predicament of Mankind* (New York: Universe Books, 1972).

[7] Although the numerical integration of differential equations representing physical phenomena was used long time before the introduction of a graphical notation, the direct programming for computers and the application for large scale social-economic systems by Forrester created the methodology nowadays known as System Dynamics.

[8] <http://www.powersim.com> (18 July 2005).

[9] Klaus Niemeyer, *Modell Ausgewählter Branchen zur Simulation von kritischen Störungen* (NOA-TB-1, 2000).

[10] Klaus Niemeyer, *Modell des Verkehrssystems einer Region für die Simulation von kritischen Störungen mit einer geringen Abstraktion* (NOA-TB-6, 2002).

[11] Klaus Niemeyer, *Modell wichtiger Branchen einer Region für die Simulation von kritischen Störungen mit einer mittleren Abstraktion* (NOA-TB-7, 2002).

[12] These seminars were performed by IABG in 2001 with a group of experts for each sector utilising the supporting software Gamma.

KLAUS NIEMEYER was born in Bremen, Germany, in 1941. He left Gymnasium in 1958 and studied at the Physikalisch-Technische Lehranstalt in Lübeck and Hamburg, graduating as Diplom-Ingenieur in Technical Physics in 1963. During this period he worked also in industry, primarily with Entwicklungsring Süd, in the computing field. On graduation, Mr. Niemeyer moved to Boelkow Entwicklungen KG in Ottobrunn, near Munich, where he worked as system analyst in a team of U.S. and German scientists that initiated the German Operations Research activities for the German Ministry of Defence.

Mr. Niemeyer has had a long and distinguished career in Military Operations Research, Simulation and Computer Applications. In 1965, he joined the Industrieanlagen Betriebsgesellschaft mbH (IABG) in Ottobrunn with other German members of the above-mentioned team, and helped in establishing the Systems Analysis area at IABG. In 1966, he was assigned to US/GE advanced V/STOL-fighter assessment at the Wright Patterson Airforce Base in Ohio. As Project Leader he evaluated and analysed airborne and airbase systems.

In 1969, Mr. Niemeyer was appointed head of a group working on optimal air force structures. In this role he developed and operated the first German computer-assisted exercise in 1970. This formed the basis for establishment of the IABG Wargaming Centre, of which Mr. Niemeyer was appointed Chief in 1972. In this position, he initiated the development of several concepts, models, approaches and solutions to assessment and evaluation of force structures, and helped in initiating international programmes such as the US/German European Conflict Analysis Program (ECAP), and the Joint Simulation (JOSIM) Project. He has been responsible for many national and international studies in the areas of weapon system assessments, air and army structures, command and control, force effectiveness comparisons, arms control, conflict research, operational support, long-term defence planning, logistics planning, war gaming, exercises, and information systems support.

Mr. Niemeyer became Chief Scientist and Head of the Operations Research Division at the SHAPE Technical Centre (now NATO Consultation, Command and Control Agency) in May 1992. In this position he was the principal advisor on scientific matters and military operations analyses that affect SHAPE and Allied Command Europe. Among other projects, the Allied Deployment and Movement System (ADAMS), the methodology for the Defence Requirements Review (DRR) and the High Level Exercises have been developed in his area of responsibility. Mr. Niemeyer initiated and co-chaired the Steering Group on Modelling and Simulation and represented his organisation in several other panels and committees within NATO.

Mr. Niemeyer retired from NATO in April 1999 and now he works as a consultant.