SIMULATION OF THE FLOOD WARNING PROCESS WITH COMPETENCY-BASED DESCRIPTION OF HUMAN RESOURCES

Štěpán Kuchař[(a)], Michal Podhorányi[(b)], Jan Martinovič[(c)], Ivo Vondrák[(d)]

VŠB – Technical University of Ostrava, IT4Innovations
17. listopadu 15/2172, Ostrava-Poruba, Czech Republic

[(a)]stepan.kuchar@vsb.cz, [(b)]michal.podhoranyi@vsb.cz, [(c)]jan.martinovic@vsb.cz, [(d)]ivo.vondrak@vsb.cz

ABSTRACT
This paper describes the flood warning process and its two main parts that are concerned with correctly predicting the potentially coming flood and issuing correct and quick response based on this warning. In order to correctly predict the magnitude of the flood, the hydrometeorology specialists in the process have to be adequately skilled, but process simulation models are not very concerned with accurate human resources modelling. A method for the description of human resources' skills in process simulations is proposed and used to extend the discrete event process simulation method called the BPM Method. This method is then used for modelling and simulation of the flood warning process to identify sections that cause the greatest delay and to propose improvements to the number and skill sets of specialists in the process.

Keywords: discrete event process simulation, flood warning process, human resource competency model, BPM Method

1. INTRODUCTION
Water is one of the most useful and one of the most destructive things on Earth. Most of the time, it is completely benign, but in large enough quantities it can overturn cars, demolish houses and even kill.

Flood waters are waters which escape from a watercourse in great volume and flow over adjoining lands in no regular channel. Floods kill millions of people, more than any other natural disaster. Flooding is also the world's most expensive type of natural disaster. The cost of global flood damage is hundreds of billions of euros.

Floods frequently affect the population of Central and Eastern Europe and therefore are studied by numerous scientific research institutes. Almost all large rivers in Central and Eastern Europe have experienced catastrophic flood events, e.g. the 1993 and 1995 flooding of the river Rhine, 1999 and 2002 Danube/Theiss rivers, 1997 Odra river, 2001 Visla river and 2002 Labe river. Floods, however, affect not only Central and Eastern Europe, but they represent a major problem in many regions all around the world (Horritt and Bates 2002; Knebl, Yang, Hutchinson and Maidment 2005).

In August 2002 the Czech Republic was hit by devastating floods, in what was the biggest natural disaster in modern Czech history. In some areas the floods - which affected over one third of the country - were the worst in 500 years. There were 17 deaths and thousands of people had to be evacuated from their homes. The floods caused damages of over 73 million crowns (2.5 million US dollars). One year later, life returned to normal in many of the affected areas, though the damage is still being dealt with in some places.

The growing number of losses caused by floods in countries around the world suggests that general mitigation of disasters is not a simple matter, but rather a complex issue in which science and technology can play an important role (Flowers 2003, Cheng 2006, Guo 2010). An important area of scientific study is modelling and simulations.

The main objective of this study is to model the flood warning process and simulate it to find a way to shorten the duration of the flood prediction preparation. The early flood forecast is very crucial because it allows the flood warning committee to quickly predict flood emergency and provide security countermeasures to potentially endangered areas. To adequately simulate this process it is necessary to possess information about all its components including all involved specialists and their specific competencies. Without this information it is difficult to reveal all bottlenecks of the process that delay the process execution because they can be caused not only by the wrong workflow structure but also by wrong allocation of human resources.

2. FLOOD WARNING PROCESS
The flood warning process has two distinct stages: flood warning and response (Sene 2008). The flood warning stage starts with a detection of the potential flooding threat. This activity should be done periodically based on river and precipitation monitoring and meteorology forecast. When a threat is detected, the flood warning committee is informed and it issues a request for more detailed forecasts to the institute of hydrometeorology and local catchment area offices. These organizations provide:

- information about actual river and reservoir situation;
- hydrodynamic modelling – flood simulations, flood maps, simulations of water elevation and water velocity, a real-time hydrological model for flood prediction using GIS, sediment transport, water quality analysis, etc.;
- rainfall runoff modelling – simulation of surface runoff;
- erosion modelling – simulation of water erosion;
- collection and archiving of flood data that can be used for estimating the magnitude of the flood based on historical evidence.

If these predictions identify possible emergency situations, the Emergency Manager (head of the flood committee) alerts relevant agencies and the process moves to the response stage. In this stage the countermeasures are implemented based on the forecast simulations from the flood warning stage. The following organizations and their responsibilities are part of the flood warning response stage:

1. Police:
   - assists with evacuation;
   - organizes and disseminates casualty information;
   - coordinates emergency services, local authorities, media etc.;
   - secures, protects and preserves the scene, and controls traffic;
   - helps with restoration of affected areas.

2. Fire & rescue services:
   - assesses hazards concerning evacuation;
   - rescues trapped people;
   - minimizes environmental dangers;
   - controls fires, released chemicals and other hazards;
   - cooperates with ambulance and medical services.

3. Ambulance and medical services:
   - saves life in conjunction with other emergency services;
   - assists and stabilizes injured people;
   - provides ambulances, medical staff, equipment and resources;
   - arranges transport for injured people;
   - alerts receiving hospitals.

4. Emergency coordinator:
   - prepares Emergency Plans for local resources and useful equipment;
   - issues warning messages to local authorities;
   - advises on weather, water flow, warnings and evacuation;
   - issues media statements;
   - issues situation updates.

In addition, the flood predictions are still provided even in the response stage to support the decision processes related to performed countermeasures and actions. During the response stage additional areas can be affected by the flood emergency and these predictions should be able to identify these areas in advance. This demands a number of skilled hydrology specialists that significantly influence the delay and precision of such forecasts and thus the efficiency of the whole process. We have therefore focused on this aspect of the process in our study.

3. THE BPM METHOD

A modelling and simulation method that is able to sufficiently model human-based processes is needed to model and simulate the flood warning process. For these purposes we used the discrete event modelling and simulation method called the BPM Method (Vondrák Szturc and Kružel 1999) that already provides simulation environment with stochastic parameters (Kuchař and Kožusznik 2010) and also specifies how the generic resources should be shared in concurrent instances and activities of the process (Kuchař, Ježek, Kožusznik and Štolfa 2012). This method defines three basic models of the process:

1. architecture of the process;
2. objects and resources utilized in the process;
3. behaviour of the process.

The most important one of these models for performing simulations is the behavioural model. This model is called the Coordination model and it specifies the behaviour of the process as a sequence of activities. It also specifies what resources the activities demand and which artefacts they consume and produce. Alternative flow in the coordination model is enabled by multiple activity scenarios and concurrency of the activities can also be modelled. This model can also be converted to a Petri net to provide exact semantics for performing simulations (Kuchař and Kožusznik 2010; Kuchař, Ježek, Kožusznik and Štolfa 2012).

4. HUMAN RESOURCE COMPETENCIES

Existing process simulation models are not very concerned with accurate human resources modelling and description (Rozinat, Wynn, Aalst, Hofstede and Fidge 2009; Aalst, Nakatumba, Rozinat and Russel 2008). But clearly each human resource in the process is unique with his own set of skills and experience, each one has specific working habits and performance (André, Baldoquín and Acuña 2010). In our paper we use a competency-based approach to differentiate individual resources in the process and to correctly allocate resources to the process activities during flood warning process simulations.

4.1. Resource Competency Description

The description of the human resources' skills in the process is commonly done by using the competency models (Dreyfus and Dreyfus 1980; Sinnott, Madison and Pataki 2002; Ennis 2008) and skills frameworks (e.g. NHS Knowledge and Skills Framework (UK Department of Health 2004). Competency models describe various competencies which are important for the process. Competencies are defined as sets of knowledge, abilities, skills and behaviour that contribute to successful job performance and the achievement of organizational results (Sinnott, Madison and Pataki 2002). Skills frameworks have the same purpose, but they describe skills particular for one domain rather than general competencies. But in fact skills are just a special type of competencies.

Competency models and skills frameworks also describe how to measure and evaluate individual competencies. In most cases competencies are measured by a number of advancing stages where higher levels of competency include everything from their lower levels. There is no standard for how many levels a competency model should have and every model defines its own set of levels.

Let us look at a small example of one hydrology specialist's competencies in the flood warning process. Some of his competencies in a 10-level model could be described as:

- catchment area of the Odra river – 8. level;
- catchment area of the Opava river – 3. level;
- rainfall-runoff modelling – 4. level;
- hydrology analysis – 6. level;
- communication – 4. level, etc.

Domain specific skills (rainfall-runoff modelling, hydrology analysis), general competencies (communication) and knowledge of the environment (catchment area) are contained in this example. It is clear that competencies in the model have to be based on the process requirements and professional domain.

4.2. Activity Requirements Description

All activities in the process also have competency-based requirements that describe what competencies the human resources performing this activity should know. Each activity will therefore be defined by the set of competency levels for each resource type performing the activity specifying that only resources with given level or higher will do the activity as planned. Resources with lower competencies are able to finish the activity, but they have to spend additional time to learn how to perform the activity and their work is prone to contain more errors. A simple example of requirements for the activity of analysing results of hydrological models could have following requirements

- catchment area – 6. level;
- hydrology analysis – 7. level;
- cartography – 4. to 7. level;
- statistics – 5. to 7. level.

By comparing these requirements with the resource competencies mentioned above, the high level limits of the requirements stand out. These limits are introduced to prevent the allocation of highly skilled specialists to simple tasks that can be done by average workers. Another difference can be found in the generalization of the catchment area. When assessing the specialist's competencies, it is better to define the competency levels in specific parts of the domain so that the workers are assessed as precisely as possible. On the other hand the activity requirements should only define a level for the whole parameterized competency and relevant part of the domain will be specified by the parameters of actual process case. In other words, if the hydrology team tackles with a case concerning the catchment area of the Odra river, then the requirement in this case will be refined as the catchment area of the Odra river.

5. INTEGRATION OF COMPETENCY-BASED DESCRIPTION TO THE BPM METHOD

The BPM Method is designed as an object oriented method so introducing the competency-based description of resources and activity requirements can be done by expanding the object descriptions of activities and resources in this method.

5.1. Resource Competency Extension

Each resource with definable competencies has to be part of any shared resource pool in the process. Each such pool contains one type (role) of resources and is shared among all process instances (Kuchař, Ježek, Kožusznik and Štolfa 2012).

Each resource object in the BPM Method is then extended by the collection of competencies and their levels that are specific for this resource. Levels of parameterized competencies (as described in the previous section on the catchment area example) have to be specified individually for each possible parameter of the competency because the resource can have different levels for different parameters.

5.2. Competency Parameters Extension

Each process instance defines several sets of competency parameters that will specify the process case and influence the allocation of resources with parameterized competencies. Each parameter set comes with the percentage probability that exactly this parameter set will be chosen for this process instance. Total sum of probabilities for all parameter sets' in one process instance has to be 100% to ensure that each process case has one of these parameter sets in each simulation. For example one parameter set of the process instance could have 20% probability that it will be a process case for the Opava river catchment area and 80% that it will be for the Odra river area.

5.3. Activity Requirements Extension

Each activity in the process can be expanded by the description of its requirements for each resource type that performs this activity. Required competencies have to come from the same set as the competencies of resources to ensure their comparability. Each activity object now contains several collections of requirements – one collection for each input resource. Each requirement comes with the low and high competency limits (as described in section 4.2) and importance of this required competency. Less important competencies have weaker impact on the suitability of resources lacking these competencies.

Parameterized competencies can be specified by one competency requirement that will be refined for each process instance and its chosen parameters, or by several requirements for specific parameters that are required in every process case.

5.4. Competency-Based Resource Evaluation

Whenever any activity with requirements in any process case needs to start its execution, the simulation needs to allocate one or more resources to perform this activity. These chosen resources have to be suitable for performing this activity by having enough skills and experience to fulfil its requirements. This suitability can be evaluated by encoding the resource competencies and activity requirements to their vector representation and evaluated in the vector space model (for more information see (Kuchař and Martinovič 2012)). The resulting suitability is then compared to the referential resource of the activity that has exactly same competency levels as those required by the activity. Workers with higher suitability than the referential resource are considered suitable to perform the activity.

5.5. Resource Utilization and Unavailability

The last extension added to the BPM Method is a method for determining the utilization of each shared resource in the process. This utilization is measured by simply counting up the time when the resource is performing any activity.

Utilization is an interesting result of the simulation but it is not very useful in optimizing the performance of the process. When optimizing the number of resources in the process we are not interested in answering how long one resource was doing something in the process, but rather how long did the process have to wait for the resource when it was needed to perform another activity. One resource cannot perform two activities at the same time but activities and processes run concurrently and they very often need the same resource to be able to continue their run (e.g. one hydrology specialist is needed to model the rainfall-runoff in one process case and at the same time calibrate another model in another case). When this happens the resource has to perform these tasks sequentially by:

- finishing the first task and then starting the second one, or
- pausing the first task and returning to it after finishing the second one, or
- switching back and forth between these tasks.

In either way one task will have to wait for the completion of the other (or partial completion in the case of the third option). It is therefore important to be able to simulate and measure these waiting times. The BPM Method is only able to model the first sequencing option. Whenever an activity is enabled but the resource is not available, the BPM Method counts and notes the time needed for the resource to become available to perform the activity. Total waiting time for one resource is then computed by adding up these noted times for this appropriate resource.

6. CASE STUDY

We implemented all extensions of the BPM Method proposed in this paper into the modelling and simulation tool called BP Studio (Vondrák 2000) and used it to model, verify and simulate the flood warning process of the Moravian-Silesian region in the Czech Republic.

This process is specified in accordance with the process description presented in section 2. Simulations in this case study focus on the flood warning and forecast stage of the process that is performed by 4 worker roles – Hydrology Manager, Hydrology Analyst, Hydrology Specialist and Database Specialist. These workers are defined by a total of 20 competencies with one being further refined by 5 parameters. This parameterized competency describes knowledge of a specific catchment area and 5 major catchment areas were used in these simulations. Forecasts for each of these catchment areas are treated as individual process instances running concurrently with all other catchment area forecasts. Execution of each process instance starts 15-30 minutes after the start of the last instance according to the delay of specified requests and data coming from the emergency committee.

The first process simulation is executed for the regional flood forecast with the whole team of 1 Manager, 2 Analysts, 5 Hydrology Specialists and 2 Database Specialists each with his own acquired competency levels. 200 simulations are performed to mitigate the unpredictability of stochastic parameters on the results. The average duration of this process is 9 hours and 44 minutes with utilization and waiting times shown in Figure 1.

This simulation shows that the Manager is appropriately utilized because his waiting time is very short. The Manager is utilized in a small part of the process because the process only describes his role in acquiring data from other organizations and flood classification. He of course works through the whole process execution to lead other roles and help with problem resolution.

Waiting times of the Database Specialists are also very short but this fact opens a question if the second Database Specialist is needed in the process. Database

Specialists only play a support role in the process because their main goal is to retrieve and archive data for modelling and analysis activities in the process. Their work is therefore very scattered throughout the process and one worker in this role could manage all the requests only with a short delay. After performing another simulation without the second Database Specialist, this hypothesis proved to be true. The waiting time of the Database Specialist increased by 7 minutes but it had no influence on process duration.

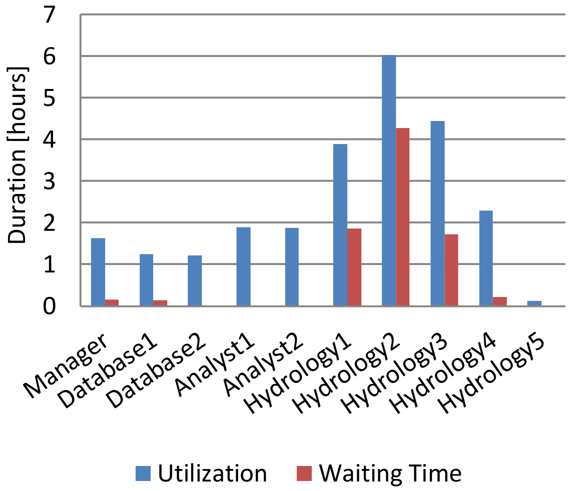

Figure 1: First Simulation Resource Utilization

The Analyst role follows a very similar pattern but the second resource in this role cannot be removed because both workers complement each other. Each Analyst is suitable for performing those activities that the other is not able to do.

The most utilized and most unavailable resources are from the Hydrology Specialist role and differences in their competencies are also very visible in this role. While the first, third and especially the second resource in this role show high waiting times, the fifth resource's competencies are so low that he cannot help with performing the standard process activities. The first step is to find the source of the high waiting time values for the second Hydrology Specialist. The simulation shows that his waiting times are caused by one activity (Calibration of the hydrodynamic model) and only this resource is able to perform this activity. But the fourth Hydrology Specialist is only a little worse than the referential resource for this activity (36% suitability of the fourth specialist as compared to the 39% suitability of the referential resource). This means that it is possible to easily gain another suitable resource by training the fourth specialist in the Hydrodynamic modelling or the Hydrodynamic calibration competencies in which he lacks the level required for performing the activity. It is enough to train him in one of these competencies to pass the suitability condition because his mastery in other required skills balances the lack of mastery in the other one.

After updating one of these competencies and executing the simulation, the results were significantly better. Total duration of the process was 8 hours and 31 minutes (more than 1 hour shorter than before) and waiting times of the second and fourth Hydrology Specialists changed to approximately 30 minutes.

To decrease the waiting times for the first and third Hydrology Specialist, a similar training is needed for the fifth specialist. There is only one possible competency to train because other competencies barely fulfil the requirements. After updating this competency, the simulations showed that several activities opened for the fifth specialist along with the one that delayed the other two specialists. This decreased the total process duration to 8 hours and 11 minutes and Figure 2 shows all resource utilizations after this change.

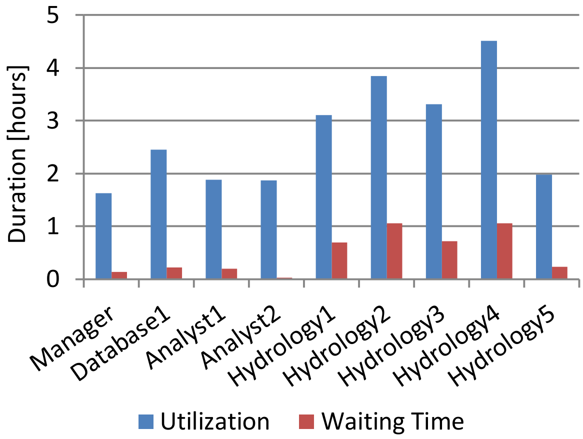

Figure 2: Updated Simulation Resource Utilization

The waiting times of Hydrology Specialists are still high and this situation cannot be solved by improving additional competences because all specialists are already unavailable throughout the whole process. Another option is to hire new hydrology specialist with the same competencies as the fourth Hydrology Specialist for him being the most unavailable worker. Total process duration of the final simulation is 7 hours and 34 minutes that is by 37 minutes lower from the previous result. By adding yet another specialist to the second most unavailable group the total process duration decreased by another 15 minutes.

7. CONCLUSION AND FUTURE WORK

This paper described a flood warning process and its importance for the safety of people's lives. To create functional countermeasures against the coming flood, it is important to predict the magnitude and location of the flood as quickly and as precisely as possible. This can be managed by employing enough experienced specialists to perform the activities of the flood prediction subprocess. To analyse the situation in the Moravian-Silesian region, we proposed to simulate the process with the current hydrology team and suggest several improvements to the team composition.

A competency-based extension for description of worker's skills was created for the BPM Method for this purpose and its results were evaluated in the case study.

The competency-based extension of the BPM Method evaluates the resources in the process in accordance to their acquired competencies and compares their suitability with this referential resource of this activity. In this version of the extension, this evaluation only specifies if the worker is competent enough to perform the activity but in reality his competencies influence the time and effort he has to spend on executing this activity. The more competent the worker is the better he performs in doing the activity (Hatch and Dyer 2004). This performance evaluation could also solve the binary nature of the suitability evaluation. By knowing their performance for given activity, even unsuitable resources could be allocated for this activity but at the cost of longer execution time and greater risk of error. This could serve well for process instances with lower priorities.

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