Developing a System for Automated Selection of Immediate Measures During Major Catastrophic Events

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Today every single operation of rescue forces such as fire brigades or emergency medical services is managed and coordinated by a scheduler. In case of an emergency or disaster the controller has to guarantee an effective and fast alerting of rescue forces to minimize the negative effects of such an event. In order to do so, he has to receive, monitor, combine and understand information from different sources at once. Especially in case of major disasters, the amount of incoming information, which has to be processed, is enormous. The derivation of the right and most effective decisions is time consuming. The time between the first incoming information of a happening disaster and the alerting of first rescue forces is called chaotic phase. The project PROMPT (Programmatic Selection of Immediate Measures for the Scheduling of Operations during Major Catastrophic Events) addresses the goal to minimize this phase by an integrated fuzzy-logic-inference-system. This system collects all incoming information from different sources and automatically generates and suggests prioritized measures. The suggested measures can be accepted or denied by the controller. In the project PROMPT, a system was developed in order to understand, interpret and combine fuzzy and discrete variables. The developed system constitutes the first step in the direction of semi-automated coordination of disaster-cases in times of regressive numbers of rescue forces and increasing numbers of natural hazards and disasters. During the development of the system, necessary technical and social requirements and challenges were identified and considered by the developers, end-users and experts. These identified aspects are representing important steps in the process of realizing such an automated and universally applicable system, which accumulates, understands and interprets information from different sources and generates prioritized measure suggestions for a controller. This contribution presents the process of developing such a system and highlights the necessary requirements regarding technical and social aspects.

Keywords: Major catastrophic events, situational awareness, fuzzy-logic, inference system, mission support system, integrated control centre, disaster management.

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1. Introduction

To guarantee an effective and fast alerting of rescue forces and minimize the negative effects of major disasters it is necessary to get as fast as possible a holistic situational picture. Based on that control centers which are managing and coordinating rescue forces like fire fighters, the Federal Agency for Technical Relief (THW), rescue forces and first responders can initiate targeted measures as fast as possible and minimize time dependent hazardous effects to human life and the environment. To do so the managing personnel at the control centers have to consider a great deal of information from lots of different sources. The increasing complexity of operational measures in case of major disaster events are leading to an increasing number of information sources that should be considered. This flood of information especially in case of major disaster events can lead to an overstraining of the personnel at the control centers. Thus there is a risk that important combinations of information which should lead to specific reactions and actions are missed. The Fraunhofer Institute for High-Speed Dynamics, Ernst-Ernst-Mach-Institut (EMI) and the VOMATEC Innovations GmbH developed a system which is addressing the aforementioned issues. To this end, all incoming information combined with inputs of already processed data from the control center personnel is analyzed and processed by the system. The system is able to combine incoming discrete and fuzzy information and to generate reasonable measure suggestions which might be missed by the control center personnel otherwise.

2. End User Requirements for the Developed System

In order to develop the mentioned system in the most target- and user-oriented way, end user requirements were gathered in numerous workshops. The most important points to consider for such a system according to the end users are the following five.

- Basically, the personnel in the control centres do not have the time to manually consult sufficient sources of information for decision-making. To consider enough sources of situational information, they should be integrated automatically.
- The most important criteria for assessing the extent of an operational situation is the estimation of the number of affected and injured people. To this end information related to resident as well as work population should be integrated automatically.
- The relation between several single events should be recognized.
- The system should produce measure suggestions which are justified and evaluated with regard to the reliability of the suggestion.
- Warnings (e.g. weather warnings) (Deutscher Wetterdienst 2020) which could affect the situation should be displayed automatically and integrated in the measure suggestions.

3. Technical Realization of the Requirements

3.1 *The general system*

The developed system consists of two technical main components depicted in Fig. 1. The two components are communicating via a message broker (RabbitMQ 2019) On the left hand side the Mission Support System (MSS) is illustrated. Additional to a GIS-Interface (Geo-information-system-interface) which supports the coordination of different operation forces, the developed system is collecting incoming situational information as a central junction. The collected information is sent as a JSON-File via Queue 1 of the message broker to the fuzzy-inference-system (FIS). The developed system part is made up of two threads. Thread 1 is responsible for the receiving and the cataloguing of the incoming information. Thread 2 processes them in the developed fuzzy-inference-system. The fuzzy-inference-system generates measure suggestions based on the incoming situational information which are then sent back to the MSS via Queue 2.To guarantee the communication between the measure suggestion system and the MSS,

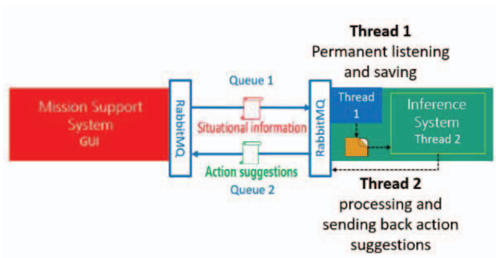

Fig. 1 Schematic visualisation of the developed system. On the left hand side, the mission support system, on the right hand side the measure generation system based on a fuzzy-inference-system.

the integration of a message broker was necessary. The chosen message broker in this project was RabbitMQ (Pivotal Software 2020). Via two different Queues the situational information and the measure suggestions were exchanged.

3.3 *Connection of different information sources*

The automatic linking of different information sources to generate an approximately holistic picture of the situation was one of the requirements that was mentioned of the end users. For the linking a uniform file format for the exchanged information was needed. All the incoming information, linguistic expressions and other variables for identification are packed in JSON-files. The generation of these files is occurring automatically. Information sources to link were the weather service, power outage and flood information, information about the population density and incoming emergency calls of affected people and rescue forces.
One of the biggest challenges with the integration of information sources is the accessibility of the sources. Most of the needed data are either commercial or property of the public government and the public administration. The problem with the publicly owned data is that they are intended for a specific purpose. Privacy protection laws are often not allowing the usage of this data in another forms than what they were determined for.

3.4 *The fuzzy-inference-system (FIS)*

There are two different types of incoming information which have to be processed of the FIS, **discrete information** and **fuzzy information**. Fuzzy information is information like the number of injured people at the beginning of a catastrophic event. Discrete Information are clearly defined variables like “weather warning levels”. The developed system is able to interpret the linguistic terms of incoming information (like “weather warning”, “injured people”) in order to reasonably combine them and generate useful measure suggestions. The defined scenarios in the project are giving the number of linguistic terms to describe it. Every linguistic term of the incoming information is having an input value. It is the combination of linguistic term and input value the system has to process. The advantage of the developed fuzzy-inference-system is that both, discrete and fuzzy variables can be processed in one system. The difference between discrete and fuzzy incoming information becomes clearer by considering its so-called **membership functions** (Ross 2017). Fig. 2 is showing a general membership function $f_{m_i}, i \in N$ in the form of a triangular function. The function values of all membership functions are defined on the interval $f_{m_i} \in [0;1]$. The $t_n, n \in N$ are the partial intervals of the universe U. Every membership function of a linguistic term is assigned to one partial interval of the universe. The partial interval of a membership function represents its definition range. The min-

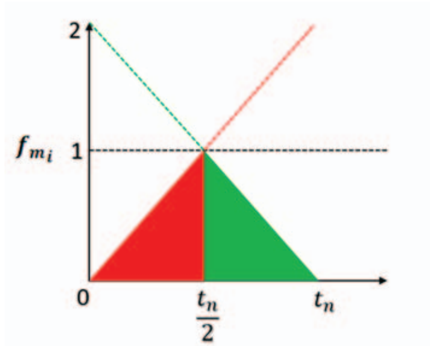

Fig. 2 Schematic visualization of a membership function as a triangular function f_{m_i} defined on the definition range $[0; t_n]$, as a sub-interval of a universe U. These are normalized to the interval of the function values $[0; 1]$.

imum value of all partial intervals and the maximum value of all intervals are representing the limits of the above described universe. Due to the limited available space for figures the entire scenario is simplified by only depicting its main structure and omitting details. The structure of the scenarios is shown in Fig. 3 with the illustration of one link from the incoming information (blue) to the measures which the system will suggest (green). The shown link represents the realization of a combination of a fuzzy linguistic variable and a discrete one. The fuzzy variable is the capacity of a place-taking festival (left hand side). The discrete one are the weather warning levels (right hand side).

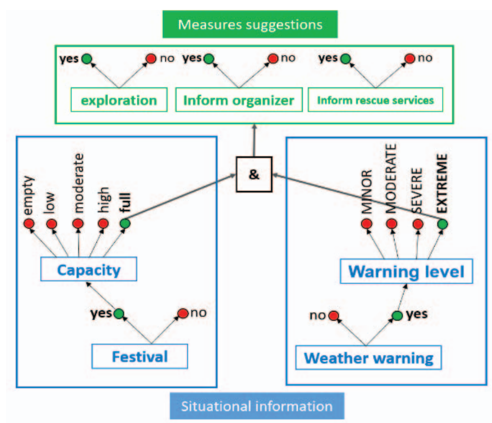

Fig. 3 Mapping of an information-measure-link from a scenario developed for the system.

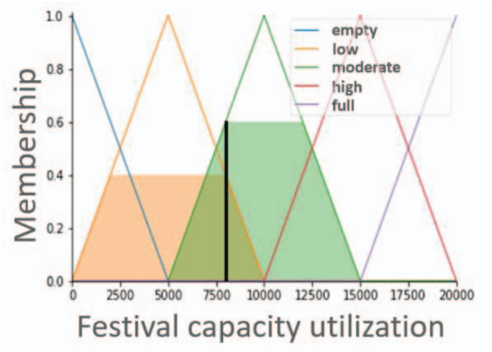

Fig. 4. Visualisation of the capacity of a festival as a fuzzy variable. The input value was 8000. The function value for the membership function according to a moderate utilization of the festivals capacity is higher than the function value of a low utilization. The interpretation of the system of this input value is that the capacity of the festival is moderate utilized.

The universe of the fuzzy variable is defined as $U = [0; 20000]$.the number of guests who visit the festival potentially is lying between 0 and 20000 but can exceed this limit. The number of guests on a festival with no ticket selling or fixed entry and exit has to be estimated. The membership functions of the available states the linguistic variable capacity can adopt are therefore not separated. They are overlapping each other. Therefore the decision the system has to make is fuzzy. The amount of overlapping of the membership functions depends on the assessments the asked end users did. The width of a membership function and the distance between the centres of several membership functions are giving the dimensions of fuzziness of linguistic variables. Fig. 4 is showing the realization of the capacity of a festival as a fuzzy variable. The incoming information was an estimated amount of 8000 people (black vertical line). This entry value is lying in the value range of the state low and the state moderate. The function value of the membership function of the state moderate is higher than the function value of the state low. Therefore the system is deciding that with an estimated value of 8000 people the capacity utilization of the festival is moderate.

Discrete incoming information in the FIS are realized as separated states with no overlapping. The incoming values of the linguistic variable weather warning level are clearly defined.

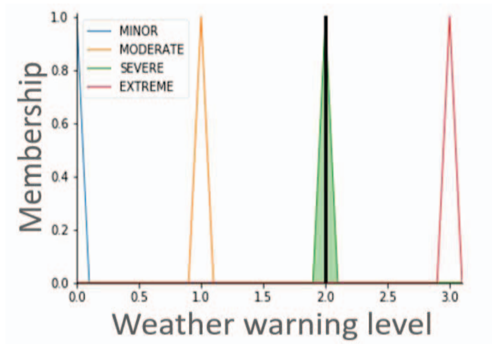

Fig. 5. Visualization of discrete, non-overlapping membership functions for the linguistic variable "weather warning level" in relation to the utilization of an event. The universe describes the interval $U = [0; 3]$. The individual linguistic interpretations of the membership functions are color-coded.

Therefore the interpretation of the values as states is explicit. Fig. 5 shows the realization of the discrete variable “weather warning level”. The chosen level in Fig. 5 is SEVERE. This combination of information is defined in the set of rules which is following Boolean algebra (Givant et al. 2009).

For the above described combination of incoming information, the triggered rule will process them and generate the measure suggestions shown in Fig. 3. They are written it in a JSON-File and sent back to the MSS.

3.5 *The set of rules*

The generation of reasonable measure suggestions out of combinations of discrete and fuzzy incoming information happens based on a set of rules, which combines reasonable connected and correlated incoming information. These rules are realized as a network of linked graphs of graph theory (Trudeau 2013). Therefore the already in the Python-Module SKFuzzy (scikit-fuzzy developement team 2019) integrated package NetworkX (NetworkX developers 2014) is used. Fig. 3 shows the realization of such a rule as linked graphs. The rules are defined in that way, that the connections which were requested by the end users and experts in the scenarios are respected. The rules themelves are following Boolean algebra (Givant et al. 2009). For the defined scenario the set of rules includes about 250 rules, which cover the requirements and connections mentioned by the end users over the whole defined universes of incoming information and measure suggestions.

3.6 *Quality of measure suggestions*

Fig. 6 is showing a schematic visualisation of an "AND-linked" rule. You can see that the quality of the generated measure suggestion depends on the function values of the input values of the membership functions of the linguistic variables. The minimum function value of all membership functions is providing a value for the quality of the suggested measures between 0 and 1. The closer the value is to 1 the better is the quality of the suggested measures.

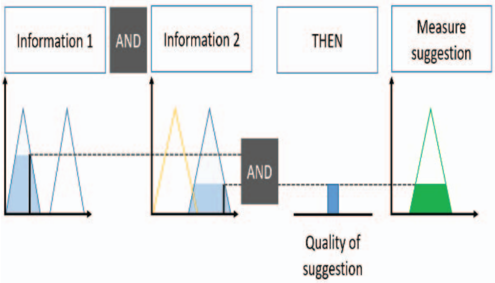

Fig. 6 Illustration of a general IF-AND-THEN connection. The quality of the generated measure suggestion (right hand side) is dependent on the minimum function value of the input values which triggered the relevant rule (left hand side). It is the Mamdami (max – min) inference method (Ross 2017).

3.7 *Combinatorial analysis and extension of the system*

The used FIS is needing explicit linguistic variables to cover a set of information which all should be considered in a set of unique rules. In case of a catastrophic event it is possible that two peaces of information regarding the same linguistic term are coming in at the same time or with a delay between them. To guarantee that all possible combinations of information will be combined, the system has to differentiate the incoming information of identical linguistic terms without overwriting them. Therefore every incoming information will get a unique information number. The system is storing the already processed combinations of information numbers and is monitoring if there are new combinations coming in. Some specific kinds of information have to be monitored and accumulated like the number of injured people in an area or in an operation until they exceed a limit which triggers another rule and generates measure suggestions. The system is able to monitor and respect the reasonableness of the recommended measures regarding the local proximity, the time dependence and seasonal differences of events to avoid generating redundant measure suggestions for the dispatcher. Additionally, the system is assigning the incoming information and combinations to the suggested measures which were generated based on them. This was a requirement the end users communicated to improve the transparency for the process of decision making for the manager at the operation centre.

3.8 *Prioritization of generated measure suggestions*

According to the end users requirements, the generated measure suggestions should be prioritized in order to rank the progression of them. Therefore a general kind of classifying the risk potential of operations and situations is necessary to be able to compare measure suggestions based on different kinds of operations. Two different kinds of events are for example hazardous fires and power outages. The system has to prioritize measure suggestions for all kinds of operations based on the same criterions independent of the kind of event. As the most important aspect for prioritizing measure suggestions and operations together with the end users we identified the risk potential for human and environmental health. These quantities can always be estimated independent of the kind of measure or operation. So a prioritization of every measure suggestion for all kinds of operations is possible in the same system and therefore comparable among each other. The idea was to prioritize the incoming information and all reasonable combinations based on their risk potential

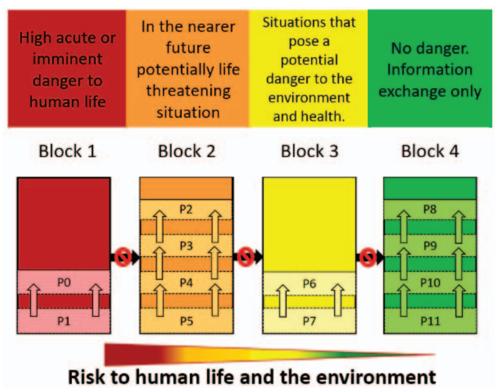

Fig. 7. Priority levels in insurmountable priority blocks. Within these blocks, the priority levels can be increased by various factors. The prioritization of proposed measures is carried out by prioritizing the messages on which they are based. The argument for choosing a prioritization level is the danger to human life and the environment. The priority decreases from P0 to P11.

and adopt this prioritization to the resulting measure suggestions. The prioritization is realized with prioritization steps. The steps are defined from $P0$ (highly prioritized) to $P11$ (hardly prioritized – no prioritization necessary). Important to say is that both single incoming information and the combinations of them have to be prioritized by experts and end users as often the combination of them is leading to a higher risk potential for humans or the environment. A planned festival itself has no relevant risk potential for human life or the environment but the risk potential of the combination of the information, a planned festival and the weather warning level "EXTREME" for this day leads to a relevant risk potential. Other relevant parameters which should have influence on the prioritization step are the number of incoming information of the same kind, the amount of affected people and the participation of sensible objects (hospitals, schools, retirement homes and others) in measure suggestions.

The influence of these additional parameters to the increment of the prioritization level was considered. Defined rules are determining the number of prioritization levels one measure suggestion can rise up dependent on the value of the possible additional parameters. For example if a sensitive object like a hospital is affected by a hazardous event the consequential measure suggestions will be prioritized two levels higher than without an affected sensitive object. Conserning the influence of the number of injured or affected people of hazardous events the prioritization is incremented with every instance of MCIs (Mass Casualty Incidents). The number of injured people which are defining an MCI is dependent by the scenario at hand. The system prioritizes dependent on the number of injured people and increments the prioritization level of a measure suggestion dependent on the severity of the specific MCI. A general estimation of a lower threshold of an MCI is around 50 injured people at one event at the same time (ElanTech 2020).

With the discretized prioritization defined above it is still possible that a high amount of low prioritized single events are prioritized higher than single hazardous events which could be much more dangerous for human life or the environment than the others. To avoid this, the prioritization levels are additionally divided in four prioritization blocks. Inside these blocks it is possible to get a higher prioritization level with the above defined criteria but it is not possible to reach a higher prioritization block than the measure suggestion is assigned to. Fig. 7 is visualizing the separation of the prioritization steps and the definition of the four blocks.

3.9 *General function and application of the mission support system*

Mission Support Systems (MMS) are needed wherever important decisions have to be made, especially in time-sensitive applications. Therefore processed and displayed information have to be reliable, transparent and well presented to provide a sustainable foundation for the user's decisions. Especially but not only in major catastrophic events, time is a relevant factor, since plenty of data from different sources has to be consumed, combined and evaluated in the first phase of the incident to be able to initiate proper measures. As a consequence, the user-interface as an interface between the actions of the dispatcher and the MSS, plays a major role. The provided GIS-view offers opportunity to oversee geographical interdependencies and interact with the system which is a relevant requirement for successful disaster management (UNOOSA 2019). Furthermore, a separate view covers the management of measures and suggestions, as well as their state of process. Besides these key features the developed prototype includes views for mission-, resource- and protocol-management and -interaction for evaluation purposes, whereas those functionalities would be represented by bidirectional interfaces with existing dispatch systems in live systems.

3.10 *Gathering and combining processable Information*

Depending on type and size of missions, different information and different sources are relevant. As a consequence interfaces to a wide range of varying sources are necessary for a successful application of the system. These sources reach from interfaces to the dispatch system for receiving missions, resources with status and position as well as feedback from the forces, to weather information, registration office, webcams or hospital ticket systems. A detailed investigation of social media was excluded, since multiple other projects address this issue (Alipour Sarvari, Nozari, and Khadraoui). Nevertheless, an integration of such an additional source, due to the systems flexible architecture, is possible at any time. Every source is either provided by public application programming interface (API) (e.g. weather warnings or has to be requested for relevant existing software systems (e.g. registration office (HSH Soft- und Hardware Vertriebs GmbH 2020)). In each and every case a unique interface was developed as a micro-service for flexible customizations with a standardized JSON-structure to the inner main component. The exchange of data between inner components is also realized via the message broker RabbitMQ, but internal queues are used as well. There the data, which never could be overseen by a dispatcher in an expedient way, is associated by time and spatial dimension. Further, duplicates are identified, and the datasets are stored and managed, before they are delivered to the FIS via message broker. Thus, an information about a call at a specific address for example can be enriched by the number of registered citizens through the interface to the registration office, which leads the FIS to derive appropriate measures suggestions.

3.11 *Visualization and processing of received measure suggestions*

Whenever a new measure suggestion is received from the FIS a blinking symbol is leading the user to the suggestions overview in the MSS (Fig. 9). In this system both, measure suggestions can be accepted or declined and running suggestions can be managed. For maximum transparency and traceability the reasons why the system suggested the advice are displayed as well. This reasons are the incoming information and combinations that triggered a rule out of the set of rules and was leading to the suggested measures. Therefore the above described information numbers which is unifying each incoming information are used.

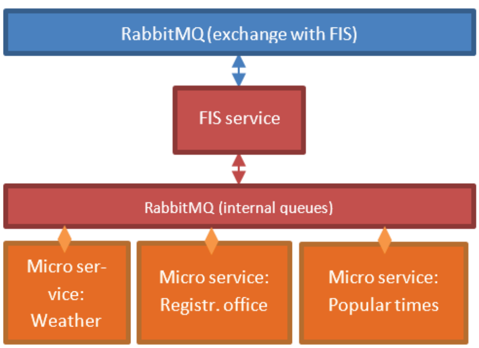

Fig. 8 Data is consumed from online services or third-party-software-systems via micro services and forwarded through internal queues via the message broker RabbitMQ. Another micro service is delivering the computed, aggregated information to the FIS and receiving measure suggestions from it.

A further issue in major incidents is to keep track of all resources and enough back-up forces for ensuring the basic safety in the area of responsibility. Above there are described quantities which are monitored by the system since they can exceed a defined limit to trigger a measure suggesting rule. One of this quantities are the operating resources of the forces. If there are to few vehicles of a type in an area defined around the hazardous event, the system is alerting the user. It is showing him the type of deficit and the area which is affected to that on a GIS (Fig. 10).

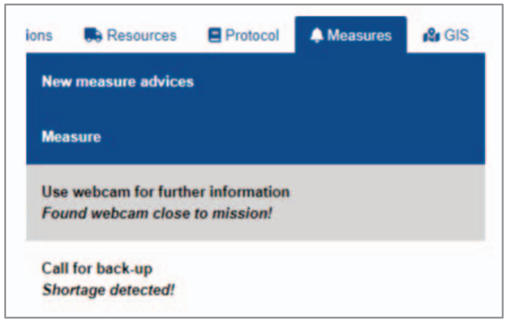

Fig. 9. Measure suggestions are received from the FIS over the message broker and Queue 2. A blinking symbol in the form of a bell is advising the personnel at the control centre, that there is potential requirement for reacting in some kind he is missing. The measure suggestions are shown in tabular form and can be accepted or declined by the user.

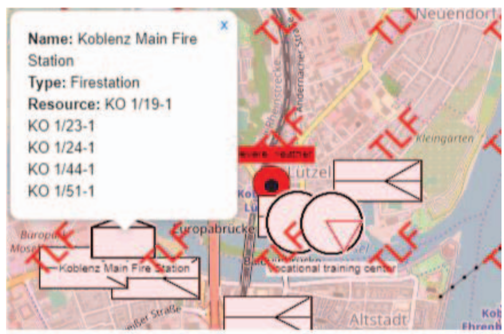

Fig. 10. The visualisation of vehicle deficit on an area around the hazardous event. The system warns the user when shortfalls of specific resources appear and visualizes the uncovered areas in the GIS by overlaying a red circle with information about the missing resource.

4. Conclusion

The developed demonstrator shows that it is possible to realize a system which interprets, classifies, assesses and combines discrete and fuzzy information from different sources automatically and generates reasonable and prioritized measure suggestions out of it in case of major disasters. Further research in this direction is necessary in times of increasing numbers of major disasters and decreasing numbers of rescue forces. Such systems are promising more efficient and lifesaving processes in the management of rescue forces. It is potentially applicable to all integrated emergency oriented control centres. One of the biggest challenges to develop and implement such a system is the missing access to all important and necessary information sources. Another challenge is the diversity in the organization of rescue forces for example in Germany. The organization and the regulations which determine the work of rescue forces in Germany is managed on a federal level. Furthermore there are several local differences in the available resources of each commune. Additional to national aspects there are a lot of differences in the organization of rescue forces between different states. To be able to establish such a system on a large scale it has to be very flexible in that way, that the generated measure suggestions, the defined linguistic variables, the form, width and overlapping of membership functions and the prioritization among other things have to be adjustable. To fulfil these requirements the involvement of end users and experts has to be international, procedures have to be unified and the system itself has to be developed further.

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