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Enhancing the efficacy of warning systems by computer simulation

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Warning systems are often complex networks of measurement devices, communication lines, decision makers, and measures to be taken. While the single units are reasonably designed, the overall performance of the whole system is often hard to estimate, especially when challenged with exceptional events.
Computer simulation is a means of assessing such situations. The warning system is subjected to a large number of (potentially dangerous) scenarios in order to discover and eliminate weaknesses and flaws. Moreover, potential counter-measures can be simulated to find the most effective actions to be taken when warnings are raised.
This concept is applied to the Flarm collision avoidance system used in glider planes in Europe. It is shown that the system breakdown is far beyond common volume of traffic. Moreover, improvements are suggested to further increase safety. Future changes can be tested in the simulation prior to release.
While the concept is demonstrated to work for Flarm, it is generally applicable to other warning systems and danger situations.

keywords: warning system, computer simulation, safety, effectiveness, counter-measures, improvement

1 Introduction

Initially, we have worked in research at ETH Zurich in computational chemistry at the level of molecular interactions and chemical reactions (van Gunsteren et al. 1996, 2001). We are experienced in parametrisation of models (Schuler et al. 2001) and developement of simulation software (Berweger et al. 1997). Nowadays we apply this expertise to industrial innovation, research and development of complex systems, for risk analysis and optimisation in security and efficacy. Computer simulation is perfectly suited for this purpose for different reasons:

- It is possible to verify or optimise extensive systems. The only limitations are imposed by available memory, programming efforts and computational power as well as the labour input.
- Events that are impossible to provoke experimentally (severe weather!) or incidents that are too dangerous to investigate in reality (floodings!) still can be observed and analysed, since in simulation no damage or harm is caused.
- If models and simulation are correctly implemented, those observed results are objective and more accurate than an estimate.
- In many cases, interdependencies and weaknesses can be found, which hint at relevant risks.
- Proposed improvements can be rapidly tested on their relevance and efficacy. After their successful implementation, they immediately contribute to damage prevention.
- Real incidents can be compared with the model. This helps to understand the circumstances that lead to incidents and allows to learn from previous errors.
- Comparisons of real damages with simulation allow to clarify weaknesses of the model and help improve it. This, on the other hand, improves the prevention of damage.

1.1 Technics

The technical or physical processes, and automated or programmed devices, can accurately be simulated in a computer if the underlying methods and laws are known. In this case, model prediction and reality will coincide. The simulation can be used for reliable statements and predictions.

Additionally, simulated processes can always be studied in detail. To log the dynamics of the system, arbitrary observables can be established at any place, whereas in reality, they only are insufficiently verified, if at all, or they would even influence the system itself.

1.2 Humans

Human behaviour is a critical factor as part of warning systems or measures: in complex and stressful situations, quick decisions are not a strength of human thinking. Simulations can help to develop simple and clear action plans. In simulation, different scenarios of danger exposure can be investigated, and counter-measures can be tested without taking risks. The most effective measures (which often are not intuitive) can then be documented. Training of responsible persons can be improved, and their reaction in case of emergency can be simplified.

Ideally a simulation can even be used to analyse dangerous situations and to advice effective counter measures in real time.

1.3 Example Flarm: An air traffic collision avoidance system in practice

Thousands of glider pilots in several European countries are using the Swiss collision avoidance system Flarm (Oetiker and Scheel 2006). It warns of risky encounters by other planes and of stationary obstacles like cable cars or electric wires. Since

2004, it continually became a de-facto standard and has been established well in practice.

The principle is simple: Every device receives its current position of the airplane via GPS and transmits it including speed and heading to all compatible collision avoidance devices in range. The messages from surrounding devices are analysed: If any motion towards close encounter is detected or a potential collision is predicted, the affected pilots get a warning signal displayed. It is within the responsibility of the pilots themselves to take measures to avoid the collision.

The benefit in security for private aviation in practice is remarkable. At the Aero trade fair 2007 in germany the system has been awarded with the Prince Alvaro de Orleans-Bourbon Fund for its technical innovation for aviation sports.

But how secure is such a system under extreme conditions? Since the time window to send the necessary informations is limited, at high traffic volumes, not all data will be properly exchanged. How can one improve its security by small expenses (software update instead of expensive hardware upgrades)? How would a thought-about-modification of the communication protocol alter the security implications? These questions of the manufacturer have been investigated and answered methodically by simulation (Berweger et al. 2008).

2 Methods

2.1 Basic concepts

As a basis our simulation software framework "ximulon" is used. It incorporates our whole experience from various simulation projects, and is continually developed. Thanks to a high level of abstraction, simulation concepts from different areas can be transferred and reused. This procedure makes it easier to implement new models and apply existing simulation methodology.

Therefore, the implementation is focused more on the model, instead of the programming. The focus is set on obtaining results, instead of the way they are obtained. Additionally, sources of flaws are eliminated, and overall reliability is improved. The trustworthiness of results is ensured by a comprehensive test suite and a consistency check, which can verify the consistency of the model automatically. Therefore, the implementation of simulation is quicker and safer, compared to developing a specific feature from scratch.

Input and output are written in XML to keep them transferable and flexible. The format is human readable and transparent, can easily be converted into other formats or be used by other programs. Additionally, the application itself can be used platform-independently.

2.2 Model implementation

New models are implemented as new modules, and are linked to the software engine. Existing concepts can be reused, and need not to be re-invented. Therefore, many sources of error are avoided, and results are obtained more quickly.

A scenario generator sets up thousands of situations from well-defined patterns and rules. Then the scenarios are calculated, and dynamically propagated in time. Afterwards, the results are analysed and summarised. Often, intermediate results point at problems, which can be investigated more closely in an iterative manner. Step by step, a more complete picture of an investigated system is obtained.

The software is oriented towards deterministic dynamics, Stochastic Dynamics or Monte Carlo simulations. Since random dynamics is internally implemented in a deterministic manner, every scenario can be exactly reproduced. If we detect an interesting effect in a certain scenario, which we would like to observe in detail, and realise we are missing relevant data of observables, we can just add the necessary observables and rerun the scenario.

All systems that are suitabledeal with agents and interactions, for example:

- molecular dynamics: atoms (agents) with chemical bonds and physical forces (interactions)
- astrophysics: suns, planets and moons (agents) with graviation (interaction)
- collision avoidance system: warning device (agent) with communication protocol (interaction)
- traffic simulation: cars (agents) with driving behaviour (interaction)
- communication networks: switchboards (agents) with their connections (interactions)

Less suitable are continuous systems (keywords: fluid dynamics, CFD).

2.3 e.g. Flarm

In practice, nobody would send thousands of glider pilots into the air for an experiment of risky encounters to find out how reliable the warning system is under heavy load. Additionally, if the system would fail, it would be rather impossible to find out the reason – and no improvement could be found.

A simulation can provide all this – and make precise statements on efficacy and suggestions for improvement.

In our models, properties of individual agents, such as senders and receivers, as well as interactions, such as the implemented communication protocol and the transmitted informations and their analysis, can be implemented exactly as known.

For this simulation, only the communication protocol had to be implemented, which is known by specification from the manufacturer. From the field of molecular dynamics, the periodic boundary conditions were used. Although the investigated airspace is finite and relatively small, the simulated system is virtually infinite, because the airspace is periodically replicated at the borders. Because of the limited range of the radio signal, the periodic replications are not influencing each other. By applying this method, statistics are dramatically increased and boundary effects can be avoided.

Then the scenario generator distributes a number of airplanes in the virtual airspace – at random, but with a typical altitude distribution and heading for gliders. Doing so, we can put all gliders of Switzerland in a small well defined airspace at once, or thousands more if needed. Imagine the costs and logistics challenge, if one were to attempt this scenario as a real experiment!

3 Results

3.1 Simulated systems and goals

In the simulation, we have investigated airplane densities of 10 to 8000 gliders in a virtual airspace of 18 km x 18 km and 5000 m altitude, and analysed 480'000 individual receiver situations at every density. We were able to detect numerous dangerous situations and analyse them.

In particular, this method works reliably because it exactly evaluates the technical risks. If the device cannot get clear signals because of high traffic load, and thus potential sources of danger are not being recognised, this will be of importance for the manufacturer (and would be for the affected pilot). These limits must be known. While the communication protocol has been designed thoroughly and tested in field experiments, the situation quickly gets intransparent at higher traffic volumes when all devices within reach are communicating with each other. Simulation is complementing the understanding in this area and shows limits of efficacy, exposes their reasons, and can deliver suggestions for improvements.

3.2 Examples of results

Flarm is able to communicate simultaneously with 20-25 neighbours in the air for every pilot, and to continuously observe them. To reach this traffic load in reality, all approximately 1000 gliders of Switzerland had to be gliding at the same time above Kanton Schaffhausen (ca. 18 km x 18 km). The implemented communication protocol of Flarm therefore is considered to be secure in reality.

This limiting value is safe, but can still be improved by another 10 %. For this to achieve, an adaption of the communication protocol could be specified. The suggestion can be thoroughly tested in the simulation well before several thousand devices have to be upgraded. A change in the communication protocol has to be performed concurrently on all devices, since the different protocols may be incompatible with each other. Therefore, nowbody would like to carry out such a change at haphazard.

3.3 Outlook

If one day, the manufacturers were to decide to enhance the warning system by implementing a reaction advisor for collision avoidance, those algorithms can be evaluated and verified by simulation again. Thousands of critical situations can be generated, the airplanes can be moved according to the advisor's recommendations, and the results can be observed – again without taking risks for human or machinery.

4 Conclusions

Simulations are increasing the efficacy of warning systems in the following manners:

- automated, rapid and riskless testing of thousands of dangerous scenarios to detect flaws and breakdowns and to find limits in security.
- Needless discussions and hypotheses are avoided by providing exact statements on reasons of flaws and deliver clearly specified improvements.
- The simulation of counter measures, which are to be taken in dangerous situations, evaluates the most efficent counter measure. With this, simple but effective action plans can be obtained, or even the simulation itself can evaluate the most promising measure in the actual situation.

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