A Crisis Classification System for flood risk assessment: the beAWARE project

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KEY POINTS

- *Crisis Classification System (CRCL) provides an innovative and holistic framework for flood management*
- *CRCL acts as an Early Warning System to notify authorities for upcoming flood hazard*
- *CRCL, during the flood crisis, acts as a Real-time Monitoring and Risk Assessment DSS*
- *CRCL combines multiple data from heterogeneous sources (sensors, WFS, social media, images etc)*
- *CRCL estimates the overall level of crisis in pre-alert and during the crisis phase*

1 INTRODUCTION

Crisis management is a dynamic, complex and multi-disciplinary process, consisting of consecutive sets of activities to collect information, analyse heterogeneous data, formulate alternatives, decision-making processes, implementation, and monitoring. Especially, in the content of the natural disaster the emergence of numerous Early Warning systems and specialised Decision Support Systems (DSS) plays an important role in assisting to reduce the risks resulting from the interaction of human societies and their natural environments. Currently, the majority of these emerged tools are not capable to provide an integrated and generalised framework for formulating decision options for crisis level estimation and risk assessment. Furthermore, the advances to the IoT as well as the increasingly volume of heterogeneous data from multiple resources (mobile phones and Apps, sensory data, drones etc) generate new capabilities and opportunities to timely alerting and tackling effectively an extreme weather or natural phenomenon. The authorities and decision makers should confront new challenges in flood risk management by operating in a holistic and interoperable framework combining data from multiple resources. A few efforts are towards on this direction by proposing generalised platforms combining the flood risk management relevant science, such as FLOODSS (*Muste and Firoozfar 2016*; *Linyao, et al. 2017*).

beAWARE is an ongoing EU H2020 project aiming to enhance decision support and management services in extreme weather climate events. The main goal of beAWARE is to provide support in all the phases of an emergency incident such as flood, fire or heatwave. The beAWARE platform will be planned to utilise innovative and state-of-the-art technological solutions in a cloud-based Service-Oriented Architecture (*Wei & Blake, 2010*; *Petrenko, 2014*). The components of the system are connected via Web Services to exchange data and messages. The Crisis Classification component will encapsulate the necessary innovative solutions that will allow to beAWARE platform to provide early warning and decision support to Public Safety Answering Point (PSAP).

2 METHODOLOGY

Crisis Classification (**CRCL**) system aims to support the beAWARE platform functionalities in two folds. Firstly, it acts as a Flood Early Warning System in order to notify the authorities and first responders for the upcoming extreme conditions such as the hazard of flood (pre-emergency phase). Secondly, when a crisis is evolved, it operates as a real-time monitoring and risk assessment system to support local stakeholders, authorities and rescue teams to make accurate and timely decisions and actions.

The components of the CRCL system are connected via Web Services to exchange data and messages. The backbones components of the CRCL system are:

a) the **Early Warning System** assesses the Overall Crisis Level based on the forecast hydrological and weather data in the pre-emergency phase;

b) the **Real-time Monitoring & Risk Assessment** module assists authorities and local stakeholders to evaluate the evolution of the flood by estimating its overall crisis level and its severity in order to make efficient decisions and timely actions.

The CRCL system exploits data from external heterogeneous sources:

c) the module **Weather Forecast Services** which provides temporal Earth Observations (EO) and forecasts based on High Resolution Limited Area Model (HIRLAM) and Numerical Weather Prediction (NWP) models;

d) the **AMICO** early warning system elaborated by AAWA, which fuels CRCL system by continuous hydrological and hydraulic data and flood warnings and provisional data, with forecast information about risk of flooding up to 54 hours ahead;

e) the **SensorThings Server API** module gathers data and information from physical sensors which have settled to weather stations in the region of interest;

f) other beAWARE components responsible for the social media text analysis, image/video processing etc. which feed the CRCL module with the outcomes of the analysis;

An overview of the proposed CRCL system is presented in the figure (Figure 1). The system receives input from heterogeneous sources, such as from Weather Forecasting systems, sensory data and forecasts for river water level from AMICO early warning system via SensorThins Server API. Moreover, beAWARE components, which analyse textual and signal/visual information from social media, images, video etc., are fueled the CRCL system with the results of analysis in terms of the event's level of severity. Then, the system fuses the acquired information by developing and deploying state-of-the-art information and decision fusion methodologies. Iterative processes are employed aiming to validate, interpret and provide timely and accurately estimations of crisis level and the risk assessment. The results of the analysis will be forward to Public Safety Answering Point (PSAP) and the Control Management Centers of stakeholders (authorities, Municipalities etc), so as to assist them in the crisis management processes.

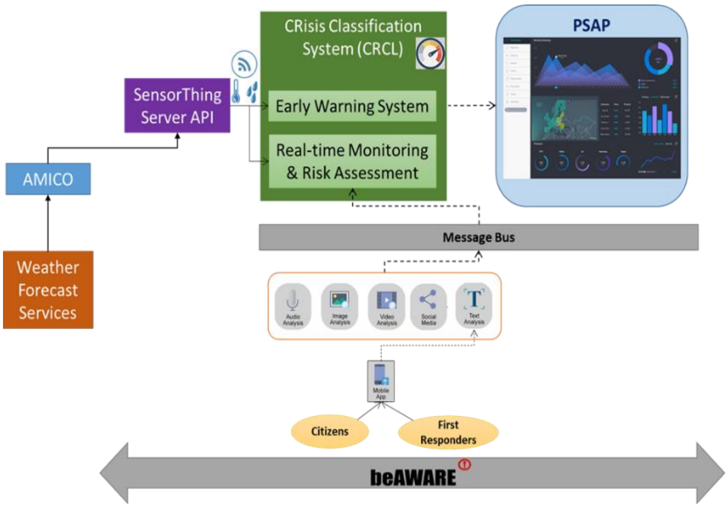


Figure 1. An overview of Crisis Classification System

2.1 AMICO

The Alto Adriatico Water Authority (AAWA) developed for the Veneto Regional Civil Protection the flood forecasting system AMICO which is currently used to predict flood in the Bacchiglione River Basin (*Ferri, et al. 2012*; *Mazzoleni, et al. 2017*). AMICO is an operational semi-distributed hydrological and hydraulic model integrated in a modelling platform which is able to provide:

- Continuous Water balance simulation from the past to the now.
- Autocalibration and Data Assimilation.
- Flood forecast based on several weather forecast (LAMI, ECMWF).
- Manual configuration of hydraulic structures.
- Data visualization on GIS.

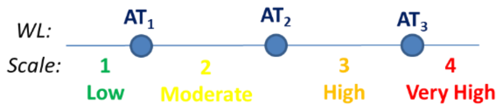
The Veneto Regional Civil Protection uses AMICO results in order to publish reports before and during a flood emergency[1]. The system is based on a central database (ORACLE) on which all the data input for the

[1] Reports are available at the following link:https://www.regione.veneto.it/web/protezione-civile/cfd.

different models are stored (parameters, geometry, etc.) and all the results of the different runs are saved to be viewed simply. A specific "Data Importer" imports continuously real time measured data and weather provisional data (54 hours HIRLAM forecast, 3 days LAMI forecasts and 5 days ECMWF forecasts) from other external servers (servers of the data owners). The runner launches the different models in cascade and the results can be visualized by means of a viewer results module. The hydrological response of a basin is estimated using an integrated model capable of reproducing the different physical and hydrological processes in place. The model is composed of different calculation modules. A correct description of the river networks geometry (extracted from DEM) and the spatial interpolations of meteorological and climate data collected are the inputs for the snow melt module, the rainfall-runoff separation module and the runoff propagation module. In particular, the runoff propagation module is based on the geomorphological theory, which links the distribution of residence time in the possible water-paths within the basin to the basin's instantaneous unit hydrograph, adopting a probabilistic approach. The geomorphoclimatic formulation implemented in AMICO takes into account that from a physical point of view the superficial velocity should be dependent on the intensity of precipitation. The model implemented is distributed in the description of the processes (info from digital terrain maps, geostatistical interpolation, maps of land use) and residence times for paths outside the river network are related to a precipitation intensity variable during the meteorological event, to describe the hydrological response with a continuous model.

2.2 Early Warning System

The Early Warning System is responsible for the timely notification for an upcoming flood event in the region of interest. It collects hourly forecasts for the river water level utilizing the SensorThing Server API for all the sections along the river. These values are compared with the predefined alarm thresholds. An alert message will be emerged whenever the forecasting values exceed any threshold. In this case, the Early Warning system classifies the event as *Low*, *Moderate*, *High* or *Very High* depending on which alarm threshold (AT) is exceeded every time. CLCR adopts the scale for the predicted values of river water level.



Then, it calculates the *Overall Crisis Level* (*OCL*) which implies the level of forthcoming flood crisis in the region of interest. This indicator is aggregated over all river sections by considaring each time the particular local conditions. In the first step, the *Overall Crisis Classification Index* (*OCCI*) for all the river sections is estimated based on the following formula:

$$OCCI = \left\lceil \sqrt[p]{\left(\frac{N_4\, 4^p + N_3\, 3^p + N_2\, 2^p + N_1\, 1^p}{N}\right)} \right\rceil \quad (1)$$

where

- p denotes the discete values of the scale (1-4). In this case p is equal to 4.
- N_i denotes the number of river sections which classified in the i-th scale. N is the total amount of river sections.

The *Overall Crisis Classification Index* (*OCCI*) is the upper bound of the generalised average of the scale of river water level over the considered river sections.

In the second step, the Overall Crisis Level (OCL) is estimated using the rule-based process as shown in **Figure 2**

If OCCI = 1 **Then**
  Overall Crisis Level = 1
ElseIf OCCI = 2 **AND** $\nexists\, river\ section\ r:\ Scale_r = 4$ **Then**
  Overall Crisis Level = 2
ElseIf OCCI = 2 **AND** $\exists\, river\ section\ r:\ Scale_r = 4$ **Then**
  Overall Crisis Level = 2+
ElseIf OCCI = 3 **AND** $\nexists\, river\ section\ r:\ Scale_r = 4$ **Then**
  Overall Crisis Level = 3
ElseIf OCCI = 3 **AND** $\exists\, river\ section\ r:\ Scale_r = 4$ **Then**
  Overall Crisis Level = 3+
ElseIf OCCI = 4 **Then**
  Overall Crisis Level = 4

Figure 2. Rule-based process to assess the Overall Crisis Level

2.3 Real-time Monitoring & Risk Assessment

This component will be able to real-time monitor and assess the severity level of the ongoing flood crisis event. To achieve this goal, it will combine heterogeneous data obtained from multiple sources during the ongoing flood crisis. The process will consist of two multi-level fusion phases. In the information/data fusion, data grabbed from sensors which are settled in specific weather stations nearby the river reach are combined. The observed data are concerned with the current river water level as well as other weather measurements such as temperature, precipitation, humidity etc. Following a similar procedure, such as that of the Early Warning System, a real-time assessment of the *Overall Crisis Level* for the whole region of interest is performed. During the decision fusion phase, this outcome will enrich with the results of the multimedia and textual analysis, available from the other beAWARE's components, producing an aggregated estimation of the flood risk for the region of interest.

3 CONCLUSION AND FUTURE WORK

In this work, a general framework of the beAWARE Crisis Classification system for flood prevention and assessment their risks are presented. Although the preliminary simulated results are promising, however more experiments should be done and the system should be evaluated in real-time flood scenarios. Furthermore, data from multiple sources such as social media, images and videos should be considered and novelty data fusion and machine learning methodologies will be developed aiming to enhance the decision making process in pre-emergency or during the emergency phase of a crisis event.

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