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D1.3: Human Swarm Interactions Requirements

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Version	1.0
Status	Final
Date	2010-March-6th

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1. Introduction

This deliverable summarizes the essential human swarm interaction requirements identified along the Guardians project. The provided material elaborates on partners' experiences during the development of human swarm interfaces, along with firefighters.

Two types of human-swarm interaction modalities are addressed: (i) proximate interactions related configuration and requirements, and (ii) remote human-swarm configuration related requirements.

Section 2 introduces the notion of "Human Swarm Interaction" (HSI), compared to the more usual and more general HRI notion.

Section 3 introduces the major aspects of firefighting activities and related impact regarding interaction with robotics systems, and swarm in particular.

Section 4 focuses on direct / proximate human (firefighters) swarm interaction requirements.

Section 5 then focuses on remote human (firefighters) swarm interaction requirements.

Then section 6 gives the conclusion of this deliverable.

2. Human-Swarm Interactions (HSI) vs. Human-Robot Interactions (HRI)

Human Swarm interactions address the specific systems where one or several human beings interacts with a swarm of robots instead of just a single (or a few) ones.

Deliverable D6.1.1 presents a scheme analysis of the human-swarm interaction for the GUARDIANS project. Two important points applicable for defining human-swarm interaction requirements can be derived from this document: *human-robot interaction (HRI) taxonomy* and the *scenario analysis*.

The HRI taxonomy provides us a guideline in defining some issues related to interaction between the firefighters and the robots.

There are three aspects that separate HSI from HRI: robot team composition, ratio of people to robot, and collectivity. In HSI, a human interacts with a group of robots which are usually homogeneous. This requires non conventional way of how human and robots interact due to limitation of both sides. On one hand, human has limited capability of processing information generated by robots. Here, information can be exchanged as direct or indirect communication. One example off indirect communication is through the behavior of the robots. On the other hand, current technology restricts the capability of the robots to receive and perceive information from human. The situation is worsened by the environment condition where the interaction takes place, in our case warehouses in fire.

The following are some important aspects for designing HSI:

- The ratio of people to robot: whether the system is design to allow different number of parties and whether it can be switched during runtime.
- Collectivity: how the message from robots to be treated by human and vice versa. Whether one message applies to the group as a whole or only to one particular individual.
- Human-Robot physical proximity: collocated interaction has different requirements from remote interaction.
- Human-swarm relative position/bearing: the interaction of the human with the sub-swarm in the front can be different with the interaction with the sub-swarm in the rear or other relative position.
- Synchronicity: whether every message needs immediate answer or one way message is enough. If both applies, when one should be used.

- Duration & intensity of the interaction: human has limited cognitive ability in processing information. Hence, care must be taken in designing an interface for human-swarm interaction.
- Modality: how the message can be effectively conveyed considering the duration and intensity of the interaction.

3. Firefighting context considerations regarding interaction with (swarm of) robots

During an incident, firefighters have almost no visibility and can only rely on their touch and hearing senses, which are themselves quite restricted. Touch is restricted by their protective clothing and equipment, and hearing is impaired by the breathing apparatus' sound and ambient noise.

In such circumstances, firefighters distinguished the following activities that could be assisted by swarm of robots:

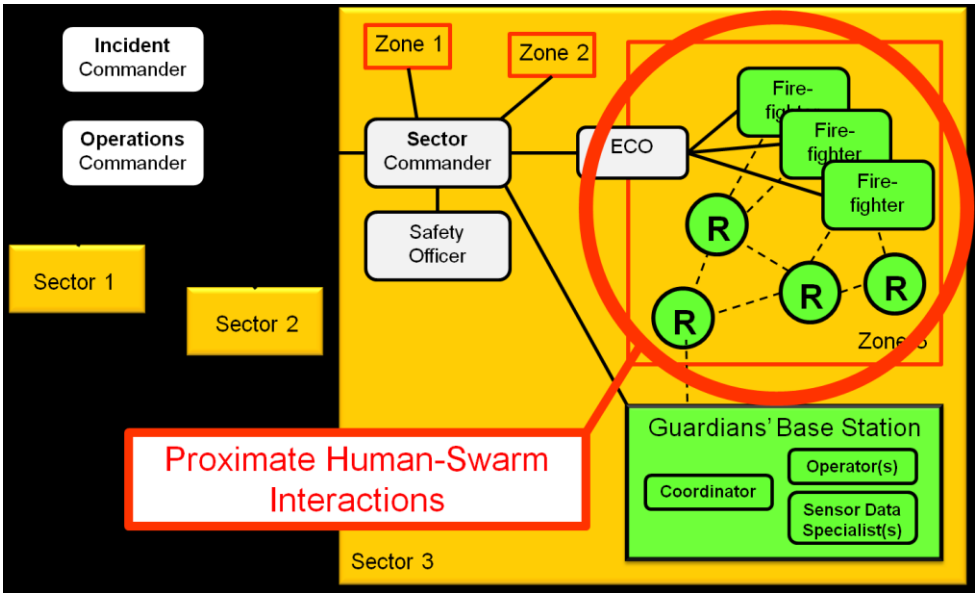
1. Notifying firefighters about possible hazards (e.g. obstacles, high temperature, chemicals);
2. Indicating unambiguously the direction to the incident location or backwards to the exit point;
3. Also, it is important for firefighters that the swarm stays within a relatively close range to them but also maintains its distance to the firefighters to allow them freedom of action.
4. Cooperatively indicating the position of the firefighter to the base station.
5. Keeping an active communication link from the base station to the firefighter.

In addition, due to high work-load during operation, the firefighters indicated the importance of maintaining needed interaction between firefighters and the robot swarm as minimal as possible. Therefore, most of the interactions should be designed to be high level to ensure convenient interaction.

In general firefighters can have two roles: team mates or bystander. As team mates, firefighters work cooperatively with the robot swarm in achieving the goal, e.g. explore the incident area, search for victims, detecting potentially-hazardous materials, etc. As bystander, firefighters have no control over or event interaction with the robot swarm, which can be the case when the people at the base station directly control the swarm for some particular task and the firefighters will just have to watch or monitor the performed task.

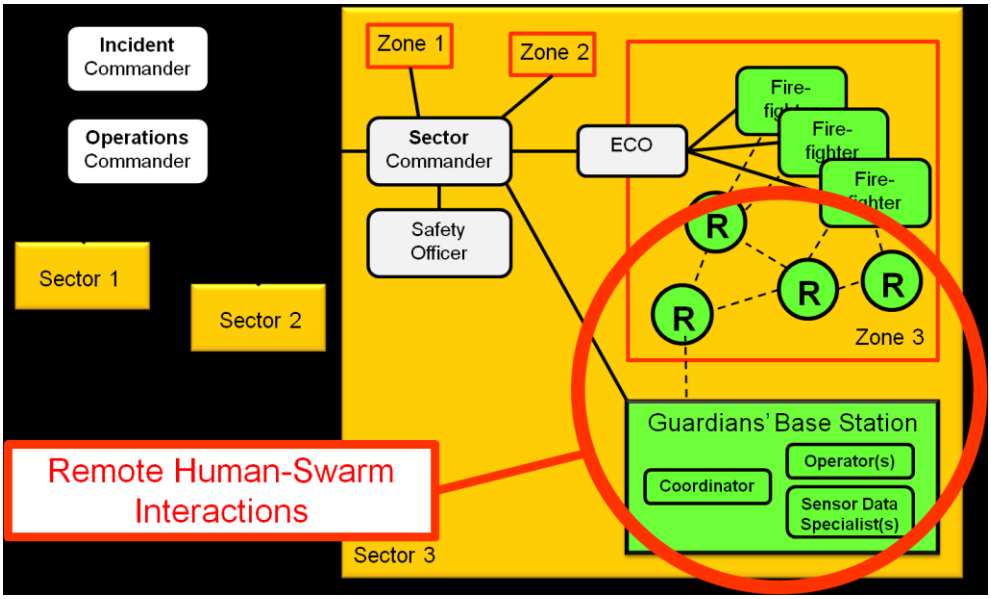
Overall firefighting working conditions and operational context are further detailed in the User Requirements document, aka. D1.1/2.

We depict below the organization of a Guardians squad, and how the robot swarm in one hand, and the base station providing remote interaction means in the other hand, can articulate along with the usual (SyFire brigade's) firefighters organization. Note: ECO stands for "Entry Control Officer".



In the case of proximate interactions, the focus is on how on-field firefighters can jointly operate and interact with the robots swarm.

Figure 1: Proximate Human-Swarm Interactions in Guardians



In the case of remote interactions, the focus is on how firefighters staff can remotely monitor and control the overall joint operations of on-site firefighters crew.

Figure 2: Remote Human-Swarm Interactions in Guardians

4. Human swarm proximate interaction requirements

4.1 Preliminary considerations for human swarm interaction requirements

A number of aspects shall be taken into consideration during the requirement analysis of collocated human swarm interaction (i.e. proximate interactions):

- How the information from robots should be provided:
  - Embedding information on actual vision (augmented reality)
  - Proper use of text/symbol
  - Proper use of color and symbol/text size
  - Proper use of animation for emphasizing information
  - Audio feedback (and how not to interfere in communications with team mates)
  - Tactile feedback (what device, where)
- How messages from humans should be conveyed to the robot
  - Modality
  - Collectivity: one message sent to all robots, or sent to a single robot that organizes with other robots
- Where is the interface best located
- Psychological effect of being surrounded by robots
  - How to know that the robot group is properly working (metrics?)
  - How to know that one or several robots have failure (is it actually convenient?)
  - How the change of information be interpreted or be used a form of indirect communication?

4.2 Experimental setup and lessons learnt

The conceptual design for direct HRI was to ensure that the robot behavior and human robot interaction represented a minimal additional mental and/or communication load for firefighters.

Based on this, the conceptual model of the firefighter being treated as an exceptional swarm member was developed. The exceptional features being the predominance of the firefighter in terms of autonomy, skill and authority. In terms of interaction, this meant that the robots will in effect be in surrounding of the firefighters and move with them.

The swarm of robots determines a direction that firefighter has to follow taking into account the firefighter position, the position of possible obstacles that have to be avoided and the destination position. Whether assisting or leading, the swarm of robots should in general not increase the navigation related load (physical or cognitive) of a human being (see V. et al. [2006]). In cases where the robots identify hazards or specific safe routes they provide information for the firefighter to employ and act on at their discretion. This conceptual model of HRI for swarms presents some questions about how to inform the firefighters about potential hazards and potential safe routes to follow during the activity of firefighting. In formulating the problem the firefighters were consulted and shown likely or possible configurations using a simple display desktop based prototype. The prototype simply illustrated possibilities and also animated the intended robot operations through a number of animated storyboards (in e.g. MS Powerpoint).

Through this consultation a peripheral visual display was chosen as the most appropriate means of helping direct firefighters. A simple operating hardware prototype was then developed to enable experimentation with alternative means of helping direct firefighters (see Fig. 10).

Based on a swarm recommended direction, the firefighter's pose and direction is calculated and presented to him using the light array. Two key alternative approaches to visually depicting directions to the firefighters have been considered: (i) an analogical view where the light array is used to depict a direction directly, and (ii) a logical view where the light array is used to portray encoded commands to the firefighter.

Figure 3: LAV1 – analogical prototype setup

Figure 4: LAV2 – digital prototype setup

The overall design and feedback from experience with end users are documented in D6.1.1/2, D6.1.4 and D6.1.5.

4.3 Human-swarm proximate interaction modalities recap

The different types of interaction modalities have been analyzed earlier in the project. The table below provides an overall description of possible human-swarm proximate interaction modalities in the context of Guardians, and comments on how it could be (or have possibly been) implemented in Guardians, along with foreseen associated tasks / interaction situations.

Interaction	Type	Priority	Installed	Availability	Possible tasks
Robot → Human	Visual	Mandatory	Fire fighters' helmet	Visual devices (e.g. LED light and small LCD displays) installed on the fire-fighter helmet can be used at any visibility level.	Displaying direction to the fire fighters. Visual warnings, for example when the temperature is extreme or a certain gas has been detected
		Optional	Robots	Devices installed on the robots can become unavailable as the visibility level reduces in an incident.	
	Audio	Optional	Robots	Audio devices are installed on the robots and can become less noticeable in noise polluted incidents.	Alarming fire fighters by using a high frequency siren
	Tactile	Mandatory	Fire fighters' gear	Available	Notifying fire fighters with possible surrounding hazards.
Human → Robot	Passive	Mandatory	Robots	Ultra-sonic and Infrared sensors can be installed on the robots to monitor fire fighter's movements.	Robots have some level of autonomy which enable them to adopt their movement in accordance to the

				Such sensors are available for any level of visibility.	fire fighters
	Visual	Not recommended	Robots	Cameras installed on robots can not be used due to the low visibility of incidents	It could be used in recognising visual gestures made by fire fighters in form of a sign language
	Audio	Optional	Robots	Audio devices on robot can be available in incidents with low level of noises	The audio devices could be used to recognise voices of other possible human beings in the incident. E.g. words such as “help”
	Tactile	Mandatory	Fire fighters' gear	Available in form of a tangible buttons easy to use for fire fighters	Assign the swarm to direct the team to the exit point in event of emergency evacuation

4.4 Human-swarm proximate interactions requirements

We provide below a list of selected, essential human swarm **proximate** interaction requirements we identified, both as a result of the formative feedback we received during interactions with firefighters, and from our own experience while designing, implementing and experimenting prototype devices for proximate human-swarm interactions in the context of Guardians. The criticality has three level: either Mandatory (M), Desirable (D) or Optional (O).

Requirement Ref	Description	Criticality
PROX-HSI-1	An overwhelming concern shall be the predominance of the firefighter in terms of autonomy, skill and authority, over the robot swarm.	M
PROX-HSI-2	Whether assisting or leading, the swarm of robots should in general not increase the navigation related load (physical or	D

	cognitive) of the firefighters.	
PROX-HSI-3	Firefighters shall not have to worry about the health status of the swarm's robots. In particular, the redundancy of robots in the swarm shall result in avoiding critical degradation of the swarm capabilities in case of loss of a number of platforms. The degradation of the system's capabilities shall be graceful as the number of robots is decreasing.	M
PROX-HSI-4	In an extreme situation, even a small group of 2-3 robots shall be able to properly guide a firefighter out of a building, in e.g. emergency evacuation.	D
PROX-HSI-5	Main interactions should be designed to be high level, in order to ensure convenient interaction.	M
PROX-HIS-6	As far as navigation support is concerned, a strong preference was expressed by firefighters, on the basis of experiments, for simplistic and unambiguous direction indicators vs. more elaborated approach requiring interpretation of perceived indications. This preference shall be taken into account in the design of interactions, wherever possible.	D
PROX-HIS-7	The swarm operation concept shall be designed in such a way that collisions with (or from) the firefighters cannot happen.	D
PROX-HSI-8	Shall collisions with (or from) firefighters with robots of the swarm nevertheless occur, the mobile robotics platforms in the swarm shall be designed in such a way that such collision minimize risks for firefighters (e.g. robots shall not have sharp edges or extremities, etc.). This is an issue with a swarm of robots, as the firefighter cannot have a continuous awareness of all robots' locations around him, thus increasing the risks of collisions.	M
PROX-HSI-9	The robots of the swarm shall not, by their presence, locally induce additional risks for the firefighting interacting with the swarm. For instance the cumulated weight of robots in the swarm shall be such that it does not exceed, for a certain surface, the	M

	weight of a firefighter (to prevent damaged ground collapsing). Also, it is obvious that the robots in the swarm shall be shielded to warrantee that they can't generate e.g. electric static currents. Also, possible collisions between robots of the swarm shall never trigger sparkles or result in risky heat levels.	

5. Human swarm remote interaction requirements

5.1 Preliminary considerations for human swarm interaction requirements

Likewise proximate interactions, a number of aspects shall be taken into consideration during the requirement analysis of remote human swarm interaction:

- How the state of the robots should be displayed:
  - Collectively
  - Individually
- How messages from humans should be conveyed to the robot
  - Synchronicity of the message
  - Collectivity: one message for all or only one

5.2 Experimental setup and lessons learnt

In order to centralize robots' measurements and data, and to supervise the joint activities of the swarm of robots and the fire fighters, a remote monitoring and control station has been developed.

Several categories of base station users, with different operational / analytical skills, have to cooperate during missions. For that purpose three roles have been identified: *Robots Operators* (RO) are in charge of teleoperating the robots; *Sensor Data Specialists* (SDS) are in charge of supporting decision making through monitoring of science data; *Base Station Coordinator* (BSC) is in charge of the overall mission and users coordination during operations.

As a baseline principle, we decided to promote touch screen interaction methods. The HMI display inspiration comes from Ecological Interface Design (EID). The most noticeable way we applied Ecological Display recipes is through e.g. limiting the amount of potential eye catching points or areas in the GUI (and in particular the amount of gauges), and making as obvious as possible the status and characteristics of the robots in their environment, with a main area of the GUI representing in a synthetic way the contextually relevant robot information. The main operator's GUI is

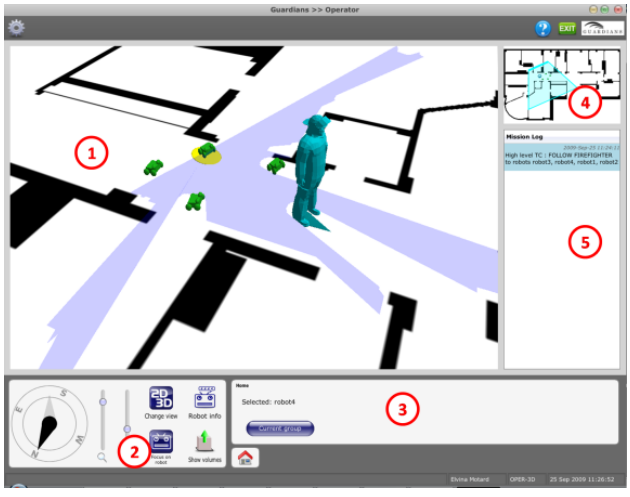


Figure 5: remote HSI baseline user interface

depicted above. Several areas can be identified: the main visualization zone (1), filling the largest screen space, provides with an overall, immediate understanding of the global situation in 2D or 3D; robots and firefighters are represented in their (known) environment. The viewport navigation (2) allows the user controlling different parameters of the main view. The operator actions area (3) includes a wizard to easily control the robots at a swarm level. The overall map view (4) helps understanding where in the overall space is situated the currently observed area. The mission log (5) displays notifications of essential events, either originating from the base station or from elsewhere in the system, during operations.

A number of Sensor Data Specialist concept views have been designed and implemented to support sensors data interpretation, and in particular temperature and chemical data interpretation. Below are a couple of such concept views, as an illustration:

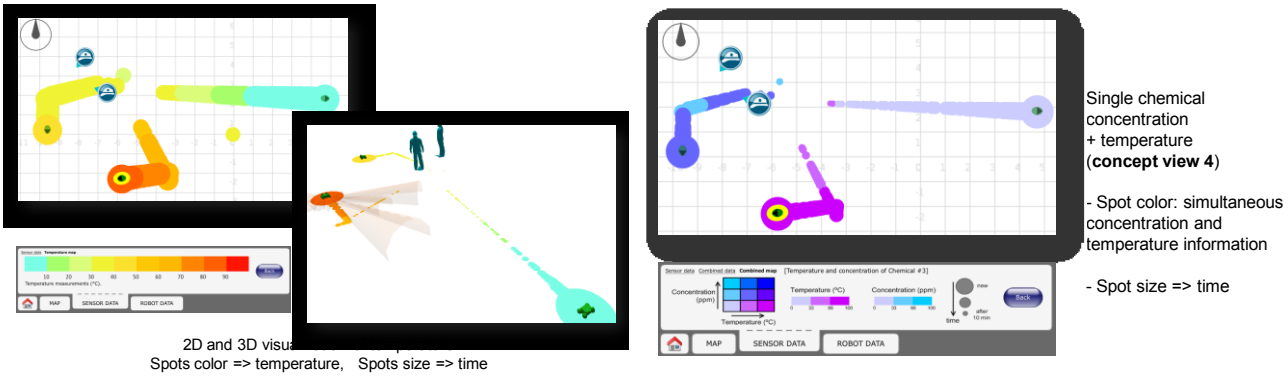


Figure 6: sensor data specialist concept views

The base station HMI has been evaluated through a process focusing on the identification of usability shortcomings that may hinder proper robots remote human swarm interactions from the operator role users. Evaluation results have been produced on the basis of tests carried out by experts and representatives of the Guardians end-user community. The focus of the evaluation so far has been on the operator role.

Three steps in the evaluation process have been carried out: early-prototype end-user test trial to gather qualitative user feedback, expert evaluation and formal end user usability evaluation session. Results confirmed a number of our design choices and helped fixing most shortcomings. These evaluation results are fully reported in D7.2. We summarize in the following some of the feedback we received:

- The mission log was considered a major component of the display: different users may need to be aware of the course of events, the status of performed actions by the robots swarm, and possibly other (outside) relevant information to point out. Moreover logged information shall be time tagged, as time is essential in successful fire fighting operations.

- The 3D representation was considered an appealing asset for training purpose, as it would allow trainers and trainees to better visualize and apprehend reference situations, thus improving the common understanding of a given situation. In the same way, such representations would be extremely useful in briefing a fire fighting brigade or team on the mission to be performed, prior to mission execution. Thus an offline use was stressed first, although an online use was also considered positively.
- Programmable alarms / alerts, according to particular states of the system was also suggested: this may e.g. rely on the perceived chemicals, temperatures, remaining time, fire fighter / robots health status, etc. Alarms would result in flashing (and/or sound based) messages.
- It was interesting to note that the proposed layout / disposition of the GUI components were not of paramount importance according to the interviewees: they claimed that they would learn how to make use of the provided interface anyway. We nevertheless still consider that the GUI layout has a strong impact on the experience firefighters can have, and thus on the overall performances.

5.3 Human-swarm remote interactions requirements wrap-up

We provide below a list of selected, essential human swarm **remote** interaction requirements we identified, both as a result of the formative feedback we received during interactions with firefighters, and from our own experience while designing, implementing and experimenting solutions for remote human-swarm interactions in the context of Guardians. The criticality has three level: either Mandatory (M), Desirable (D) or Optional (O).

Requirement Ref	Description	Criticality
REM-HSI-1	The remote human-swarm interfaces shall provide the means to simultaneously visualize / monitor all the (connected) robots of the swarm.	M
REM-HSI-2	The remote human-swarm interfaces should offer high level, *group* of robots policy options for setting the “behaviour” of sets/subsets of robots, such as “explore an area”, or “observe simultaneously a given target from different points of view”, or “follow the firemen” etc.	M
REM-HSI-3	The remote human-swarm interfaces shall offer the possibility to unambiguously monitor and, in a certain extent, to control *human squad members* activities on the field, in addition and in synergy	M

	with remote human-swarm interactions.	
REM-HSI-4	Remote interfaces shall have the means to provide, in a synthetic way, combined and pre-processed swarm sensors information. It's more interesting and convenient for firefighters to obtain high level, processed and cleaned information, than individual, rough robots sensors data. This shall be considered while designing remote human swarm interactions.	M
REM-HSI-5	The loss of a connection with (some) robots shall never result in unsafely operating the system: backup plans & solutions shall be available to cope with the any situation of communication loss with the robots of the swarm. The swarm behaviors shall be such that temporary communication loss do not impact essential functions, and especially those related to vital support to on-site firefighters crew.	M
REM-HSI-6	Although the main operational modality in remote HSI is to consider high level policy for the monitoring and control of the robots in the swarm, it is nevertheless recommended to provide means for individual robot "low level" teleoperation. This was deemed very useful in a number of situations, during experiments, and for the purpose of testing the system too during development phases and maintenance of the system.	D
REM-HSI-7	The chosen approach of decoupling responsibility of swarm monitoring and control (i.e. operator role) from the responsibility of monitoring specific sensors and interpreting data outputs (i.e. sensor data specialist role) proofed to be a convenient approach during experimentations. This actually resulted in lower cognitive loads for all remote users, and typically allows sharper specialization of the staff. This approach is strongly recommended.	D
REM-HSI-8	Scalability issue makes it unlikely to get all robots' telemetry all the time. Priorities shall be defined, focusing either on certain robots or group of robots in the swarm, and/or certain types of telemetry only, and/or certain quality of wireless communication.	M

	Nevertheless the remote interfaces shall have means to unambiguously inform users about which robots of the swarm are connected, active/transmitting telemetry (and which type). It shall moreover be possible for users to dynamically adjust the policy.	

6. Conclusion

Human swarm interactions have specific characteristics, that implies specific requirements considerations while designing those interactions. In this deliverable we report on the relevant experience we obtained during the Guardians project through both physical experiment setups and the involvement with (and formative feedback from) a number of end users, and in particular firefighters from SyFire, as far as requirements specification is concerned.

Both proximate and remote human swarm interaction aspects are considered and we accordingly identify and provide in this document a selected set of requirements that we consider essential for the design of human swarm interactions in a Guardians-like context, as a result of partners' experience.

We consider these requirements as applicable to other related field of applications involving human-swarm interactions, especially in harsh environment or applications, where the nature of the interactions is critical to the success of the operations and to the safety of human beings.