

A Variability-Based Model to Support the Design of Public Crisis Information and Communication Systems

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ABSTRACT

A crisis is an inherently unpredictable event. However, it often exhibits patterns that can help authorities anticipate challenges and respond more effectively to crisis situations. Current information systems for public communication during crises tend to focus on disseminating standardized messages across various communication channels. This approach contradicts effective communication practices, as different audiences have different information needs. Inappropriate public communication messages can generate noise, amplify perception of risk, and increase feelings of insecurity. This paper proposes a novel model to guide the development of information systems for crisis communication. To ensure flexibility and adaptability across diverse crisis scenarios, our approach maps and models variability in the crisis communication process. This variability model enables the rapid creation of tailored yet consistent crisis communication, delivered through appropriate channels to meet the needs of different audiences - such as crisis responders, authorities, press and the general public — who are the intended recipients of the system.

Keywords

Crisis Communication, Public Communication, Information System, Document Variability

INTRODUCTION

A crisis is defined as a “sudden and usually unforeseen event that requires immediate measures to minimize its adverse consequences” (UN-DHA, 1992). A relevant aspect of crisis management is to provide effective public communication regarding the crisis. The term “crisis communication” is typically used in two different contexts: (i) the communication between organizations involved in the crisis management, and (ii) the communication between the crisis management team and different audiences (e.g. authorities, press, citizens) to inform and alert about the crisis (CDC, 2018). The latter aligns with the scope of our research, which aims to address some of the challenges

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faced by crisis managers when performing public crisis communication. Crisis management has been the focus of numerous computer-based studies across various fronts. These include the development of ontologies (Malizia et al., 2010) (Wu et al., 2013), crowdsourcing research (Villela et al., 2014) (Pestana et al., 2024), evacuation simulation algorithms (Pan et al., 2007) (Liu et al., 2018) (Tan et al., 2015), methods to support crisis decision-making (Wang et al., 2017) (Dusse et al., 2021), and techniques for monitoring and extracting crisis-related information from social media reports (Hughes & Palen, 2009) (Laylavi et al., 2017).

During crisis and emergency situations, establishing effective communication between the crisis management team and the general public is a critical step in minimizing the impact on those affected. However, achieving good communication is not a straightforward process. Crisis are complex situations often characterized by stress, panic, fear, and uncertainty (Reynolds et al., 2004) – both for the communication team and for those directly or indirectly affected by the consequences of the crisis / emergency. Additionally, communication professionals must ensure that appropriate messages are tailored to each target audience, aligning with their specific needs and interests (WHO, 2009). This involves crafting the messages using clear and accessible language, appropriate vocabulary according to the target audience, providing only the most relevant information, and ensuring consistency and trustworthiness across all communications.

Current solutions for public crisis communication are generally designed to disseminate a single message to the affected population (Malizia et al., 2010) (Pereira Filho et al., 2015). These solutions mainly focus on the task of distributing messages across various communication channels. While disseminating messages through multiple channels is an important aspect of public crisis communication, it is counterproductive if the message does not address the specific information needs of each target audience. The primary issue with sending the same message to all audiences is that the information may fail to meet the needs of specific groups, leading to information overload. This is particularly problematic in crisis situations, where the public may already struggle to process and manage multiple pieces of information (CDC, 2018).

In recent decades, numerous studies and guidelines for public crisis communication have been proposed to identify challenges and recommend best practices for communication during crisis situations (CDC, 2018) (CISV, 2017) (WHO, 2009) (Reynolds et al., 2004) (Seeger, 2006). Among the challenges faced by public communication teams, one of the most significant is the difficulty of creating and disseminating appropriate communication during critical situations such as crisis and emergencies. These challenges arise due to the complexity of such scenarios, the lives at stake, and the vast range of variabilities that characterize crisis situations, requiring messages to be adaptable to address these dynamic conditions. Furthermore, the need to inform affected individuals as quickly as possible, while ensuring consistency in a situation often characterized by "more questions than answers" (CDC, 2018), poses a significant challenge for crisis communicators. In essence, effective public communication during a crisis must consistently deliver reliable information, craft coherent messages tailored to the interests of each audience, and disseminate them through multiple channels to reach stakeholders as quickly as possible.

In this work, we present a variability-based model to guide the development of information systems solutions designed for crisis public communication, enabling the semi-automatic creation and dissemination of messages. The model was developed in alignment with established best practices and key guidelines for public communication during crises (CDC, 2018) (Seeger, 2006). This study aims to answer the following research question: How can variability-based models support the design of public communication information systems during crisis situations?

The key contribution of this work is a novel model for designing systems that generate crisis public communication from dynamic models which adapt to the current status of the crisis. In other words, content can be included or removed automatically according to the type of incident and the target audience to which it is communicating.

The remainder of this paper is structured as follows. In the following section, we explain the methodology used in this work. We then present the study in public communication. Next, we introduce the variability analysis on crisis public communication. Next, we detail the variability-based model to design crisis public communication information systems. Lastly, we summarize our findings and suggest future research directions.

METHODOLOGY

Figure 1 presents the research methodology, which we divided into stages and research activities, used to achieve the goals of this study. The following sections of this paper will provide a detailed explanation of each stage illustrated in Figure 1.

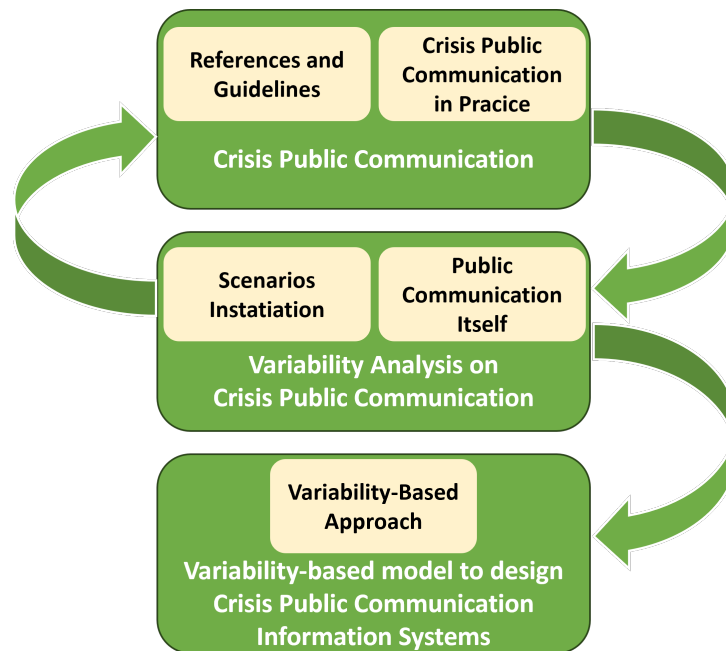


Figure 1. Research Methodology

Practitioners from real-world, operational forces and crisis management teams were involved. The study of crisis public communication analyzed the process that those practitioners applied in real-world situations and also looked at guidelines, good practices and manuals about effective crisis public communication. After understanding the basic requirements for good communication during crisis situations, we instantiated them for a specific crisis. To this end, we carried out an analysis of the public communication life cycle in order to map the variability present in this process for various situations. Based on our variability analysis, we introduced the public communication model developed in our study.

CRISIS PUBLIC COMMUNICATION

One key aspect of crisis management is communication. Clear communication during a crisis can help people and organizations handle the situation in a better way. A big challenge is to establish a good strategy for communication with all target audiences in order to maintain them informed, considering the specific needs and restrictions of each audience.

The studies CDC, 2018 and CISV, 2017 also indicate the basic information that crisis communicators need to know about a situation.

- WHAT happened?
- WHERE did it happen?
- WHEN did it happen?
- WHO is involved?
- HOW did it happen?
- WHAT is currently being done?

Concerning the content of the public messages, Reynolds et al., 2004 proposes a set of good characteristics that these messages need to have. This principle is called “STARCC” and states that the messages must be:

- Simple: Frightened people do not want to hear big words;
- Timely: Frightened people want information NOW;

- Accurate: Frightened people will not get nuances, so give it straight;
- Relevant: Answer their questions and give action steps;
- Credible: Empathy and openness are key to credibility;
- Consistent: The slightest change in the message is upsetting and dissected by everyone.

In addition, based on studies of good communication principles (CDC, 2018) (Seeger, 2006) (Goldfine, 2011) (Glik, 2007) (WHO, 2009), we consider the following principles essential for effective communication with the public during a crisis:

- communicate repeatedly (repetition helps with recall, especially during a crisis);
- be clear (use simple language and do not use technical terms, statistics or probabilities);
- communicate by different tools, media and communication channels (never trust a single method of communication);
- transmit consistent information; and
- provide only relevant information.

This set of principles and good practices is necessary to establish good communication during crisis situations. Information systems designed to support public communication must be modeled in order to help achieve these premises.

We collected information on how public communication occurs during a crisis (Pereira Filho et al., 2015) from the user organizations, either as official partners or as collaborators. To get this information, we held a workshop with representatives of the Camaçari Industrial Development Committee (COFIC)¹ - Brazil; the Command and Control Center of the Public Safety & Security Department of the State of Bahia (CICC-BA)² - Brazil; and FireServ³ - Austria.

During the workshop, COFIC was in charge of providing information from the perspective of industrial parks (indoor scenarios) in Brazil; CICC-BA brought the perspective of large-scale events (outdoor scenarios) in Brazil; and Fireserv provided information from both the perspective of industrial parks and large-scale events in Europe. All of these organizations have real hands-on experience in crisis management that involves the communication and evacuation of thousands of people in simulations or real events. We also analyzed the communication templates and processes provided in the partner security manuals. The next section presents the results obtained during this phase of the work.

The first step was to identify potential target audiences of crisis public communications by analyzing the model of organizational behavior and structures in crisis of our partners (Simões Júnior et al., 2015). As result of this analysis, we elaborated the list of potential stakeholders that should receive public communications: Crisis Responders, Press, Public Authorities, Employees / Visitors / Event Audience, Spectators and Neighboring Community. In addition to capturing the aforementioned stakeholders, it was important to keep the public informed about those who are not directly involved in the crisis (a.k.a. general public). It helps mitigate anxiety and uncertainty while preparing individuals for necessary actions during a crisis (CDC, 2018).

- Crisis Responders
- The Press
- Public Authorities
- Employees / Visitors / Event Audience

¹COFIC is an organization that manages the integration and safety of a park of more than 90 large industries in northeast Brazil, <http://coficpolo.com.br/>

²The CICC-BA is the command and control center responsible for the statewide management of crisis in Bahia (a 14 million people state of Brazil)

³Fireserv is an European company that specializes in safety and crisis management, with outstanding performance in chemical industrial parks, <http://www.fireserv.at/>

Table 1. Stakeholders x Information needs

Crisis-related Information	Stakeholder		
	Employee, Visitor, Event Audience, Community, Neighbor Community, General Public	Crisis Responders, Trustee	Press, Politician
Incident Location, Incident Type, Incident Time, Taken Measures, Consequences (physical, material, financial, etc.) and Crisis Status	x	x	x
Injured People	x	x	x
Fatalities		x	
Type of Released Chemicals		x	
Schedule for Press Conferences			x

- Trustees
- Spectators
- Neighboring Community
- The General Public.

During the mentioned workshop, participants not only informed what information is relevant but also linked it to each of the stakeholders. Table 1 shows the resulting mapping. This step helped to reveal that the information sent to the Press and Politicians is the same. The same was observed for Visitors / Employees / Event Audience, Neighboring Community and General Public.

VARIABILITY ANALYSIS ON CRISIS PUBLIC COMMUNICATION

A further challenge for a crisis public communication information systems designed to be used in different applications is to ensure a simple instantiation and adaptability. These characteristics are necessary due to the particularities of each type of crisis. One strategy to manage the variability between these different crisis situations is the analysis of the feature-oriented domain.

Software Product Line (SPL) (Clements & Northrop, 2002) is a software engineering paradigm to abstract and represent the concept of variability in software that shares a set of similarities. Feature modeling is the compact visualization of different features of a SPL and their relationships.

Feature modeling is one of the Feature-Oriented Domains Models presented by Kang et al., 1990. Feature-Oriented Domain Analysis (FODA) is a domain analysis method proposed to support Software Reuse (Krueger, 1992) at the functional and architectural levels. The main goal of this method is to manage the commonalities and variabilities within a product line.

In a feature model, features are arranged in a hierarchical structure: one feature (parent feature) can have sub-features (child features). The relationship between the parental feature and its sub-features can be of the type AND (all child must be selected); Alternative (only one sub-feature can be selected), or OR (one or more can be selected). The relationship between features is defined by two types of constraints: Implies and Excludes. When a feature needs one or more feature, there is a relationship of Implies. When the selection of a feature disables the selection of another feature, we have the relationship of Excludes (Batory, 2005).

Table 2. Constraints of the configuration feature model

Set of Constraints	Constraints
Scenario and Crisis Type	Outdoor EXCLUDES Building Fire; Indoor EXCLUDES Car Crash;
Scenario and Stakeholder	Outdoor EXCLUDES Trustee;
Stakeholder and Communication Channel	Press OR Public Authorities REQUIRES Email; Employees OR Neighboring Communities REQUIRES SMS OR Information Systems Applications; General Public REQUIRES Website OR Twitter OR Facebook OR Google Public Alerts OR Information Systems Applications

We decided to model the variability of the crisis public communication domain through feature modeling. We use this approach to guide the development of our variability based model in order to enable the addressing of different stakeholders' needs in the most different crisis. As mentioned previously, different crises present different patterns; however, there are particularities related to crisis situations. As a consequence, we mapped the variation points to enable the configuration of our solution.

Figure 2 presents the resulting feature model. We identify that five parental features are essential to instantiate a solution of crisis public communication: *scenario*, *stakeholder (target audience)*, *communication channel*, *crisis phase* and the *crisis type*. The relationship between the *scenario* and its child features is *ALTERNATIVE*, i.e. the solution is configured for a certain organization, which implies a specific scenario. Other relationships are *OR* (i.e. one or more sub-feature can be selected when configuring). The selection of the child features for the five parental features defines what will be possible in terms of public communication for the organization owing the resulting instantiation.

The selection of *crisis phases* that the application will make available for the generation of public communication templates is an alternative feature because of temporal characteristics of these phases in each crisis scenario. We identify that, in some situations, certain phases have a short lifetime, making it impossible to create and disseminate a public communication. A practical example of this affirmation is the initial phase of an indoor scenario crisis. As it is a highly controlled scenario, the time between the confirmation of a crisis and the response action (start of the being controlled phase) is so fast that the public communication possibly will inform about this last phase (being controlled).

Table 2 presents the constraints that apply to the instantiation feature model. The *crisis types* are different depending on the *scenario*. For example, car crashes are not expected with indoor scenarios. Based on this, we defined two constraints to specify the valid combinations of scenarios and crisis types. Likewise, we specified one constraint between *scenario* and *stakeholders*. For example, trustees are not part of the target audience of any communication in outdoor scenarios.

The remaining constraints capture valid associations between *communication channel* and *stakeholder*. Some communication channels are more efficient in reaching particular groups of stakeholders. For example, it is highly unlikely that the organization in charge of a football match at a stadium has the cell phone number or email address of visitors to be able to send an SMS or e-mail. However, this target audience can be notified by a mobile solution based on their geographical position. Based on this, we present four constraints to define the set of valid associations.

The communication of a crisis varies according to the type of incident, the crisis phase and the target audience who will receive the information. The communicator needs to provide each target audience with relevant information from their perspective, always trying to address their main concerns in a clear and objective way (WHO, 2009). Therefore, it is essential to determine which information should be sent to each specific stakeholder, when and using which means of communication.

Techniques used for variability modeling in software product line engineering can be useful for modeling commonalities and variabilities in variant-rich situations. Considering crisis public communication, the benefits of using variability modeling techniques are related to an efficient generation of customized messages for specific audiences, a comprehensive model to consolidate the variation points of the public communication process, and the ability to perform consistency checking of the generated messages.

We worked on the identification of commonalities and variabilities in the composition of public communication messages. To do this, we analyzed a set of templates of our partners (COFIC and FIRESERV) and the models proposed in best practice manuals (CISV, 2017) (CDC, 2018) (WHO, 2009) in crisis public communication in order to identify the structure of this model and the relationships between their information. Figure 3 presents the result of our variability mapping of the content of public communication messages.

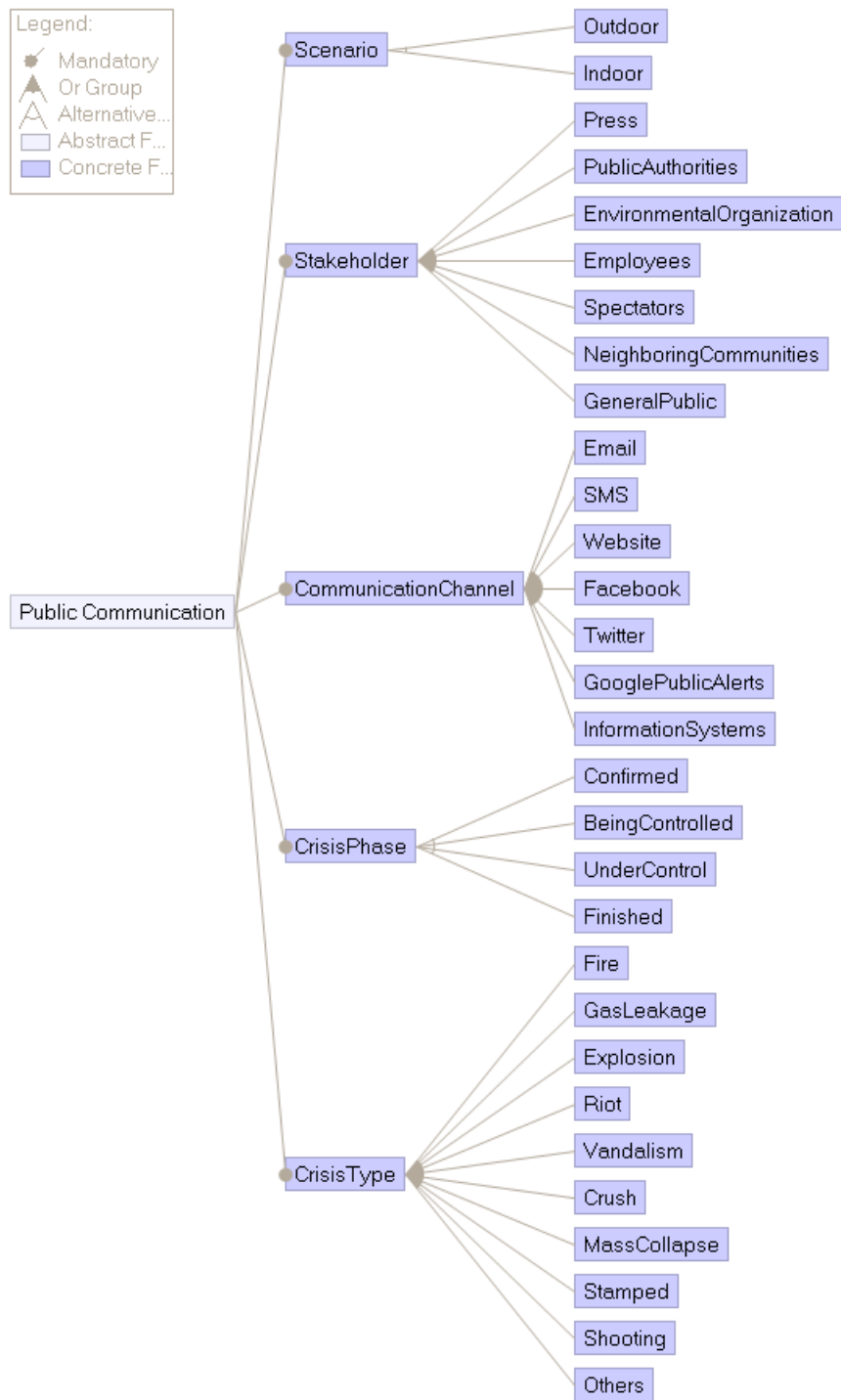


Figure 2. Instantiation Feature Model

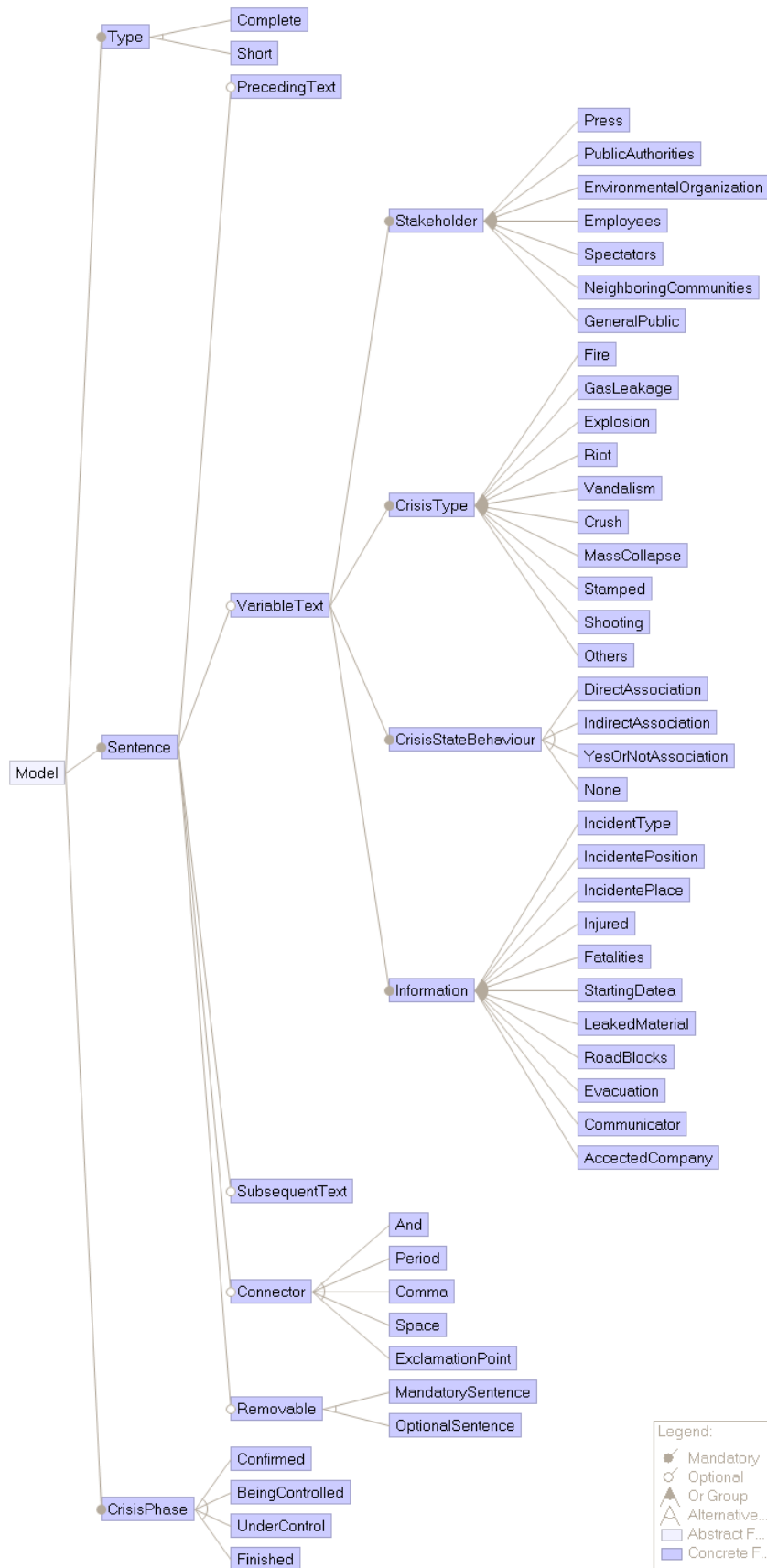


Figure 3. Feature model for the Public Communication Itself

First, we observed that there are public communication templates for the different *crisis phases*. This happens because the goals of communications in each crisis phase are different (CDC, 2018). To exemplify, we put in our feature model for public communication itself (Figure 2) the four crisis phases that our partners disseminate public releases in practice: *confirmed*, *being controlled*, *under control* and *finished*. It is important to highlight that nothing in our study prevents other crisis phases from being covered by other organizations in other crisis.

Another important aspect that influences the communication template is the *message type*. Communications channels such as social networks, SMS, and mobile applications have limitations in message size or are used on small screens; this means *short communication templates*. In cases where communication channels do not have such limitations means *complete (or extended) communication templates*.

After analyzing the messages templates, we defined a generic structure for public communications messages. This structure consists of: Title, Signature Topics and Sentences. Title and Signature are self-explanatory, representing the title of the public communication and the complete signature of the person responsible for the public communication. Topic represents a paragraph or, in our proposed structure a set of sentences. Each topic has a communication goal, such as informing the occurrence of a crisis, or the actions taken to control it.

Sentences represents a phrase or part of a phrase. Sentences are structured pieces that allow the public communicator to interact and customize part of their content according to their interest. We structure *sentences* in: *the text preceding* the variable information (optional), the *variable information* (mandatory), the *subsequent text* (optional) and one connector between sentences (mandatory).

Another characteristic of a sentence is its *removability*. When the *information* in a sentence is essential for the precise understanding of a public communication (e.g. the incident location, occurrence time, etc) this sentence is considered *mandatory*. However, if the information in a sentence may not be relevant, in a specific situation (e.g. information about evacuation may not make sense in some situations) this sentence is considered *optional*.

Finally, some sentences are restricted to the interest of one or more stakeholders. Sentences are directly linked to the target audiences (*stakeholders*), as they have different concerns (WHO, 2009).

VARIABILITY-BASED MODEL TO DESIGN CRISIS PUBLIC COMMUNICATION INFORMATION SYSTEMS

Figure 4 presents our proposal of a variability based model to design Crisis Public Communications Information Systems. We will present our approach according to the steps of crisis directly linked to the tasks of creation and dissemination of public communications: *Verify the Situation*, *Prepare Information* and *Release Information through Prearranged Channels*.

Verify the Situation

The task of communicating to the public about the occurrence of a crisis and its consequences begins with gathering accurate, reliable and detailed information. Situational awareness is essential to guarantee that only consistent information will be transmitted to the public and thereby gain public confidence.

In some cases, reliable information can be obtained from other software for crisis management or alert systems. Because of this, the first interaction described in our model is an automatic search of information from external systems. The responsibility of the communication module, more specifically, the sub-module of External Communication is to implement interfaces that periodically and automatically get information from external sources and provide it to the context module (interaction 2).

The set of information obtained from external sources composes the *External Information* in the *Context Module*. We call *Internal Information* the information obtained from the input of the users during the interaction within the Assisted Message Composition Module (AMC) (Interaction 4). The Context Module is responsible for automatically managing the information of the Internal and External Information and to provide the most recent information to the AMC module (Interaction 3).

However, in some cases, it is not possible to obtain certain information automatically from External Sources of information. This information will be obtained by alternative means and included manually during the composition of crisis public communication by the crisis communication team. In this case, it is important to share this reliable information with other crisis management information systems and or this reason, the Internal Information is automatically sent to the External Communication Sub-module (interaction 5) which, in sequence, share this information with external systems (interaction 6).

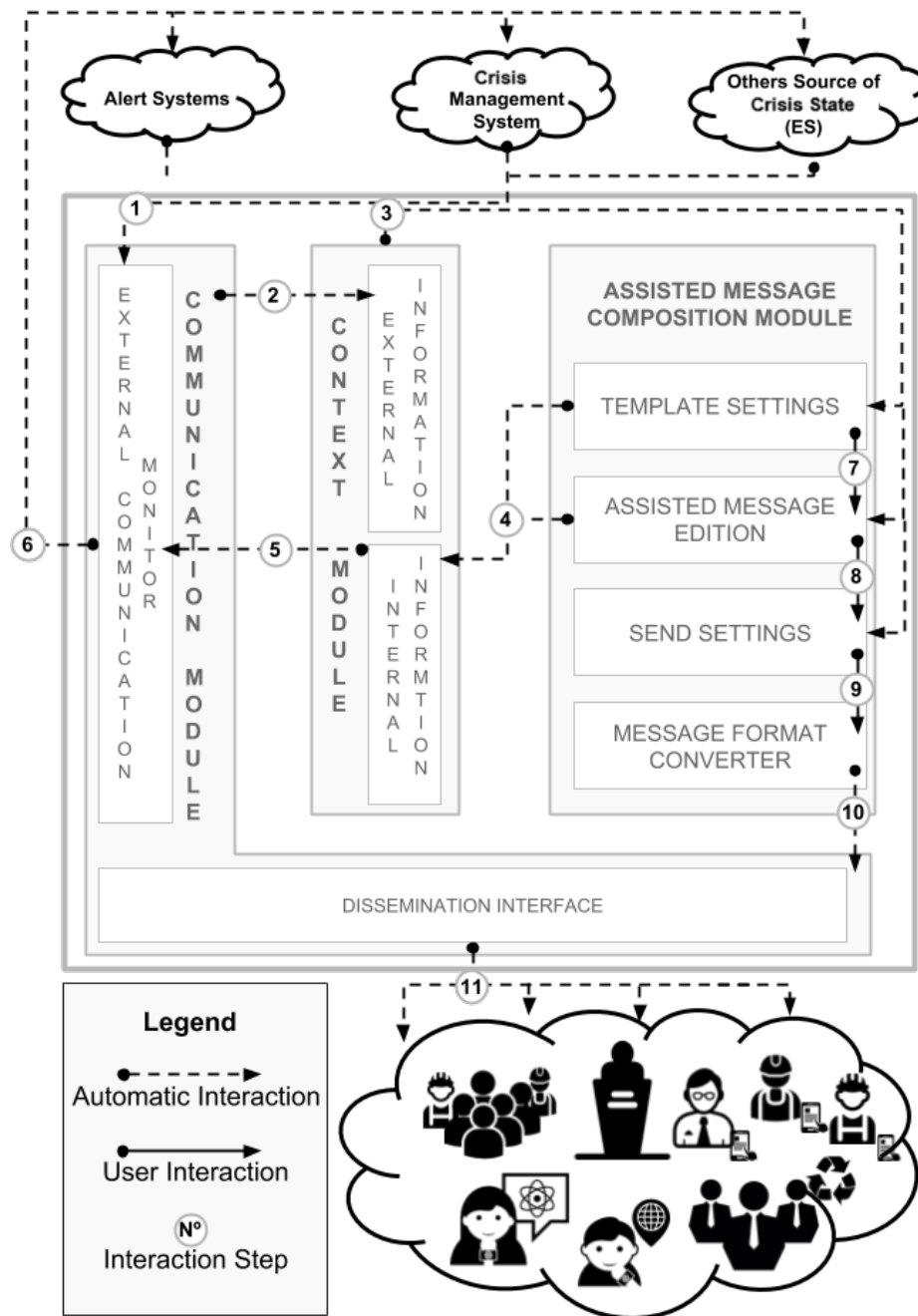


Figure 4. Our variability based model to design Crisis Public Communications Information Systems

Prepare Information

The process of creating public communications begins with the configuration of the Template Message. Some characteristics are essential to select the appropriate template for the current crisis. We generate the most appropriated model according to the response of 4 questions: *WHAT happened?* (what is the type of crisis); *WHAT is the current status?* (what is the current phase of crisis); *WHICH the target audience will be communicated?*; and *HOW the target audience will be communicated?* Some of these questions are linked to the crisis status. So, the Template Settings sub-module can consume (interaction 3) or provide (interaction 4) information to the Context Module.

After obtaining the essential information about the communication of crisis, the *Assisted Message Edition* sub-module generate a dynamic template according to these information (interaction 7). We map the variability in the composition of public communication messages and as a result, we create structured templates that adapt to the current crisis status in order to reduce the necessity of interactions to compose the public communication. This

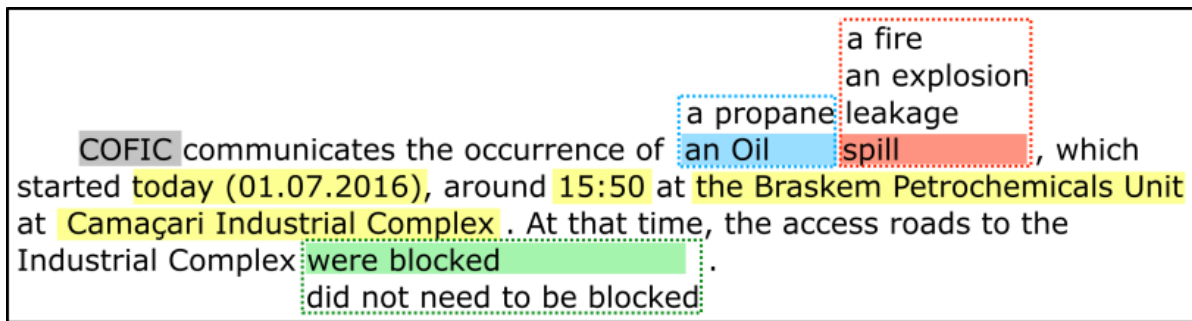


Figure 5. Examples of different behavior on the content of sentences according to the crisis status

process includes the exclusion of sentences that are not applicable to specific targeted audiences or to the crisis type. Furthermore, we observed a set of behavior in the information of some sentences according to the context of the crisis. We propose four generic types of variation in the content of a sentence depending on the status of the crisis, the variation can be either:

1. A direct association, where the value of the variable information is an crisis status data;
2. An indirect association, in which the value of the variable information depends on crisis status data, but it does not have the same value;
3. Based on the occurrence (or not) of a fact, which might come from the crisis status; or
4. Information not associated with the crisis status.

Figure 5 shows practical examples of each different behavior identified and its influence on the content of the sentences. The information marked in yellow are the contents that present a *behavior of direct association* with the crisis status, such as the crisis start date and time, the name of the affected company and so on. This information was put directly into the sentence.

In red, we present an example of *behavior of indirect association* between crisis status and part of the sentence. The sentence will read “a fire” when crisis type is “Fire”, “an explosion” when crisis type is “Explosion”, “leakage” when it is “Gas Leakage” crisis, and “spill” if the crisis type is “Environmental”. Another example of qualifier for the crisis type is shown in blue. The leaked material is a type of information indirectly associated with the incident “Gas Leakage” or “Environmental”.

We marked in green a sentence in which the variable content is based on the *occurrence or not of a fact*. In this case, the occurrence or not of road blocks.

Finally, an example of a sentence not associated with the crisis status is given in gray. The name of the company that is responsible for handling the crisis, in this case, information that comes from system instantiation.

Release Information through Prearranged Channels

Disseminating public communication through the most appropriate communication channel for each targeted audience is essential to ensure the success of public communication of a crisis.

In the *Send Setting* sub-module, the user can select the dissemination area, email and cell-phone list and other configurations of the selected communication channels. Afterwards (interaction 9), the *Message Format Converter* (MFC) sub-module generate the specific message for each targeted audience from the structured template that results from the *Assisted Message Edition* sub-module). The MFC needs to convert each message to the appropriate format for each communication channel (interaction 10).

Finally, the messages are sent automatically by the *Dissemination Interface* (interaction 11). It is in this Interface that is implemented the logic to send messages for each communication channel.

CONCLUSION

Public communication plays a key role in crisis management. The main challenge of this activity is to establish a good strategy for communication with other stakeholders who should be informed. A crucial aspect is to ensure that the right people receive the information they need, when they need it.

We conducted a variability analysis in the public communication process in order to instantiate our work for different crisis. We also addressed the variabilities of sending customized public communications in a semi-automatic way regarding the crisis status, target audience and communication channel.

As a result of this analysis, we propose a variability-based model to design Crisis Public Communications Information Systems, with the benefit of using dynamic templates to allow the semi-automatic and flexible creation of public communications taking into consideration the target audience, incident type, crisis phase and adapt the content of the message according to crisis status information.

The proposed variability-based model provides a structured approach to customize crisis public communications. Our findings indicate that variability analysis can significantly support the creation of targeted messages for different audiences. Additionally, the participating organizations shared their experiences, good practices, guides, and manuals; which enriched the development and refinement of the model. However, the model has some limitations. The study was conducted based on workshops with specific organizations, which may limit the generalizability of the results. Furthermore, the model has not yet been fully evaluated in real crisis scenarios.

As a future enhancement, the model can be refined to support customization within the general public, addressing the needs of vulnerable populations such as the elderly, individuals with disabilities and people with language barriers. Incorporating these considerations into the system could increase accessibility and the overall effectiveness of crisis communication.

We will use the results of this work to guide future research, namely the full evaluation of the proposed model. Our aim is to apply the model in simulations or even in real crisis case studies. For that, we need to specialize it into an information system that embedded our variability-based model. This concrete application of the model should overcome the constraints of our work so far.

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