Deliverable 2.5.2

Final Innovation Platform Results

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Acronyms and abbreviations

Acronym/Abbreviation	Description
PPS	Personal Protective System
PPE	Personal Protective Equipment

Definitions

For the purpose of the project Personal Protective System (PPS) means: all parts of the equipment worn by an individual fire fighter including auxiliary elements and that protect the individual from hazards to his health and safety. All parts from head to toes and from skin to outer layer are included. This includes (non-exhaustive list) : Personal Protective Equipment (PPE), non PPE clothing, ICT hardware and software, data logging, monitoring sensors, warning systems, localization equipment, … Accurate monitoring and warning for both the individual fire fighter and the incident management are part of the PPS.

Executive summary

This project deliverable forms the **final report of the Smart@Fire innovation platform**, organized during the months September and October 2013. The final presentation of the gathered insights was held October 10th 2013.

To better protect firefighters, the Smart@fire project envisions the **next generation Smart Personal Protective System (PPS)**: an integrated system covering ideally localization and positioning, environmental sensing, body monitoring, data transfer and visualization for remote coordination, data interpreting intelligence, intuitive audiovisual feedback, smart textiles, etc. This report contains the elaborated results of the innovation platform discussion sessions with demand and supplier side, synthesizes **potential priorities for a smart PPS prototype** and defines next steps for the set-up of a pre-commercial procurement phase (PCP).

As the innovation platform manager, Addestino coordinated the entire Innovation Platform, facilitated the workshops, and stimulated the necessary interaction between the different stakeholders participating to the meetings by adopting a structured approach and methodology (e.g. guided discussions as regards content and thinking processes). The platform manager observes, gathers all information, and performs an objective assessment of the innovation potential.

The conclusions of the Smart@Fire innovation platform situate on three levels:

As first conclusion: a smart PPS is highly innovative for the end-users. End-users encompass different actors, the firefighters, intervention coordinating officer, PPS manager, etc. This is proven by the high amount of "WOW" use-cases, signifying a high added value compared to the present alternatives today. Next to that, these needs are common across European firefighters as high commonality is noted between the distinctively consulted user-groups across Europe through in-depth working sessions and via the survey. Primary user requirements hold:

- **Localization** of the firefighter and his team, in buildings and open areas, displayed on a **map**, made available to the firefighter and the intervention coordinating officer.
- **Remote parameter monitoring and historical logging**, making the info accessible via an **intuitive dashboard** for the officer (e.g. a map), enriched with the status of the team, their PPS, and the environment, enabling to set thresholds, generate (automatic) alerts.
- Monitoring the environment, more in particular **temperature, temperature evolution, hotspot detection and presence of explosive gasses**.
- Specific PPS requirements as: **avoiding sweat being turned into steam** inside the turnout gear and **active illumination** to be seen as first responder.
- General requirements as robustness under mechanical friction, maintenance, repair, cleaning, with easy mounting/dismounting of the ICT and ideally with self-assessment.

As second conclusion: a smart PPS holds a high innovation potential from technological perspective. This innovation potential is identified across the different angles of a smart PPS, in line with the key user requirements, listed below:

- Focus area 1: ICT localization systems embedded in PPS
- Focus area 2: PPS sensors/active subsystems and their integration in smart textiles
- Focus area 3: ICT solutions for remote connectivity & visualization systems in PPS
- Focus area 4: Integration of ICT solutions with textile

Putting these angles together, the overall innovation potential of a smart PPS results in a number of clustered challenges, of which 1 principal and 4 smaller, summarized below

CHALLENGE 1: PPS backbone

The backbone architecture:

- Communication network with sufficient indoor penetration and near real-time update rate towards the intervention coordinating officer
- Trade-offs between distributed and central processing, scalability of system, local performance vs. remote responsiveness (online vs. offline operation), interfaces, etc.

Limited integration with textile (underwear, turnout gear):

- Woven-in, layered-on ICT-textile integration comprises too many risks w.r.t manufacturing costs, durability, etc.
- Cabled and/or wireless. When cabled: easy mounting/replacing of cables/connectors; durability of cables/connectors; dealing with different turnout gear sizes; integrating UIs. When wireless: limiting interference; easy start-up and self-assessment of correct operations via minimal # UI's
- Electromagnetic shielding of the different devices (sensors, processing unit,…), without implementing military-grade measures.

Localization engine:

- A hybrid localization system (preferentially GPS + inertial) with limited indoor drift.
- A relative track & trace map, enabling 'meet point' and 'recovery path' instructions. Available Cartesian coordinated maps (e.g. Google maps) used as overlay.
- Beacon-based solution at increased risk, principally fast & accurate deployment and TCO.

Intuitive user feedback (restitution, visualization):

- For the intervention coordinating officer: intuitive UI dashboard, conform way of working.
- For the firefighter: multimodal combination of audio, simple UI (button/lights) and haptic belt. Risk reduction on automated feedback modality selection and ergonomic use.

Coupling via defined application interfaces (e.g. Bluetooth application profile) with

- (Standalone) environmental temperature measurement device
- Optional, when available: (standalone), cheap, simple and robust explosive gas detector (e.g. indicating just the presence of explosive gasses)

CHALLENGE 2: Sweat absorbing multilayer underwear

A pure textile issue, needing lobby effort to enable reviewing tenders and firefighters' comfort balance (e.g. skin resistance). Note that it is not the goal to develop a new better performing sweat absorbing multilayer material, these materials exist. Underwear in this context reflects anything worn underneath the turnout gear.

CHALLENGE 3: IR thermal hotspot detector

Finding the balance between a cheap, miniature IR thermal imaging sensor/camera with relevant resolution and detection range in high temperature environments holds significant risk.

CHALLENGE 4: HMD/HUD firefighter visualization system

Providing visual feedback to the firefighter via helmet mounted displays (HMD) or head-up-displays (HUD) in the helmet visor holds major risks in balancing trade-offs between cost, ergonomic use (brightness, contrast, "see-through", etc.), robustness.

CHALLENGE 5: "BE SEEN" omnidirectional active illumination

Active illumination to achieve omnidirectional "be seen" could be simply solved via a cheap, standalone clip-on/Velcro system (limited integration with textile). The risk is to make it usable to allow for easy operation (somewhere fixed on the firefighter suit), but not being destroyed in an intervention due to the increased temperature or mechanical friction. An alternative cabled solution impacts design and integration complexity (durability of connectors, cabling, etc.).

Note that explosive gas detection and physiological monitoring are not withheld within the innovation potential from technological perspective of a smart PPS, as for these building blocks mature technological solutions exist on or close to the market. It is not the goal to develop a next generation of better, smaller, cheaper explosive gas detectors or physiological monitoring devices. The real added value is the coupling with the PPS backbone, captured in Challenge 1.

As third and final conclusion, given the high innovation potential both in terms of added value for the end-user as in terms of risk from technological and implementation perspective, **significant research and development effort is needed to reduce the risks associated to the technologically innovative elements to enable the high-value use-cases for the end-users, firefighters and officers.** As today a commercial smart PPS is not available on the fire and rescue application market, it is recommended to initially launch a **pre-commercial development phase**. During this prototyping phase, focus is laid on reducing these risks with limited means.

In consensus with the end-users (i.e. firefighters and affiliated public procurement agencies), the priorities for the minimal prototype scope cover primarily CHALLENGE 1, **PPS backbone**, and CHALLENGE 2, **sweat absorbing multilayer textile solution.** Regarding CHALLENGE 3 and 4, the IR thermal hotspot detector and the HMD/HUD firefighter visualization system, it is recommended to dedicate a similar but different project to solving these. CHALLENGE 5, "BE SEEN" omnidirectional active illumination, qualifies to be withheld within the minimal scope of the prototype, but it is currently left out, taking into consideration the project budgetary and timing constraints.

Subsequent steps are basically setting up a detailed budget and timeline for the pre-commercial development phase (solution exploration, prototype development, first batch manufacturing). It should be noted that the minimal scope of CHALLENGE 1 and CHALLENGE 2 may equally result in one integrated or two parallel pre-commercial development tracks. Interested parties or consortia can submit an offer that covers the development of CHALLENGE 1, CHALLENGE 2, or both.

For a more detailed description of the pre-commercial development phase, evaluation criteria and testing procedures, reference is made to D3.1 "Tender Documents PCP".

Finally, Addestino wishes to thank the project partners and partners from industry and research centers for their expertise and enthusiastic cooperation!

0. Introduction

Innovation Platform Objectives

The Innovation Platform brings together the demand/buyer's side (the public purchasers which have a specific need or request) and the supplier's side (private companies, R&D organizations, Research Centers, Industry sector organizations).
The objective is to formulate a detailed answer on following key questions:

- What is the **innovation potential** of the project initiative from an **end-user perspective**?
  Is there any added value for the end-user? Which needs are being answered?

- What is the **innovation potential** of the project initiative from a **technological point-of-view**?
  What is achievable, feasible today, where are extra breakthroughs required?
  What are the potential implementation risks and challenges?

- **What are the priorities for a potential prototype?**
  *What is the **overall innovation potential**, both from an end-user and technological perspective?*
  The priorities for a potential prototype are those elements bearing a high innovation potential both from an end-user perspective, as from technological point-of-view.

- Given the prioritized broader scope of a potential prototype, which choices will be made to set the **effective scope and functional specifications of the prototype**?

Market consultation sessions

Based on the insights gained from the state-of-the-art research, a reference *architecture* was developed i.e. a representation of 41 capabilities derived from the use cases (see D1.4 for more info). Mapping the prioritized use cases and potential suppliers on this reference architecture resulted in 4 focus areas that are homogenous in challenge, use cases & potential participants.

- **Focus area 1**: ICT localization systems embedded in PPS.
- **Focus area 2**: PPS sensors/active subsystems and their integration in smart textiles.
- **Focus area 3**: ICT solutions for remote connectivity & visualization systems in PPS.
- **Focus area 4**: PPS integration

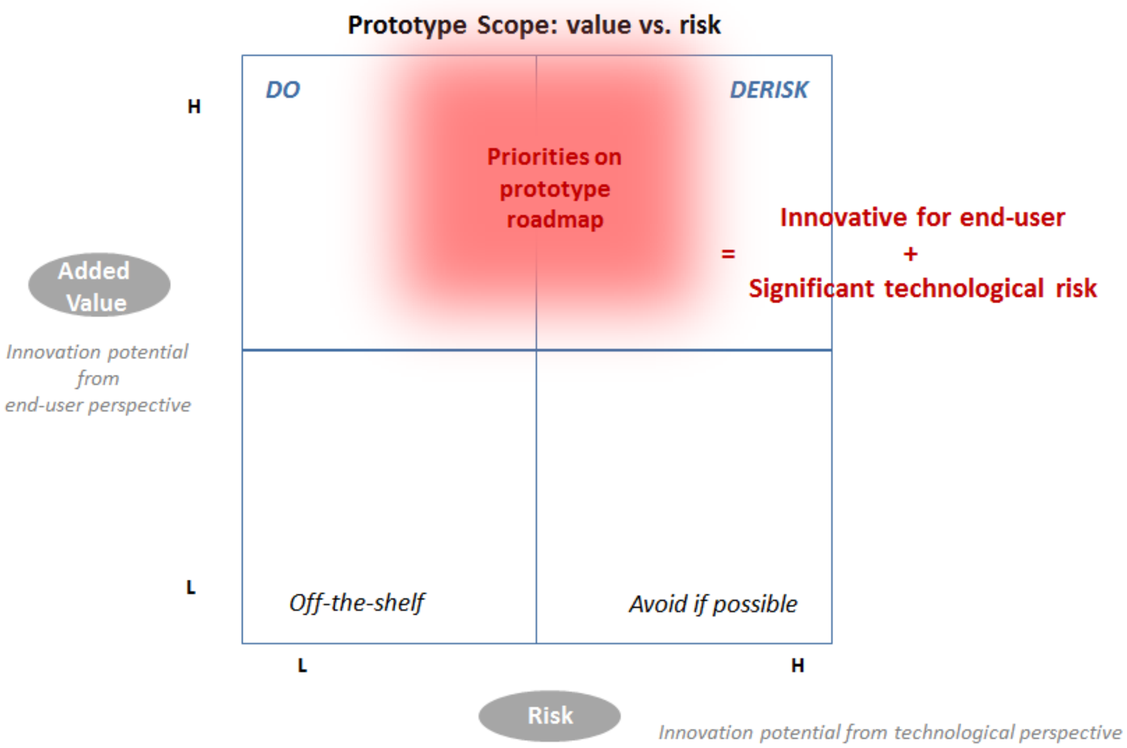
Sessions focusing on these areas will allow understanding the vendors' capabilities to satisfy the most important & commonly shared user needs. The common needs in terms of robustness & maintainability will be applied in all sessions as a boundary condition. If necessary, all constraints imposed by any of the procurers' countries (i.e. the minimum requirements set), will be taken into account in a similar way.

During these market consultation sessions, the *Planning Poker* methodology is used to assess the innovation potential from a technological perspective. The technique is based on domain expert evaluation and attaining consensus.

Added value vs. technological risk matrix

Based on the user needs assessment and affiliated prioritized use cases (D1.1, D1.2…), the value or innovation potential for the end-user of functional elements is determined. The discussions captured during the market consultation sessions will subsequently determine the actual stand of technology (what is feasible today) vs. the innovation potential from a technological perspective (where is risk reduction needed). The basis for the discussions during the market consultation sessions has been established during the preliminary state of the art study (D1.3, D1.4).

Both (innovation potential for the end-user, and innovation potential from a technological perspective) can be mapped on the following ***value vs. risk*** **matrix**:



The **scope of potential prototypes** focuses on those facets of a potential solution that deliver high added value for the end-user and bear significant technological risk, on which substantial de-risking needs to be applied before being turned into a commercially ready product or system.

1. Methodological instrument: Planning Poker

Planning Poker is a ‘best practice’ methodology to estimate e.g. added value, level of complexity, required implementation effort, risk. The technique is based on domain expert evaluation and attaining consensus. Used to estimate the implementation risk, the interpretation of the values of the cards becomes:

0	No worries, **of-the-shelf** standard solutions exist.
2-3	**A frequent problem**, potentially some hazardous cases, but certainly solvable.
5-8	**Significant attention, effort and risk reduction** required to be successful.
13	**Absolutely not a standard problem.** A solution requires important choices, thorough elaboration, and specific expert effort. Success can be achieved with significant time and effort.
100	**Impossible**, requires physical laws breakthroughs .
?	**Don’t know**, no experience with this subject.

2. Design constraints

- **Price of PPS:** Today firefighter turnout gear prices vary around 600-750€ per piece (i.e. vest, trousers). In line with budgetary provisions, the price of the envisaged PPS final system is expected to amount ~1500€ per firefighter PPS, including the turnout gear garment and excluding helmet, additional HW/SW (application servers, licenses, etc.) for the intervention coordinating officer.
- **Standardization and guaranteeing safety:** At all times the Smart@Fire PPS prototype should fulfill basic health and safety requirements. At PPE level these requirements are fulfilled through standard testing procedures. Standard testing procedures which do not necessarily apply (according to regulation) on ICT related products exposed to the same hazardous conditions.

  Therefore, in addition to the known standards and directives for PPE and for ICT related firefighting products and solutions, it is recommended that the conformity assessment procedure of the Smart@Fire PPS prototype describes a selected set of testing procedures, especially for those parts of the PPS that are exposed to the extreme conditions including potential cabling/connectors. The parts of the PPS system that are kept underneath the PPE are not exposed to extreme conditions. For intended use in these conditions existing standard procedures apply to test for operational temperature range, humidity level, etc.

  The mentioned additional tests can directly be derived from the most common standard tests used on fire fighter suits. Structured from relatively easy to fulfill towards more challenging, the Smart@Fire PPS as a system should be subjected to following tests:

Heat resistance	ISO 17493	5min at 180°C	No melting, no dripping, no ignition, remain functional, able to remove
Radiant heat	EN ISO 6942	40kW/m²	
Convection heat	EN 367	80kW/m²	
Flame engulfment	SCBA EN 137	…	

Whether the results of these tests should be used as knock-out criteria during the evaluation of the PPS prototype(s), is yet to be decided. At least the results should be known to the user community. As such this recommended testing procedure will be included in the pre-commercial procurement tender. Tenants will be asked to clarify their view on the conformity assessment procedure of the PPS prototype(s).

3. Functional requirements

- **Configuration of the PPS system:** different types of interventions require different functionalities (e.g. in a forest fire a lighter helmet and turnout gear is chosen/required), the system architecture should allow for flexible operation and configuration. 4 main configurations can be distinguished:
    - **Basic configuration:** localisation + remote connectivity + intuitive visualization
    - **Physio configuration:** localisation + remote connectivity + intuitive visualization + physiological monitoring
    - **Urban configuration:** localisation + remote connectivity + intuitive visualization + environmental monitoring
    - **Full functional configuration:** localisation + remote connectivity + intuitive visualization + physiological monitoring + environmental monitoring
- **Autonomy:** given that different types of interventions require different types of PPE according to norms (forest fire vs. urban fire in confined areas), a different set of functionalities is required (e.g. in forest fire no toxic gas detection or IR camera sight is required, only localization and communication suffice), and span different durations. A typical intervention in an urban setting with breathing apparatus takes 20 to 40min, depending on the intensity of the intervention in relation to the air volume in the bottle. In a forest fire situation, intervention times of up to 3 hours are noted in case of no excessive efforts, 1 to 2 hours in case of running. So in summary, the minimally required autonomy for the PPS system is about 2 hours when all functionalities are operational, and up to 4 hours in a forest fire configuration.
- **Weight:** Current firefighter turnout gear weight amounts around 25 to 30kg of which 3 to 4kg is due to turnout gear garment. The remaining weight covers boots, helmet, breathing apparatus, handheld illumination, water hose, etc. As a consequence the Smart@Fire PPS prototype should be kept as lightweight as possible striving to maximally add 1-2 kg, well balanced around the body.
- **Speed of deployment:** today's procedures aim to minimize the delay between the first alert arriving at the dispatch center and the arrival onsite. Typically during daytime (and in the case of an online brigade), firefighters are given 3 minutes to get in the turnout gear, receive short intervention briefing on location and situation, and gather in the truck. (At night time this is 5

minutes). The breathing apparatus, water hoses, etc. are kept in the truck. They remain fixed during transit, resisting shocks up to 10g. The aim is to arrive on site within 5 to 10 minutes, so the time to launch the PPS ICT system and reach the operational state is of the same order of magnitude (~10 minutes).

- **Refresh rate of data transfer** from the deployed firefighters in the field towards the remote intervention coordinating officer/command center is ideally performed in near real-time (~1Hz). This is considered sufficient to keep track of the firefighters' movements as firefighters in the field move at limited walking speed.
- **Accuracy of the localization system:** in open areas an accuracy of localization of about 3 to 4 meters is sufficient. In confined areas, a higher accuracy is requested up to 1m. In confined areas the aim is to find a victim, make a correct assessment whether a person is on one side of the wall or the other, etc. In case inertial or alike localization technologies are used, measurements should be updated at least at a 10cm interval or less.
- **Standard interfaces between wirelessly connected devices on the firefighter:** in case for example a firefighter is equipped with wirelessly connected environmental sensing devices (e.g. temperature, explosive gas detection), the communication protocol applied should be a known standard (preferably Bluetooth) with known application profile.
- **Lifecycle:** today the average lifecycle of PPE turnout gears is ca. 8 years (with variation between 2 to 14 years. The lifecycle of the additional ICT components in the PPS ideally corresponds to the lifecycle of the PPE turnout gear. (Standalone component of the PPS could possess a shorter lifecycle of e.g. 2-3 years).
- **Robustness under washing and exposure to specific substances** (in case the PPS holds functional building blocks which are exposed to the hazardous environment)
  - **washing procedures:** <details of washing procedure and expected results>
  - **exposure to chemicals, toxic gasses, etc.:** <details of test procedure and expected results>

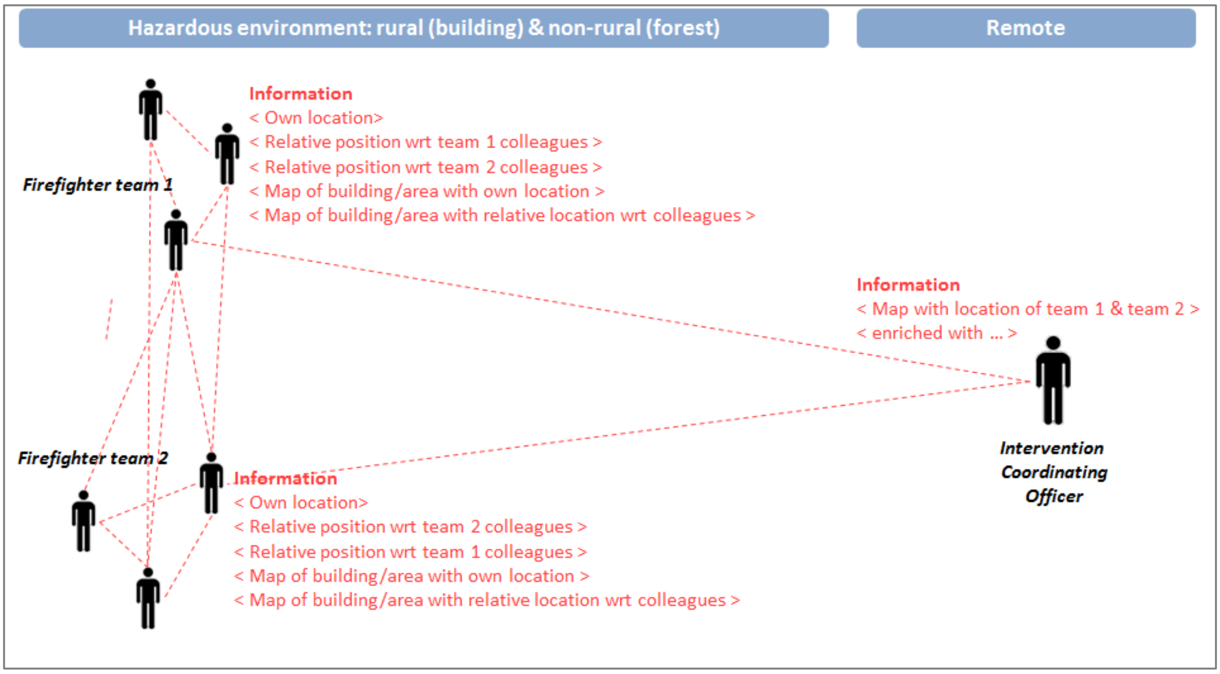
- **Test scenarios of the prototype:** <tbd by IBZ and SDIS13>

4. Focus Area 1: ICT localization systems embedded in PPS

1. Key use-cases to enable the innovation potential from an end-user perspective

Nr	As a...	I can... <do something>	so that... <value is created for me>
10	Firefighter	have information on my location and my relative position towards my colleagues	I know where to help colleagues; who can help me; where safe areas are; and to avoid that I would get isolated
12	Firefighter	receive a map of the building I'm in with my exact location (and my colleagues)	I can better navigate through the building
13	Firefighter	receive a map of the area (e.g. forrest) I'm in with my exact location (and my colleagues)	I can better navigate through the area
14	Firefighter	'see' the hotspots in my environment (e.g. with IR-camera)	I can have a better understanding of where the danger is located
25	Intervention Coordinating Officer	consult a map to locate my fireman	I can direct them in an accurate and safe way
26	Intervention Coordinating Officer	consult a map enriched with info about their body functions, health status	I can direct them in an accurate and safe way
27	Intervention Coordinating Officer	consult a map enriched with info about their environment (e.g. fire location)	I can direct them in an accurate and safe way
28	Intervention Coordinating Officer	consult a map enriched with info about their personal equipment status	I can direct them in an accurate and safe way
36	Trainer	use similar remote monitoring info as the intervention coordinating officer during training in controlled	I can make the trainees understand where and how they can improve
37	Department Head	have an aggregated view of all the remote monitoring info of all my teams	I can coordinate large actions during crisis situations
38	Department Head	have a historical logging of all important parameters	I can do a route cause analysis to improve my policies
40	Department Head	use the recorded parameters to create an audit trail	we can afterwards understand what really happened and prove everything happened conform policies

In short, the picture below summarizes which information should be made available to the intervention coordinating officer and the deployed fire fighter teams.

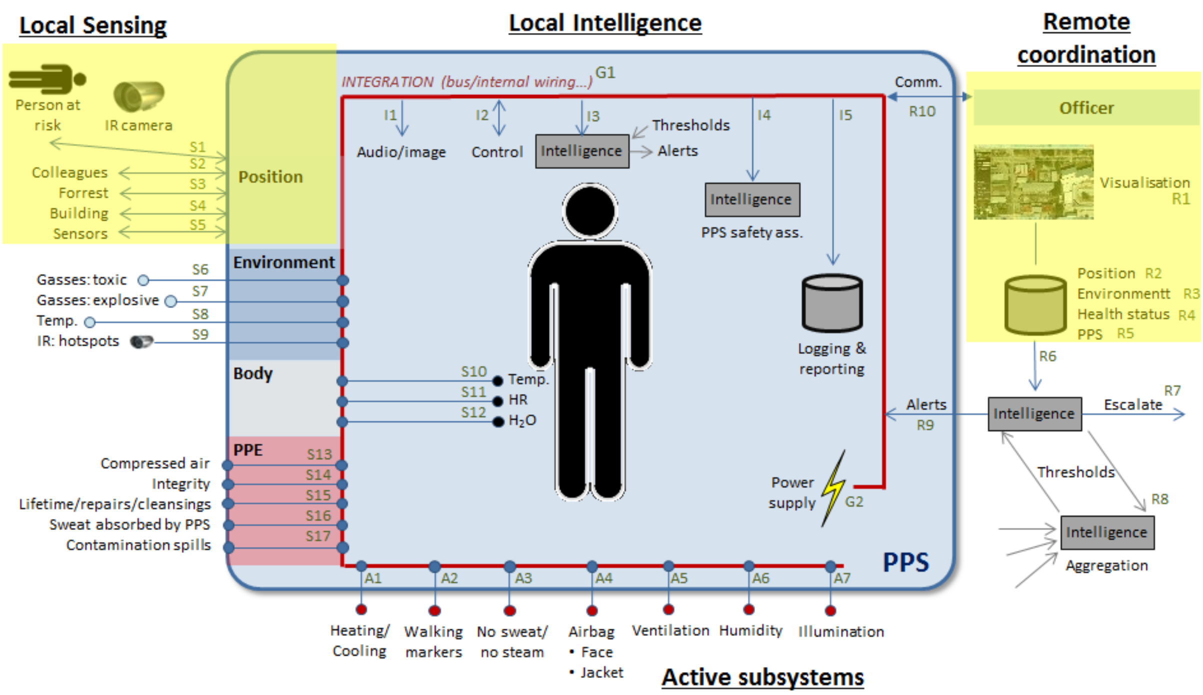


2. Focus area 1 on the PPS reference solution

As illustrated below, focus area 1 considers only the functional building blocks of the reference architecture related to localization, such as the fire-fighter's local positioning sensing components and the remote coordinating officer's map and historical logging of tracked trajectories.

Important to note is that the reference architecture does not imply a technological choice, but merely identifies from a functional perspective the required building blocks.

In the subsequent sections, potential technological solutions/choices and related capabilities and associated sources of risk/challenges are explained. For each challenge an estimation of the innovation potential is made.



3. Technological facets related to the reference solution

Multiple solutions and technologies exist in terms of localization and map building systems. In following sections these are elaborated.

MAP

MAP-1: Availability of up-to-date maps of areas/buildings

Risk score: ***20-40***

Expert opinion and primary sources of risk:

In the ideal case a manually generated up-to-date map of the environment or building is available, where entrances, walls, escape routes, etc. are marked. While these maps are available for a rather small number of buildings (mainly in utilities sector), for most environments and buildings maps are

not existing and if existing not up-to-date. The main alternative is a Google maps satellite image of an area.
It is fair to say that it is a nearly impossible task to construct a database of readily available up-to-date maps of most environments and buildings. Although software to build in a relatively fast and intuitive way maps of an environment or building does exist. With these software packages interesting applications like geo-fencing can be pursued.

MAP-2: Plug-in in existing "asset tracking" systems

*Risk score: **40***

Expert opinion and primary sources of risk:

Buildings such as warehouses, hospitals, industrial buildings, etc. may be equipped with systems to log the trajectory of e.g. customers, patients, doctors. This facet considers the seamless coupling of the fire-fighters' localization solution to these tracking systems.
This facet can be linked to the increasing trend of "smart buildings". As part of an intelligent building management system focusing on safety and security, fire detection and alarm systems may trigger fire containing actions such as disabling ventilation and air-conditioning, controlling smoke extraction systems, unlocking emergency exits, etc.
Note that connecting to the status of the fire detectors (see use-case 15) in the building was not considered a key use-case for the firefighter.

Nr	As a...	I can... <do something>	so that... <value is created for me>
15	Firefighter	consult the status of the fire detectors in the building	I can have a better understanding of where the danger is located

While these tracking systems typically use commonly available technologies such as Wi-Fi, it may be questioned how open these systems are. Also, no standardized interfaces exist today. Enabling a standardization and accordingly a coherent regulation is not considered feasible within the near future, hence a high risk score of 40.
A minor issue might be the reliability of such systems while there is fire in the building. While in general only a part of the building is on fire, the system may still work in other areas as such providing valuable info to approach the fire easier and faster.

MAP-3: Plug-in in existing Cartesian coordinated map

*Risk score: **3***

Expert opinion and primary sources of risk:

In case a map of the environment is available (e.g. Google maps, or offline map created by UAVs) and the map is referenced w.r.t. absolute Cartesian coordinates, it is feasible to use it as e.g. an overlay.

MAP Building

MAP-4: Map building using UAV equipped with Time-of-Flight cameras (at intervention time)

*Risk score: **40***

Expert opinion and primary sources of risk:

In order to operate the unmanned aerial vehicle outdoor, line of sight is required. Due to the 360° Time-of-Flight (TOF) cameras mounted, these UAV can be deployed to overview a large area relatively fast.

It is agreed by state-of-the-art experts that within the context of the Smart@Fire envisaged solution, it is not at all trivial to tackle speed of deployment, speed of the map building, accuracy of the built map, etc. to achieve the added value for the end-user.

SLAM (Simultaneous Localization and Mapping)

The envisaged solution consists of a Time-of-Flight (TOF) camera mounted on the helmet of the firefighter and a radio link to a base station, where the captured image streams are reconstructed using data fusion principles into a relative map of the firefighter environment (in 2D and/or 3D). Without reference position, the result is a real-time gradually built map of the environment indicating obstacles, etc.

SLAM-1: Weight, size, power consumption, local processing power

Risk score: ***20***

Expert opinion and primary sources of risk:

While multiple TOF cameras exist, it is considered difficult to carry the weight and size on a firefighter's helmet, unless a miniature camera of decent quality and reasonable cost could be found. Issues like power consumption and embedded processing have even not been considered.

SLAM-2: Accuracy ~1m

Risk score: ***20-40***

Expert opinion and primary sources of risk:

The TOF cameras have a typical viewing range of 10 to 15 meters. For each pixel in the image an estimation is made of the distance of the corresponding object to the camera sensor. While map reconstruction and localization might work well in conditioned environments using smooth camera movements (e.g. on robots), human behavior during a crisis intervention, changing environmental conditions, smoke, etc. significantly increase the complexity.

Note: temperature gradients do not impact the quality of the camera images.

SLAM-3: Intelligent image processing

Risk score: ***20-40***

Expert opinion and primary sources of risk:

Differentiating between images of good and bad quality (due to e.g. smoke) greatly affects ultimate accuracy of the map building process. Given the extreme conditions in which image capturing is performed, more images of bad quality will have to be discarded during processing. It is considered absolutely non-trivial.

Solution based on GSM/3G/4G & triangulation

A localization solution using the GSM frequency bands (900MHz, 1800MHz) and based on the signal strength of nearby antenna masts to determine the absolute geo-location.

GSM-1: Confidence measure

Risk score: ***3-5***

Expert opinion and primary sources of risk

The confidentiality measure indicates to what extent localization results can be trusted. Important to know for the intervention coordinating officer is to what extent decisions can be built upon mapped localization information.

It is considered feasible to derive an indication of uncertainty from a localization measurement. Note that this technological solution relies on the availability of public nets, risking congestion in case of a crisis situation.

GSM-2: Outdoor accuracy ~3-4m

Risk score: ***100***

Expert opinion and primary sources of risk

In order to be useful for in a fire and rescue application, significant accuracy is needed on the order of magnitude of 3 to 4m. Note that indoor accuracy is irrelevant with this technological solution.

This is impossible to achieve, as typical accuracy ranges around 200 to 500m.

Solution based on GNSS (GPS)

A localization solution using the GNSS/GPS frequency bands (L1: 1,575GHZ; L2: 1,227GHz) requiring line of sight to minimum 3 geo-orbiting satellites.

GPS-1: Confidence measure

Risk score: ***1***

Expert opinion and primary sources of risk

Multiple types of GPS receivers exist: from simple, cheap for consumer applications (with lower accuracy) to more expensive professional receivers (with better accuracy, even up to a few centimeters but extremely expensive).

This is only attainable in case a professional GPS receiver is used, which is more expensive, but still feasible within the design constraint of a limited budget per firefighter. A GPS receiver for consumer applications does not indicate a measure of confidence.

GPS-2: Indoor propagation of GPS signals

Risk score: ***40***

Expert opinion and primary sources of risk

This facet covers the intelligent use of an outdoors available and sufficiently strong GPS signal and propagation of this signal indoors, instead of using the currently available indoor GPS signal which is embedded in noise and hence returns low localization accuracy.

It is estimated as nearly an impossible exercise to achieve without having all details of the signal provided by the GPS system.

GPS-3: Electromagnetic shielding

Risk score: ***1***

Expert opinion and primary sources of risk

GPS signals are significantly weak and are easily degraded by interference from nearby electronic devices such as laptop computers. To cope with this electromagnetic shielding may be applied in the GPS receiver.

The risk can be overcome by applying a professional GPS receiver, designed with electromagnetic shielding to minimize the effect of electromagnetic interference. With a commonly available consumer GPS receiver this is not possible.

GPS-4: Outdoor accuracy ~3-4m

Risk score: ***3***

Expert opinion and primary sources of risk

An accuracy of around 3-4 meters is achievable in case a Differential GPS (DGPS) enabled professional GPS receiver is used. Centimeter-accuracy can even be achieved, but with an extremely expensive GPS receiver.

Objective measures of accuracy to compare GPS receivers accuracy cover: Circular Error Probable (CEP) being a circle's radius centered at the true antenna position which contains 50% of the measurements in the horizontal scatter plot; or Horizontal Root-Mean-Square (HRMS) referring to the horizontal distance from truth within which 63% of positions are predicted to fall.

Solution based on beacons

A localization solution using flexibly deployable beacons (transceiver devices) to create a floating localization system (in case no absolute reference position is obtained). Multiple technologies can be selected for the beacons: WiFi, Bluetooth, MyriaNed, Zigbee, RFID, etc. (operating at 2,4GHz).

Note: the case where an environment/building is pre-equipped with beacons is handled in "MAP-2".

BEACON-1: Confidence measure

Risk score: ***1***

Expert opinion and primary sources of risk

A confidence measure is easily obtainable when working with beacons.

BEACON-2: Indoor accuracy ~1m

Risk score: varies between ***3-5*** *and* ***8-13***

Expert opinion and primary sources of risk

Given the assumption that no absolute reference position is specified, accuracy in this context relates to the determination of the relative position within the reference coordinate system set-up at system launch.

In ideal situations (reasonably vast areas or rooms with wide angle of sight) when the beacons have been deployed in a good way, attaining an indoor accuracy of the order of magnitude of 1 meter is feasible, and hence the risk is relatively acceptable (3-5). Given that reality is often far from the ideal situation and taking into account the human error factor in the deployment of the beacons the real risk is estimated higher (8-13).

BEACON-3: Fast deployment (<10 min) without impacting the quality/accuracy

Risk score: ***13***

Expert opinion and primary sources of risk

Note that it is not envisaged to deploy this solution over the complete building. Merely, the aim is to gradually, locally and virally grow the beacon network within the intervention area.

Conform the risk assessment of "BEACON-2", a precondition for a fast and qualitatively good deployment of the beacons requires insight of the firefighter in the context of the environment, e.g.

to immediately determine the needed amount and maximal spread of the beacons to deploy. As it requires lots of field trials to train the firefighters and consolidate the approach in a reproducible deployment procedure, the estimated risk is significant.

BEACON-4: Self-calibrating, self-referencing

Risk score: ***3***

Expert opinion and primary sources of risk

Another precondition of easy deployment is that the beacon network is self-calibrating, self-referencing, which is claimed by the industry experts to be achievable.

BEACON-5: Low-cost, lightweight, small, low power consuming but ruggedized manufacturing

Risk score: ***8***

Expert opinion and primary sources of risk

Given these beacons will be exposed to hazardous and extreme environmental conditions, their design should be made ruggedized and safe, while retaining a reliable operation over the duration of the intervention (for reference, a compressed air bottle covers an intervention time of around 25 minutes). Today, non-ruggedized, lightweight, small, low power consuming, non ATEX-proof beacons exist. In order to make them ruggedized and safe for fire and rescue applications efforts remain to be spent.

BEACON-6: Low TCO, low logistical impact

Risk score: ***20***

Expert opinion and primary sources of risk

One of the main challenges w.r.t. beacons covers that before deployment beacons should be readily available in all trucks for all firefighter teams, as such needing a massive amount of beacons. An additional complexity is the charging of these beacons. A third issue is that re-use of the beacons will be minimal unless they are recovered from the hazardous environment, implying a longer exposure of the firefighters to the hazardous environment.

Hybrid device incorporating multiple complementary technologies (no beacons)

A localization solution comprised of a hybrid device worn by the firefighter, which incorporates one or more complementary technologies, such as:

- inertial measurement units with built in accelerometers, gyroscopes, magnetometers, barometer (allowing to provide additional info on orientation, body posture, altitude, etc.)
- TOF sensors operating in (ultra) wide band and forming a mesh network across deployed firefighter teams,
- Radar (system with 2 fixed beacons), etc.

Together with a GPS receiver to provide an absolute localization reference, these technologies specifically focus on enabling indoor localization (relative distance measuring w.r.t. last known absolute GPS position).

Note that the use of ultra wide band is allowed as FCC allows for an increased emissive power of +20dBm during a crisis/intervention (as stated by industry experts).

HYBRID-1: Confidence measure

Risk score: ***1***

Expert opinion and primary sources of risk:

A confidence measure on the localization measurements through the combination of one or more aforementioned technologies can be achieved reasonably easy.

HYBRID-2: Self-calibrating, self-referencing

Risk score: ***3-5***

Expert opinion and primary sources of risk:

It is confirmed by the industry experts to be achievable that once deployed the network of hybrid localization devices (mesh or point-to-point) becomes operational seamlessly. While it may seem not straightforward to calibrate these systems in an operational environment, smartly addressing the limitations of each technology can result in a better calibration.

HYBRID-3: Time synchronization between the complemented technologies

Risk score: ***1***

Expert opinion and primary sources of risk:

In order to reference the measurements of one technology vs. the other, synchronization is needed. It is agreed upon that given the narrow operational timeframe of a few hours of an intervention, time stamping in the order of magnitude of 1 second through generally applied running clocks suffices to maintain goo accuracy. However, the more accurate synchronization occurs, the less impact of the time delays between measurements will have on e.g. a data fusion process using Kalman filters.

HYBRID-4: Drift, maximum elapsed time without update of absolute reference position

Risk score: ***8***

Expert opinion and primary sources of risk:

It is agreed by the state-of-the-art industry experts that in order to achieve a limited drift of maximum a few meters after 10 to 20 minutes without reference position update, thorough testing should be set-up in indoor environments during fire and rescue applications. (10 to 20 minutes suffices, given the capacity of a compressed air bottle amounts around 25 minutes.) These tests will further clarify any implications on design of the device and motion tracking modeling. It is believed that by implementing smart measures (e.g. transferring absolute position updates between team members or re-calibrating fast when standing still) the required performance level can be approached, within tradeoffs of the envisaged Smart@Fire PPS.

Of course anything is possible for the right price, given the capability of navigating fighter jets through valleys for hours relying primarily on inertial measurement units.

HYBRID-5: Indoor accuracy ~1m in estimating distance between persons

Risk score: ***8-13 (between firefighters of the same team) vs. 20 (between firefighters of different team)***

Expert opinion and primary sources of risk:

This relative indoor accuracy between two devices is assessed under the assumption that the system is anchored, meaning the absolute reference position is known.

Note that this relative distance is primarily important information for the firefighter in the field. The remote intervention coordinator can estimate this relative distance by verifying on the map the tracked positions of the deployed firefighters/teams.

In theory, this indoor relative distance measurement can be discarded on the precondition that the intervention coordinator's map aggregates all tracked positions, then estimations are made about relative distances between team members, and finally these relative distance estimations are communicated back to the respective firefighter.
Measuring the distance between different teams holds a bigger risk, as these teams are typically deployed to attack the incident from different angles. As such more noise and interference occur, especially in the changing environment they are deployed.

HYBRID-6: Weight, size, power consumption
Risk score: ***2-3***
Expert opinion and primary sources of risk:
In case carefully designed, this should not pose a problem.

HYBRID-7: Speed of deployment < 10min
Risk score: ***1***
Expert opinion and primary sources of risk:
Under the precondition that the system is well integrated, with charged batteries, etc. and given the system is self-referencing and self-calibrating, it should not pose any problem to be immediately operational when arriving at the intervention site.

Intelligent hypothesis-based location update engine

This building block of a localization system refers to an aggregation engine that receives all location related measurements and parameters as inputs, and is able to produce more accurate localization results by applying reasoning algorithms.

INTEL-1: Location update engine
Risk score: ***3***
Expert opinion and primary sources of risk
Under the assumption that hypotheses are restricted to simple rule-based reasoning (e.g. excluding non-physical movements such as a person cannot rise in altitude for 3m al of a sudden), the estimated risk is moderate. This could be made much more complex, significantly impacting the risk assessment. But then the question arises, to what extent should the intervention coordinating officer trust the hypotheses and base crucial decisions on reasoning algorithms?

Smart rescue line as backbone of localization system

This option for a solution is in line with the EU project PROFITEX demonstrator, where a special rescue line is developed to serve as medium for data and energy transmission. Inside the rescue line several beacons are embedded, enabling navigation of the fire fighters in smoky environments and exchange of information.

However, in reality, the rescue line (rope) is very rarely used, only in complex rescue situations. As such the implications of this option were not assessed.

Alternatively, the water hose could fulfill a 'backbone' function for information exchange.

General facets

GEN-1: Fraud-proof

*Risk score: **5-8***

Expert opinion and primary sources of risk

Fraud-proof inherently refers to measures against jamming and spoofing. Jamming refers to intentionally electromagnetically interfering with the system to make it unavailable. Spoofing is more advanced in the sense that the system is interfered by falsifying data without the system detecting it. Today, relatively cheap but narrowband jammers are on the market for around 40$. To jam on a broader spectrum requires significant emission power.

Concerning making the system fraud-proof, the risk depends on how far measures are pushed. For fire and rescue applications, the risk is estimated taking the assumption of normal civil environments. Military-grade measures are considered out of scope for this project.

GEN-2: Tracking of individual firefighter IDs

*Risk score: **1***

Expert opinion and primary sources of risk

With all mentioned techniques and solutions it is feasible to keep track of individual firefighters.

GEN-3: Availability of useful location information > 80% of operational time

Observations

An SLA on localization information availability of say 99,99% is not feasible, given the multitude of unknown and extreme environments that can be encountered during an intervention (e.g. metal “Faraday” cage, underground cave). As soon as an intervention is underground, traditional radio-based systems fail, unless repeaters are used.

Although the firefighters desire to make maximal use of the localization information, in case the information is not available due to system or performance failure, fallback scenarios will be kept in their training programs.

Risk score: not scored

GEN-4: Intuitiveness of use, technological transparency

Observations

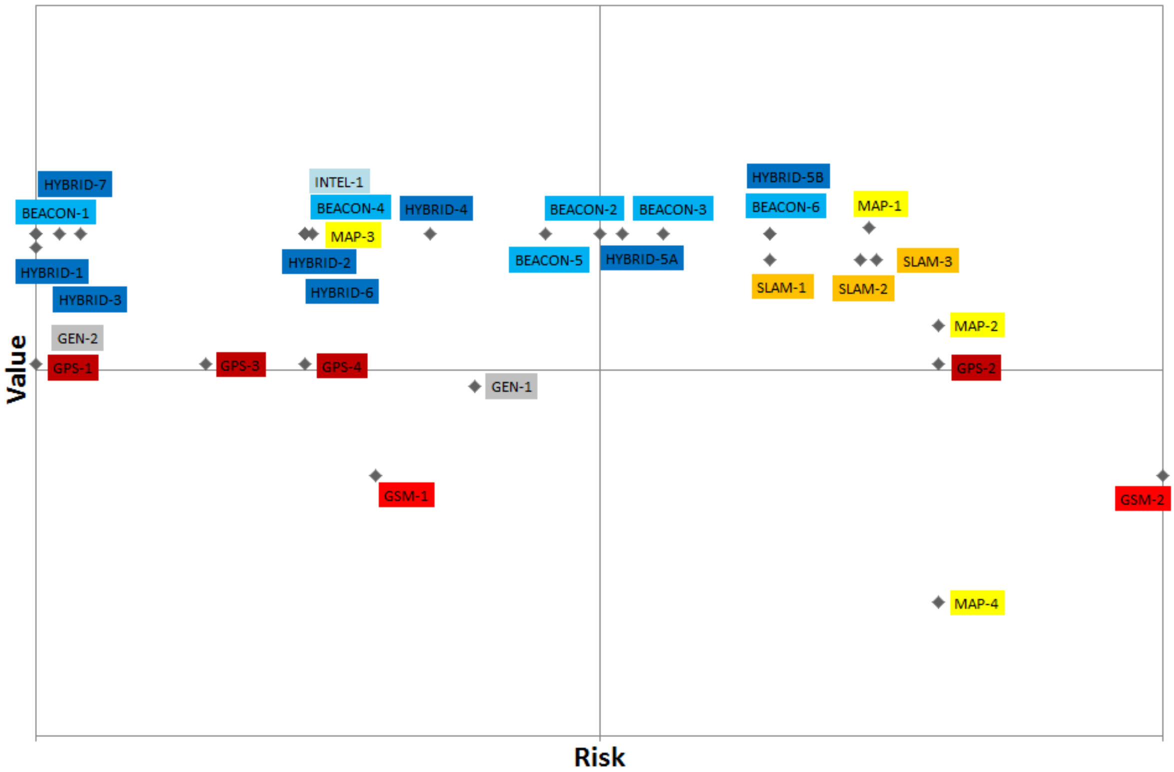
This is an evident non-functional requirement, underlined by the fact that across Europe the firefighter population consists of more volunteers than professionals.

Risk score: not scored

4. Value vs. risk prioritization grid

Following facets are plotted on the value vs. risk prioritization grid:

LOCALIZATION
MAP
MAP-1: Availability of up-to-date maps of areas/buildings
MAP-2: Plug-in in existing "asset tracking" systems
MAP-3: Plug-in in existing Cartesian coordinated map
MAP Building
MAP-4: Map building using UAV equipped with TOF cameras (at intervention time)
SLAM (Simultaneous Localization and Mapping)
SLAM-1: Weight, size, power consumption, local processing power
SLAM-2: Accuracy ~1m
SLAM-3: Intelligent data processing
Solution based on GSM/3G/4G & triangulation
GSM-1: Confidence measure
GSM-2: Outdoor accuracy ~3-4m
Solution based on GNSS (GPS)
GPS-1: Confidence measure
GPS-2: Indoor propagation of GPS signals
GPS-3: Electromagnetic shielding
GPS-4: Outdoor accuracy ~3-4m
Solution based on beacons
BEACON-1: Confidence measure
BEACON-2: Indoor accuracy ~1m
BEACON-3: Fast deployment (<10 min) without impacting the quality/accuracy
BEACON-4: Self-calibration, self-referencing
BEACON-5: Low-cost, lightweight, small, low power consuming but ruggedized manufacturing
BEACON-6: Low TCO, low logistical impact
Hybrid device incorporating multiple complementary technologies (no beacons)
HYBRID-1: Confidence measure
HYBRID-2: Self-calibrating, self-referencing
HYBRID-3: Time synchronization between the complemented technologies
HYBRID-4: Drift, maximum elapsed time without update of absolute reference position
HYBRID-5A: Indoor accuracy ~1m in estimating distance between persons (same team)
HYBRID-5B: Indoor accuracy ~1m in estimating distance between persons (# teams)
HYBRID-6: Weight, size, power consumption
HYBRID-7: Speed of deployment < 10min
Intelligent hypothesis-based location update engine
INTEL-1: Location update engine
General facets
GEN-1: Fraud-proof
GEN-2: Tracking of individual firefighter IDs



5. Synthesis on focus area 1

The main implications for the PPS prototype following the value vs. risk prioritization grid are:

1. A **hybrid localization system** (GPS + inertial) is preferential, given the high added value at reasonable technological risk. Risk reduction should focus on limiting **indoor drift**.
2. The relative distance between firefighters is recommended to be obtained through relay via the intervention coordinator's map at minimal risk. It could be estimated directly between firefighters of the same team via a hybrid localization system at increased, significant risk.
3. The concept **'MAP'** should be merely seen as relative **'Track & Trace'** map, enabling **'meet point'** and **'recovery path'** instructions. These instructions can be automatically generated via **simple reasoning and location update engines**. In case a **Cartesian coordinated map** is available (e.g. Google maps satellite view of the area), it should be used as overlay in the intervention coordinator's intuitive map.
4. A localization system based on beacons bears a high risk in terms of ease of deploying the beacons without losing accuracy and TCO, which is unlikely to be acceptable for the firefighters.
5. GSM, GPS (too low value), SLAM (too high risk) are discarded as standalone solutions.
6. Envisaging to couple the PPS with existing area/building maps or asset management systems are discarded as solutions due to respectively: the in general unavailability of maps and if available outdated; and the lack of asset management system standards and hence a high variety on coupling protocols.

5. Focus Area 2: PPS sensors (environmental and physiological) and active subsystems

1. Key use-cases to enable the innovation potential from an end-user perspective

Highlighted use-cases in red represent the WOW for the end-user.

Nr	As a...	I can... <do something>	so that... <value is created for me>
Physiological monitoring			
1	Firefighter	consult my vital body functions (body temp), which are normally shielded to me due to my Personal Protective	I can better make an assessment and decide what to do
2	Firefighter	consult my vital body functions (heart rate), which are normally shielded to me due to my PPE	I can better make an assessment and decide what to do
3	Firefighter	consult my vital body functions (dehydratation level), which are normally shielded to me due to my PPE	I can better make an assessment and decide what to do
26	Intervention Coordinating Officer	consult a map enriched with info about their body functions, health status	I can direct them in an accurate and safe way
Environmental monitoring			
6	Firefighter	measure and consult the environmental parameters (toxic gasses)	I can better make an assessment and decide what to do
7	Firefighter	measure and consult the environmental parameters (T)	I can better make an assessment and decide what to do
8	Firefighter	measure and consult the environmental parameters (accumulated heat and evolution of T of my PPE)	I can better make an assessment and decide what to do
9	Firefighter	measure and consult the environmental parameters (evolution of T of the environment)	I can better make an assessment and decide what to do
16	Firefighter	measure and consult the environmental parameters (explosive gasses)	I can better make an assessment and decide what to do
28	Intervention Coordinating Officer	consult a map enriched with info about their personal equipment status	I can direct them in an accurate and safe way
Thermal Imaging			
14	Firefighter	'see' the hotspots in my environment (e.g. with IR-camera)	I can have a better understanding of where the danger is located
17	Firefighter	'see' victims in my environment (e.g. with IR-camera)	I can better locate, decide whether to enter,...
27	Intervention Coordinating Officer	consult a map enriched with info about their environment (e.g. fire location)	I can direct them in an accurate and safe way
Specific PPS enhancements			
11	Firefighter	rely on my body suit not to accumulate sweat and transform it into steam	I don't get suddenly burned
18	Firefighter	use the active illumination equipment on my PPE (on top of current passive means)	other people on the road are aware of my presence, even in full dark conditions (no light

2. Focus area 2 on the PPS reference solution

As illustrated below, focus area 2 considers primarily the functional building blocks of the reference architecture related to physiological sensors, environmental sensors, thermal imaging sensors, and active subsystems on active illumination and avoiding sweat being turned into steam.

Important to note is that the reference architecture does not imply a technological choice, but merely identifies from a functional perspective the required building blocks.

In the subsequent sections, potential technological solutions/choices and related capabilities and associated sources of risk/challenges are explained. For each challenge an estimation of the innovation potential is made.

3. Technological facets related to the reference solution

PHYSIOLOGICAL MONITORING

Physiological monitoring in the Smart@Fire context primarily involves monitoring skin temperature, estimating body core temperature, monitoring heart rate and estimating dehydration level (by monitoring temperature and humidity).

SEN-PHYS-1: BODY CORE TEMPERATURE ACCURACY 0,3°C (BELT) vs. COST

Risk score: ***3***

Expert opinion and primary sources of risk

Envisaging a belt worn around the chest (so implying sufficiently good body contact) comprising 5 off-the-shelf skin temperature sensors, it is feasible to estimate the core temperature of the body in the range of 33°C to 41°C up to 0,3°C accuracy.

SEN-PHYS-2: BODY CORE TEMPERATURE ACCURACY 0,3°C (IR) vs. COST

Risk score: ***5-8***

Expert opinion and primary sources of risk

Instead of using a belt, a similar solution with infrared temperature sensors can be envisaged. In this case food body contact is not necessary. However, skin wetness can disturb the measurement accuracy and this system is more expensive, as such resulting in a higher risk looked at from the Smart@Fire project constraints.

SEN-PHYS-3: HEART RATE ACCURACY (BELT) vs. COST

Risk score: ***0***

Expert opinion and primary sources of risk

A chest belt to accurately measure heart rate exists.

SEN-PHYS-4: HEART RATE VARIABILITY (BELT) vs. COST

Risk score: ***20***

Expert opinion and primary sources of risk

According to various research initiatives, heart rate variability is a good indicating measure for mental health (e.g. panic). However, to make accurate derivations, one needs very accurate measurements (thus electrical sensing, not optical) over a longer period of time, ideally without interruption on the measurements due to bad contact. With a simple chest worn belt, this is too hard, and a more elaborated system incorporating electrode sensing patches is not feasible for a firefighters working context.

SEN-PHYS-5: HYDRATATION (MICROCLIMAT SENSORS): SATURATION - RE-CALIBRATION

*Risk score: **2***

Expert opinion and primary sources of risk

Off-the-shelf microclimate sensors comprising ambient temperature and humidity sensors exist. A particular challenge is saturation of the humidity sensors when direct contact with sweat of the firefighter or condensation occurs. Once the sweat has dried up or is removed, the sensor becomes operational again (after a short regeneration time). Saturation can be easily detected in the measurements, re-calibration is not needed.

SEN-PHYS-6: LIFECYCLE, DEGRADATION #YEARS

*Risk score: **2-3***

Expert opinion and primary sources of risk

Typical lifecycles of a chest belt measuring physiological parameters is around 2 to 3 years. This is not in line with the average lifecycle of the turnout gear. However, it is not considered a problem as these physiological belts are worn completely independent of the turnout gear.

SEN-PHYS-7: OPTICAL SENSING (HR, T,…) ('WATCH') - ACCURACY

*Risk score: **13-20***

Expert opinion and primary sources of risk

Accuracy of optical heart rate measurements (e.g. via a wrist watch) is lower compared to chest worn belt. Main reasons include: noise and vibration due to dynamic movement, taking into account the correction factor of the accelerometer data inside the wristlet.

SEN-PHYS-8: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): GENERAL RULES TO INDIVIDUAL

*Risk score: **8***

Expert opinion and primary sources of risk

This facet reflects on the issue that a lot of data points need to be transformed into relevant information leading to alerts on known phenomena such as ‘ heat stress’ and ‘skin burn’. On a general level, ergonomic guidelines exist reflecting on working environment and link to physiological parameters (e.g. @ 38°C of estimated body core temperature it is best to leave the intervention). However, these general rules do not apply for every individual. So individualizing these type of alerts requires lots of parameters to be tested and determined on the individual level. On the other hand, professional firefighters (~20%) are tested regularly, so thresholds are quite easily determined. For volunteers (~80%) this is not the case. On the other hand, in case of recent diseases, fitness issues, etc., ideally all parameters should be reviewed, which is nearly impossible to keep all these parameters up-to-date.

SEN-PHYS-9: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): SIMPLE RULE ENGINE (NON-PHYSICAL JUMPS IN DATA)

*Risk score: **3***

Expert opinion and primary sources of risk

Non-physical jumps in the data can be relatively easily detected.

SEN-PHYS-10: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): MAKE GENERAL ALERT RECOMMENDATIONS

Risk score: ***3***

Expert opinion and primary sources of risk

Interpretation of all the data can occur semi-autonomously using either general or individualized ruling engines. These ruling engines should be constructed in close collaboration with medical and technical experts (e.g. including safety margins impacting algorithm sensitivity and having implication on medical level). This interpretation could lead to the generation of recommended alerts. The final decision to launch an alert to a firefighter is left to the intervention coordinating officer.

SEN-PHYS-11: ERGONOMICS OF BELT

Risk score: ***2***

Expert opinion and primary sources of risk

It is considered that a chest worn belt has relatively little impact on the ergonomic comfort level of the firefighter, given a proper design of the belt.

SEN-PHYS-12: AVOIDING PHYSIOLOGICAL DATA TO BE SEEN AS 'PERFORMANCE THRESHOLDS' (VOLUNTEERS & PROFESSIONALS)

Risk score: ***2-3***

Expert opinion and primary sources of risk

Currently, firefighters (even volunteers) are monitored during training sessions, so they have the habit to handle 'being monitored'. By clearly explaining that the monitoring is to improve personal safety levels, this can be solved.

SEN-PHYS-13: DATA PRIVACY (VOLUNTEERS & PROFESSIONALS)

Risk score: ***3***

Expert opinion and primary sources of risk

It is considered in the risk assessment by state-of-the-art that a harmonized legal framework is not existing today. However, it is not considered a battlefield for the Smart@Fire project. Workarounds are rather envisaged by making agreement directly with the firefighters.

ENVIRONMENTAL MONITORING

Environmental monitoring in the Smart@Fire context primarily involves monitoring external temperature and temperature evolution; and explosive gas detection.

SEN-ENV-1: TEMPERATURE TECHNOLOGY (CALIBRATION, CONFIDENCE, UPDATE RATE 1Hz,...)

Risk score: ***1***

Expert opinion and primary sources of risk

From a technological point of view, off-the-shelf temperature sensors that are easily calibrated, and provide fast measurements are readily available.

SEN-ENV-2: GAS DETECTION TECHNOLOGY (CALIBRATION, CONFIDENCE, TIME TO MEASURE 20s,...)

Risk score: ***1***

Expert opinion and primary sources of risk

From a technological point of view, off-the-shelf gas detection sensors exist that are easily calibrated via do-it-yourself kits or come with pre-calibrated cartridges, and provide relatively fast measurements

(~10 to 20s to generate an alert) are readily available. However, when integrated in a commercial product with screen, alerts, battery, etc. typical price ranges from a few 100€ up to several 1000€. The more complex the gas detector is, the higher the power consumption as well.

SEN-ENV-3: GAS DETECTION TECHNOLOGY: ACCURACY (PPM, %) TO GENERATE ALERT

Risk score: ***1***

Expert opinion and primary sources of risk

From a technological point-of-view this is all feasible, however at significant cost typically. This trade-off is treated in SEN-ENV-4.

SEN-ENV-4: TRADE-OFF COST/TCO vs. ACCURACY vs. POWER CONSUMPTION (for # selected gasses)

Risk score: ***13***

Expert opinion and primary sources of risk

On this facet, industry experts did not reach consensus: while some claim to have integrated small, cheap gas detection sensors, the disadvantages are primarily accuracy and high power consumption. From another perspective, pushing these trade-offs is a known problem tackled by the globally present gas detection solution manufacturers. As such it is considered not a priority to solve this within the scope of the Smart@Fire project. If a simple, cheap (fitting within budgetary constraints), sufficiently robust (so not requiring too much maintenance) gas detection system is available, it can be incorporated in the Smart@Fire project scope. Solving the sensor-specific barriers is not included in the scope. The risk assessment of 13 reflects on investigating these aspects deeper during the solution exploration and prototyping phase.

SEN-ENV-5: IMPACT ON WAY OF WORKING: MAINTENANCE CHECKS of ALL GAS DETECTORS

Risk score: ***8***

Expert opinion and primary sources of risk

Maintenance of gas detection sensors should be considered in a similar fashion as maintenance on the breathing apparatus, i.e. at east after every intervention and cleaning. On top of the cleaning, for the gas detection system a regular recalibration is required (e.g. when exposed to too high gas concentrations). The risk assessment includes closely the pursued trade-offs of facet SEN-ENV-4 and aims to minimize maintenance (re-calibration) of the gas detection subsystem.

SEN-ENV-6: IMPACT OF FALSE POSITIVES OF GAS DETECTORS

Risk score: ***8***

Expert opinion and primary sources of risk

This item needs further investigation and testing. As in high temperature environments depending on the measurement technology applied, sensor characteristics vary as well, calibration is not easily done. This is again closely linked to facet SEN-ENV-4, where the right trade-offs are pursued between measurement technology, cost, accuracy, and power needed.

SEN-ENV-7: SMALL, CHEAP SPECTROSCOPIC GAS DETECTION SYSTEMS

Risk score: ***13-20***

Expert opinion and primary sources of risk

While handheld spectroscopic gas detection systems exist, the typical price ranges mount from around 500€ up to several 1000€. While the advantageous are clear (e.g. no oxygen needed, no chemical measurement, less sensitive to calibration errors, etc.) the measurement relevance is highly depending on the positioning of the device. As in facet SEN-ENV-4 industry's state-of-the-art did not reach consensus on whether it is achievable to reach the right trade-offs within the Smart@Fire project constraints.

SEN-ENV-8: ENVIRONMENTAL SENSORS: INTEGRATION IN TEXTILE

*Risk score: **20-40***

Expert opinion and primary sources of risk

It is concluded in consensus that the complexity of trying to integrate the environmental sensors in textile is too hard today: issues like robustness, durability of connectors, woven-in cables, etc. have not been solved yet.

SEN-ENV-9: USER INTERACTION: POWER ON, RESET DEVICE ALERTS

*Risk score: **2-3***

Expert opinion and primary sources of risk

It is key to minimize manipulations by the firefighter during the course of an intervention. Ideally all info is relayed to the intervention coordinating officer, however in the particular case of presence of explosive substances, the firefighter should receive a local alert telling him to get out or make a detailed measurement of the explosion thresholds. On the level of user interaction, some smart designing could help minimizing the manipulations of the firefighter.

SEN-ENV-10: UAV/UGV ROBOTIC ENVIRONMENTAL SENSING

*Risk score: **20-40***

Expert opinion and primary sources of risk

While technologically feasible, at least in open areas or on easy accessible indoor environments, in smoky environments these vehicles are difficult to operate, but in particular cases these systems can prove added value. It is concluded that within the scope of the Smart@Fire project constraints this option is not achievable.

THERMAL IMAGING

SEN-IRCAM-1: TRADE-OFF MINIATURE, CHEAP vs. RESOLUTION

*Risk score: **13-20***

Expert opinion and primary sources of risk

Today, relatively small and simple infrared thermal imaging sensors exist at limited resolutions of even 16 by 4 pixels. These sensors are the edge of today's technology w.r.t. miniature thermal imaging sensors. However multiple of these sensors need to be combined to provide the firefighter a minimal resolution to detect hotspots in his environment. Balancing these trade-offs is not at all straightforward.

SEN-IRCAM-2: DETECTION RANGE 'VICTIMS' AT HIGH T, SMOKE

*Risk score: **13***

Expert opinion and primary sources of risk

Under normal temperature conditions, these miniature thermal imaging sensors have a detection range of around 10 to 12m given a relative temperature difference of environment and subject of around 15°C. It is unknown how these sensors will perform in terms of detection range, relative temperature scaling granularity, etc. under high temperature, smoky environments.

Today, the handheld thermal imaging camera is considered a preferred equipment for the firefighter to use, given the high resolution, the ability to see through smoke. However, these handheld devices are significantly expensive. If a miniature cheap alternative cannot provide a similar added value, it will be swiftly replaced again by the handheld devices. On the other hand, handheld thermal imaging cameras are only used by few firefighters who explore the environment before others enter.

SEN-IRCAM-3: DATA RATE, SITUATIONAL AWARENESS

*Risk score: **3***

Expert opinion and primary sources of risk

With proven technology a sufficiently high frame/measurement capture rate can be obtained to provide the firefighter a sufficiently good situational awareness on the temperature gradients in the environment.

SEN-IRCAM-4: INTEGRATED DISPLAY, in HMD, VISOR, BA

*Risk score: **13-20***

Expert opinion and primary sources of risk

From a technological point-of-view it is feasible to build a prototype given a complete R&D track is devoted to this subject. Given the scope and constraints of the Smart@Fire project it is considered significantly risky to solve this.

ACTIVE ILLUMINATION

SEN-ILLUM-1: "BE SEEN", OMNIDIRECTIONAL, no blinding

*Risk score: **2***

Expert opinion and primary sources of risk

This facet reflects on creating visibility for others to see the first responders at work on the highway even under full dark conditions. These systems (e.g. simple LED lamps with small battery) exist in cheap form and can for example be clipped onto the turnout gear, e.g. as an external belt.

Note that the intended goal is not to create “be seen” omnidirectional lighting that remains operational under extreme conditions (e.g. 8s in 800°C as indicated in the optional flash-over test in EN469 directive). A potential use-case could be to enhance visibility between firefighters of the same couple deployed in smoky environments, however this is not expressed as such during the needs assessment by the firefighters.

SEN-ILLUM-2: ILLUMINATION - HEAT DISSIPATION AT HIGH T

*Risk score: **2***

Expert opinion and primary sources of risk

This risk assessment of this facet depends on how many lumen you need to light the space in front of the body to perform the activities. It is considered that

Note: this facet elaborates on illumination, not on “be seen” omnidirectional lighting.

SEN-ILLUM-3: AUTO ACTIVATION - LIGHTING SENSOR

*Risk score: **0***

Expert opinion and primary sources of risk

Lighting sensors exist (e.g. automotive applications).

SEN-ILLUM-4: INTEGRATING ACTIVE LIGHTING: DEVIATION LOS EYE/LIGHT

*Risk score: **3***

Expert opinion and primary sources of risk

In case the active illumination can be integrated, the firefighter has both hands free to perform the tasks. To obtain ideal sight in the smoky environment, there's best a deviation between the line-of-sight of the eye vs. the direction of the lighting beam (e.g. to not blind the firefighter when confronted with dense smoke). This is considered solvable by selecting the right integration location on the body.

SEN-ILLUM-5: INTEGRATING ACTIVE LIGHTING: LAYER ON TEXTILE

*Risk score: **20***

Expert opinion and primary sources of risk

It is considered not feasible to integrate active lighting in a layer on the textile covered by protective polymers, given the extreme demands w.r.t. durability and robustness against mechanical frictions and exposure to chemical substances during operational use and washing throughout the lifecycle of the suit.

SEN-ILLUM-6: CABLED LIGHTING: USABILITY

*Risk score: **13-20***

Expert opinion and primary sources of risk

It should be carefully looked at whether a cabled system with active illumination could solve the firefighter's need for omnidirectional "be seen" visibility. A number of constraints apply that should be considered together. First, in order to wash the suit the cabling system should be easily removable and re-mountable. Second, in case the cabled lighting system is mounted in/on the suit (e.g. somewhere between the layers), how to guarantee waterproofness. In this case the lighting system is not resistant against extreme temperatures, so in the ideal case, the firefighter should remove the system when fighting a fire in an urban confined setting. Suppose it is easily removable, then the firefighter, before going on intervention should decide whether to wear the lighting system or not, a judgment typically resulting in not wearing the lighting system. And thirdly, this lighting system cannot replace the existing fluorescent and reflective material (stripes) on the turnout gear, as EU directive EN471 on high-visibility clothing a certain surface in these materials.

So from a technological point of view, it would be feasible given significant effort, but to make it really usable for the firefighter holds significant risk.

AVOIDING SWEAT BEING TURNED INTO STEAM

Concerning the issue of avoiding accumulated sweat inside the turnout gear being turned into steam and causing skin burn, two approaches exist. Primary approach is a pure textile solution by looking at the full garment design and layering, i.e. look at the underwear and turnout gear as a system. A secondary approach is technologically inspired. The aim is to forecast the steam build-up and calculate the time left for the firefighter to get out.

SWEAT-STEAM-1: TENDERS underwear + turnout gear

*Risk score: **3-5***

Expert opinion and primary sources of risk

Today buying cycles for underwear and turnout gear are not aligned resulting in different tender documents, completely independent of each other. According to the industry, leveraging on initiatives as the Smart@Fire project to push things further and under the precondition that firefighters really desire this, new combined tenders are expected to be launched in the near future. However, it will cost significant lobby effort.

SWEAT-STEAM-2: STANDARDIZATION: LAYERED DESIGN

Risk score: ***20***

Expert opinion and primary sources of risk

Currently applicable standardization directives on PPE turnout gear (EN469) always make reference to a 3 or 4-layered system (inner layer – thermal barrier – membrane – outer layer). Within the standard, several fabrics can be combined to optimize performance, but at system design level the standard is firm. It is not believed by industry's state-of-the art that standardization bodies can be easily influenced. (as already experienced on the subject of ventilation tests, where standards only account for static testing while the main benefits for the firefighter lies in the dynamically generated ventilation airflows).

SWEAT-STEAM-3: LOBBY TO WORK OUTSIDE STANDARDS

Risk score: ***20***

Expert opinion and primary sources of risk

This facets treats the question whether or not firefighters and their procurement administrations will allow manufacturers to come up with better turnout gear layering systems to e.g. adding a moisture binding layer near the inner layer to cope with sweat accumulation capacity, etc., however outside today's standards. The answer is simple, no (hence risk 20). One should neither hope on a fast evolution of existing standards (given the last real modification dates back to 1995)…

SWEAT-STEAM-4: ADOPTION OF FF: REVIEW BALANCE COMFORT - SWEAT-STEAM

Risk score: ***2-3***

Expert opinion and primary sources of risk

Today, fabric or garment manufacturers could use better performing materials and fabrics to cope with this issue. However, typically these innovative fabrics augment the weight of the garment (by 100 grams) and have a higher 'skin resistance' value, hereby negatively impacting the comfort-assessment by the firefighter. It is believed by the industry that by clearly explaining the benefits of these new garments, the small impact on comfort can be overcome.

SWEAT-STEAM-5: ADOPTION OF FF: REVIEW BALANCE: ADMIN/LOBBY

Risk score: ***8***

Expert opinion and primary sources of risk

Once the firefighters are convinced, it is considered a much more challenging task to lobby with/convince the public procurement administrations to alter their current tendering templates (and budgets as these other materials might be more expensive).

SWEAT-STEAM-6: STEAM BUILDING WARNING SYSTEM - PERFORMANCE, ACCURACY,…

Risk score: ***8-13***

Expert opinion and primary sources of risk

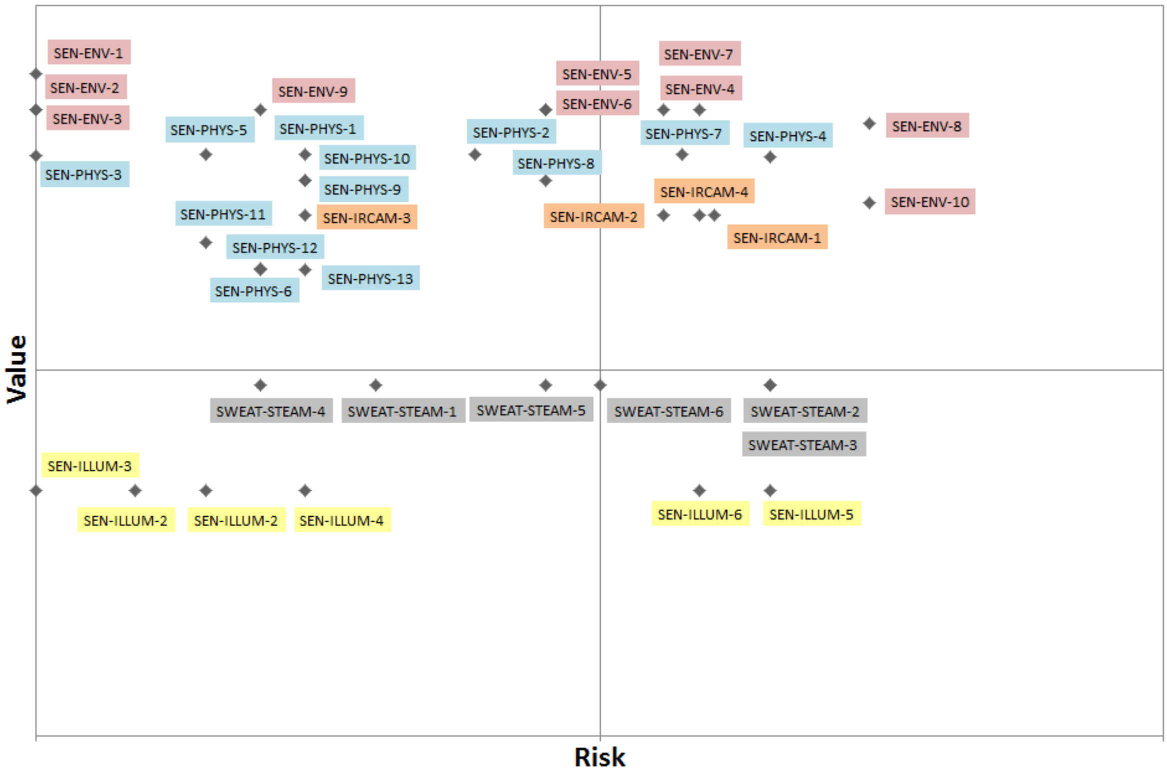
The steam building warning system primarily consists of following components: an ambient temperature sensor, skin temperature sensors (e.g. 5), humidity sensor inside turnout gear, some contextual info on clothing (e.g. measure of sweat absorption capacity), predictive model or algorithm.

It is considered not at all straightforward to predict the '30s before skin burn threshold reached'-alert. For example, to make it highly robust against false negatives and false positives a large safety margin would probably be needed, limiting the intervention time of the firefighters.

4. Value vs. risk prioritization grid

Following facets are plotted on the value vs. risk prioritization grid:

ACTIVE ILLUMINATION
SEN-ILLUM-1: "BE SEEN", OMNIDIRECTIONAL, no blinding
SEN-ILLUM-2: ILLUMINATION - HEAT DISSIPATION AT HIGH T
SEN-ILLUM-3: AUTO ACTIVATION - LIGHTING SENSOR
SEN-ILLUM-4: INTEGRATING ACTIVE LIGHTING: DEVIATION LOS EYE/LIGHT
SEN-ILLUM-5: INTEGRATING ACTIVE LIGHTING: LAYER ON TEXTILE (ROBUSTNESS, WASHING, LIFECYCLE,...)
SEN-ILLUM-6: CABLED LIGHTING: USABILITY
THERMAL IMAGING
SEN-IRCAM-1: TRADE-OFF MINIATURE, CHEAP vs. RESOLUTION
SEN-IRCAM-2: DETECTION RANGE 'VICTIMS' AT HIGH T, SMOKE
SEN-IRCAM-3: DATA RATE, SITUATIONAL AWARENESS
SEN-IRCAM-4: INTEGRATED DISPLAY, in HMD, VISOR, BA
AVOID SWEAT TO STEAM
SWEAT-STEAM-1: TENDERS underwear + turnout gear
SWEAT-STEAM-2: STANDARDIZATION: LAYERED DESIGN
SWEAT-STEAM-3: LOBBY TO WORK OUTSIDE STANDARDS
SWEAT-STEAM-4: ADOPTION OF FF: REVIEW BALANCE COMFORT - SWEAT-STEAM
SWEAT-STEAM-5: ADOPTION OF FF: REVIEW BALANCE: ADMIN/LOBBY
SWEAT-STEAM-6: STEAM BUILDING WARNING SYSTEM - PERFORMANCE, ACCURACY,...
PHYSIOLOGICAL MONITORING
SEN-PHYS-1: BODY CORE TEMPERATURE ACCURACY 0,3°C (BELT) vs. COST
SEN-PHYS-2: BODY CORE TEMPERATURE ACCURACY 0,3°C (IR) vs. COST
SEN-PHYS-3: HEART RATE ACCURACY (BELT) vs. COST
SEN-PHYS-4: HEART RATE VARIABILITY (BELT) vs. COST
SEN-PHYS-5: HYDRATATION (MICROCLIMAT SENSORS): SATURATION - RE-CALIBRATION
SEN-PHYS-6: LIFECYCLE, DEGRADATION #YEARS
SEN-PHYS-7: OPTICAL SENSING (HR, T,...) ('WATCH') - ACCURACY
SEN-PHYS-8: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): GENERAL RULES TO INDIVIDUAL
SEN-PHYS-9: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): SIMPLE RULE ENGINE (NON-PHYSICAL JUMPS IN DATA)
SEN-PHYS-10: PROCESSING DATA to RELEVANT INFO ('HEAT STRESS', 'SKIN BURN'): MAKE GENERAL ALERT RECOMMENDATIONS
SEN-PHYS-11: ERGONOMICS OF BELT
SEN-PHYS-12: AVOIDING PHYSIOLOGICAL DATA TO BE SEEN AS 'PERFORMANCE THRESHOLDS' (VOLUNTEERS & PROFESSIONALS)
SEN-PHYS-13: DATA PRIVACY (VOLUNTEERS & PROFESSIONALS)
ENVIRONMENTAL MONITORING
SEN-ENV-1: TEMPERATURE TECHNOLOGY (CALIBRATION, CONFIDENCE, UPDATE RATE 1Hz,...)
SEN-ENV-2: GAS DETECTION TECHNOLOGY (CALIBRATION, CONFIDENCE, TIME TO MEASURE 20s,...)
SEN-ENV-3: GAS DETECTION TECHNOLOGY: ACCURACY (PPM, %) TO GENERATE ALERT
SEN-ENV-4: TRADE-OFF COST/TCO vs. ACCURACY vs. POWER CONSUMPTION (for # selected gasses)
SEN-ENV-5: IMPACT ON WAY OF WORKING: MAINTENANCE CHECKS of ALL GAS DETECTORS
SEN-ENV-6: IMPACT OF FALSE POSITIVES OF GAS DETECTORS
SEN-ENV-7: SMALL, CHEAP SPECTROSCOPIC GAS DETECTION SYSTEMS
SEN-ENV-8: ENVIRONMENTAL SENSORS: INTEGRATION IN TEXTILE
SEN-ENV-9: USER INTERACTION: POWER ON, RESET DEVICE ALERTS
SEN-ENV-10: UAV/UGV ROBOTIC ENVIRONMENTAL SENSING



5. Synthesis on focus area 2

The main implications for the PPS prototype following the value vs. risk prioritization grid are w.r.t:

1. **Physiological data capture** and general alert recommendation generation holds no risk. Generating alerts on an individual level requires more effort.

2. Monitoring **environmental temperature** holds no risk. Regarding **gas detection**, finding the trade-offs between size, cost/TCO, accuracy, power consumption, etc. is difficult, while good, standalone, but expensive gas detectors exist. However, in case a simple not all-too accurate detector of explosive natural gasses is envisaged, these trade-offs might be easier to solve. Mitigation measures should then be incorporated to cope with the increased number of false positives and the potentially higher required maintenance effort.

3. Using a cheap, **miniature IR thermal imaging sensor/camera** with relevant resolution and detection range in high temperature environments holds significant risk. Providing visual feedback via HMD, HUD, etc. is even more difficult.

4. Active illumination to achieve **omnidirectional "be seen"** holds no risk under the precondition that a simple clip-on system will be used by the firefighter. There lies the risk, creating a user-friendly system that allows for easy operation (somewhere fixed on the firefighter suit), but is not destroyed in a fire-facing intervention due to the increased temperature.

5. **Avoiding sweat being turned into steam** can be improved/solved through a pure textile approach, by reviewing tenders and FF's comfort balance (e.g. skin resistance). Significant lobby effort should be put in place to achieve this.

6. Focus Area 3: Data transfer and visualization

1. Key use-cases to enable the innovation potential from an end-user perspective

Additionally to the aforementioned key use-cases regarding localization and environmental/ physiological sensing, intuitive visualization systems and interpretation of data are equally important.

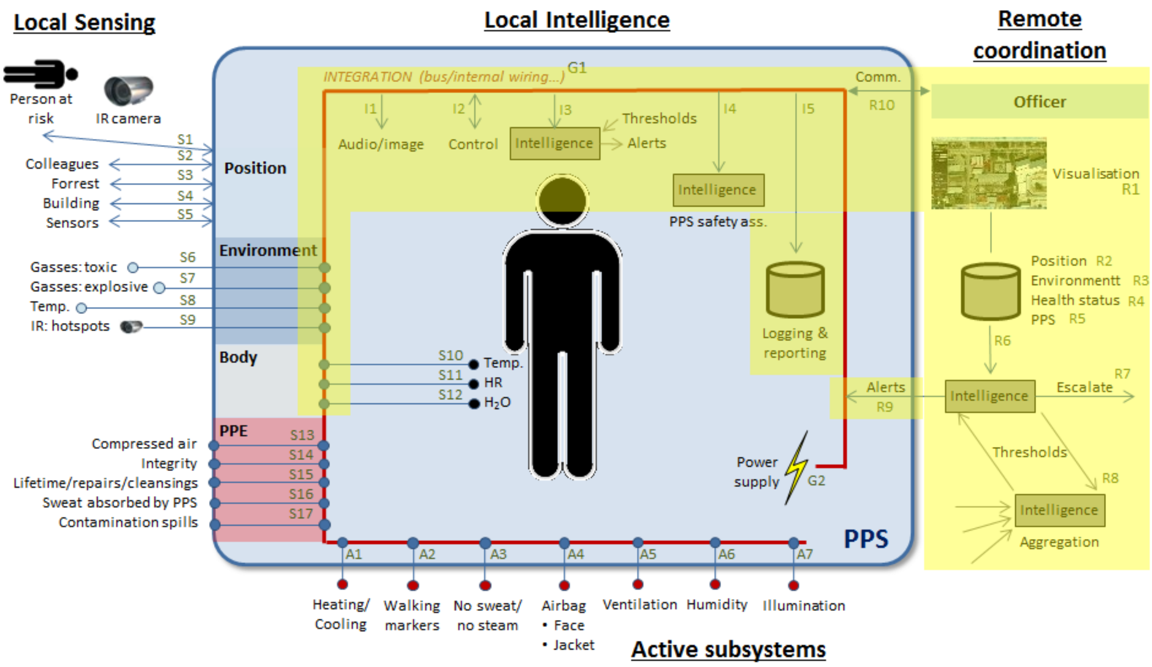
Nr	As a...	I can... <do something>	so that... <value is created for me>
30	Intervention Coordinating Officer	use an intuitive visualization system about all the above mentioned data	I can more easily interpret what's going on
31	Intervention Coordinating Officer	rely on (partially) automated interpretation of data	I can reduce my workload and focus on most important parts and intervene in an efficient way
32	Firefighter	use an intuitive UI system about all the above mentioned data	I can understand what's going on without being distracted

2. Focus area 3 on the PPS reference solution

As illustrated below, focus area 3 considers only the functional building blocks of the reference architecture related to remote data connectivity and transfer, and user feedback, for the remote intervention coordinating officer as well as for the firefighter. In addition, and related to the data transfer, historical logging is also treated in this section.

Important to note is that the reference architecture does not imply a technological choice, but merely identifies from a functional perspective the required building blocks.

In the subsequent sections, potential technological solutions/choices and related capabilities and associated sources of risk/challenges are explained. For each challenge an estimation of the innovation potential is made.



3. Technological facets related to the reference solution

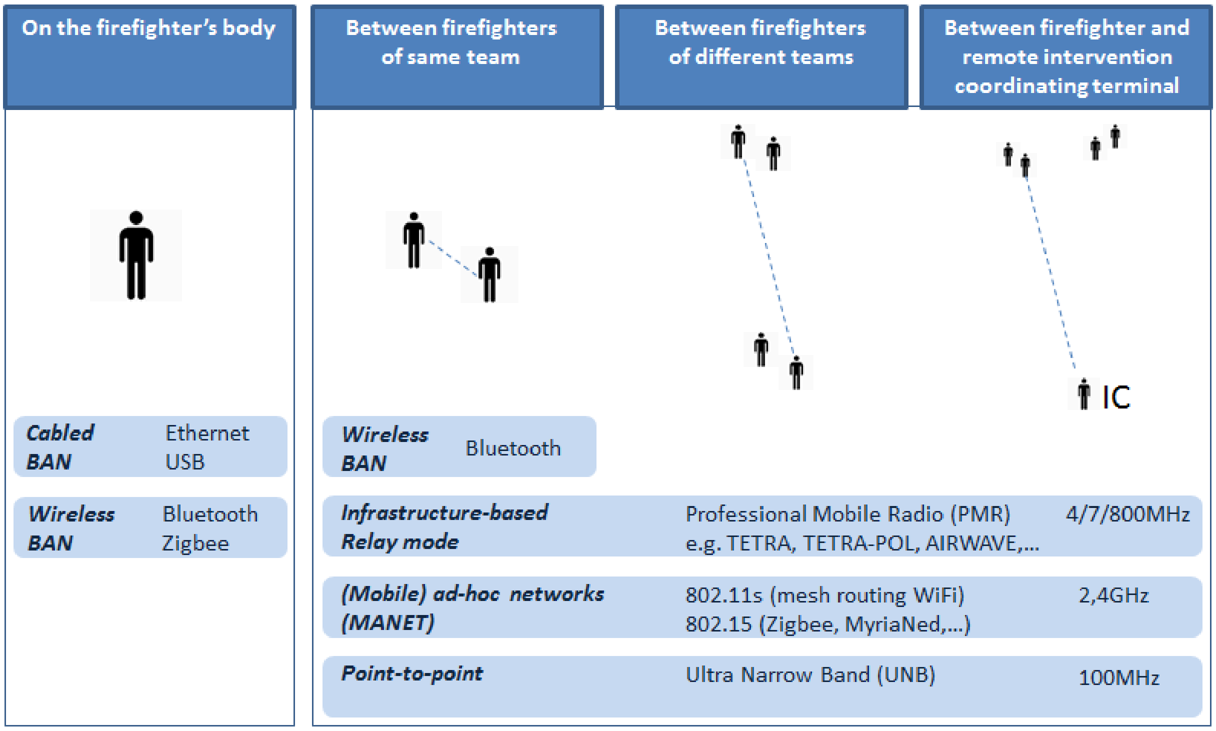
Multiple solutions and technologies exist in terms of data transfer technologies and visualization systems, hereafter listed

REMOTE CONNECTIVITY AND DATA TRANSFER

Multiple technologies qualify to be applied in the Smart@Fire PPS prototype. Distinction should be made whether intended use of the remote connectivity and data transfer technologies is:

- on the firefighter's body interlinking different devices;
- between firefighters of the same team (couple);
- between firefighters of different teams;
- between firefighters and the remote intervention coordinating communication terminal.

The illustration below summarizes non-exhaustively the main technologies qualify within the context of the PPS prototype, as indicated by the industry experts. In following paragraphs the main sources of risk for each of the indicated approaches will be elaborated.



CONN-1: CABLED BAN (USB, ETHERNET)

*Risk score: **0***

Expert opinion and primary sources of risk

As indicated by industry experts, a cabled body area network has as main advantage the data transfer at high bandwidth throughput and low energy consumption. With respect to the energy consumption, it is indicated that USB is preferential compared to Ethernet. These technologies are available off-the-shelf.

CONN-2: WIRELESS BAN (BLUETOOTH, ZIGBEE) – ROBUSTNESS TO INTERFERENCE

*Risk score: **5***

Expert opinion and primary sources of risk

Main strong points related to these wireless body area network technologies include flexibility and compatibility due to the use of standards (on the precondition that all devices apply the correct application profile), bidirectional secured data transfer at low emissive power (1-2,5mW and less). Compared to a cabled alternative, energy consumption is a disadvantage, which can be countered by applying reduced duty cycle principles. Compared to Bluetooth, Zigbee offers a better energy consumption performance. But Zigbee's attainable data rate is lower compared to Bluetooth. Taking into account these typical trade-offs between data rate, emission power, signal reach (signal to noise ratio) and autonomy, industry experts tend to choose Bluetooth over Zigbee for the PPS BAN.

Main source of risk however, remains the robustness to electromagnetic interference given its operation in the unlicensed frequency spectrum (2,4GHz). By indicating the quality or reliability of the connection the data reliability can evenly be taken into account.

CONN-3: WIRELESS BAN (BLUETOOTH) – IN-TEAM AUDIO

*Risk score: **3***

Expert opinion and primary sources of risk

Today, all firefighters are equipped with a Professional Mobile Radio (PMR, e.g. Astrid – TETRA; Anteres - TETRAPOL) system allowing them to communicate directly. It could be envisaged to provide the firefighters with a back-up Bluetooth communication system used within couples to communicate directly, in case the TETRA is unavailable. Typical line of sight ranges amount 10m with standard emission powers of 2,5mW. Between couples this will work as it is 1 hop away.

Note that this is not a direct user request and as such will not be withheld in the delineation of the PPS prototype scope.

CONN-4: INFRASTRUCTURE BASED – PMR RELAY MODE –DATA RATE

*Risk score: **20***

Expert opinion and primary sources of risk

Main advantages of the widely used Professional Mobile Radio (PMR) is that it operates in the public services frequency spectrum (4/7/800MHz), using encrypted secure signal links, to transport voice and data over large distances (2W emission power of a tactile radio results in 2km line-of-sight signal range, 10W of an antenna results in 10km signal range). However, the available bandwidth is rather limited, when considering a near real-time (1Hz) complete network update rate towards the intervention coordinating officer. Typical data transfer throughput amounts 7,2kbps. Latest versions of the TETRA standard support 115,2 kbps in 25 kHz or up to 691,2 kbps in an expanded 150 kHz channel, however no deployed networks supporting such data rates are currently in operation.

Given that the firefighter is only communicating 5 to 10% of the time during an intervention, up to 90% of the time the link could be used to transmit data. Solutions exist to modulate the part of bandwidth dedicated to voice by prioritizing data transfer. Difficulty then is to automatically negotiate bandwidth reservation, knowing that the firefighter is in a hazardous situation and needs to be able to communicate when required necessary. Such bandwidth negotiation systems exist, but is easily perturbed due to background noise, shouting between firefighters of the same couple, etc. One step further still would be the use of speech recognition, automatically recognizing code words and opening the voice channels. These techniques bear at least an equally significant risk in terms of reliability and usability.

CONN-5: INFRASTRUCTURE BASED – PMR RELAY MODE –INDOOR PENETRATION

Risk score: ***8***

Expert opinion and primary sources of risk

In a point-to-point setup, indoor penetration depends heavily on the construction material of walls, etc. A more objective indication related to indoor penetration is the sensitivity of the receiver. As such state-of-the-art test results with PMR receivers indicate a sensitivity up to -133dBm. While this is better than MANET approaches in the 2GHz frequency spectrum (-110dBm), ultra-narrow-band approaches possess a better indoor penetration performance (up to -160dBm).

However, by applying a direct mode operation (DMO), i.e. without using the TETRA network infrastructure but interlinking directly different tactile radio's, it is possible to extend TMO (trunked mode operation) network coverage to indoor confined environments. This is done by incorporating 'repeater/relay' and 'gateway' functionalities. Although these functionalities exist, tests will have to be carried out to make sure a sufficient level of indoor penetration is achieved.

CONN-6: MANET – 802.11s – DATA RATE

Risk score: ***2***

Expert opinion and primary sources of risk

Main advantages of a MANET making use of standardized RF data transmission include the transmission of data over a wireless self-configuring infrastructureless mesh network via the optimal path by applying routing protocols (such as HWMP, OLSR,…). As such every node in the network maintains network information to optimally route data packets. Taking into account an emission power of 1W signal range attains up to 1km line-of-sight.

Typical data rates attainable amount 50 to 100kbps, taking into consideration the aforementioned tradeoffs between data rate, emission power, signal reach (signal to noise ratio) and autonomy. This way compressed video frames at reduced frequency (5Hz) can be sent across the network. Voice transfer is more challenging due to the dynamic and multi-hop nature of the mobile ad-hoc network, which may cause delays.

CONN-7: MANET – MYRIANED – DATA RATE

Risk score: ***13***

Expert opinion and primary sources of risk

MyriaNed is a wireless sensor network protocol based on standard radio broadcasting and applies 'gossiping' to transfer data. Messages are sent periodically and received by adjoining neighbors. Each message is repeated and duplicated towards all nodes that span the network. MyriaNed applies a very simple stack and message structure, and has many other advantages: reliability, self-configuring (no coordinator as in Zigbee for example), etc. However, MyriaNed is typically used for sensor data gathering in e.g. building automation systems and due to the gossiping approach, attainable data rates are rather limited. Transmission of video frames (of e.g. an IR camera) is not possible.

CONN-8: MANET –INDOOR PENETRATION

Risk score: ***5***

Expert opinion and primary sources of risk

As indicated above, MANET implementations in the 2GHz frequency spectrum possess a limited receiver sensitivity especially in comparison with ultra-narrow-band. However, by its nature MANETs are mesh networks, hereby extending the network coverage in indoor confined environments. Although these functionalities exist, it is considered that tests will have to be carried out to make sure a sufficient level of indoor penetration is achieved.

CONN-9: P2P –UNB – DATA RATE

Risk score: ***40***

Expert opinion and primary sources of risk

Ultra-narrow-band technology uses free frequency radio bands (no license needed) to transmit data over a very narrow spectrum to and from connected objects. Designed for low throughput transmission (<1kbps), the UNB wireless technology benefits from a high level of sensitivity. Data transportation becomes very long range (distances up to 40km in open field) and communication with buried, underground equipment becomes possible, all this being achieved with high reliability and minimal power consumption. Furthermore, the narrow throughput transmission combined with sophisticated signal processing provides effective protection against interference.

However, for the envisaged PPS prototype (multiple data sources, multiple agents, near real-time refresh rate, etc.), it is impossible to rely the data transfer solely on UNB, the attainable data rate is simply too limited.

CONN-10: P2P –UNB – INDOOR PENETRATION

Risk score: ***5***

Expert opinion and primary sources of risk

As described above, the high level of sensitivity allows for signal penetration into confined environments. As with the other technologies, tests will have to be carried out to make sure a sufficient level of indoor penetration is achieved.

LOCAL AUTOMATIC DATA PROCESSING

PROC-1: LOCAL PROCESSING COPING WITH DEGRADED MODUS

Risk score: ***1***

Expert opinion and primary sources of risk

In case remote connectivity and data transfer is temporarily not available, remotely initiated alerts and alarms will not reach the firefighter. To cope with this, fallback scenarios should be foreseen where the captured data of a firefighter's situation is processed locally to immediately generate alerts. This is key, but solvable.

PROC-2: PREPROCESSING OF CAPTURED DATA TO OPTIMIZE DATA TRANSFER

Risk score: ***2***

Expert opinion and primary sources of risk

Given the multitude on sensors and functional devices within the firefighter's PPS, preprocessing of this data and structuring into an efficient data transfer format makes sense to limit the needed bandwidth and can be readily achieved.

PROC-3: PREPROCESSING OF CAPTURED (IR) VIDEO

*Risk score: **1***

Expert opinion and primary sources of risk

In case the firefighter is equipped with an integrated IR camera, key frames can be easily captured at reduced frame rates (e.g. 5Hz), encoded using standards codecs (e.g. JPEG, MPEG) and transferred over the network to the remote coordinating command center, under the assumption network bandwidth is sufficiently available, so that frames do not congest the network.

DATA LOGGING

LOG-1: LOCAL DATA LOGGING & DATA PUSH ON ALERT

*Risk score: **3-5***

Expert opinion and primary sources of risk

Instead of updating the complete information available on the deployed network of firefighters to the remote intervention coordinating officer in near real-time (~0,2-1Hz), only those datasets of firefighters in trouble are pushed towards command center. All other data is logged locally, and can later still be used for debriefing purposes. This way needed bandwidth is kept to a reasonable amount, in line with the capabilities of data transfer technologies. Hence, risk is kept manageable (3-5).

LOG-2: NEAR REAL-TIME DATA LOGGING OF COMPLETE NETWORK

*Risk score: **20***

Expert opinion and primary sources of risk

In case the complete information available on the deployed network of firefighters is updated to the remote intervention coordinating officer in near real-time (~1Hz), bandwidth needs are expected to exceed the capabilities of the listed qualified data transfer technologies. So scalability of the PPS solution is limited. Hence, risk is significant (20).

INTUITIVE VISUALIZATION / USER FEEDBACK SYSTEMS

Both for the firefighters in the field of intervention (local) as for the remote intervention coordinating officer, a number of alternative user feedback approaches and related sources of risk are identified, described hereafter:

VIZ-1: LOCAL – HEAD MOUNTED DISPLAY SYSTEMS

*Risk score: **13***

Expert opinion and primary sources of risk

Included under the term head mounted displays (HMD's) are both systems considered integrated in the visor of the firefighter's helmet as systems mounted in/on the helmet. Main sources of risk with these approaches include:

- Minimizing the cognitive load to prevent distraction, fatigue, loss of attention, etc.
- Dealing with "see-through", contrast and brightness variations in the continuously changing environment of the firefighter.
- While prototypes exist (e.g. DITSEF 2012), the cost of manufacturing is not in line with the envisaged budget. Other technologies like electroluminescence may be envisaged, but potentially at the cost of higher energy consumption.
- Fitting these systems in multiple different helmet variants.

In conclusion, if the system can be kept simple, displaying a minimal subset on information in line with the user requirements, from a technological perspective (and cost of manufacturing perspective) it is not that far away. Within the boundaries of the envisaged PPS solution, this facet balances at the edge of what can be considered feasible, if sufficient resources can be thrown at it.

VIZ-2: LOCAL – DISPLAY ON SLEEVE

Risk score: ***20-40***

Expert opinion and primary sources of risk

An integrated display on sleeve is considered not usable for firefighters. Usability with thick gloves, smoke, contrast and brightness issues will prevent the display from being used, as considered by the industry state-of-the-art.

VIZ-3: LOCAL – HAPTIC BELT

Risk score: ***5-8***

Expert opinion and primary sources of risk

Haptic belts refer to belts worn under the turnout gear generating local vibrations to indicate an alert, a direction to go to, etc. While commercially available and used in military navigation tasks, the main source of risk is that the belt should not impact ergonomics and toleration level given the stress of the intervention.

VIZ-4: LOCAL – AUDIO

Risk score: ***1***

Expert opinion and primary sources of risk

As commonly used today, the technological risk can be discarded. Moreover, given the short, clear audio messages given today between firefighters, there is no active interference with a firefighter's focus and attention.

VIZ-5: LOCAL – SIMPLE UI

Risk score: ***1***

Expert opinion and primary sources of risk

Under the precondition that a simple UI is in the form of existing approaches like e.g. 1 panic button, auditory sirens on remaining air level in SCBA air bottles, on toxic gas detection, man-down detection, etc. the feasibility is assessed high, hence the risk is low. Gesture recognition methods are not envisaged in the risk assessment, given the robustness of the method under low image quality, etc.

VIZ-6: LOCAL – AUTOMATIC USER FEEDBACK MODALITY SELECTION

Risk score: ***8***

Expert opinion and primary sources of risk

An option is to provide the firefighter a combined user feedback system, comprised of multiple modalities (e.g. HMD + audio + haptic belt). Ideally, feedback is provided to the firefighter through the best modality, taking into account the type of feedback and the circumstances of the firefighter. To this end an automatic user feedback modality selection unit should be incorporated in the PPS, which holds reasonable risk.

VIZ-7: REMOTE – UI DISPLAY

*Risk score: **1***

Expert opinion and primary sources of risk

A visualization display can be easily provided to the intervention coordinating officer under the form of a ruggedized laptop, a tablet computer, or even a display integrated in the sleeve, to remain as operational as possible when relocating in the intervention area.

VIZ-8: REMOTE – GUI CONFORM WAY OF WORKING

*Risk score: **3-5***

Expert opinion and primary sources of risk

In France, way of deploying firefighters occurs as follows: per truck there is a "penetration officer" coordinating typically 2 teams of firefighters. At a second coordination level, 1 "group commanding officer" coordinates up to 4 penetration officers. In parallel, a "security officer" who disposes of own firefighter couples focuses on the safety and potential rescue of colleague firefighters.
So the GUI needs to be adaptive in the level of data aggregation/escalation and visualization. Under the assumption that enough effort is spent to incorporate these coordination procedures and decision/action triggers, the risk estimation score amounts 3 to 5.

REMOTE AUTOMATIC DATA INTERPRETATION

INTEL-1: AUTOMATIC ALERT/ALARM GENERATION

*Risk score: **2-3***

Expert opinion and primary sources of risk

Under the assumption that data gathering is performed in near real-time and environmental and individual firefighter thresholds are implemented and correctly set, a simple rule-based engine suffices to generate alerts & alarms. Evidently, implementation requires some effort.

INTEL-2: HANDLING SPARSE DATA

a. **CONFIDENCE MEASURE**

b. **ARTIFICIAL INTELLIGENCE – LEARNING ALGORITHMS**

*Risk score: a. **1** - b. **5** (up to 40)*

Expert opinion and primary sources of risk

In case the remote connectivity and data transfer to the intervention coordinating officer is obstructed, the system can easily detect this and express the impact in a "confidence measure" indication. One step further is the use of artificial intelligence algorithms to form hypotheses and make a forecast on the potential situation. This can be complemented with learning and feedback mechanisms. It is believed by the industry experts that while intellectually interesting, such an approach is in the given context not to be considered, given the impact of wrong hypotheses may be catastrophic (hence risk 40). Under the assumption that simple reasoning and rule-based deduction can be applied, the risk is kept manageable.

GENERAL FACETS

GEN-5: Data privacy

*Risk score: **2-3***

Expert opinion and primary sources of risk

In case of accidents, physiological monitoring data of individual firefighters will be transferred to authorities to conduct a (medical) investigation. It is important that the interpretation of these data occurs in correspondence with the individual stress levels, "an individual calibration".

Also, the firefighter's physiological monitoring data should not directly be considered as an indication of his/her performance level. As there are many firefighter volunteers, they should be offered the possibility to respect their data privacy. It is believed by industry experts that these issues are rather minor.

4. Value vs. risk prioritization grid

Following facets are plotted on the value vs. risk prioritization grid:

DATA TRANSFER & VISUALIZATION
REMOTE CONNECTIVITY AND DATA TRANSFER
CONN-1: CABLED BAN (USB, ETHERNET)
CONN-2: WIRELESS BAN (BLUETOOTH, ZIGBEE) – ROBUSTNESS TO INTERFERENCE
CONN-3: WIRELESS BAN (BLUETOOTH) – IN-TEAM AUDIO
CONN-4: INFRASTRUCTURE BASED – PMR RELAY MODE –DATA RATE
CONN-5: INFRASTRUCTURE BASED – PMR RELAY MODE –INDOOR PENETRATION
CONN-6: MANET – 802.11s – DATA RATE
CONN-7: MANET – MYRIANED – DATA RATE
CONN-8: MANET –INDOOR PENETRATION
CONN-9: P2P –UNB – DATA RATE
CONN-10: P2P –UNB – INDOOR PENETRATION
LOCAL AUTOMATIC DATA PROCESSING
PROC-1: LOCAL PROCESSING COPING WITH DEGRADED MODUS
PROC-2: PREPROCESSING OF CAPTURED DATA TO OPTIMIZE DATA TRANSFER
PROC-3: PREPROCESSING OF CAPTURED (IR) VIDEO
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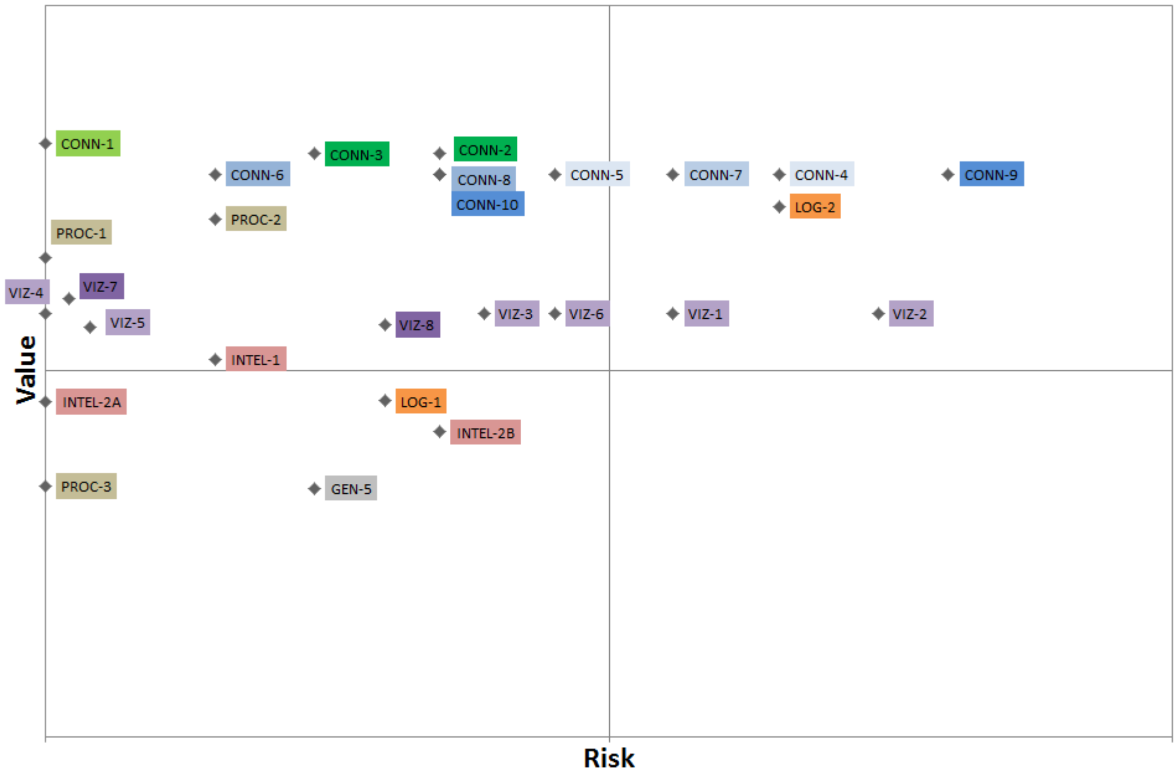
INTUITIVE VISUALIZATION / USER FEEDBACK SYSTEMS
VIZ-1: LOCAL – HEAD MOUNTED DISPLAY SYSTEMS
VIZ-2: LOCAL – DISPLAY ON SLEEVE
VIZ-3: LOCAL – HAPTIC BELT
VIZ-4: LOCAL – AUDIO
VIZ-5: LOCAL – SIMPLE UI
VIZ-6: LOCAL – AUTOMATIC USER FEEDBACK MODALITY SELECTION
VIZ-7: REMOTE – UI DISPLAY
VIZ-8: REMOTE – GUI CONFORM WAY OF WORKING
REMOTE AUTOMATIC DATA INTERPRETATION
INTEL-1: AUTOMATIC ALERT/ALARM GENERATION
INTEL-2A: HANDLING SPARSE DATA - CONFIDENCE MEASURE
INTEL-2B: HANDLING SPARSE DATA - AI LEARNING ALGORITHMS
GENERAL FACETS
GEN-5: Data privacy



5. Synthesis on focus area 3

The main implications for the PPS prototype following the value vs. risk prioritization grid are w.r.t:

DATA CONNECTIVITY:

1. Intended use of Professional Mobile Radio (PMR) is for trunked mode operation (TMO) and direct mode operation (DMO) voice and limited data. Mobile ad-hoc networks (MANET) for data and selected compressed images, Ultra Narrow Band (UNB) for small data sets at low update frequencies.

2. Regardless of the connectivity architecture chosen, risk reduction should primarily focus on: **indoor penetration performance**, and sufficient data rate.

3. Regarding connectivity between devices of the PPS on the firefighter's body, both a **cabled** (USB) **and/or wireless** (Bluetooth) can be envisaged. In case wireless, risk reduction should explain measures coping with **interference** risk.

4. The **update rate** of logging the network data **to the remote intervention coordinating officer** should approach **near real-time (~1Hz)**. Risk reduction should primarily focus on maximizing the scalability trade-off of deployed network nodes vs. update rate.

USER FEEDBACK / VISUALIZATION:

1. The intervention coordinating officer should be provided an **intuitive UI dashboard**, which is **aligned with way of working.**

2. The user restitution system for the firefighter should ideally be multimodal: **audio combined with simple UI (button/lights) and a haptic belt.** Risk reduction should focus on automated feedback modality selection and ensuring the ergonomic use of the feedback system, in particular the haptic belt.

3. Providing **visual feedback** to the firefighter via helmet mounted displays (HMD) or head-up-displays (HUD) in the helmet visor holds **significant risk** in balancing trade-offs between cost, ergonomic use (brightness, contrast, "see-through", etc.), robustness. A solution comprising a display on sleeve is considered not usable, hence discarded.

7. Focus Area 4: Integration of ICT solutions with textile

Current approaches towards the integration of ICT technologies with textile can be roughly divided into two tactics:

- A **limited textile integration** through intelligent use and design of Velcro strip, pockets, clips, or design within/throughout the layers of the turnout gear. Two extremes can be considered then with respect to the integration of the ICT building blocks of the ICT solution:
    - A **vertically integrated ICT solution**, referring to a system composed of multiple distinct devices, multiple HW/housings, multiple batteries, multiple connections, etc.
    - A **fully integrated ICT solution**, meaning all functional building blocks integrated in 1 device/HW with 1 housing and 1 battery.
- A **fixed on/in textile integration**, where distinction can be made between:
    - **woven-in conductive materials** (e.g. copper wires) specifically envisaging applications such as data transfer, power supply or physiological monitoring (e.g. to allow for a better spread of body temperature measurements resulting in a more accurate model of estimating the core temperature of the body, in an ideal setting with an accuracy of even 0,1°C.
    - **fixed/glued on textile** approaches, covering technologies like a polymer layer where sensors, circuits and even LEDs could be integrated to foresee active illumination; nanomaterial coating to e.g. prevent corrosion of woven in copper wires; or even thermochromic substances may be envisaged changing color in line with temperature changes.

1. Technological facets related to the reference solution

LIMITED TEXTILE INTEGRATION – VERTICALLY INTEGRATED ICT SOLUTION

Distinction is made between cabled and wireless interconnectivity between the different components. In a cabled approach, cabling is assumed to be designed in into the turnout gear layers.

INT-1: CABLED – DESIGN, IMPACT ON ERGONOMICS

Risk score: ***3***

Expert opinion and primary sources of risk:

It is estimated that by spending some effort on the textile design aspects for the envisaged new PPS, these can be resolved with minimal risk. However, when envisaging integration of a cabled solution into the existing “installed base” of firefighter PPE suits, the risk easily increases towards 13.

INT-2: CABLED – EASY REPLACING/(DIS)MOUNTING

Risk score: ***8***

Expert opinion and primary sources of risk:

Under the assumption that the total duration of replacing the cabling designed in into the layers of the turnout gear can maximally take 15 minutes to not heavily impact the workload of the PPS maintenance crew, it is key to keep cabling as simple as possible. Under this precondition a score of 8 is given: “feasible given significant effort and right design choices to keep the cabling simple”. Main difficulties situate around the external sensor devices. In case complex cabling is envisaged, risk increases towards 20.

Ultimate goal is to reduce the risk so that a PPS maintenance responsible can easily carry out the replacement task, without specialized help of a textile specialist.

INT-3: CABLED – DURABILITY/ROBUSTNESS of CABLES/CONNECTORS

Risk score: ***13***

Expert opinion and primary sources of risk:

Durability and robustness of operations refers both to the normal operational conditions (heat, chemicals, etc.) during interventions, as to the cleaning operations. Throughout the lifecycle of a turnout gear (5 to 8 years), around 20 to 25 cleaning operations are carried out, during which the turnout gear is subjected to special treatments, like restoring waterproofness, etc. This is not easily resolved. Easy (dis)mounting (and recuperating) the cabling could lighten the risk severance, but connectors remain an issue, especially those used to connect external sensor devices.

INT-4: CABLED – MULTIPLE SIZES of TURNOUT GEAR

Risk score: ***5-8***

Expert opinion and primary sources of risk:

Under the assumption that 3 variants will suffice for the 8 turnout gear sizes and under the constraint that impact on ergonomics is nihil, a moderate risk severance is estimated. ‘Only’ 3 variants do not impact manufacturing costs too much. Solutions incorporating “stretchable cables” are not envisaged given a risk severance of around 20.

INT-5: CABLED - MULTITUDE of UI

Risk score: ***5***

Expert opinion and primary sources of risk:

Aiming to reduce the amount of UI’s in a vertically integrated cabled solution into eventually 1 central UI, may impact cabling complexity to a certain extent, unless e.g. a central data processing unit connects directly to a simple UI. The main functionality of the UI in this context is launching the system operational and knowing that all connected devices work properly.

INT-14: CABLED - ELECTROMAGNETIC INTERFERENCE: SHIELDED CABLES

Risk score: ***2-3***

Expert opinion and primary sources of risk:

Making use of shielded cables without impacting volume and weight is considered relatively straightforward.

INT-6: WIRELESS – BODY AREA NETWORK – INTERFERENCE PROBLEMS

Risk score: ***8***

Expert opinion and primary sources of risk:

Tests need to be performed to make sure that the frequency spectrum is optimally used, balancing communication between sensor devices (body and environment) on the firefighter's, localization system and radio communication towards the remote intervention coordinating terminal. These issues are known and tackled by today's state-of-the-art industry.

INT-7: WIRELESS – CHARGING MULTIPLE BATTERIES & IMPACT ON WAY OF WORKING

Risk score: ***2***

Expert opinion and primary sources of risk:

It is not considered a risk that in the PPE maintenance center multiple batteries should be charged at all times to ensure an immediately available and operational PPS. Some procedures should be updated, but that can be easily done.

INT-8: WIRELESS – "PLUG & PLAY" START-UP of the SYSTEM and KNOW THAT IT WORKS

Risk score: ***8-13***

Expert opinion and primary sources of risk:

Starting up the system should be straightforward, even in case there are several wireless interlinked devices on the firefighter. The firefighter should as fast as possible know that the system is fully operational in line with his time to arrive on site (order of magnitude of 5 to 10 minutes). Compared to a centralized system, a wireless approach is more complex, especially when the aim is to restrict the amount of UI's to a minimum.

Next to start-up and launching the system operational, this should be launched in the right configuration, with auto-detection mechanisms, etc. Again with minimal operations/manipulations required from the firefighter. Typically to select the right gear (and hence configuration) the firefighter relies on the intervention briefing by the security officer.

As the risk estimation indicates, this is not easily resolved. A simple self-calibrating, self-connecting system should be aimed for.

INT-9: WEIGHT

Risk score: ***3***

Expert opinion and primary sources of risk:

Given that the total weight of a turnout gear is 3 to 4kg and equipment next to the turnout gear (helmet, tactical radio, breathing apparatus, etc.) weighs around 20 to 25 kg, an additional weight of around 1 to 2 kg for the total ICT solution is envisaged. Evidently some efforts need to be spent to minimize this.

INT-10: WEIGHT BALANCING on FIREFIGHTER BODY

Risk score: ***5***

Expert opinion and primary sources of risk:

Given a total autonomy of the system is required of maximally 2 hours in urban fire interventions when all envisaged functionalities are operational up to 4 hours in open area interventions where not all functionalities are useful (e.g. toxic/explosive gas detection), suitable battery packs are readily available on the market. Some efforts need to be spent on optimally balancing the weight on the firefighter's body, making use of clips, Velcro strips, pockets, etc.

LIMITED TEXTILE INTEGRATION – FULLY INTEGRATED ICT SOLUTION

INT-11: EXTENDABILITY, MODULARITY

Risk score: ***1***

Expert opinion and primary sources of risk:

Under the assumption that the central architecture allows for wireless connections on standardize protocols, a fully integrated ICT solution is made extendable, future proof when envisaging additional sensor functionalities, etc.

FIXED ON/IN TEXTILE

INT-12: WOVEN-IN CONDUCTIVE MATERIALS

Risk score: ***20-40***

Expert opinion and primary sources of risk:

Today, practical use of woven-in conductive material in industrial applications occurs rarely. Envisaging an intended use within a smart PPS for firefighting, multiple sources of risk are identified by the industry experts. Primary sources of risk include: corrosion by sweat, limitations on electrical conductance/resistance, durability of the connectors both during normal operation under extreme conditions as during washing/cleaning operations, the cost of manufacturing, potential impact on ergonomics, etc. For these sources of risk, significant risk reduction needs to be performed, hence a high risk score.

INT-13: FIXED/GLUED ON TEXTILE

Risk score: ***40***

Expert opinion and primary sources of risk:

Potentially, these polymer and nano-materials hold advantages in terms of weight, corrosion protection on woven-in copper wires, extended waterproofness in combination with breathing textile capabilities. However, sources of risk like durability under normal operating conditions and during cleaning/washing procedures, large scale manufacturing at low cost, etc. are not easily resolved, hence a high score of 40.

SYSTEM LEVEL FACETS

INT-15: ELECTROMAGNETIC INTERFERENCE: SHIELDED SENSORS, MICROCONTROLLERS,…

*Risk score: **8***

Expert opinion and primary sources of risk:

In case a sensor or microcontroller are brought at close distance to a broadcasting transmitter, all conductive part may saturate making the sensors 'deaf' and microcontrollers make unforeseen jumps between programmed states.

The risk assessment reflects on the complexity to find a fitting balance between engineering effort, cost and additional weight for the intended fire and rescue applications and without evolving close to military-grade measures.

INT-16: FLEXIBILITY, SCALABILITY OF SYSTEM

*Risk score: **8-13** (doing the right things) up to **20-40** (building a fully flexible, configurable 'usine-a-gaz')*

Expert opinion and primary sources of risk:

This facet includes following angles: determining the right architecture, setting the balance between distributed and central processing taking into account trade-offs between local processing performance of selected data and responsiveness when remote relay of data (e.g. in case of physiological alerts), defining interfaces for hierarchical aggregation and escalation, building the suited data model, allowing for online and offline operation with careful consideration of polling and synching events, coping with the multimodality in firefighter user restitution means, modularity allowing for coupling with new peripherals (e.g. sensors), etc.

It is considered a key element for the PPS prototype by the industry's state-of-the-art, and should be the starting point of the solution conceptualization ("look at the whole system"). The objective is not to develop a 'usine-a-gaz' allowing for endless flexibility, merely it is the goal to 'do the right things' allowing for some future improvement and coupling with new peripherals. It should be thought through which future peripheral devices might be coupled.

A final point brought up in the discussion reflects on start-up of the system, which should be in line with present routines when preparing for an intervention and arriving at the scene. Additional manipulations by the firefighter should be minimized.

SERVICING/MAINTENANCE

INT-17: Servicing/maintenance: general inspection procedure (cfr. BA) done @ station, incl. tags, logbook prescriptions, etc.

*Risk score: **3***

Expert opinion and primary sources of risk:

Concerning the turnout gear, recommended maintenance and washing procedures exist and are provided in detail by the turnout gear manufacturer. Additionally, general textile maintenance guidelines exist and known as "SUCAM" (Guidelines for **S**election, **U**se, **CA**re and **M**aintenance of protective clothing against heat and flame). Every turnout gear contains a tag (barcode, RFID,…) which can be scanned into an event log. There applied maintenance procedures can be easily noted.

However, in practice, turnout gear maintenance procedures and habits differ between countries and even between fire brigades. In general, turnout gears are maintained either at the fire brigade station, either at home (even with contamination), either by 3rd party maintenance service providers (whose internal processes are optimized to treat working gear, and not firefighter turnout gear). In theory, suits only need re-impregnation every 2-3 washes, but in practice without keeping track of the number of washes, suits are re-impregnated after every wash.

Given these considerations it would not be the smartest thing to align the recommended maintenance procedure of the Smart@Fire PPS with those applied on the turnout gear. A better approach is to align with the inspection procedures on the breathing apparatus. For the breathing apparatus recommended inspection procedures are applied after every intervention at the fire brigade station. The inspection procedure includes filling an event log (through barcode identification of the breathing apparatus). And more important, the inspection procedure is strictly followed by the PPE maintenance responsible. It is considered feasible to produce similar recommended inspection procedures (including barcode identification, event log) for the Smart@Fire PPS. This procedure should describe the general inspection methods, but should leave some flexibility w.r.t. performing these tests (as different brigades may use different inspection approaches).

INT-18: Servicing/maintenance: in depth inspection, on call/on demand interventions, spare parts, training/certification,… + business model

Risk score: ***3-5***

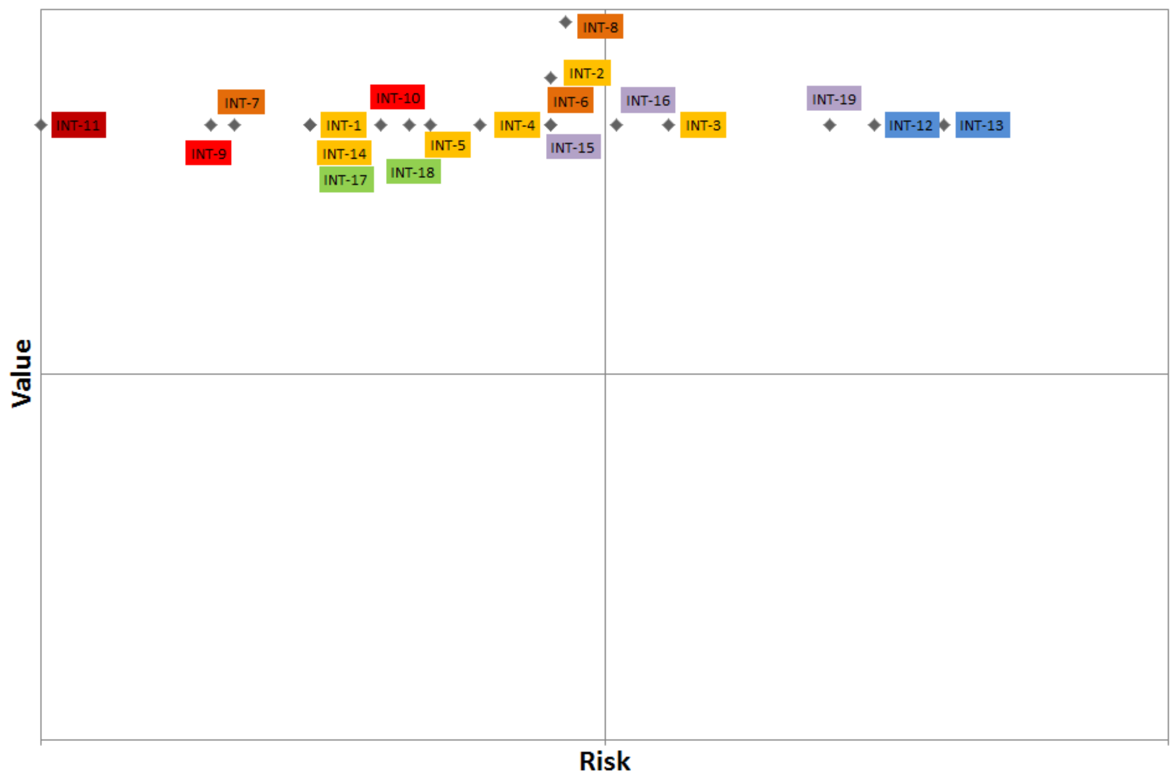
Expert opinion and primary sources of risk:

Next to the recommended inspection procedure of the breathing apparatus performed at the fire brigade station by the PPE responsible, a yearly in-depth check-up of the apparatus is performed, either by the manufacturer's service teams, either by certified (through training) personnel at the fire brigade station. For the Smart@Fire PPS, a similar service should be provided by the offering consortium. This service should for example include, yearly on-site maintenance and repair, certification programs, on-call maintenance or repair, back-to-back service contracts with component suppliers, etc.

2. Value vs. risk prioritization grid

Following facets are plotted on the value vs. risk prioritization grid:

INTEGRATION
LIMITED TEXTILE INTEGRATION – VERTICALLY INTEGRATED ICT SOLUTION
INT-1: CABLED – DESIGN, IMPACT ON ERGONOMICS
INT-2: CABLED – EASY REPLACING/(DIS)MOUNTING
INT-3: CABLED – DURABILITY/ROBUSTNESS of CABLES/CONNECTORS
INT-4: CABLED – MULTIPLE SIZES of TURNOUT GEAR
INT-5: CABLED - MULTITUDE of UI
INT-14: CABLED - ELECTROMAGNETIC INTERFERENCE - SHIELDED CABLES
INT-6: WIRELESS – BODY AREA NETWORK – INTERFERENCE PROBLEMS
INT-7: WIRELESS – CHARGING MULTIPLE BATTERIES & IMPACT ON WAY OF WORKING
INT-8: WIRELESS – "PLUG & PLAY" START-UP of the SYSTEM and KNOW THAT IT WORKS
INT-9: WEIGHT
INT-10: WEIGHT BALANCING on FIREFIGHTER BODY
LIMITED TEXTILE INTEGRATION – FULLY INTEGRATED ICT SOLUTION
INT-11: EXTENDABILITY, MODULARITY
FIXED ON/IN TEXTILE
INT-12: WOVEN-IN CONDUCTIVE MATERIALS
INT-13: FIXED/GLUED ON TEXTILE
SYSTEM LEVEL
INT-15: Electromagnetic interference: shielded sensors, microcontrollers, etc.
INT-16: Flexibility, scalability of system: architecture, distributed vs. central processing, trade-offs performance local, selected data, responsiveness
INT-19: FULLY FLEXIBILE SYSTEM, ALIGNED WITH WOW, CONFIGURATION, ARCHITECTURE,…
SERVICING/MAINTENANCE
INT-17: Servicing/maintenance: general inspection procedure (cfr. BA) done @ station, incl. tags, logbook prescriptions, etc.
INT-18: Servicing/maintenance: in depth inspection, on call/on demand interventions, spare parts, training/certification,… + business model



3. Synthesis on focus area 4

The main implications for the PPS prototype following the value vs. risk prioritization grid are w.r.t:

1. Setting-up the **right architecture** is key and holds significant risk (data model, distributed/central processing, flexibility/modularity, scalability of system, trade-offs local

performance vs. remote responsiveness (online vs. offline), interfaces for escalation & aggregation, etc.)

2. **Limited integration with (underwear, turnout gear) textile** is preferential. Woven-in, layered-on ICT-textile integration comprises too many risks w.r.t manufacturing costs, durability, etc.

3. PPS on FF can be cabled and/or wireless. The additional weight and balancing this weight effectively around the firefighter's body is considered achievable.

4. **Cabled**: risk reduction on: **easy mounting/replacing** of cables/connectors; **durability** of cables/connectors; dealing with different **turnout gear sizes**; integrating UIs

5. **Wireless**: risk reduction on: limiting **interference** (cfr. data connectivity); **easy launch**, start-up and **assurance** of correct operations via **minimal # UIs**

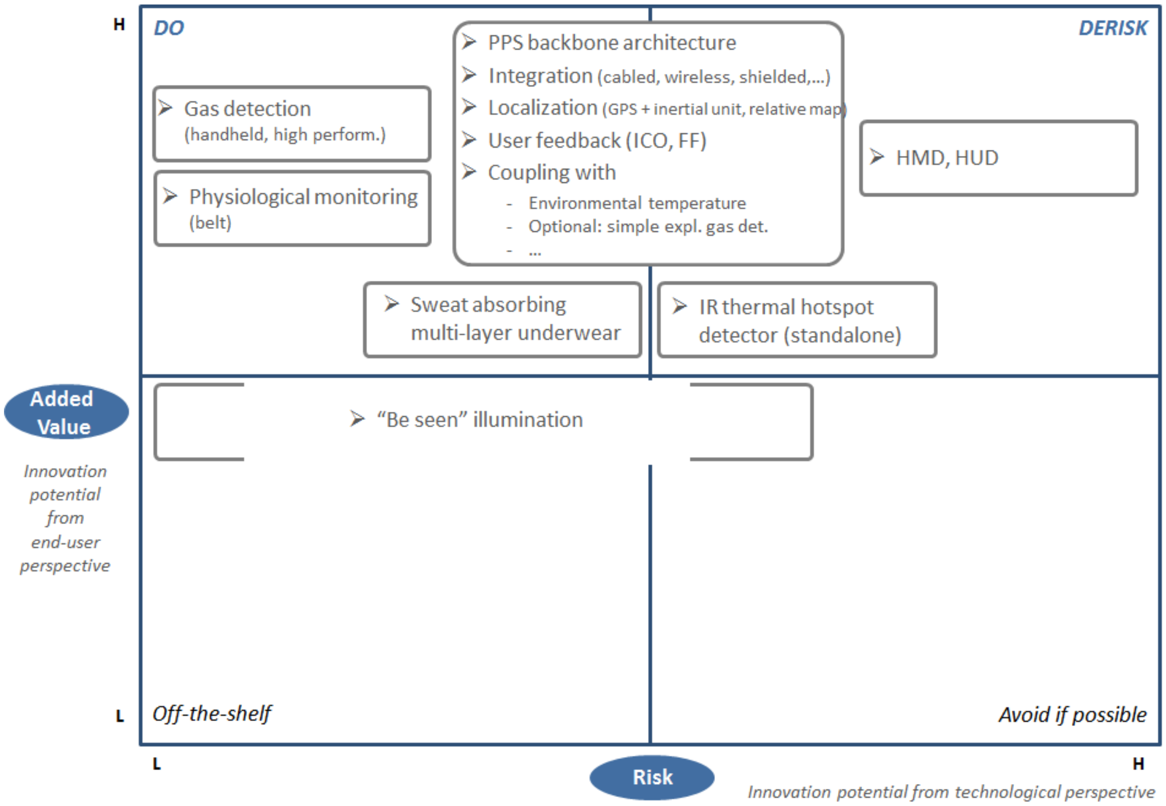
6. **Electromagnetic shielding** of the different devices (sensors, processing unit,…) on the firefighter should be taken into account, without implementing military-grade measures.

7. Setting up a suited 2-level **service model** is considered achievable (level 1: recommended inspection procedure at station, level 2: on-demand assistance, repair, certification, etc.

8. Concluding implications for the PPS prototype

1. Overall innovation potential of a PPS

In previous sections, for each focus area the innovation potential has been synthesized following the resulting mapping of the technological facets on the value vs. risk prioritization grid. When putting the 4 focus area together, a number of clustered challenges can be distinguished. These challenges cover the overall innovation potential of a Smart@Fire PPS and are summarized below:



CHALLENGE 1: PPS backbone

The PPS backbone encompasses following elements and affiliated sources of risk:

- The backbone architecture:
  - Communication network with sufficient indoor penetration, data rate/model/preprocessing, and near real-time update rate towards the intervention coordinating officer
  - Trade-offs between distributed and central processing, scalability of system, local performance vs. remote responsiveness (online vs. offline operation), interfaces for escalation & aggregation, etc.
- Limited integration with textile (underwear, turnout gear):
  - No woven-in, layered-on ICT-textile integration comprises too many risks w.r.t manufacturing costs, durability, etc.
  - Cabled and/or wireless, with careful consideration of respective risks: when cabled: easy mounting/replacing of cables/connectors; durability of cables/connectors; dealing with different turnout gear sizes; integrating UIs; when wireless: limiting interference (cfr. data connectivity); easy launch, start-up and assurance of correct operations via minimal # UIs
  - Electromagnetic shielding of the different devices (sensors, processing unit,…), without implementing military-grade measures.
- Localization engine:
  - A hybrid localization system (preferentially GPS + inertial) with limited indoor drift.

- A relative track & trace map, enabling 'meet point' and 'recovery path' instructions. Available Cartesian coordinated maps (e.g. Google maps), used as overlay.
- Beacon-based solution increases risk in terms of ease of deployment without losing accuracy and TCO.

- Intuitive user feedback (restitution, visualization):
  - For the intervention coordinating officer: an intuitive UI dashboard, aligned with way of working.
  - For the firefighter: multimodal combination of audio, simple UI (button/lights) and haptic belt. Risk reduction on automated feedback modality selection and ergonomic use.
- Coupling via defined application interfaces (e.g. Bluetooth application profile) with
  - (Standalone) environmental temperature measurement device
  - Optional, when available: (standalone), cheap, simple and robust explosive gas detector (e.g. indicating just the presence of explosive gasses)

The PPS backbone holds significant added value for the end-user: with successful risk reduction it will enable following highly valued use-cases:

Enabled use-cases	WOW BE	WOW FR
An ICO consulting a 'relative' map to locate the FF teams	★★★★	★★★★
An ICO consulting a 'relative' map to locate the FF teams enriched with env. T, ΔT	★★★★	★★★★
An ICO consulting a 'relative' map to locate the FF teams enriched w equipm.status	★★★★	★★★★
An ICO using an intuitive visual. system and semi-automated data interpretation	★★★★	★★★★
An ICO informing the FF by generating an alert (using the available data)	★★★★	★★★★
A FF using an intuitive feedback system not distracting his operations (no visual.)	★★★★	–
An ICO escalating alerts/available data to create an aggregated view	★★	–
A FF measuring (~~consulting~~) env. parameters (temperature and evolution)	★★★★	★★★★
A FF, PPE manager relying on self-assessment of available, coupled sensors, devices	★★★★	★★★★
A trainer using similar remote monitoring available info to improve trainees	★★★★	★★★★
A department head using historical logging of available data for RCA, audit trails,...	★★★★	★★★★
A FF measuring, ~~consulting~~ env. parameters (explosive gasses)	★★★★	–

CHALLENGE 2: Sweat absorbing multilayer underwear

Avoiding sweat being turned into steam can be improved/solved through a pure textile approach, by reviewing tenders and firefighters' comfort balance (e.g. skin resistance). Significant lobby effort should be put in place to achieve this.

Note 1: it is not the goal to develop a new better performing sweat absorbing multilayer material, as the innovation platform discussions revealed that these materials exist.

Note 2: underwear in this context reflects anything that can be worn underneath the turnout gear.

The sweat absorbing multilayer underwear would enable following highly valued use-case:

Enabled use-cases	WOW BE	WOW FR
A FF relying on the suit to avoid sweat being turned into steam	★★★★	★★★★

CHALLENGE 3: IR thermal hotspot detector

Using a cheap, miniature IR thermal imaging sensor/camera with relevant resolution and detection range in high temperature environments holds significant risk. In this case the sensor is considered not integrated/coupled with a firefighter visualization system (see Challenge 4), but this could very well be envisaged. It is not excluded as option.

Once solved, this would enable following high-valued use-case:

Enabled use-cases	WOW BE	WOW FR
A FF 'seeing' hotspots in the environment (e.g. only audio feedback)	★★★★	★★★★
A FF 'seeing' victims in the environment (e.g. only audio feedback)	★★★★	★★★★

CHALLENGE 4: HMD/HUD firefighter visualization system

Providing visual feedback to the firefighter via helmet mounted displays (HMD) or head-up-displays (HUD) in the helmet visor holds significant risk in balancing trade-offs between cost, ergonomic use (brightness, contrast, "see-through", etc.), robustness. A solution comprising a display on sleeve is considered not usable, hence discarded.

However, once solved it would enable following use-cases:

Enabled use-cases	WOW BE	WOW FR
A FF using an intuitive visualization system not distracting his operations (no visual.)	★★★★	–
A FF having information on own/team position, on a building/area map	★★★★	★★★★

CHALLENGE 5: "BE SEEN" omnidirectional active illumination

Active illumination to achieve omnidirectional "be seen" holds no technological risk under the precondition that a simple, cheap, standalone clip-on/velcro system is used by the firefighter (as limited integration with textile is preferred). There lies the risk, creating a user-friendly system that allows for easy operation (somewhere fixed on the firefighter suit), but is not destroyed in a fire-facing intervention due to the increased temperature or mechanical friction.

An alternative is a cabled solution, making the design and integration a lot more complex (durability of connectors, cabling, etc.).

As a result, this focus is spread along the horizontal risk axis

This would enable following highly valued use-case:

Enabled use-cases	WOW BE	WOW FR
A FF using active illumination to be seen on the road in darkness	★★★★	★★★★

CHALLENGE 6: Explosive gas detection

Regarding monitoring explosive gas detection, finding the trade-offs between size, cost/TCO, accuracy, power consumption, etc. is difficult, while good, standalone, but expensive gas detectors exist. However, in case a simple not all-too accurate detector of explosive natural gasses is envisaged, these trade-offs might be easier to solve. Mitigation measures should then be incorporated to cope with the increased number of false positives and the potentially higher required maintenance effort.

Following high-value use-case would be enabled:

Enabled use-cases	WOW BE	WOW FR
A FF measuring, consulting env. parameters (explosive gasses)	★★★★	–

CHALLENGE 7: Physiological monitoring

The innovation platform discussions learned that physiological data capture and general alert recommendation generation holds no risk. Generating alerts on an individual level requires more effort, especially to gather and keep the parameters up-to-date.

Coupling physiological monitoring with CHALLENGE 1 would enable following high-value use-cases:

Enabled use-cases	WOW BE	WOW FR
if coupled with PPS backbone (FOCUS1):		
An ICO consulting a map to locate FF teams enriched with health status	★★★★	★★★★
An ICO setting indiv. thresholds on parameters of FF to generate true-pos. alerts	★★★★	★★

2. Qualification for pre-commercial prototyping phase

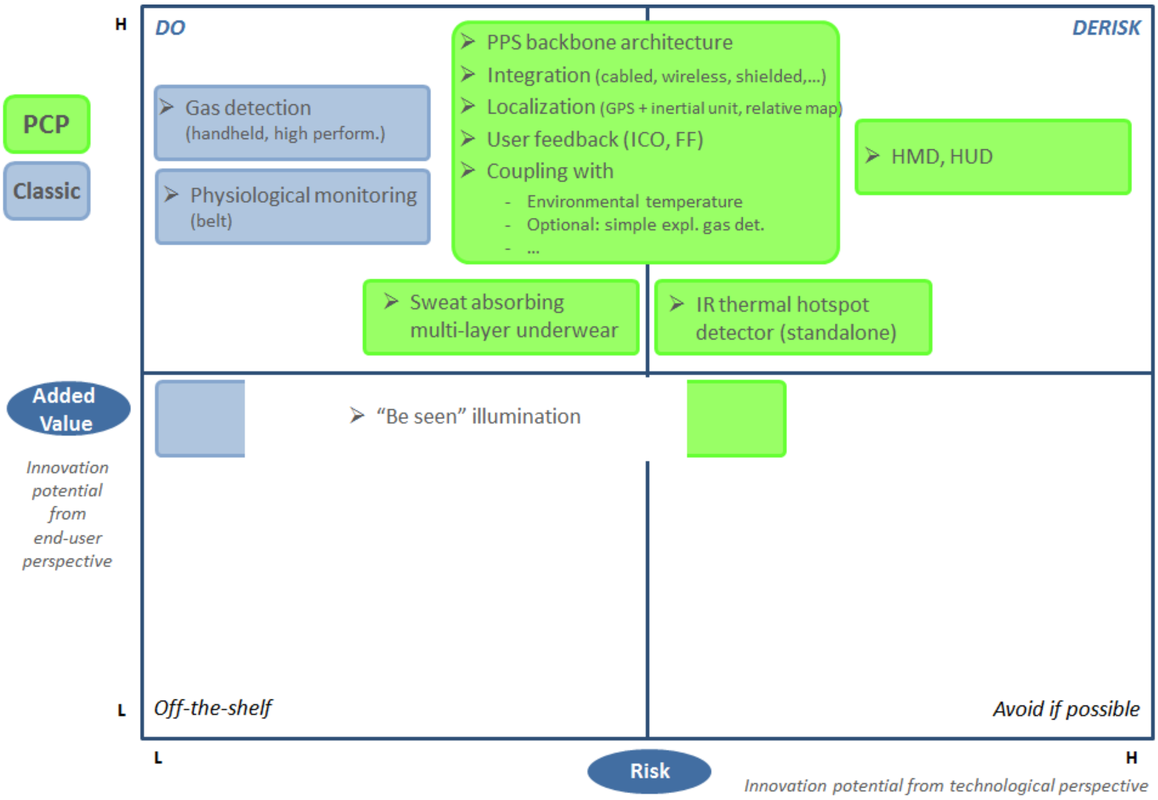
The scope of the Smart@Fire PPS is covered by the high number of highly scored use-cases and the (technological) challenges as presented in the previous section. Overviewing these, it can be concluded that a smart Personal Protective System holds a **high innovation potential both from user point-of-view as from technological perspective**.

In order to successfully realize the ambitious potential of the project, the necessary budgets and efforts will have to be put forward. From the discussions with industry experts, it is noted that a number of distinct technologies and building blocks seem to exist in different maturity stages (R&D Demonstrator, Prototype, Commercial Product). The innovation platform learned that **significant research and development effort is needed to reduce the risks associated to the transformation and integration**

of these partial building blocks/technologies to a working prototype, enabling the high-value use-cases for the end-user, the firefighter. As such, before starting to build one main integrated system incorporating multiple sources of risks, it is recommended to initially launch a **pre-commercial development phase**. During this prototyping phase, focus is laid on reducing these risks with limited means.

Not all foci qualify for this pre-commercial procurement phase (PCP), as this requires both high added value for the end-user as well as significant innovation potential from technological perspective (hence significant risk). The recommended approach for the identified challenges is summarized below:

CHALLENGE	Eligible for:	Because:
1: PPS backbone	PCP	High added value, significant risk
2: Sweat absorbing multilayer underwear	PCP	Significant added value, significant risk
3: IR thermal hotspot detector	PCP	Significant added value, high risk
4: HMD/HUD firefighter visualization system	PCP	High added value, high risk
5: "BE SEEN" omnidirectional active illumination	PCP	Reasonable added value, significant risk (to make it usable)
6: Explosive gas detection	Classic	High added value, no technological risk as the goal is not to develop the next generation of small, cheap explosive gas detectors. Coupling with PPS backbone is considered in CHALLENGE 1.
7: Physiological monitoring	Classic	High added value, no technological risk. Coupling with PPS backbone is considered in CHALLENGE 1.



3. Priorities for the Smart@Fire PPS prototype

The highest priorities on the prototype development roadmap are typically those elements with the highest added value for the end-user and significant risk reducible within reasonable time elapse. The higher the risk, the more difficult to reduce it sufficiently within time and budget constraints. In order to set-up this prototype development phase, the **right priorities for the prototype scope** should be selected. In line with Smart@Fire project constraints (mainly budget and timing), this means making the right choices in challenge clusters, as tackling them all at once is too ambitious.

In consensus with the end-users (i.e. firefighters and affiliated public procurement agencies) following recommendations emerge w.r.t. the PCP scope:

1. First and foremost, the central challenge of the PPS prototype situates around the **PPS backbone** and related elements (i.e. CHALLENGE 1). This is the basis of the PPS prototype.
2. Given the limited technological risk associated with the **sweat absorbing multilayered textile solution**, but merely an administrative/lobbying risk, CHALLENGE 2 is withheld within the PPS prototype minimal scope.
3. Regarding CHALLENGE 3 and 4, the IR thermal hotspot detector and the HMD/HUD firefighter visualization system, it is recommended to dedicate a similar but different project to solving these. Main reasons include: they add-up in terms of added value enablers; complexity and risk are of another order compared to CHALLENGE 1 and 2. Potentially a firefighter's 'walhalla' use-case of 'seeing through smoke' can be incorporated in the prototype development phase.

4. CHALLENGE 5, "BE SEEN" omnidirectional active illumination, qualifies to be withheld within the minimal scope of the prototype, but it is currently left out, taking into consideration the project budgetary and timing constraints.

4. Prototype with minimal scope: plan of attack

As a result of the previous minimal scoping, the PPS prototype covers CHALLENGE 1, the PPS backbone, and CHALLENGE 2, sweat absorbing multilayer textile solution. During the pre-commercial development phase this minimal scope will be further elaborated to perfectly respond to the needs of the firefighters. Elaboration involves solution exploration and development to reduce the technological risks while securing that the added value as described by the high-value use-cases is effectively realized.

It should be noted that the minimal scope of CHALLENGE 1 and CHALLENGE 2 may equally result in one integrated or two parallel pre-commercial development tracks. Interested parties or consortia can submit an offer that covers the development of CHALLENGE 1, CHALLENGE 2, or both.

The envisaged timing of the subsequent phases is:

- Solution exploration phase: maximum 2-3 months
- Prototype development phase: maximum 12 months
- Creation of first batch of prototypes (e.g. 8-12): 3 months

9. Concluding insights

While from a technological perspective multiple technological approaches and initial building blocks exist in different maturity stages, however today, for fire and rescue operations there is no complete system on the market, due to the specific trade-offs required in the fire and rescue niche, explained hereafter:

1. State-of-the-art problems like indoor penetration of communication and localization are **broader technological problems** than just for fire and rescue applications. As such in affiliated research projects and commercial system developments, more attractive sectors such as defense, security, retail or utilities are chosen by manufacturers.
2. The environment of operation of the firefighter varies from a complex intervention in an urban confined environment to a forest fire in an open area to a technical intervention on the highway. All these specific conditions have a common need for an **underlying system architecture** (for communication of data for example). However, this architecture should be made **flexible** to allow for other functional configurations (e.g. couple 3rd party components), which is under normal market conditions not easily achieved.
3. The fire and rescue market consists of a **fragmentized procurement** landscape with in general rather limited budgets (at least compared to military, security, etc.). Under these conditions it is hard to unite on selected user requirements and **push** these onto **vendor development roadmaps**.
4. These user requirements cover all together **robust operation, easy maintenance** and **high performance**, at relatively **low cost**.