MurGame: Protect your village from debris flows!

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Abstract. Past debris flow events, like in Bondo (2017) and Brienz (2005) in Switzerland have been heavily covered in the (Swiss) media, illustrating how destructive such events can get. Protection measures play an important role in dealing with natural hazards. Debris flows are considered to be very rare, complex and multidimensional processes. Imagining and foreseeing the course and progression of a debris flow as well as estimating the potential damage and the influence of protection measures is a difficult task. Serious games offer a possibility to simulate these kinds of situations. With the *MurGame*, we have developed an application for natural hazard prevention. In the three-dimensional, interactive game, a village is created by selecting different objects, such as residential buildings or schools. Debris flow simulations show, which buildings would be destroyed and what damage would occur in the event of a debris flow. Different protection measures can be implemented to protect the village and their effectiveness can be monitored during the simulations. After the event, it is necessary to evaluate which measures offer the desired protection, what they may cost and how the needs of the population are met. The *MurGame* can be played online at *www.murgame.ch*.

1 Introduction

Raising the public awareness of natural hazards, their destructive forces as well as ways to prevent damage is an essential element of the integrated risk management system. In order to achieve this goal, it is crucial to maintain a well-balanced, target group-oriented communication. New means of communication, such as serious games, make it possible to address additional target groups or to convey scientific content in an innovative way. The *MurGame* is an interactive 3D game focusing on hazard prevention and raising risk awareness. It breaks new ground in communicating and presenting the contents of the integrated risk management system for natural hazards within the setting of a serious game. The aim of the interactive game is to reduce the damage caused by debris flows by means of various measures, while taking into account the needs of the population as well as the cost-effectiveness (cost-benefit ratio) of the measures. As a server-based web game that is flexible in terms of time and location, the *MurGame* can be used for education, at events or integrated into a website. The *MurGame* is available in English, German, French and Italian and can be played online at *www.murgame.ch*.

2 Overview of the MurGame

The first step of the game includes the construction of a fictional village. Dwelling houses, a school, barns, bridges or a campsite can be placed in order to fulfil a number of tasks (Fig. 1). As the number of dwellings increases, so does the number of inhabitants.
Building costs are continuously added up and the acceptance among the population changes depending on the built objects. The simulation of a small or large debris flow can be started, as soon as the minimal tasks are completed and the village is set up. After a debris flow event, the damage report provides information on construction costs, damage caused and acceptance by the population in respect to the village infrastructure.

Fig. 1. Overview impressions *MurGame*. A village is built on the alluvial fan (top right) which is then severely damaged by a debris flow (bottom left) and protected by a dam / dyke (bottom right).

The next step consists of finding ways to protect the village from future debris flows. Structural protection measures in and around the village such as dams / dykes and debris flow barriers, as well as organisational

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protection measures can be set up. Existing buildings may be relocated (Fig. 2, top).

A second debris flow can be simulated as soon as protection measures are placed and considered satisfactory. The updated damage report allows the player to assess the effects of the protection measures, their construction costs, the damage caused or prevented and the acceptance of the measures by the population. In addition, the cost-effectiveness (cost-benefit ratio) of the protection measures is calculated (Fig. 2, bottom).

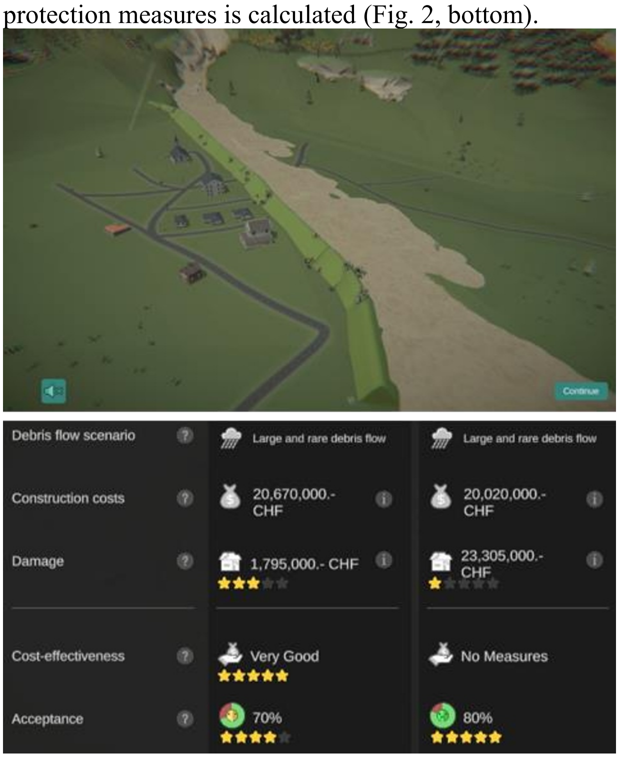

Fig. 2. Debris flow event through a protected village in the MurGame (top). The updated damage report compares the unprotected village (bottom right) to the protected village (bottom left).

The damage reports of the different village designs can be compared with each other to find an optimal balance between minimal damage, reasonable construction costs and a sufficient acceptance of the protection measures within the population (Fig. 2). However, as in reality, it will not be possible to achieve an absolute protection against natural hazards and still be cost-effective at the same time. Therefore, the player must find the best possible balance between the degree of protection, the costs of implementing the protection measures and the residual risk.

3 Background information

The *MurGame* is set in a fictional environment. A typical torrent flows from a steep catchment area to a larger river on the valley floor. On the alluvial fan of the torrent, there is a settlement with a main access road running along the river in the valley floor. The elevation model (cell size 2 m) used for the *MurGame* is taken from a real torrent catchment and was prepared for use in the game.

3.1 Debris flow modelling

The *MurGame* uses the simulation model RAMMS::DEBRISFLOW [5] to represent the debris flow and the damage calculation based on it. RAMMS::DEBRISFLOW is a numerical model developed at the WSL Institute for Snow and Avalanche Research SLF. The simulation model is based on the Voellmy model using two friction parameters. Flow depths and velocities are calculated on 3D digital terrain models (DTM) by using an efficient 2nd order numerical solution of the depth-averaged equations of motion [6].

For the *MurGame*, two realistic debris flow scenarios were assessed for the torrent. Debris flow volumes are 10,000 m^3 for the large and 5,000 m^3 for the small debris flow. An input hydrograph with peak discharge at 150 m^3/s for the large and 100 m^3/s for the small debris flow was defined. Friction parameters were set at $\mu = 0.25$ and $\xi = 200$ m/s^2. For the check dam and retention net, a retention volume of 5,000 m^3 is assumed. Therefore, for the scenario "small debris flow with check dam / net", the entire debris flow is retained. For the scenario "large debris flow with check dam / net", the debris flow with 5,000 m^3 volume is considered.

Large objects (church, school, farm) as well as robust structural measures (dams / dykes, concrete walls, retention structures) influence the flow path of a debris flow. These elements are considered in the simulations and lead to a protective effect behind dams / dykes, for example. Small objects (residential buildings, shops, stables, garages) and in-effective measures such as sandbags do not significantly influence the course of a debris flow. Therefore, they are not taken into account in the simulations.

A differentiation was made regarding bridges: The bridge close to the river outlet and the "small bridge" in the middle of the fan are considered as insufficient in capacity and were integrated into the DEM as an obstacle in the torrent. However, the capacity of the large bridge is assumed to be sufficient and this bridge is not taken into account as an obstacle and is neglected in the simulations.

Debris flows for every possible combination of objects and measures have been pre-simulated and are available at stock. Depending on the village design, the corresponding simulation is loaded, visualised and used for the damage calculation. A total of approx. 1,200 simulations were pre-simulated for the *MurGame*.

3.2 Loss calculation

Basically, damage occurs when a hazard process hits an object. The extent of the damage depends on the type and value of the object as well as the natural hazard process and the intensity of the process. In Switzerland, the detailed calculation of the risk to settlement areas and infrastructure facilities from the threat of natural hazards is carried out according to the EconoMe methodology [1]. This forms the basis for the integrated risk management system and thus the handling of natural hazards. In the *MurGame,* damage is calculated according to the approaches used in practice in Switzerland [1], [2], [4] (see publication [7] for a summary in English).

In a first step, the debris flow intensity is determined in the corresponding village setting per existing object and road section as a function of the respective flow depth at the object or road from the corresponding RAMMS::DEBRISFLOW simulation. For simplification, flow velocity was neglected and 3 classes of intensity were assigned from maximum flow depth: low (0 – 0.3 m), medium (0.3 – 1 m) and high intensity (> 1 m).

Based on this intensity, the parameters for the personal injury and property damage calculation are derived. The spatial probability of occurrence is assumed to be 100 %, as the debris flow simulations represent discrete process areas. Recurrence periods were set at 100 years for the small and 300 years for the large debris flow.

The damage calculation in the *MurGame* takes into account personal injury and property damage for objects and roads according to EconoMe [1] as well as supply damage due to the interruption of traffic routes according to the approach of the Canton of Zurich, Switzerland [4].

The personal injury and property damage (probable extent of damage) are determined according to the methodology by EconoMe [3]. Furthermore, the values for the respective objects according to EconoMe [1] were used for the parameter vulnerability and lethality. For the basic values of the buildings, reference values of the Swiss insurance industry (Vereinigung Kantonaler Gebäudeversicherungen VKG, Mobiliar) were used. The movable property was added to the tangible value by a surcharge of 20 %. The costs of measures could be derived from empirical values for construction projects.

In the game, typical values for Switzerland were used and currency is Swiss franc CHF. The monetization of injured / death people is calculated using the value of a statistical life. This value is set at CHF 6.6 million according to EconoMe [1]. Further parameters for buildings (number of occupancies and presence probability factors) and road traffic (speeds, values for average daily traffic and number of average journeys) were specified to the setting in the *MurGame*.

For reinforced construction, elevated windows / entrances and elevated arrangement, probable extent of damage of the specific object is reduced by 100%, 80% and 50% for low, medium, and large debris flow intensity respectively. For organizational measures, probable extent of damage is reduced by 20% for siren and emergency planning, and by 5% for using an information bulletin. If the gate is installed, probable extent of damage on the main road between the barrier is reduced by 100%.

The calculation of the supply damage is based on the methodology of the risk analysis of the Canton of Zurich, Switzerland [4]. This approach is based on a qualitative determination of the risk for the interruption of traffic routes (municipal, main road and bridge). As soon as a debris flow buries a section of a road, a corresponding damage due to the interruption of supply is calculated. A distinction was made between the smaller roads on the fan and the main access road. For a better comparison with the other damages, the qualitative values were monetized (marginal costs 500'000 CHF).

3.3 Key performance indicators

In addition to the key performance indicators damage and cost-effectiveness, a third element called “acceptance” was introduced to the game in order to design a well-balanced challenge to the game. In the damage report, acceptance among the population for the specific village consists of the individual evaluations for the selected buildings, bridges, structural and organisational protection measures. The values of acceptance for these objects were assessed subjectively and range from 0 to 10. The acceptance of a village equals to the average of the individual values.

In the damage report, key performance indicators were classified. For damage, classes were

- 1* with damage > 20 million CHF
- 2* with damage between 20 and 8 million CHF
- 3* with damage between 8 and 1.5 million CHF
- 4* with damage between 1.5 million and 400,0000 CHF
- 5* with damage < 400,000 CHF

For cost-effectiveness, a linear interpolation was applied between the minimum value of 0 (equals to 1*) and maximum value of 12 (equals to 5*).

For acceptance, a linear interpolation was applied between the minimum value of 3 (equals to 1*) and maximum value of 8 (equals to 5*).

4 Simplifications / gaming assignments

In order to visualise the topic of integral risk management in a clear and informative way, a number of simplifications have been made and certain aspects of the risk assessment have been excluded.

Basically, the term risk is understood as the possibility that damage may occur as a result of a certain event. In the context of natural hazards, the risk is composed of the frequency or return period of several events and the possible extent of damage (persons and property). In Switzerland, the collective and the individual risk are considered for the assessment of the risk [2], [7]. The risk concept consists of three elements: risk analysis, risk assessment and risk management. An important basis for this are the hazard and intensity maps that exist throughout Switzerland in the vicinity of settlements. The calculated risk is assessed as part of the risk evaluation and, if necessary, measures are taken. However, even after protection measures have been taken, there is still a residual risk, as absolute safety from natural hazards cannot be achieved in a hazard-prone area.

A variety of different systems can be used for the implementation of protection measures. However, aspects such as additional hazards or the shifting of hazards and legal requirements such as ecology and the cost-effectiveness of the measures must be considered. Furthermore, the possibilities for protection measures are often limited due to spatial, social and economic framework conditions. All these aspects were not included in the *MurGame*. However, depending on the type of application and moderation, these points can be addressed. Depending on the target audience, different emphasis can be given, especially in the context of education and training events. Single aspects of risk management, such as cost-effectiveness or damage minimisation can be addressed. More complexity can be added by focusing on several aspects simultaneously (e.g., damage, cost-effectiveness and acceptance) or on specific topics such as economy by limiting the available budget for construction measures or vulnerability by assessing the impact of the different bridges on the hazard situation.

5 Conclusion

The *MurGame* teaches various aspects of the integrated risk management system by focusing on hazard prevention and raising risk awareness through the example of the debris flow hazard process. If a debris flow occurs, human lives, buildings and infrastructure facilities are threatened. The aim of the interactive 3D game is to reduce the possible damage caused by debris flows by means of various structural and organisational measures and spatial planning, while obtaining the best possible cost-benefit assessment. In order to achieve this goal, the *MurGamer* has to fulfil a minimal number of tasks, which include the expansion of the village as well as the implementation of effective protection measures. A focus should be given to the cost-effectiveness (cost-benefit ratio) of the measures. Therefore, it is crucial to achieve an optimal balance between the prevented damage and the construction costs. Besides the cost-benefit considerations the success of protection measures will also be dependent on the acceptance of the measures by the village population. All these aspects must be coordinated in order to best protect the village that has been built.

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