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# Virtual Reality to Train for Crisis Management

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## ABSTRACT

The EGCERSIS project aims at using virtual reality to improve the efficiency of the crisis management preparation phase. The idea is to tackle the drawbacks of regular crisis management exercises thanks to fully configurable scenarios taking place in digital twins of real critical sites. Virtual exercises will improve, among other things, the frequency, efficiency, and modularity of crisis management preparation, while reducing its costs. In this article, we demonstrate the idea of the project through a simple use-case taking place in a metro station and involving three crisis responders. By linking virtual exercises to our crisis management platform, we also want to demonstrate the usefulness of decision-support systems during a crisis.

## Keywords

Virtual reality, Crisis Management, Exercises, Decision-Support System.

## INTRODUCTION

Sites in which incidents or dysfunctions are threatening people's life must be prepared to face any time of crisis that might occur. In this paper, we are referring to those sites as critical sites. To be prepared to deal with a crisis, those critical sites are required to set up and conduct crisis management exercises. The frequency of those exercises depends on the site and the legislation: once or twice a year, or more or less frequently. However, the complexity of setting up such an exercise and identifying relevant feedbacks, the costs (both in terms of resources and time), and the lack of realism and flexibility, limit the positive impact of crisis management preparation, as stated in (Congès et al. 2019). The EGCERSIS research program aims at overpassing those limitations thanks to the use of virtual reality. Based on the idea that simulation-based training helps trainees to gain skills thanks to safe and guided practice (Lateef 2010), we propose a training platform allowing trainees to be immersed in a virtual reality simulation of a crisis. This platform is connected to a technological crisis management platform (TCMP) to improve situation awareness and decision making in crisis response.

This article underlines the advantages of coupling our training platform with a TCMP. It is structured as follows: first an overview of the context, then a presentation of the training platform and TCMP through a use case and an analysis of the benefits of such a coupling. Finally, we list the perspectives and the next steps of our project.

## ABOUT CRISIS MANAGEMENT EXERCISES IN CRITICAL SITES

### Disadvantages of current crisis management exercises

In crisis management, preparation is crucial to be ready to deal with the crisis as well as possible. This is why critical sites are required to implement internal and external plans, and to perform crisis management exercises regularly. Those exercises are intended for the different actors of the crisis response, such as first or second aid, or institutional responders such as firefighters. They are useful, as they allow the responders to assimilate the intervention plans as well as the specificities of the site on which they have to intervene. However, they present a lot of drawbacks, and their efficiency could be improved. As put (Ardila et al. 2013), traditional exercises are “expensive and offer little flexibility (e.g. it is not possible to simply burn up a building every time a drill is carried out)”. Mobilizing actors and a site is difficult: implication and impact on the actors’ side are unpredictable, and the economic impacts on the site make it impossible to carry out exercises very often. This means that the coverage of a potential crisis is low, which leaves a lot of room for the unexpected. The realism of a scenario is currently difficult to obtain, which limits the lessons that can be learned from an exercise.

### The need for a decision support system

Another complicated aspect of crisis management is the interagency aspect: “real training in the field of emergency management is very expensive and complicated regarding the harmonization of procedures between agencies” (Ardila et al. 2013). In a context where decision making must be quick and extremely efficient, it is important for each kind of actor to be able to rely on others to do what they must do. However, decision making in a crisis situation is complex because of the complexity of the system itself, the difficulty to gather and sort information, and the need to constantly adapt to the evolution of the situation. According to (Prelicean and Boscoianu 2011), “inadequate communication between different actors and different levels; the relative inadequate data fusion, selection, filtering, and standardization impacted information database; the difficulty to update information about the development of the extreme risk” are problems that enhance the need of a decision support system. (Drudzel and Flynn 1999) defines decision support systems “as interactive, computer-based systems that aid users in judgment and choice activities”. (McNurlin and Sprague 2001) described them as “computer-based systems that help decision-makers confront ill-structured problems through direct interaction with data and analysis models”. They are very valuable tools in complex situations where decision-makers need to analyze multiple sources of information (Martinsons and Davison 2007), as it is the case in crisis management. In a crisis context, a lot of information need to be gathered and analyzed: what happened, when, where, are there casualties, who are available to help, what is the geographical context (e.g. are there critical infrastructure around to evacuate or secure), what are the possible evolutions of the crisis... Useful information come from different sources: institutional infrastructures, first responders, institutional responders, social media... That information has to be used in order to determine the best course of action in order to solve the crisis, not only at the beginning of the response phase, but all along the evolution of the crisis. The best solving process will probably change as the situation evolves, and this has to be noticed and taken into account by all the responders.

### Virtual reality as a training and learning tool

First of all, we are going to define what we mean by virtual reality. Definitions of the word go back to 1990s, with the definition of (Steuer 1992): “virtual reality is electronic simulation of environments experienced via head-mounted eye goggles and wired clothing enabling the end-user to interact in realistic three-dimensional situation”, and the definition of (Beroggi et al. 1995): “virtual reality is an immersive, synthetic or computer-generated environment that provides the experience of “being there””. The most important part of those definitions for us is the notion of immersion: being there and being able to interact with the environment. Immersion will help the user to feel involved and committed to the exercise. (Louka and Balducelli 2001) completes this: “a computer-generated system that generates an artificial world that tricks the user into feeling part of it would not be a complete definition of virtual reality, because it lacks the vital component of interactivity. Virtual reality is a three-dimensional user interface in which the user can perform actions and experience their consequences”. This ability to experience consequences, along with “first order experience” and a sense of “presence” is the key to the learning experience in virtual reality, according to (Mikropoulos and Natsis 2011) in their ten-years review of empirical research on the educational application of virtual reality.

**Coverage and repeatability:** As stated before, one of the biggest drawbacks of current exercises is the low coverage of possible crisis scenarios. The cost and difficulty of mobilizing actors and sites make it impossible to set up exercises very often or to repeat a scenario. Thanks to virtual reality, we can imagine any kind of scenario, under any conditions (rain, strong wind, night or day, with or without equipment...). The use of a scenario editor will make it easy to recreate any type of crisis, and even to change the course of a crisis during the exercise. Once

the digital twin of the considered site is built, it will not be more expensive to run multiple exercises instead of one, which will allow repeating a scenario (or a variation) as often as needed to master it.

**Immersion and practice:** Virtual exercises will increase the realism of the exercises. Instead of imagining a fire while sitting around a table, the trainees will have to face it in the digital twin of the critical site. This will increase the implication of the trainees, without endangering them. Because everything is simulated, trainees will be able to make mistakes and fail without consequences, and to try again. As put by (Kang et al. 2019), "for training and education purposes, virtual reality allows trainees to practice cognitive, and sometimes physical, skills in simulation as risks to safety and material costs can be much lower in VR than in physical training". Thanks to the immersion allowed by virtual reality, "better retention of information" is achieved (Gallerati et al. 2019). "Players are encouraged to learn by trying different strategies, succeeding and failing as they would in an entertainment game" (Saunders et al. 2019), which increases the impact and the lessons that are to be learned from the exercise.

**Testing new technologies:** We want to enable the practitioner to test new tools or new technologies. Implementing them in the virtual environment will allow the players to use them to solve the crisis. Comparing the outcomes of an exercise with and without that particular tool or technologies will help determine its relevance and decide whether the investment is worth it.

**Decision-making:** Quick and efficient decision-making is, as stated earlier, a huge part of crisis management. We believe that virtual reality can also help improve decision-making. With a virtual exercise, all the data can be recorded in real-time, thanks to its numerical nature. Everything can be monitored, replayed and analyzed to gather feedback, which will lead to improvement of the crisis management, including the intervention plans and the actor's skills. The more data gathered, the more difficult it is to analyze and effectively treat it. In that too, we believe that virtual reality could help, thanks to its ability to go beyond reality. The idea is to use virtual environments to "extend the user's capability to feel data that would normally be beyond the range of their senses or experiences" (Mikropoulos and Natsis 2011). We want to use virtual reality as a tool for data visualization and analysis. As shown by (Millais et al. 2018), data exploration is more successful and satisfying in virtual reality than in 2D, thanks to the "wider field of view, increased dimensionality and sense of presence".

To this day, the main drawback of virtual reality is technologic, with haptic rendering. The lack of resistance and haptic feelings can reduce the realism of certain scenarios, for instance with weight and feel-less casualties, or pressure-less fire hoses. However, virtual reality as a learning and practicing tool remains at least as effective as reality, and "professional training can be fruitfully enhanced by VR", as shown by (Saunders et al. 2019).

## THE EGCERSIS RESEARCH PROJECT AND OUR DECISION SUPPORT SYSTEM

### EGCERSIS

The EGCERSIS research program, described in (Conges et al. 2019), aims at providing a framework dedicated to preparation and training for crisis management on critical sites. The idea is to use virtual reality and a decision support tool to provide an immersive crisis management scenario, set in the digital twin of a critical site, and to link that experience to monitoring and supervision tools to get reports and capitalize on the exercises.

Four components are to be implemented, to achieve those objectives and tackle the identified drawbacks of real-life exercises:

- An **exercise editor**, to model and define scenarios. This editor will allow greater coverage of possible crisis in a given critical site. Besides the creation of crisis scenarios, we propose to allow the scenario designer to make the crisis evolve during the exercise, for instance adding weather conditions or new casualties.
- A **virtual environment**, to enact multi-player scenarios. This environment will be a digital twin of the considered critical site, to improve immersion and realism. We want several players to be able to evolve in this virtual environment, interacting with each other and with the environment.
- **Decision-support tools**, to accompany decision-makers in the crisis cell. The virtual environment will be fed by our decision-support tools, to gather and analyze the data of the exercise and to be able to determine the best course of action to solve the crisis.
- **Dashboard tools**, to enable real-time and a posteriori analysis of players, exercises, and plans. These tools will help improve crisis management in real-time, acting as a decision support tool; and a posteriori capitalize on the exercise to improve it.

The EGCERSIS program will follow four main steps, presented in Figure 1.

The first step will be to use plans of the building and maps to create a 3D digital twin of the considered critical site. To do so, formalized protocols for the establishment of digital twins will have to be set up in the project. The crisis management exercises will take place in those digital twins of critical sites, which will improve the realism of the scenario.

The second step will be to implement a given scenario. To do so, we are developing a scenario editor that will enable site managers, responders or authority representatives to design a realistic scenario, taking into account the available resources (humans and materials) and the condition in which they want the exercise to take place. This scenario editor will allow designing a scenario before the exercise, but also to make this scenario evolve throughout the exercise.

Thirdly, the exercise will be enacted thanks to virtual reality. The trainees will face the exercise in the digital twin of the critical site. We want to make sure that they can have access to realistic virtual tools, close or identical to the ones they use in a real crisis, and train in conditions as close to reality as possible. During this exercise, crisis managers will help the trainees thanks to the technical crisis management platform developed in our lab, R-IO Suite.

Fourth, the numerical nature of the exercise will finally allow all the data to be easily recorded and analyzed to capitalize on the exercise. The idea is to get precise feedback to improve the exercise, but also crisis management (intervention plans and the actors' skills).

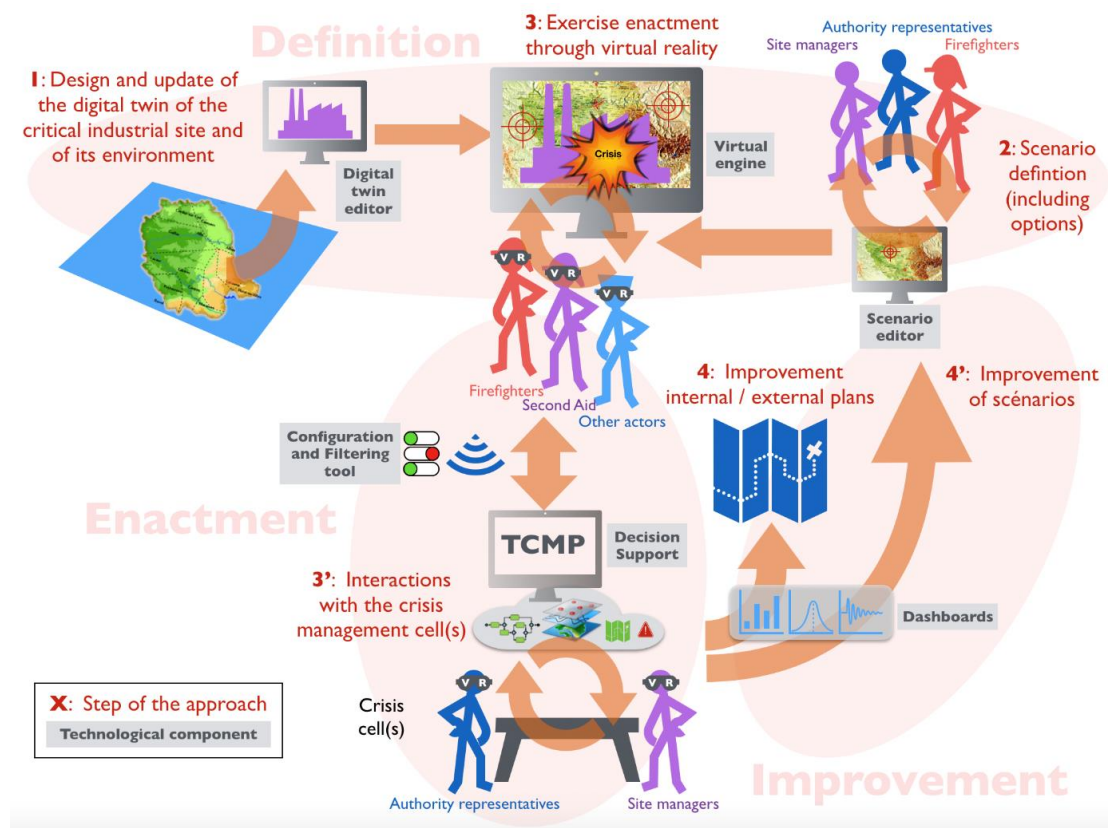


Figure 1: Big picture of the EGCERSIS research program

### R-IO Suite

The exercise, enacted in the virtual environment of the critical site, will be linked to R-IO Suite. This decision-support tool, described in (Benaben et al. 2017), aims at “managing the collaboration” interagency, and “dealing with the very huge amount of data”. It is a software suite composed of four tools:

- A design assistant, to support the situation modeling and the deduction of a response plan. The idea is to fill three models – context (what are the stakes and the impacted part of the world), partner (who are the responders and what can they do) and objective (what are the missions to be achieved) – based on which a response plan will be deduced. The software provides the responders with a BPMN (Business Process Management Notation) collaborative process to solve the crisis.

- A workflow assistant, to orchestrate the collaborative process. Human tasks are deployed on smartphones, tablets or computers for the actors to deal with them, while software tasks are dealt with through the service-oriented architecture of the workflow assistant.
- A tracking assistant, to monitor the crisis and the workflow progress. The idea is to check for any difference between what is happening and what is supposed to happen, to deduce a new response plan if need be.
- A governance assistant, to manage the models and the knowledge base associated.

In the EGCERSIS project, we use R-IO Suite to collect data, analyze and interpret them to describe the situation, use this description to help manage the crisis through the proposal and orchestration of a response plan. All those steps must result from a constant exchange of data between R-IO Suite and the virtual environment hosting the crisis management exercise. The initial situation, as well as its evolution, must be constantly analyzed to always propose the response plan best adapted to the actual situation.

## METHODOLOGY

For each exercise scenario in this project, we follow the cycle presented in Figure 1. Once the digital twin of the critical site is available, we define the scenario of the exercise. To make it as realistic as possible, we work with people responsible for security at the site, with the first people that are going to have to respond should a crisis occur, as well as with firefighters. Then we enact the scenario inside the digital twin of the critical site. The targeted trainees of those exercises are the people who will have to deal with a real crisis: first the witnesses of the start of the crisis, then the people in charge of the response on-site, and finally the first official responders such as policemen or firefighters. The final step of the exercise will be to analyze the results and feedback to be able to improve the response to the crisis.

## A USE-CASE TO DEMONSTRATE THE LINK BETWEEN VIRTUAL REALITY EXERCISES AND OUR TMCP

In this section, we want to demonstrate the usefulness of R-IO Suite thanks to our virtual exercises. To do so, we set up a scenario of crisis management that we enacted as a virtual exercise and run once without R-IO Suite and once with it. To ensure realism, we validated this scenario with the firefighters of Albi.

### Presentation of the use-case

*Nota Bene: The following example is fictional and is not meant to be realistic. This simple use-case is dedicated to illustrating the usefulness of using a decision-support system in crisis management.*

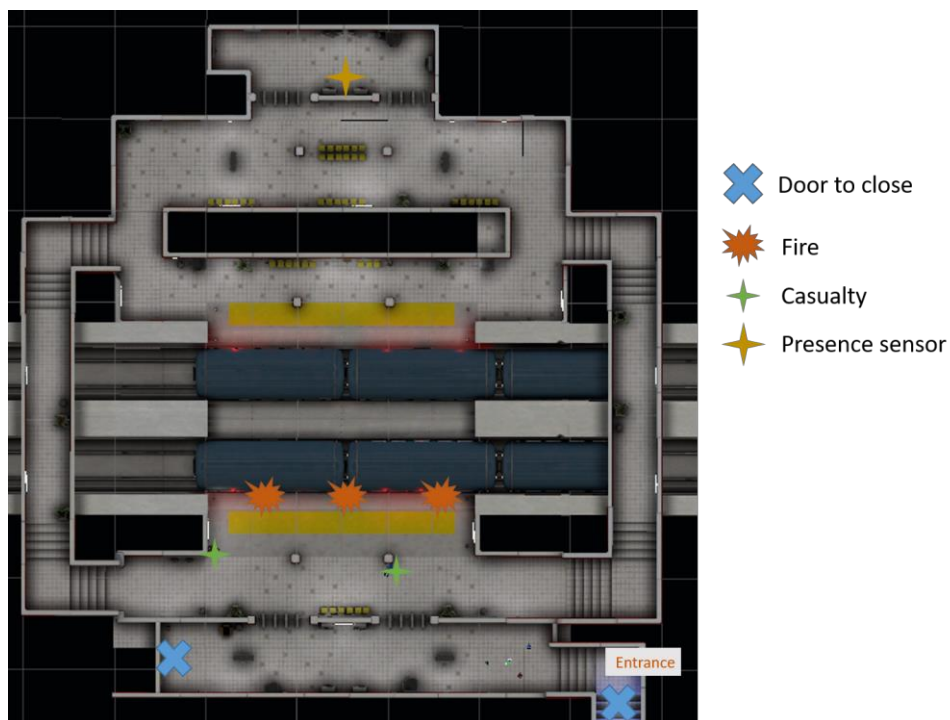
At 9:00; on the 16<sup>th</sup> of January 2020, a fire declared in the Madeleine metro station. Three fire starts have been reported, as well as two casualties. The station has to be evacuated, and a security perimeter must be set up. Three actors are going to be sent on the field to deal with the crisis and stabilize the situation before sending reinforcement: a fireman, a medical doctor, and a policeman.



**Figure 2: Madeleine metro station in the virtual environment.**

Two versions of the scenario are going to be played. The first one with no link to R-IO Suite, and the second one linked with it.

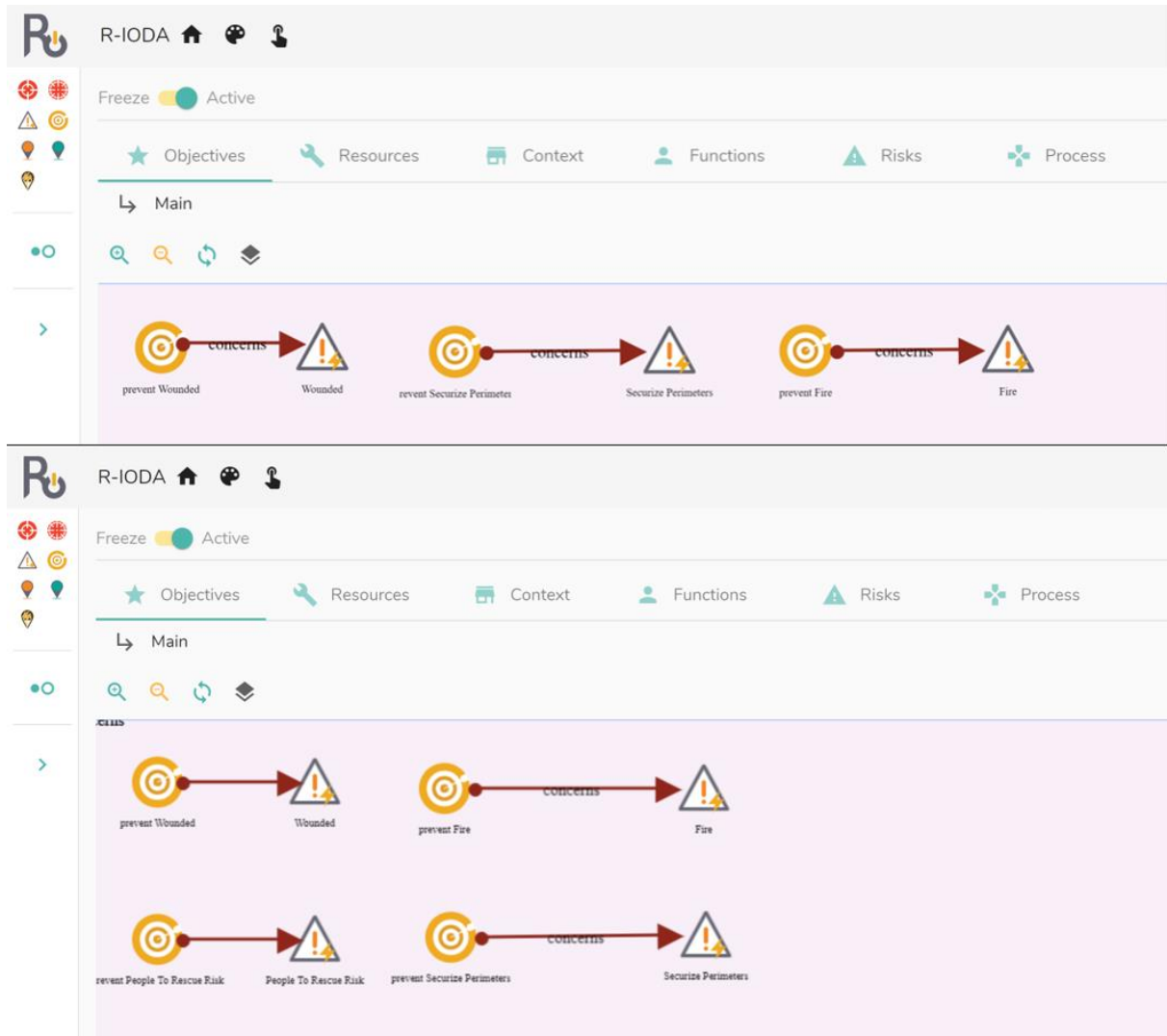
When we ran the first exercise, a briefing was given to the three players. Each of them was informed of the situation as described above and given a task to perform to solve the crisis. The fireman is to extinguish the fire starts, the medical doctor is to evaluate the state of the casualties, and the policeman is to close the access to the station to prevent people from coming in. Each of them also has access to a specific tool depending on the task they must perform: a fire hose for the fireman, a first aid kit for the medical doctor, and barricade tape to place on the entrances for the policeman.



**Figure 3: Plan of the metro station in the initial state of the scenario**



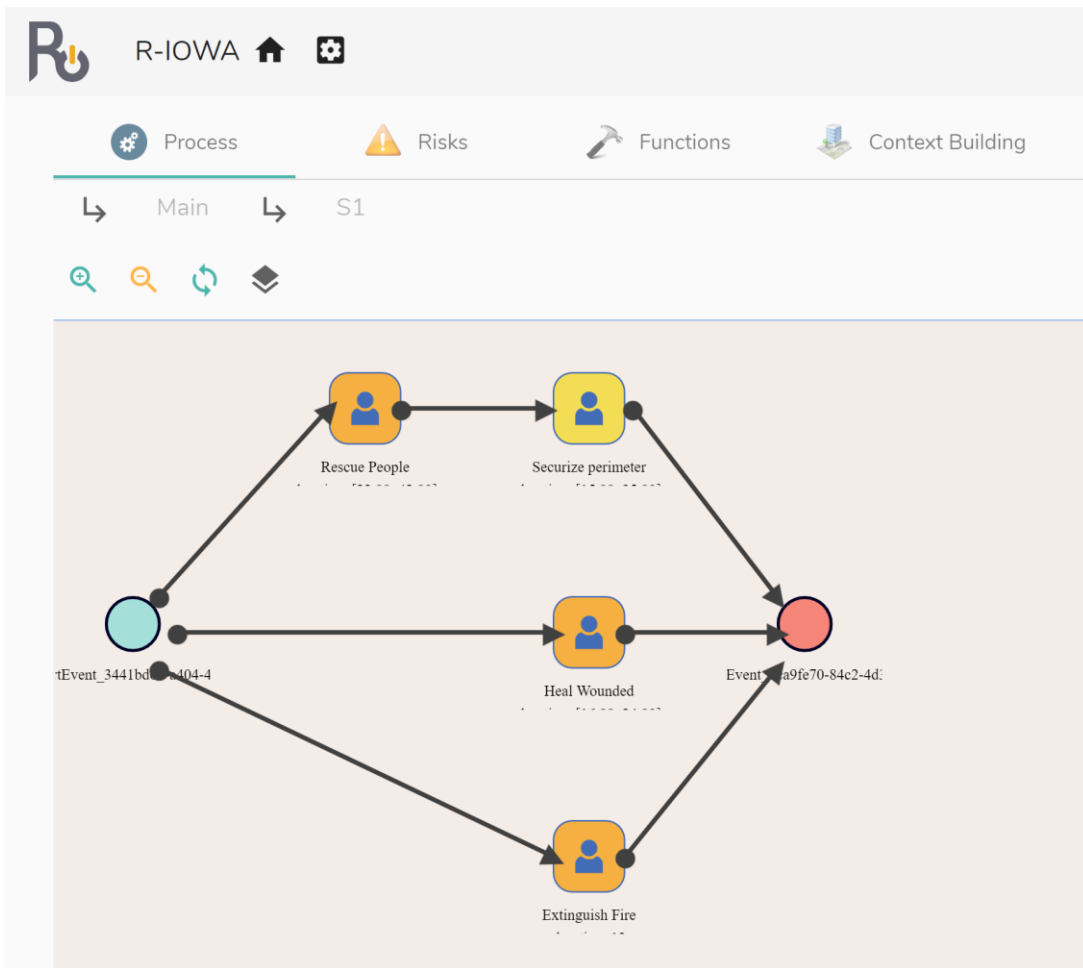
The second version of the use-case is played linked with R-IO Suite. Before the beginning of the exercise, the knowledge database of the platform has to be filled in. The available partners (fireman, medical doctor, and policeman) are registered along with their abilities. The context and objective models are also completed: the context is the metro, and the objectives are the ones identified before (extinguish the fire, heal the casualties and secure the perimeter). The platform is connected to virtual sensors that send data to analyze. Among them, one presence sensor detects a movement on the second platform of the metro station. From this, R-IO Suite deduces a new objective: someone or something is there, it has to be checked.



**Figure 4: Comparison between the objective model before and after the analysis of the data from the presence sensor.**

From those models, the decision-support platform deduces a response plan to the crisis. This plan is presented as a BPMN process that can be modified if needed. In this exercise, we decide not to change it, and to deploy it. The process is shown in Figure 5. Each line corresponds to an actor and shows the tasks that he will have to perform. The first line corresponds to the tasks attributed to the policeman. First, he will have to go check the presence detected by the sensor on the second platform of the metro station, then he will have to secure the perimeter. The second line is for the medical doctor, whose only task is to deal with the wounded. Finally, the third line is for the fireman, who has to extinguish the fire. For now, all those tasks are orange on the platform. This means that the process has been deployed, ready to be played, and waiting for an update from the actors on their first tasks.





**Figure 5: Process deduced by the platform to solve the crisis.**

Each actor, now evolving in the digital twin of the metro station, has a virtual watch (which could be replaced by smartphones or connected watches in real life) on which their first task had appeared (Figure 6). This replaces the briefing needed without R-IO Suite. Thanks to this virtual watch, the actor can access all available information about the task he has to perform. It also allows them to indicate that they are done with a task. The information is sent to R-IO Suite, and the process goes on: a done task now appears in blue on the process page, and a new task is sent to the actor if its line is not over. Thanks to its first task, the policeman went to the second platform fast enough to find a child there, and deal with him.



**Figure 6: Virtual watch of the fireman**

### Technical aspect

This simple use-case is the first realized within the frame of the EGCERSIS project. Its objectives were to get familiar with the technologies and to provide proof that exercises in virtual reality allow realism and a sense of immersion. Besides, it aimed at showing that virtual reality exercises could also be used to determine the relevance of a tool for crisis management. The trainees are evolving in a virtual 3D environment built with Unity®<sup>1</sup>, in its version of 2019. It has the advantage of being mastered quickly and allowing you to build sufficiently advanced prototypes for research projects. Trainees interact with the environment through HTC Vive Pro®<sup>2</sup> virtual reality headsets and controllers. In this first scenario, the movement was achieved through teleportation, however, in the coming use-cases, we plan to use Kat VR®<sup>3</sup> omnidirectional treadmills.



**Figure 7: Avatars of the other players as seen by the fireman.**

One of the main difficulties encountered with the implementation of this scenario was to deal with the multi-player aspect. The different trainees are evolving in the same environment, and they can see each other, as shown in Figure 7. However, for now, they can't cooperate yet. We used Photon Network®<sup>4</sup>, for its advanced state of game customization and connection between users. This system uses its own hosting network, preventing the users from having to deal with panels of configuration to be deployed to be together in the virtual world. In this case, all the players were in the same room (Figure 8), however, it is not mandatory and they could have been at different places or different countries.



**Figure 8: Players equipped with controllers and headsets, on the Kat VR treadmills.**

<sup>1</sup> <https://unity.com/fr>

<sup>2</sup> <https://www.vive.com/fr/product/vive-pro/>

<sup>3</sup> <https://www.katvr.com/>

<sup>4</sup> <https://www.photonengine.com/>

Steam VR<sup>5</sup> allowed us to quickly deploy virtual reality for playing in a virtual environment. This technology is polyvalent, and adapt to various virtual reality equipment. We choose non-wired HTC Vive Pro<sup>®</sup> for their digital rendering and lightness.

To achieve multi-playing in this scenario, several links had to be implemented. They are presented in Figure 9. First, an executable is implemented in Unity<sup>®</sup>. Data on the position, moves, and actions of the player are sent to Photon<sup>®</sup>. Photon<sup>®</sup> hosts the game and sends the data to the other players. The information about each player is sent to all the other players at any time.

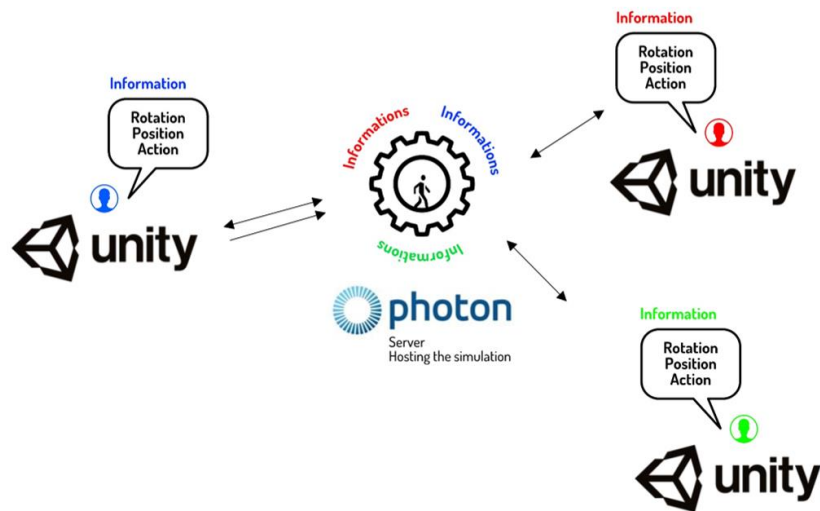
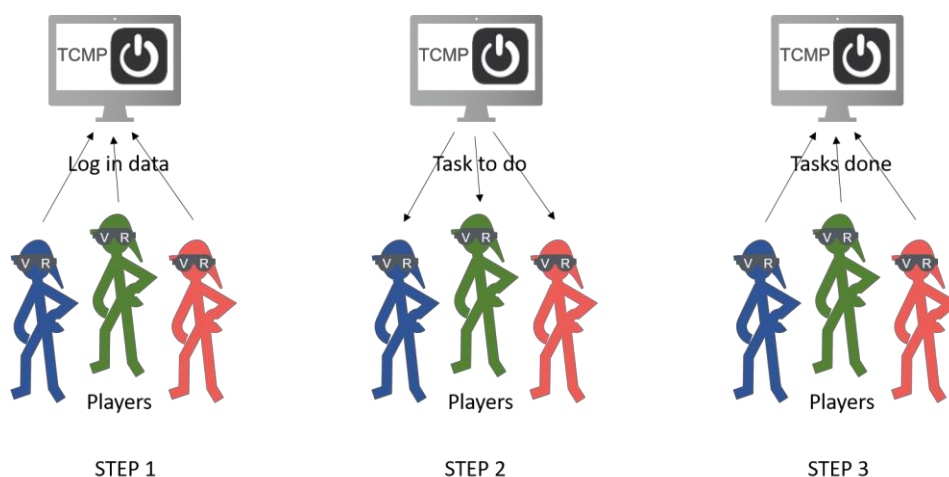


Figure 9: Architecture of the multi-player aspect.

Finally, the virtual environment had to be linked to R-IO Suite. The process, summed up in Figure 10, is the following. Before starting the exercise, each player needs to be connected to R-IO Suite server when launching the simulation with their roles, sending their IP address and other information. The aim is to send and receive information in real-time. Each information sent or received is in the JSON format, which enables a common programming language between the different users. And when all of the users are in the virtual environment, R-IO Suite will send tasks' information to the player to whom it is attributed. For example, the firefighter will receive the task of extinguishing fires, with information such as the type of fire, its sources or even its location.

We call the objective a "TO DO" to ask the person to realize their task. When the player has done it, he has to inform R-IO Suite and can push on a button linked to its TO DO and send the message "Task Done". R-IO Suite reloads its process and sends the next task.



NB: steps 2 and 3 are to be repeated as long as there are tasks to do.

Figure 10: Links between R-IO Suite and the virtual world

<sup>5</sup> <https://store.steampowered.com/steamvr?l=french>

### Analysis of the exercise

In the first scenario, it is easy to miss the child because we can't see him from the first platform of the metro station. It is necessary to look for him to find him. Of course in a real crisis, the responders would probably have searched the whole station to make sure that no one would remain anywhere, however they could have arrived too late where the child was. Thanks to R-IO Suite, it is impossible to miss it since it is a whole task of the process to go and check the place.

Thanks to R-IO Suite, the sorting and analyses of the data are quick and thorough and lead to a proposal of a response plan to solve the crisis. This process can still be reviewed and changed by the crisis managers and can evolve as the situation evolves. The idea is not to explain their job to the responders, but to help them find the best way to act collaboratively to solve the faced crisis: it is about coordination and not interfering. Thanks to the virtual watches, each actor receives a notification of its tasks, following an order determined by the priority of each task. This will allow reducing the time taken to brief the actors and quicken the response to the crisis.

Another great advantage of R-IO Suite is to be able to follow the crisis in real-time. On the one hand, the crisis management cell can follow the completion of the tasks, and so determine when the situation is under control enough to send reinforcement, or it can decide that the resolution of the crisis takes too much time, and decide what to do. On the other hand, the tracking assistant will keep on analyzing the data from the field to compare the real situation with the situation as it should be if the process was strictly followed. This will enable a quick reaction to any difference, with the deduction of a new process and new tasks sent to the actors if necessary. This will speed up and improve the agility of the crisis response.

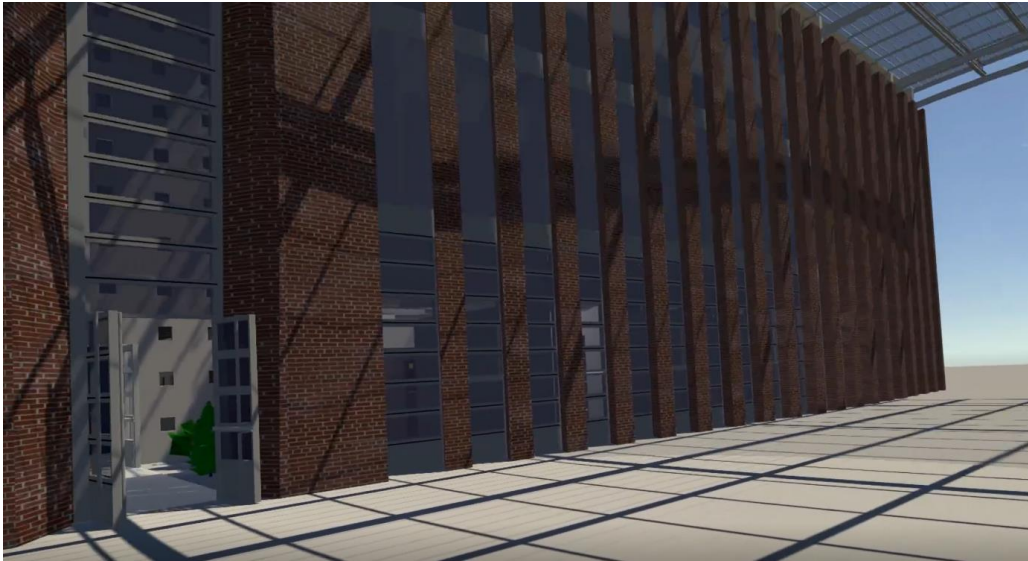
This first virtual exercise, intended as a proof of concept, is very simple. Of course, the process could have been deduced without the help of R-IO Suite. In a real crisis, the child would probably have been found anyway, and the repartition of the tasks was pretty obvious. However, in a much more complicated situation, with dozens of actors, several different agencies, each of them with their communication and decision-support tools, with a more complex geographical context and more casualties or risks to the population, it will be important to have a tool capable of dealing with all the information and propose a relevant course of action, taking into account the strengths and weaknesses of every actors, and prioritizing the tasks to limit the number of casualties (both human and material).

### NEXT STEPS AND CONCLUSION

The approach presented in this article aims at using virtual reality to improve the efficiency and relevance of crisis management exercises in critical sites. It allows access to a fully-configurable crisis, in immersive and realistic conditions. It also enables the interfacing of the exercise with emulated or real tools, to decide their relevance in crisis management, as we have done with R-IO Suite. Comparing the outcomes of the exercise with and without the tool can highlight its usefulness or uselessness. Finally, training in a virtual environment instead of just theoretically will improve the assimilation of practices and procedures.

We are still at the beginning of the project; however, we will need to be able to evaluate the improvement allowed by training in virtual environments. We want to measure the evolution of the responders' efficiency after those training: will it be significantly improved; will the presented virtual watches prove to cause attention deficits or misplacement?

The use-case presented in this article is very simple. Our ambition, through this project, is to propose several other use-cases, more and more complex, to prove our points. First of all, we want to further improve the realism of the user's experience. Several actions are intended to do so, the first of them being to transpose our fictional scenario into actually existing buildings. We already have a digital twin of our university's lab, in which we plan to train the security teams of the university (Figure 11). To do so, we are working on a scenario with the security team of the university and with the firefighters of Albi. Several other companies' digital twins will follow.



**Figure 11: Digital twin of our lab**

We are also working on the implementation of the scenario editor that will enable the managers to adapt a crisis scenario in real-time, to make it fully adapted to the training needs. To do so, we want to make it possible for the scenarist to drop new objects or new crisis elements (fire starts, casualties, block a door; change the weather conditions...) in the scene while the scenario is being played. Those new conditions and evolution of the situation will have to be taken into account by R-IO Suite to change the response plan if needed. An important aspect of achieving realism in the exercise is to get the best digital twin possible of the critical site. To do so, we plan to set up a formalized protocol to digitalize the sites. We also want to increase the users' interactions with their environment and co-players. So far, multi-playing is reduced to evolving in the same environment and being able to see each other. We want to make collaboration and cooperation possible, for instance lifting a casualty in a stretcher would only be possible with the efforts of two people. We also want to enable interactions with the environment, with tools or objects, on non-player characters that could be passive (wounded) or active (crowds, malevolent actors, terrorists or agents whose naive actions have to be taken into account...).

To make our scenarios more complex and realistic, we will need to improve the way they are built. The use-case presented in this article was built following no particular structure or procedure. We could add an underlayer to the scenario editor, using, for instance, the Analytic Decision Game framework, presented in (Graham and Stephens 2018; Kretz et al. 2012), to create more realistic, challenging, engaging, and adaptable scenarios.

Beyond the training environment, we also want to provide crisis managers with a virtual piloting environment, dedicated to situation awareness and decision-making. Our idea is to provide a virtual and real-time twin of the crisis, where crisis managers will be able to see what is happening and will have the ability to safely walk into the crisis if they need to. Zooming in or out of the site to get multiple points of view will improve situational awareness and thus decision-making. We also want to further explore the ability of virtual reality to go beyond reality, to offer better tools for data visualization and decision-support, making abstract concepts and information concrete and almost touchable.

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