Development of a Coupled Geo-information and Simulation System for Early Warning

Eva Ortlieb, Wolfgang Reinhardt, Franz-Xaver Trauner

Abstract. Recurring disastrous landslides cause great damage worldwide and many people were affected during the last decades. Obviously there is a strong demand for developing and improving early warning systems to save lives and properties. Although strong efforts were made in the last decade, the understanding of the hazards and the forecasting of critical events are still particularly weak points of the early warning chain. In an ongoing research project a new approach to improve these critical points in the field of early warning systems of landslides is pursued: complex finite element (FE) simulations of landslides are coupled with geo information systems (GIS). This paper researches the interconnection between the GIS and the FE-Analysis system. Further, two main operational modes, the learning system and the decision support system mode, for such a coupled system are introduced and a workflow for these system is proposed and investigated in detail.

1 Introduction into the coupled system

"Early Warning Systems include a chain of concerns, namely: understanding and mapping the hazard; monitoring and forecasting impending events; processing and disseminating understandable warnings to political authorities and the population and undertaking appropriate and timely actions in response to the warnings" (NDMA 2008). Over the past years the evaluation of natural danger has been nationally and internationally identified as an important task and is still responding to a growing interest (Alexander

2006; Dilley et al. 2005; Fuchs et al. 2005). Nevertheless the understanding of the hazards and the forecasting of impending events are still particularly weak points of the early warning chain. A number of studies exist for the early warning of volcanic eruptions with sensor net approaches and for the early warning of floods (Handmer 2001; Plate 2002; Werner-Allen et al. 2005) Early warning systems for landslide hazards are hardly researched. Some approaches exist with particular sensors, e.g. ground based SAR interferometer (Casagli et al. 2002) or other sensors (Zan et al. 2002).

In order to advance research in the field of early warning systems for landslides the joint project “Development of suitable Information Systems for Early Warning Systems” was launched. The project aims at the development of components of an information system for the early recognition of landslides, their prototypical implementation and evaluation (Breunig et al. 2007, 2008) One subproject of the joint project addresses the coupling of complex finite element simulations with geo information systems (Ortlieb et al. 2008; Trauner et al. 2008). Numerical simulations are set-up to examine the physical processes of landslides induced by various scenarios and to improve the understanding of the causes of slope instability and triggers of ground failure. This allows for the evaluation of instable slopes and their imminent danger for human infrastructure. The coupling with the GIS allows for a user-friendly preparation of the complex simulation results in the GIS for decision support.

At present the FE simulations of landslides are a subject of research. Due to their complexity the corresponding simulation systems are predominantly used by experts and scientists. For disaster prevention and management such tools are currently not available, but would obviously be very helpful. A FE simulation of a landslide requires detailed input information. Therewith the configuration of the simulation input data is very complex and usually not sufficiently supported by the simulation system. On the other hand simulation outputs are extensive and complex and the interpretation of the simulation results is usually only weakly supported by the simulation system. For a broader use of simulation systems of landslides their handling should be more intuitive and user-friendly. GIS with their ability to store, manage and visualize geographical information provide a good basis for setting up the inputs of a FE simulation, analyzing and integrating the outputs and finally support a decision.

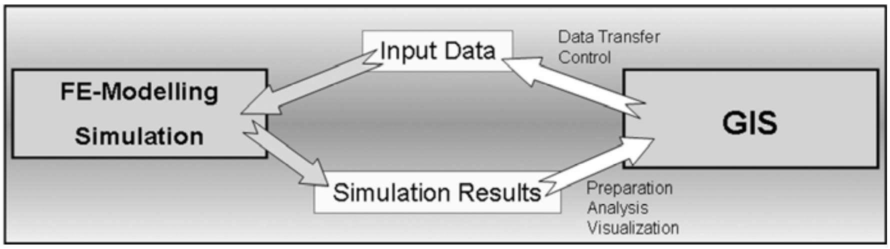

Fig. 1. Interconnection between Simulation System and GIS

The interconnection between simulation system and GIS is schematically shown in Fig. 1. The process starts with the selection of relevant parameters which are needed for the simulation. These parameters include basically geometry, the subsoil structure and several boundary conditions (Sect. 2.3). The parameter transfer is controlled by the GIS. Within the simulation system the modelling of the slope and the simulation of the landslide is executed.

After the simulation the results are transferred to the GIS for visualization, assessment and for processing into a form which is understandable for decision makers. Furthermore, stability indices and movement vectors can be calculated from the simulation results to assess the slope stability, the likely system behaviour in future and the potential risk scenario. Uncertainties in the data used in the simulation and in subsequent processes should also be modelled and visualized in the GIS. In particular for the support of the user in the decision-making process the uncertainties have to be recognizable, in order to allow for validation of the results by the user. Additionally, rule-based GIS components support the user in the decision whether to issue an early warning or not.

Because the simulation of landslides is complex and requires a number of manifold and extensive input information the whole dataflow between the simulation system and the GIS is complex. In the following chapter a proposal for a possible workflow is made and a detailed insight is given.

2 Workflow of the coupled system

Comprehensive and exhaustive simulations are complex and computationally intensive and can be in case of an early warning decision too time-consuming. Therefore two main operational modes of the coupled system with differing computational costs are identified:

1. Learning system for better understanding of landslide movements
2. Decision support system (DSS) for reaction after a hazardous event.

In the following sections a workflow of the coupled system is proposed. Some components of the workflow are only used by one operational mode, but there are also components which are used together.

2.1 Learning System Workflow

In the learning system mode the user can evaluate the consequences of many scenarios to learn how certain parameters (e. g. certain amounts of rainfall) influence the stability of slopes. This allows for a better understanding and prognosis of landslides. Furthermore the learning system enables to compare observed historical events with simulated ones. This enables for the calibration and refinement of simulations and supports the improvement of the understanding of the geotechnical characteristics of the slope. Further the comparison of historical events with simulated ones allows for the determination of critical events (e. g. a critical flood discharge). This allows for the announcement of warnings at an early stage when the critical event is expected or forecasted (e. g. intense rainfall).

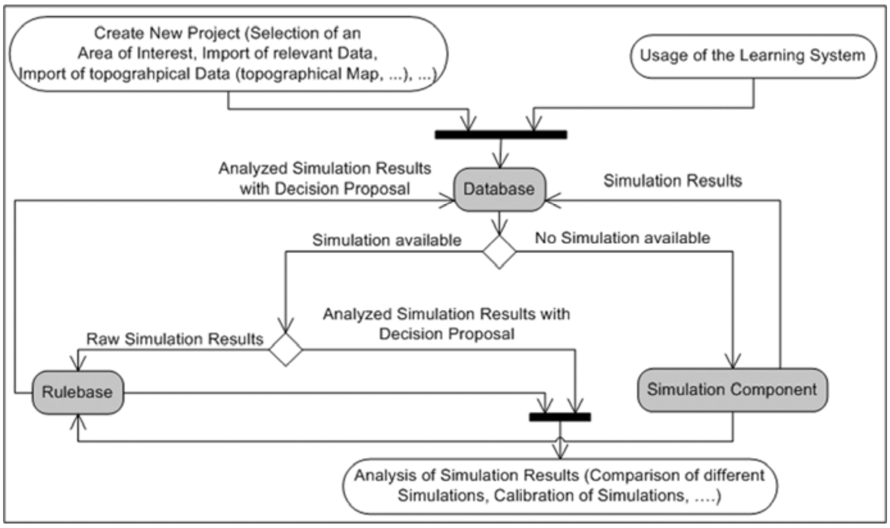

Fig. 2. Workflow of the Learning System

The learning system workflow is schematically shown in Fig. 2. If the user wants to investigate a scenario, he has the possibility to check whether there have already been simulations for this scenario in the past. Therefore the user has to query first the database. In the database several results from previous simulations and previous analyses are stored. To inform future users of the available simulations they are stored with their simulation parameters and metadata. Simulation parameters include all parameters, which were used to perform the simulation (Sect. 2.3). Metadata include e. g. the responsible person of the simulation and the date of the simulation.

If there are simulations available in the database they are either transferred to the rulebase for linkage with decision rules to provide a decision proposal for the user or, if the simulation results are already linked with decision rules, directly to the learning system. If there are no simulations available a new simulation has to be calculated in the simulation component related part of the workflow (Sect. 2.3).

2.2 Decision Support System Workflow

In contrast to the learning system mode, the DSS mode is used if an acute danger exists. This can be the case if an ascertained event, e. g. an intense rainfall event, occurs, which may destabilize the slope and causes a potential risk. This occurrence requires a fast decision whether to issue an early warning. Therefore the focus is put on performance and fast assessment routines, to allow for the announcement of a warning timely to the critical event.

The DSS workflow is schematically shown in Fig. 3. To assess, whether the ascertained event is critical or not, the user has to adapt actual measured values of this event. Because in most cases there is no time for complex and comprehensive and therefore time-consuming numerical modelling of the slope and simulation of landslide hazard it is from particular interest that there are already simulations existing in the database. In case there has been a simulation calculated before, the simulation results are either transferred to the rulebase for preparation or, if the simulation results are already prepared, they can be transferred for visualization in the DSS. If there hasn't been a simulation before a new simulation has to be carried out (Sect. 2.3).

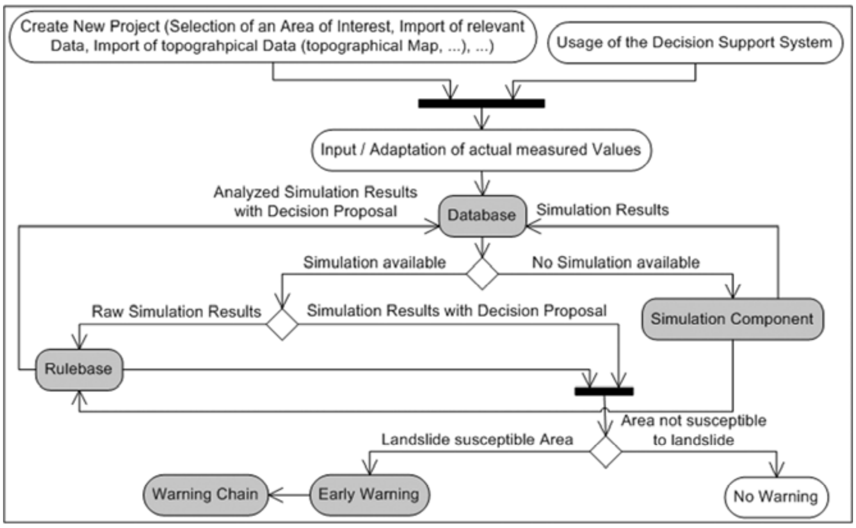

Fig. 3. Workflow of the Decision Support System

In the DSS the landslide susceptibility of the slope and the associated uncertainties can be visualized. In case the area of interest is landslide susceptible the user has to trigger an early warning to activate the early warning chain. Subsequently, a warning is disseminated to authorities and to the population and appropriate actions can be undertaken.

2.3 Shared Components of the Workflow

As shown above, for the DSS and the learning system a specific workflow has been defined. But there are also components, which are used in both cases. This includes the simulation, the database and the rulebase component related parts of the workflow. For further information about the database and the rulebase component, see (Breunig et al. 2009) and (Ortlieb et al. 2009a). The simulation component related part of the workflow is described in the following paragraphs.

The process in the simulation component related part of the workflow starts with the selection of the required input data (Fig. 4). For a numerical simulation various kinds of data are needed. Some of them are user-defined parameters and some can be imported from the database. The user-defined parameters include:

- The area of investigation,

- The event, which influence on the slope shall be examined (e.g. rainfall),
- The dimension of the event (in case of rainfall liter per square meter).

A fundamental input is a FE-mesh, which represents the geometry of the slope. It consists of a collection of nodes and edges, which defines the finite elements. To generate the FE-mesh two specifications are needed, which are queried from the database:

- A digital terrain model, to define the upper model boundary of the slope,
- A three-dimensional model of the subsoil structure (geology), which shows the distribution of different soil types in the slope.

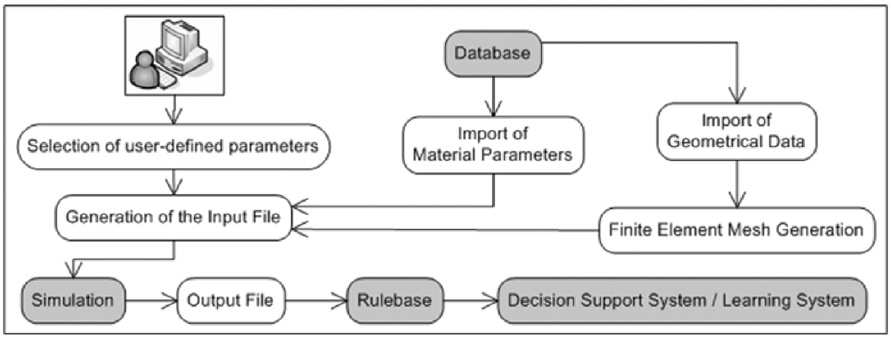

Fig. 4. Simulation Component related Part of the Workflow

Additionally to the user-defined parameters and the FE-mesh, the material of the soil layers is needed for the simulation and is therefore also written in the input file. Afterwards the input file is transferred to the simulation system. Within the simulation system the finite element modelling of the slope and the analysis of the landslide susceptibility is executed (Boley and Trauner 2009). Results of the simulation are several parameters, e.g. deformations of the nodes of the FE-mesh. Because the simulation results are very complex and extensive they have to be linked with decision rules in the rulebase to allow for a user-friendly visualization with appropriate methodologies in the learning and the decision support system, respectively (Ortlieb et al. 2009b).

3 Conclusion and Outlook

In this paper a workflow for a coupled system and two modes of the coupled system are presented. At the moment the presented workflow is tested and implemented with real mass movement scenarios. Therefore a part of the hillsides in the Isar valley in the south of Munich has been selected for exemplary simulations. In this area, the height difference of the slope reaches up to almost 40 meters and potentially endangered human infrastructure is located nearby to the edge of the slope. In the seventies there have been several landslides. After these events and because of the high risk potential several measuring devices were installed by the Bavarian Environment Agency. Today, after more than thirty years of investigations, extensive knowledge of the subsoil structure and the failure mechanism are available and can be used in the project (Baumann et al. 1988).

Future research will basically address the FE-modelling of the slope and the simulation of the landslide. Another focus is put on the preparation of the complex simulation results for the support in the DSS. Therefore they have to be linked with decision rules, which have to be defined in the presented project. Further, the simulation results have to be prepared with appropriate aggregation techniques, to allow for a user-friendly visualization in the learning and the decision support system, respectively.

Besides the user-friendly visualization of the simulation results corresponding uncertainties should also be modelled and visualized. In particular for presentation in the DSS the uncertainties have to be recognizable, in order to allow for validation of the results by the user. Both, the modelling and the visualization of the uncertainties are still a subject of research in the presented project.

Acknowledgements

The funding of the research project by the German Ministry of Education and Research (BMBF) and the German Research Foundation (DFG) under grant no. 03G0645A et al. is gratefully acknowledged. This is publication no. GEOTECH-1217 (http://www.geotechnologien.de).

References

Alexander D (2006) Globalization of Disaster: Trends, Problems and Dilemmas. Journal of International Affairs 59: 1 – 22

Baumann H (1988) Bruchvorgänge in Folge der Isareintiefung südlich Münchens und die kritischen Höhen der Talhänge. Schriftenreihe des Lehrstuhls und Prüfamt für Grundbau, Bodenmechanik und Felsmechanik der Technischen Universität München, Heft 12

Boley C, Trauner F-X (2009) GIS-gestützte numerische Analyse von Rutschhängen als Komponente von Frühwarnsystemen. Paper accepted for 24. Christian Veder Kolloquium – Stabilisierung von Rutschhängen, Böschungen und Einschnitten, TU Graz, Austria

Breunig M, Broscheit B, Reinhardt W, Ortlieb E, Mäs S, Boley C, Trauner F-X, Wiesel J, Richter D, Abecker A, Gallus D, Kazakos W, Bartels A (2007) Developement of suitable information systems for early warning systems (EGIFF). In: Stroink L (ed) Geotechnologien Science Report No. 10, pp 113 – 123

Breunig M, Broscheit B, Reinhardt W, Ortlieb E, Mäs S, Boley C, Trauner F-X, Wiesel J, Richter D, Abecker A, Gallus D, Kazakos W, Bartels A (2008) Towards an information system for early warning of landslides. EnvironInfo 2008, Lüneburg, pp 476 – 481

Breunig B, Broscheit B, Thomsen A, Butwilowski E, Jahn M, Kuper PV (2009) Towards a 3D/4D Geo-database supporting the analysis and early warning of landslides. In: Konecny M, Zlatanova S, Bandrova T (eds) Cartographie and Geoinformatics for Early Warnings and Emergency Management: Towards better Solutions Proceedings, pp 100 - 110

Casagli N, Farina P, Leva D, Nico G, Tarchi D (2002) Monitoring the Tessina landslide by a ground-based SAR interferometer and assessment of the system accuracy. Geoscience and Remote Sensing Symposium 2002, Toronto, pp 2915 – 2917

Dilley M, Chen RS, Deichmann U, Lerner-Lam AL, Arnold M (2005) Natural Disaster Hotspots: A Global Risk Analysis. The World Bank. Hazard Management Unit. Washington D C

Fuchs S, Keiler M, Zischg A, Bründl M (2005) The long-term developement of avalanche risk in settlements considering the temporal variability of damage potential. Natural Hazards and Earth System Sciences 5: 893 – 901

Handmer J (2001) Improving flood warnings in Europe: a research and policy agenda. Environmental Hazards 3: 19 – 28

NDMA (2008) National Disaster Management Authority. Terminology of disaster risk reduction. http://www.ndma.gov.pk/BooksPublications.html

Ortlieb E, Mäs S, Reinhardt W, Trauner F-X (2008) Coupling Simulations of Landslides with Geoinformation Systems for Decision Support and Early Warning. In: Bernard L, Friis-Christensen A, Pundt H, Compte I (eds) 11th AGILE Proceedings, Girona, Spain

Ortlieb E, Reinhardt W, Trauner F-X (2009a) Development of a coupled geo information and simulation system for early warning systems. In: Konecny M, Zlatanova S, Bandrova T (eds) Cartographie and Geoinformatics for Early Warning and Emergency Management: Towards better Solutions Proceedings, Prague, Czech Republic, pp 483 -492

Ortlieb E, Reinhardt W, Trauner F-X (2009b): Kopplung von Geoinformations- und Simulationssystemen zur Entscheidungsunterstützung. Paper accepted for 45 AgA-Tagung, Frankfurt

Plate EJ (2002) Flood risk and flood management. Journal of Hydrology 267: 2 – 11

Trauner F-X, Meyer F, Boley C, Ortlieb E (2008) Neue innovative Methoden zur Frühwarnung auf Basis von gekoppelten Informations- und Simulationssystemen am Beispiel gravitativer Massenbewegungen. Tagungsband 6. Kolloquium Bauen in Boden und Fels, Technische Akademie Esslingen, pp 433 – 439

Werner-Allen G, Johnson J, Ruiz M, Lees J, Welsh M (2005) Monitoring Volcanic Eruptions with a Wireless Sensor Network. Proceedings of the 2nd European Workshop on Wireless Sensor Networks (EWSN ’05), IEEE Press, pp 108 – 120

Zan L, Latini G, Piscina E, Polloni G, Baldelli P (2002) Landslides Early Warning Monitoring system. Geoscience and Remote Sensing Symposium (IGARSS ’02), IEEE International, pp 188 – 190