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***An Anticipative Effects Driven Approach for crisis
management process analysis***

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ABSTRACT

This paper aims to present and illustrate how using formal verification approaches and techniques could allow managing and controlling efficiently a given system exposed to crisis. Indeed, a few methods to participate to crisis resolution and use formal verification are developed. The here presented research proposes an approach based on verification techniques namely (1) the development of modeling means to increase the formal level including the actors' knowledge and; (2) the development of specific reasoning mechanisms adapted to the expected actors' objectives such as risk detection, performance improvement, *etc.* The foundations of an anticipative effect-driven approach using formal verification are introduced. Our approach aims to model, characterize and detect the different effects that are caused by the partners, the environment and the activities involved throughout a collaborative process, using properties proof mechanisms.

Keywords

Collaborative crisis management process, formal verification, validation, risk, effect, anticipation

INTRODUCTION

"We are increasingly faced with catastrophes that don't fit our usual terms of reference, response doctrines or traditional operational scripts. [...] It is urgent to reinvent our preparedness architecture, whether in terms of our understanding, response plans, mechanisms and organizational protocols, and to develop broader visions and specific guidelines, if we wish to regain a balanced and effective operating response underpinned with legitimacy and credibility in this fast emerging universe" (Guihou et al., 2006). Based on this observation, the development of innovative approaches to manage crisis response plans from innovative manner becomes crucial. These response plans are here described as collaborative processes aiming to solve the crisis. Their efficiency depends on their capacity to react, guide and adapt the actor's actions and means to different situations. This implies a good understanding of the different actors that are involved in the collaborative process and having to share data, knowledge, best practices, resources and skills. For this various facets of knowledge are required: organization, skills, expected or classical behaviors when facing given situations, potential actions that can be deployed with their expected outcomes, etc. Indeed, these actors must first trustfully and efficiently interact with each other reaching various and common objectives of crisis resolution and minimizing impact on the civil population, living areas, environment, economic, industrial and cultural criteria. Second, traditionally, actors' actions are coordinated and synchronized, and then adapted taking into account reactions coming from the crisis theatre. Beside the achievement of the main desired outcomes others results can be also noticed. Some harmful and undesirable effects can be induced for example on the population. These effects remain difficult to predict due to other interactions between the different elements involved during the crisis management and concerned by the collaborative process. All these interactions are difficult to understand, to analyze and then to be as soon as possible avoided. As a consequence, the anticipated examination of all possible outcomes that can be produced by each actor, resulting from each action during the collaborative process is crucial. This analysis can be done with the adaptation and application of both a formal modeling and a verification approach to a model of the target collaborative process (Chapurlat et al. 2006). This paper aims to present an Anticipative Effect-Driven Approach (AEDA) to analyze potential complex effects that can be caused by the actors and the activities implemented during a collaborative crisis management process. It presents the bases of the anticipative effect-driven approach with the consequences, both positives and negatives, of using formal approaches in this application field. Then, it introduces a supporting tool currently being developed to implement anticipative effect-driven approaches. Finally, the method applied by this tool is presented through a concrete example.

HOW ANALYSING CRISIS MANAGEMENT PROCESS?

Basic principles of AEDA

The main hypothesis of this work consists to dispose of a model, even incomplete, of the collaborative crisis management process. This describes different actions, actors, information and goals, flows between action, etc. The proposed AEDA approach consists to analyze i.e. in this case to verify and to validate this model. In the current state of

the work, verification consist to specify and to prove from a formal manner various kinds of properties the process model must respect. The validation is now under development. It is based on a model translation and simulation approach and supporting framework using multi agents systems introduced in (Rebai et al. 2008). This paper focuses only on the verification orientation. In this way, the AEBA ambition is to allow a better analysis of a collaborative process, to detect and avoid hazardous situations that can be caused by interactions between different elements of the collaborative process (resources, environment, activities...). The achievement of such a goal can be made *via* the use of formal verification that analyzes the behavior of the collaborative process, assuming that the model of the collaborative process has been already verified and is correctly built with regards to the meta-model.

V&V

Classically, the verification aims to confirm that '*a model is correctly built*' and the validation aims to confirm that '*a model is relevant from the reality*'. In the common sense, verification allows to detect misunderstanding about the use of modeling concepts and relations to check coherence of the studied model and to check its behavior. Moreover, in AEDA context, it permits to prove some requirements or expectations modeled as properties (Chapurlat et al. 2008, Accelera 2004). These properties describe the different potential effects interactions must induce on the different element concerned by the crisis: population, buildings, environment, etc.

Several techniques and tools can be used to verify and validate models or systems (Love et al. 2003, Yahoda 2008). Particularly for properties proof, different formal techniques can be used. At the origin, they were essentially developed and used for software and electronic systems engineering (Berard et al. 2002, NASA 1998). (Dindeleux et al. 1998, Dubois et al. 1994, Kalfoglou et al. 2004, Leger et al. 1999, Kamsu et al. 2006) propose to adapt and to apply some of these techniques to other domains and provide concepts, tools and techniques such as complex algebras for modeling and checking behavior of manufacturing processes (Canuto et al. 1998) or Conceptual Graphs analysis for modeling and proving properties in the case of a multi view model (Chapurlat et al. 2006). All these approaches insist on the relevance of formal techniques such as AEBA intents to do.

Formal approach interest

Indeed, using formal techniques allows us:

- To provide proofs of possible evolutions of the process independently from any human interpretation;
- To be able to provide counter examples in the case of a property cannot be checked, focus actors' attention on a given phenomena, or highlight a given crucial situation that was not taken into consideration.

Nevertheless, it induces also limitations that will require improving first the modeling language used during crisis management process model building phase, second, the proving mechanisms:

- Modeling concepts and relations must be described at the required level of formalization to allow the use of formal mechanisms of reasoning;
- These modeling concepts and analysis mechanisms must take into account the relatively limited level of knowledge and the need for actors' autonomy when facing modeling tasks.

AEDA development

As a consequence, this research has to provide an integrated modeling and analysis framework for collaborative processes, which would allow both to guide the modeling task and to provide rapidly a set of analysis results without ambiguities. This is done by (1) the enrichment of the existing modeling concepts and the formalization of the resulting extended modeling concepts; (2) the definition of a set of properties that describes the possible results of the interactions (also called effects) between the elements involved in the process, and (3) the definition of mechanisms that allow to prove these properties in other words to assume effects modeled using properties that are strictly respected or not.

Anticipative Effects-Driven Approach is currently developed to participate to the reduction of a crisis situation throughout various actors (firemen, nurses, policemen, and peoples living in the concerned country...) that are interacting. These interactions must provide good and efficient effects *i.e.* relevant for the crisis resolution strategy. In other cases, these interactions can have unpredictable effects and cause trouble or prejudices on one or several elements. As a consequence and according to the requirements mentioned above, the Anticipative Effects-Driven Approach has to provide:

- **Modeling means**, *i.e.* a set of concepts and rules to model the process, the different configurations and characteristics of any actors involved as well as the environment in which this collaborative process evolves;
- **Verification means**, *i.e.* formal representation and characterization of potential effects induced by the interactions. These means are the follow up of the property model proposed by (Lamine 2001) and reasoning mechanisms that allow to handle these properties to define what the effects of actions that partners may execute are.

It is to note that the anticipative effects-driven approach is an extension of the Effects-Based Operations approach (EBO) developed specifically in the military field (Smith, 2002). The EBO approach consists in analyzing the effects that are induced by the execution of a set of actions in order to achieve a desired final outcome. Nonetheless, EBO remains focused on the conceptual and the theoretical levels with a lack of practical application (Duczynski, 2004). As a consequence, this paper focuses on the determination of properties and their proofs, which allow characterizing the potential effects that can be produced by an existing collaborative process deployed in crisis situation.

ANTICIPATIVE EFFECT-DRIVEN APPROACH: CONCEPT AND DEFINITION

The anticipative effect-driven approach is based upon three fundamental concepts – namely *Time Shape and Space*, *Modalities and Interaction*, *Effect* – that allow the clear characterization of all objects affected or involved into the collaborative process. These objects are those defined in the crisis metamodel (Benaben et al., 2008) such as population, civil society, natural environment, goods, human means, material means and service of mediation (*i.e.* an activity performed by resources).

The concept of *Time Shape and Space* represents a set of attributes related to crisis situation (*e.g.* capacity, state of health, state of protection...) that defines objects. The concept of *Modalities and Interactions* allows characterizing a service of mediation, resource or other object according to its nature and its role in the collaborative process. Modalities and interactions are explicitly specified using time shape and space attributes. The concept of *Effect* represents the results of the interactions between objects. An effect is defined according to a property defined beforehand. A property is expressed using the knowledge capitalized through modalities and interactions. The following sections present the three concepts *Time Shape and Space*, *Modalities and Interaction* and *Effect* in detail.

The Time Shape and Space (TSS) referential

The **TSS referential** (Le Moigne, 1977) allows defining and formalizing the physical attributes that characterize any element, in a quantitative or qualitative manner, and evolve in the time or space, or take into account its shape. Any element can “be a part of” or “interact” with another element. In both cases, the evolution of each element affects and modifies the referentials of the surrounding elements. As a consequence, defining which elements evolve in a given referential allows to know the impact of these elements on their environment. The characterization of elements can be refined in terms of time shape and space with their decomposition into sub attributes. The time attribute is defined by the sub-attribute called *date and duration*. The space attribute is defined by the sub-attribute called *location in a defined space*. The shape attribute is defined by the sub-attributes called *capacity*, *dimension* (volume, length...), *vulnerability* (improvement or degradation of the object), *quantity*, *complexity* (organic, structural...), *cost* (related to or inferred by the element or its utilization), *etc.* Examples of time shape and space attributes are given in figure 1.

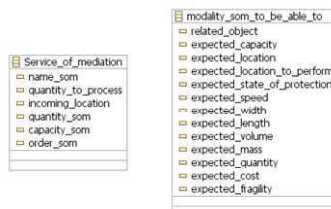


Figure 1. Examples of TSS attributes for a service of mediation (activity) and a modality

Modalities and interaction

The concept of **modality** (Mayer, 1995) allows characterizing the nature of the links in which a resource or an action (or activity) can be involved. The modality ‘to know’ represents what is required in terms of knowledge and skills to achieve a mission. Five modalities are implemented. The modality ‘to be able to’ represents the set of resources that are required to manage a crisis situation. A resource provides skills, capabilities, data, information, knowledge, matter, and energy that are needed to achieve a mission. The modality ‘to want’ represents the set of inputs such as data, information, knowledge, rules, events and orders that are required to control a behavior and to achieve a mission. The modality ‘to have’ represents the set of inputs required to achieve finality. The modality ‘to have to’ represents the sets of outputs that must be obtained by the activity representing its mission. All these modalities are specified with the time shape and space referential.

The concept of **interaction** (Leger et al., 1999) allows formalizing how, in which condition, and with which effects an element can dynamically interact with another one. The interactions are typed as: (1) “know-how”, the flow of knowledge and skills; (2) “want-do”, the flow of inputs that triggers the object; (3) “can-do”, the flow of inputs considered as resources and (4) “must-do”, the flow of final outputs.

Figure 2 illustrates the concept of *Modalities and Interactions* for a given activity (service of mediation). It is to note that for a resource (human mean or material mean), the concept of *Modality and Interactions* do not exist as an input. Indeed, a resource cannot directly process anything.

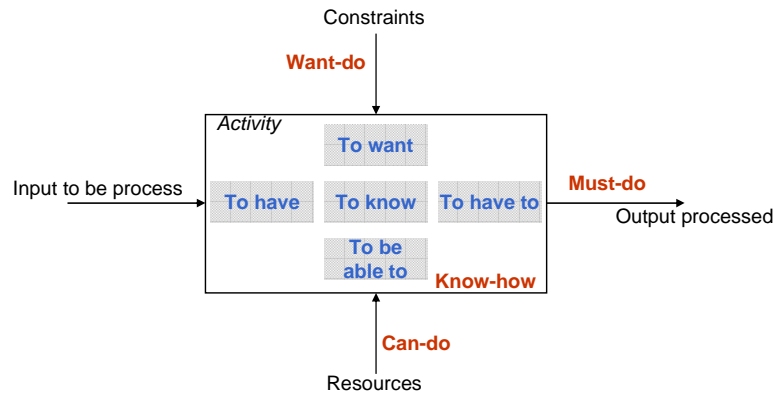


Figure 2. Modalities and interaction for an activity

The effect “characterization”

An effect can be defined as an undesired and dreaded situation that can occur. It always only results from an interaction between one object, defined as the source, and one or several other objects, defined as the destination. An effect can be modeled by the possible variation (or dependence) between one or several TSS attributes of the destination under the action of the source. An effect can be (1) predictable *i.e.* assessable and observable indicators exist either on the source object or the destination object(s), (2) potential *i.e.* a logic relationship between the cause and the effect exist, or (3) unpredictable or emergent (this third kind of effect is not taken into consideration by the approach). An effect can be defined as direct or indirect depending on the causal relation between situations that have induced the effect. The nature of an effect can be classified with the following terminology (Mann, 2002):

- Harmful. This effect is produced when the source can induce a deterioration of the destination characteristics. These effects have to be annihilated.
- Good. This effect is produced when the source can induce an expected variation of the destination characteristics. These effects have to be maintained.
- Excessive. This effect is produced when the source can induce a variation of the destination characteristics beyond expectations. In this case, the effect has to be reduced.
- Insufficient. This effect is produced when the source can induce a variation of the destination characteristics with less amplitude than expected. The effect must be improved in order to become efficient.

In addition, according to the property concept proposed by (Lamine 2001), an effect is modeled by a causal temporized and constrained relation between two predicates that are called respectively cause or *Condition* and effects or *Conclusion*. *Condition* is described by taking into account the TSS referential and the modalities of the source element. The definition of *Conclusion* takes into consideration the different TSS referentials and modalities of each element of destination. The causal relation describes the interaction role between the source and the destination elements, that is to say how, under which specific conditions and when the interaction is made. Various properties may be necessary to describe entirely a given interaction. So properties can be decomposed into sub properties, each of them specifying the way to interpret the variation of a given TSS attribute of a destination object under the action provided by a source element. The set of property models lists the possible effects and provides a formal support of reasoning allowing analyzing the model of the collaborative process. As a result, an effect can be characterized completely if a set of sub-properties that formalizes a given property is verified, .For example, let consider the property defined as:

$$\text{Modality_to_have (Activity)} \supseteq \text{TSS (Input_element)} \Rightarrow \text{Effect (Input_element, Activity)} := \text{good}.$$

This property means that if the modality “to have” of an activity contains the expected TSS attributes of an element to be processed, then the effect of the input element on the activity can be considered as good. This property can be decomposed in sub properties specifying the way to interpret the variation attributes of the activity under the effect of the input element. In this case, the property $[\text{Quantity (Shape (Input_element))} = \text{Quantity (To_have (Activity))}] \Rightarrow [\text{Effect (Input_element, Activity)} := \text{good}]$ means that the effect of an input element on an activity is defined as good if the sub attribute *quantity* of the input element is equal to the sub-attribute *quantity* of the modality “to have” of the activity, *i.e.* the quantity of inputs required by the activity to achieve finality. Currently, our research work focuses on the definition of a set of reference- and domain-independent properties related to the interactions between objects.

TOOLS FOR APPROACH IMPLEMENTATION

In order to implement the anticipative effect-driven approach, the Eclipse Graphical Modeling Framework (GMF 2008) is used. The GMF presents the advantages to allow:

(1) Carrying out the model of the collaborative process. The modeling tool allows performing the collaborative process implemented in response to crisis situation (Figure 3). An Edit menu allows, *via* the palette, to model a process and to embed a concept such as modality.

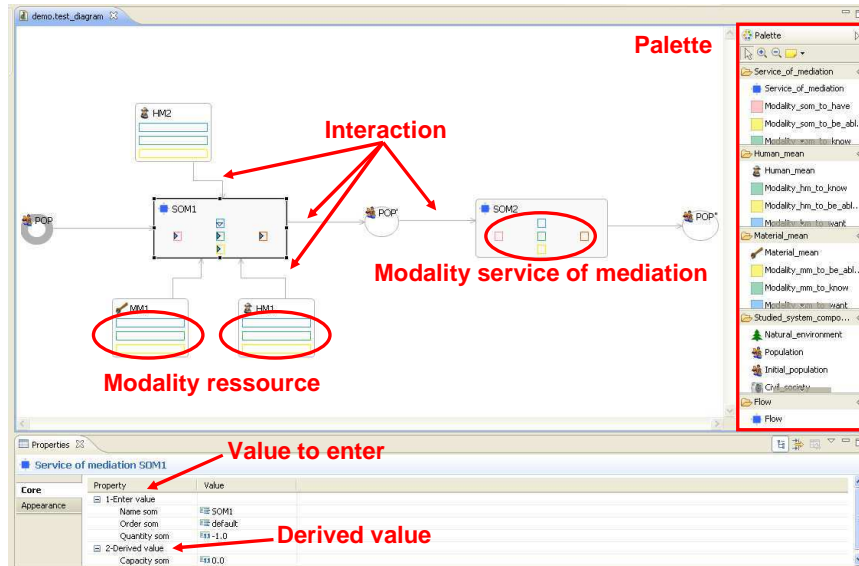


Figure 3. Collaborative process modeling tool with the approach's concepts

(2) Modeling properties that define the effects between objects. In order to determine effects, the model object “*metric rules*” and the validation methods “*audit rules*” concepts provided by Eclipse platform.

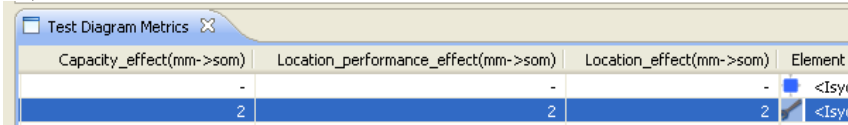
Metric rules are used to express the properties that allow to characterize the nature of effects between objects and to return its numerical value in the “metric view” (1.0 represents an insufficient effect, 2.0 a good effect, 3.0 an excessive effect and 4.0 a harmful effect). Writing a property consists in comparing the attributes of an object considered as source of interaction (consequently the source of the effect) with the attributes of another object considered as destination. According to the result of this comparison, an effect can be determined.

Figure 4 shows the implementation of a simple property. This allows to characterize the effect value of a human mean on the modality “to be able to” of a service of mediation, precisely on the attribute location performance.

```

public static Double calcLocation_performance_effecthmsom(Human_mean target) {
    EList<Service_of_mediation> list_som = target.getHm_TO_som();
    String name_hm = target.getName_hm();
    String location_performance_hm = target.getLocation_hm_performed();
    String expected_location_performance = default_value_string;
    String related_object = default_value_string;
    Double effect = 0.0;
    for (int i = 0; i < list_som.size(); i++) {
        EList<modality_som_to_be_able_to> list_mstbat = list_som.get(i).getContains_som_tbat();
        for (int j = 0; j < list_mstbat.size(); j++) {
            expected_location_performance = list_mstbat.get(j)
                .getExpected_location_to_perform();
            related_object = list_mstbat.get(j).getRelated_object();
            if (related_object.equals(name_hm)
                && !(related_object.equals(default_value_string))
                && !(name_hm.equals(default_value_string))) {
                if ((location_performance_hm
                    .equals(expected_location_performance)
                    && !(location_performance_hm
                        .equals(default_value_string))
                    && !(expected_location_performance
                        .equals(default_value_string))) {
                    effect = good_effect;
                }
                if ((!(location_performance_hm
                    .equals(expected_location_performance))
                    && !(location_performance_hm
                        .equals(default_value_string))
                    && !(expected_location_performance
                        .equals(default_value_string)))) {
                    effect = harmful_effect;
                }
            }
        }
    }
    return effect;
}

```



Capacity_effect(mm->som)	Location_performance_effect(mm->som)	Location_effect(mm->som)	Element
-	-	-	<Isyc
2	2	2	<Isyc

Figure 4. Example of a property deployed in metric rules and its result in metric view

Audit rules allow to interpret the result of the metric rules and to indicate this interpretation to the user by suing specific interface. The results of audit rules are displayed in the “problems view” from Eclipse. Finally, the validation statuses provided by GMF are used to draw the attention of actors on the different effects. The status *info* reports a good effect, the status *warning* reports an insufficient or an excessive effect and the status *error* reports a harmful effect. As a consequence an effect is described in the form of {Status} the effect of {object 1} on {object 2} {name of related modality} for the {related attribute} is {nature of the effect} as shown in the following figure.

```

public static class Adapter137 extends AbstractModelConstraint {
    * @generated NOT
    public IStatus validate(IValidationContext ctx) {
        final Number context = MyMetricProvider
            .calcQuantity_effectsompop((Service_of_mediation) ctx
                .getTarget());
        Service_of_mediation som = (Service_of_mediation) ctx.getTarget();
        EList<Population> list_pop = som.getSOM_TO_pop();
        String name_pop = "initialisation";
        for (int i = 0; i < list_pop.size(); i++) {
            name_pop = list_pop.get(i).getName_population();
        }
        if (context.equals(insufficient_effect)) {
            return ctx
                .createFailureStatus(new Object[] { som.getName_som(),
                    list_pop.get(0).getName_population() });
        } else {
            return ctx.createSuccessStatus();
        }
    }
}

```

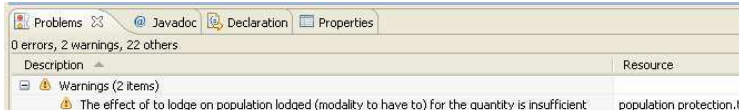


Figure 5. Example of audit rules and its displayed expression in problems view

USING THE APPROACH: A CONCRETE APPLICATION

To carry out the approach, the actors have to follow different steps. First of all, the collaborative process is modeled either upon an existing procedure, a feedback experience or entirely built. The modalities, interactions and referential TSS of each element (*e.g.* population, natural environment, activity...) are characterized. The nature of the potential effects (harmful, good, insufficient and excessive) has to be determined. This step is performed using the referential of effect characterization properties. If the process is approved, the managers can valid or perform some adjustments before starting execution. The results of the process are evaluated (resolution, worsening, modification... of the crisis) and re-submitted to the approach in order to detect other effects.

The following application of the approach refers to the rain event of September 2002 in the Gard (southern region of France) (Ruin *et al.* 2008; BAPC 2006). On 8-9 September 2002, a strong storm breaks over the south of France and produces a series of flash flood on the Gardon River. During this period, numerous mayors of towns affected by the floods have triggered the population protection plan. This plan is composed of three activities such as to evacuate, to lodge and to nourish the population. The last two activities are performed in parallel. The resources that are allocated to the evacuation are the human means *firemen* and the material means *vehicles*. The start of the evacuation is given or planned by the mayor. The resources that are allocated to the accommodation and the nourishment are the material means *town hall* and *meal* respectively. Finally, the population that is strongly affected by the flood is the one living in the old town, close to the river. The analysis of this process - proposed in figure 6 - is based on the knowledge of the actors. Seven anomalous situations (four warning and three error icons) and nineteen right situations are highlighted. In this example, only the critical effects, displayed as *error* in the view, are analyzed.

The effect on the interaction “to can” between the material mean *vehicle* and the activity *to evacuate* (more precisely on the modality “to be able to”) is determined as harmful. Indeed, the *vehicle* cannot be at the location required by the activity to perform the evacuation. As a consequence, the totality of the population cannot be evacuated and an harmful effect of the activity (modality “to have to”) is caused to the population. It is to note that the effect of the material mean on the activity can be characterized as a direct effect while the effect of the activity on the population is indirect, *i.e.* the second effect results from the first). In this case, the actors have to implement corrective actions to ensure the safeguard of the population.

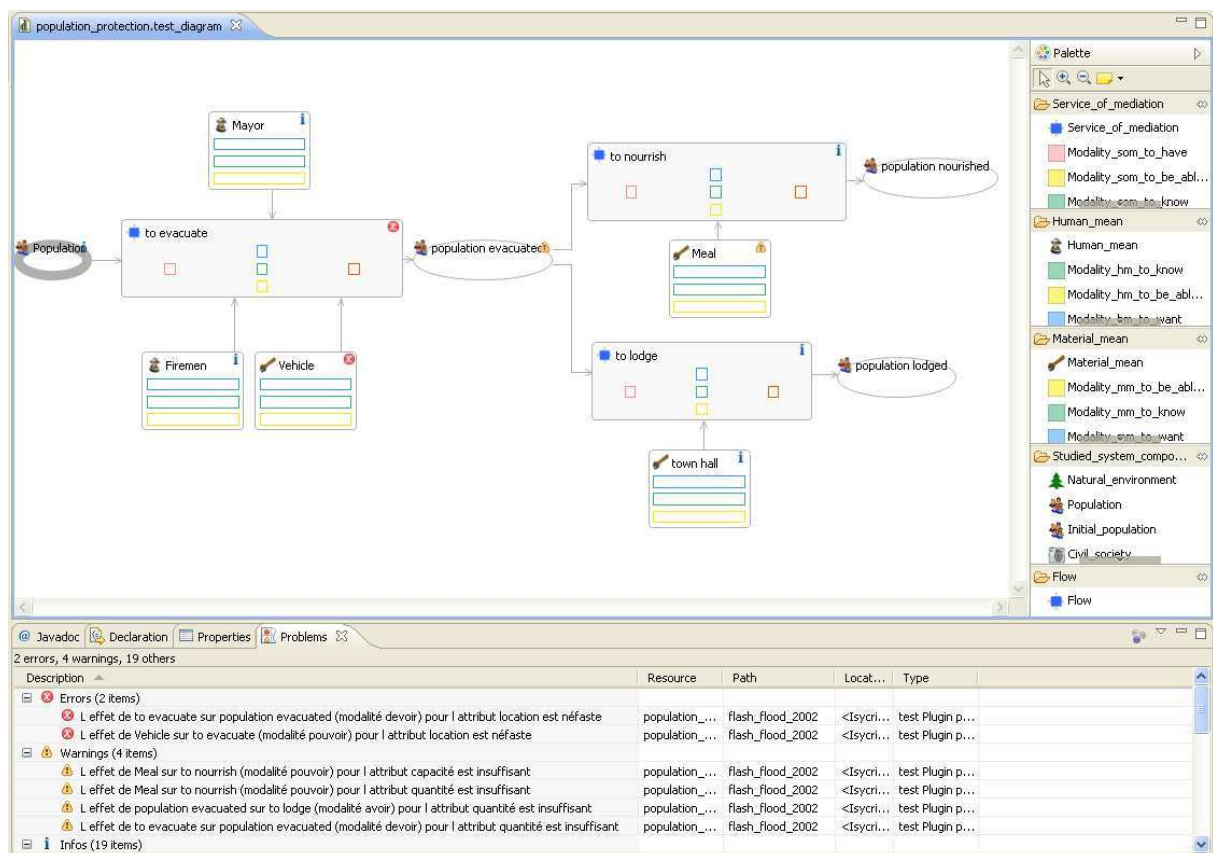


Figure 6. Implementation of the population protection process and analysis of the effects

This short application demonstrates the interest to have an anticipative view of a crisis situation to face up effectively so far as possible. This view can be obtained by the capture of a maximum of knowledge about the elements involved in the crisis and modeled through a collaborative process; and the knowledge of the effects between these elements. Whilst

this example focuses on two critical situations occurring during the population protection process only (other processes are triggered in this kind of crisis, such as good protection process, pillage prevention process...), when the real crisis happened the problem came from the material means that were not able to reach several towns, which were completely isolated by flood water. The evacuation had started without the support of material means and had strongly disturbed and slowed down the rescuing of the population.

CONCLUSION

This paper presents an approach that highlights the possibilities to use formal verification techniques to help crisis managers to increase their control and their level of knowledge all along a given crisis. Such an approach allows to analyze and to anticipate potential effects of the implemented response plan during which the crisis has to be coped. Currently, a referential of property is able to be deployed (64 metric rules and 153 audit rules). The existing properties are continuously improved and the referential is regularly updated. Future work is concerned by the development of a set of domain-independent properties that will propose alternatives to managers and the development of a resolution algorithm that will allow to build new collaborative processes.

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