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GUARDIANS

Description of the Warehouse Search Scenario and User Requirements Document

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User Requirements Document.

Table of Contents

List of Figures:

List of Tables:

Foreword

The current document is Deliverable D1.1/2, Description of the Warehouse Search Scenario and User Requirements Document.

The full list of user requirements is given in Appendix 1: User requirements table: and a first list of system requirements in Appendix 2: System Requirements table.

The body of the document contains descriptions of processes environment etc, and aims to provide a context for the user requirements and where appropriate system requirements.

The document is organised as follows:

Section 1: Gives an overview of the intervention process, from the first alarm up to the establishment of a full crew for a major incident.

Section 2: Here initially the basic (and standard) fire fighting unit is described, that is the non-specialised unit that will first arrive at the scene, moreover when non-specific assistance is called for then more of such units will arrive. Some specialised units are also detailed.

Section 3: Describes the human interaction in the emergency of a fire.

Section 4: Describes a warehouse and the procedures applying to incidents in a large scale building.

Section 5: Describes a trial scenario, intended to be tested in January 2008. The trial scenario is a simplification of a warehouse search in a limited space with no real smoke. Though a simplification, the scenario touches on some essential questions that will also arise in an actual warehouse incident.

Section 1: Intervention Process Overview

When the fire brigade is alerted to an incident they initially have very little information. They respond to any call, and therefore when arriving at the incident they have to establish first whether it is a real or false alarm.

The dominating factor for an intervention by fire fighters is safety; the safety assessments influence what strategies will be chosen. If it concerns fire fighting only, they may choose a 'defensive' or an 'offensive' strategy. Defensive means that they try to avoid the spreading of the fire; offensive means that they try to extinguish the fire.

The safety of the fire fighters is a priority. Many of the procedures described below are aimed at ensuring the safety of the fire fighters.

User requirement: The safety of the fire-fighter can never be negotiated.

Alert Process

The diagram in Figure 1 provides an overview of the processes taking place up to the arrival of the first appliance at the incident site. The standard crew and appliance are described below.

Obviously, until the first crew has arrived (in the UK estimated within 6 to 8 minutes maximum after the alarm has been received) there is a dearth of information. First of all, it is unknown whether the incident is serious or false. Moreover one does not have information about the scale of the incident. If the incident concerns a large building or facility, more than one appliance will attend (local term: Predetermined Attendance).

The first task of the arriving crew is to assess the incident, in particular from the point of view of safety. If the incident appears to be of a large scale the crew will call for further assistance.

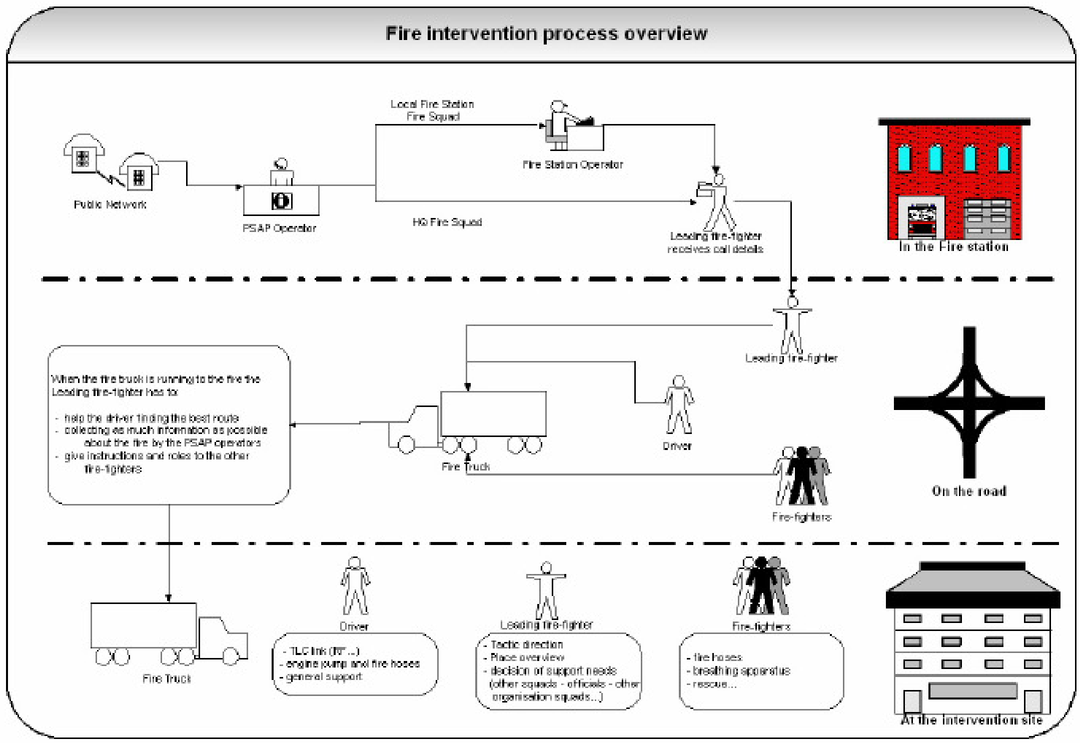

Figure 1, Overview of the alert process.

The Incident Commander decides whether or not cordons will be employed. The *Inner Cordon* is by definition a high hazard zone, access is restricted to a minimum; personnel only enter this area after being fully briefed and having a specific task allocated to them. The *Outer Cordon* prevents access by the public; the police usually control the outer cordon.

User requirement: Fast gathering of information in order to determine the seriousness, and scale of the incidents and request adequate resources.

Incident Command structure

When an incident is reported a first appliance is sent to the site. The standard appliance for South Yorkshire Fire and Rescue (SYFIRE) carries a crew of 5 fire fighters including a crew commander (local term: Crew Manager). The crew commander is automatically designated the Incident Commander (IC).

When the incident turns out to be of a large scale, calls for assistance are made. With the arrival of more appliances and crew the role of Incident Commander is passed on to senior officers and a further division of labour and command occurs.

The early phase of a major incident is very dynamic and neither the Fire Service nor the police will have the appropriate amount of personnel present, with the arrival of more personnel the appropriate command structure will be built up.

At larger incidents and depending on the particulars of the incident, specific areas of resource control may be delegated to appointed officers. Frequently occurring delegations are:

-*Operational sectors*: the site is divided into sectors with sector commanders. A sector may comprise one or more hose teams, ladder teams and one or more entry points for fire-fighters equipped with Breathing Apparatus (BA) to enter. Operational sector commanders are physically located at and should stay in their sector to provide visible leadership.

Each entry point has an 'Entry Control Officer'. (Refer to the search procedure below).

Other 'sectors' of control may include, depending on the incident, of any particular specialised support:

-*Crew Rehabilitation and Welfare*. A recognised problem exists at protracted incidents where personal commitment to victims is high. Under these circumstances the crews' level of fatigue needs to be measured against their continued desire to work.

-Logistics

-Decontamination. In the case that chemicals are present, a Hazmat (hazardous materials) officer is called in.

-Foam.

-*BA Main Control.*

-*Water*. The adequate supply of water can be an issue so a water sector commander may be appointed.

Other roles may be:

- Commander in charge of the contact point.
- Incident investigation commander.

The span of control for any officer is arranged to be between 3 and 5 lines of communication, in order to avoid an overload (and consequently neglect of) information. To achieve this, Syfire makes a distinction between the roles of Incident Commander and the Operations Commander (OpsComm). Currently the Operations Commander deals with the crews and appliances that are directly involved. The Incident Commander (IC) deals with the overall supervision of the incident, the operations support and the off site communication. Off site communications (depicted below in Figure 2) concern local authorities, ambulance, press etc.

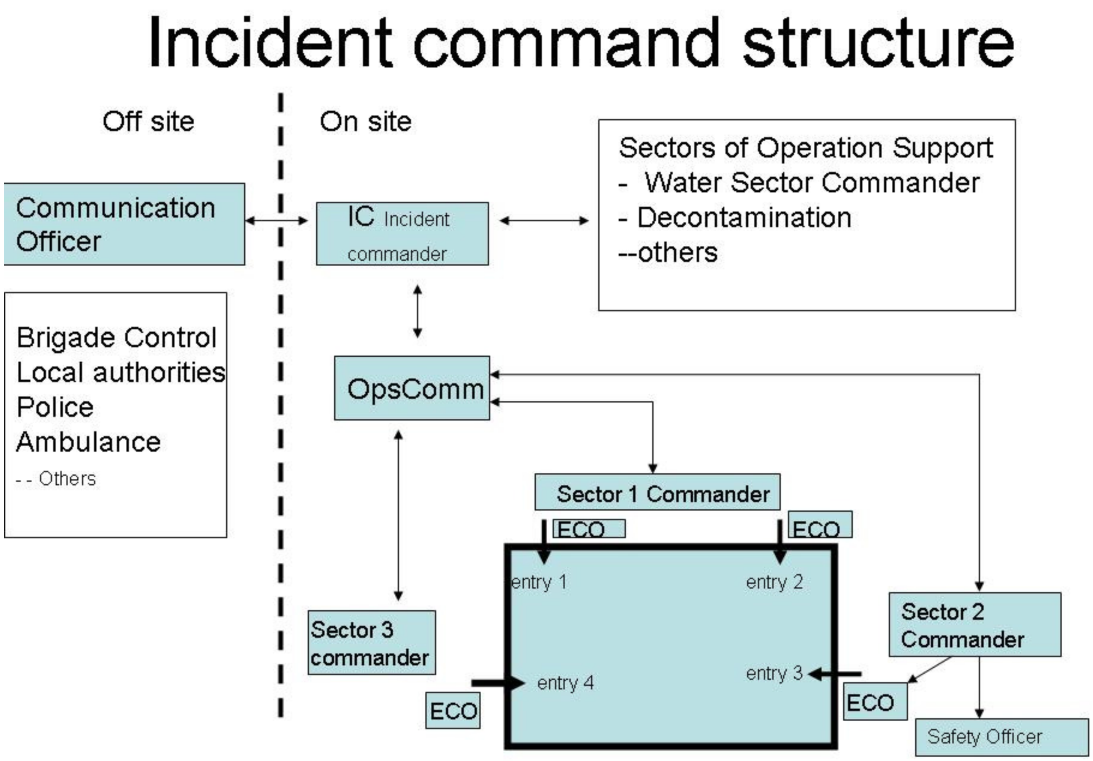

Figure 2, Incident Command Structure

User requirements:

- The command structure is clearly defined and visible.
- Sector commanders stay physically in their sector to provide direct and visible leadership.
- Each commander is given only a limited span of control. Procedures related to deployment and use of the Guardians robots should reflect this.
- Information flows are limited to the essential parts in order to avoid information overflows.
- The chain of command should not be interrupted.
- Crews are employed in the vicinity of their appliances as they use their own equipment etc.
- The Inner cordon is by definition a high hazard zone, access is restricted to the minimum number required to work safely and effectively; personnel should enter only after being fully briefed and allocated a specific task.
- Communications to crews within the inner cordon is restricted to safety critical information passing.

Incident Risk Assessment

- Fire-fighters will take some risk to save saveable lives.
- Fire-fighters will take a little risk to save saveable property.
- Fire-fighters will not take any risk at all to try to save lives or property that are already considered lost.

The key elements of any assessment of risk are:

- Identification of the hazards;
- Assessment of the risks associated with the hazards;
- Identification of who is at risk;
- The effective application of measures that control the risk.

User requirements:

- Risk assessment precedes any operation and is continually reviewed while operations are on-going.
- Robots could assist the Incident Commander in making risk assessments.
- First appliances at a scene will generally not be specialist appliances; the assessment of a situation is dynamic however, so the specialist units may be requested at any time.

Appliances

Standard Appliance

The appliances have a standard crew of 5 persons, though 4 or 6 is possible as well. All crews within Syfire are trained to the same standard. Besides that crews may have a further specialist training, for instance water rescue (divers) etc. Each crew brings its own equipment. In general terms the crews will work in proximity to their appliance and with equipment from their appliance.

User requirement: New pieces of equipment are either common to all appliances or are only provided to specialised appliances. It is likely that the Guardians robots and base station will be attached to one of the specialist appliances.

Figure 3, Standard Appliance

Fire Engines.
Basic vehicle: **Atego Rescue Pumping Appliances**

The South Yorkshire Fire & Rescue Service operates 33 frontline fire engines which cost approximately £180,000 each and remain operational for 12 years. They are designed to give Fire-fighters the capability to immediately deal with a variety of emergency situations and carry a wide range of equipment including ladders, breathing apparatus, rescue cutting and lifting gear and chemical protection suits.

The brigade currently has five new Mercedes Benz "Atego" Rescue pumps in service. These appliances have a four/five person crew safety cab and are fitted with radio equipment providing the vital communications link between operational crews and Fire Control.

The Mercedes Benz “Atego” Rescue pumps are based on a 1328F fire fighting Chassis, with a 4 person crew safety cab conversion by Macneillies, with the fire engineering, bodywork, and the stowage of equipment carried out by Saxon Specialist Vehicles Ltd.

Gross Vehicle Running Weight 12360 Kg; 0 to 40 MPH in 13.66 sec; Maximum Speed governed to 80 MPH = 100 km/h.

Gradabilty = capable of a restart on a 1:3 upwards incline.

Bodywork: - comprising of 3 Locker stowage areas fitted to each side, each containing sliding trays for the equipment, each locker is secured by a Roller Shutter door which is equipped with an air operated central locking system.

The rear of the appliance has a fully enclosed pump bay, in which is situated the main fire pump driven from an engine driven Power Take Off. This is a multi pressure fire pump manufactured by Hale and is a Godiva World Series WTA 2010. This pump is supplied by water carried within a rotationally moulded water tank of 1800 Ltr capacity.

New vehicles: Combined Aerial Rescue Pump

Four Combined Aerial Rescue Pumps (CARPs) are on order for South Yorkshire Fire & Rescue Service. They will have a Mercedes Econic Chassis with TVAC cab conversion and bodywork/fire engineering. The platform is by Hilton, a Dutch company. The expected delivery dates are June 2007, August 2007, December 2007 and February 2008. They will go into service following a suitable training period.

The chassis arrangement is of a three axle, second axle drive with rear axle power steering, making the vehicle more manoeuvrable. The appliances will accommodate six crew members, will carry the same amount of equipment as normal rescue pumps and are to replace the second rescue pumps at Central, Rotherham, Barnsley and Doncaster Fire Stations.

SyFire have collaborated with Humberside Fire and Rescue Service to order a total of five CARPs, the first of which was delivered to Humberside in November 2006. SyFire are involved in the development of the Humberside CARPs and will follow the performance of the Humberside vehicle so that any modifications required are passed on to their models.

The Fire Service Procurement Association (FSPA) are to include the South Yorkshire/Humberside specification CARP into their purchase framework agreement so any other brigade will be able to order the same specification appliance through the same supplier.

Figure 4, Combined Aerial Rescue Pump

Scania Rescue Pump

South Yorkshire Fire & Rescue Service has ordered 13 new (Type 'B') Rescue Pumps from One UK Ltd. These new appliances are being built on Scania P Series 17 Ton Chassis with a CP31 crew cab, powered by a 310 hp Euro 4 engine, using Exhaust Gas Recirculation (EGR) technology. The first six are expected to be delivered by 31st March 2007, with the other seven by 31st May 2007.

The Scania cab is a factory built version (not a coach built conversion). This is seen to be much more attractive from the point of view of giving full major manufacturers' warranty. Also, there is a large amount of interchangeability between cab components within the Scania range, giving better parts availability and researched and developed components.

Other appliances

Specialist incident support Units:

Water Rescue Unit

Designed for water rescue, this unit carries various items of equipment designed to rescue people stranded in water or on ice. It carries on the roof an 8 person inflatable boat and, within the vehicle, floating pathways, sand lance (for releasing people trapped in mud) and animal extrication equipment.

Heavy Rescue Unit

Designed to provide specialist heavy rescue capabilities to support and supplement the Rescue Pumps, it carries heavy jacking, cutting and trench collapse equipment.

Pollution Containment Unit

This vehicle also carries an inflatable boat which can be used to deploy barriers on waterways to contain chemical spillages. It also carries a special water driven suction pump to transfer chemical and other spillages into special containment units.

Each of these specialist units contains an *Incident Command/Community Safety Compartment* which is fitted with I. T. equipment as follows: -

- 5 Computers c/w 17" LCD Monitors on a mini network running Windows 2000 Professional (1 Server and 4 Workstations).
- 1 Colour Inkjet Printer.
- 3 VHS Video Recorders.
- 1 Fax Machine.

The Equipment compartment is accessible from either side of the vehicle by means of a dropdown flap/step and roller shutter. Within these compartments are swing out equipment trays, and sliding trays for equipment stowage, two further lockers are located above the rear axle these are also fitted with sliding trays for the equipment.
A Roller Shutter door secures each locker which is equipped with an air-operated central locking system operated from within the driving compartment.
The rear of the appliance has an incident Command area which can be fully enclosed by the erection of a weather proof awning. Within this area is fitted a large Plasma Screen and an Electronic Whiteboard connected to a 20" Touch Display.

On the roof of the appliance is the following equipment: -

- A windspeed / direction indicator.
- Cooling system for the onboard self contained generator.
- A “Nighthawk” Folding lighting mast fitted with two 500w floodlights.
- A Beam Gantry System on which is mounted either an 8 person inflatable boat (Pollution containment & Water Rescue) or 2 x 150 tonne NT air bags (Heavy Rescue Unit).
- Air conditioning Unit for the Command/community Safety Section.

Argocat: This is an all terrain 8-wheel drive vehicle which is transported to moorland fires by trailer and is capable of carrying equipment and personnel across most terrains.

User Requirements

- An Incident Command unit is automatically requested at five appliances (though it can be requested earlier).
- The robots will be applied with a specialised unit, crew as well as appliance.
- A specialist rescue facility is to be built in Dearne Valley. It will house 28 staff, all who should be trained to use the robots.
- On a large scale incident such as the recent floods (Sheffield June 2007) every appliance will be deployed and may be dealing with non-specialist incidents, though they could be redeployed to where they are most appropriate.
- During the flood rescue operations Syfire had an officer to prioritise calls for assistance.

Warehouse search procedure

Procedures for searching a smoke ground are (in the UK) laid down in the breathing apparatus (BA) procedures.
Breathing apparatus command and control procedures distinguish stage I and stage II incidents. Stage II incident procedures supersede stage I procedures. An incident qualifies as stage II if one of the following applies: (a) large scale, protracted, (b) more than two entry points, (c) more then 10 BA wearers, (d) branch guidelines are used.

A warehouse fire would probably classify as a stage II incident (requiring more than two Entry Control Points), meaning that numerous control procedures apply:

1) Appointment of an Entry Control Officer for each entry point.
Duties include:

- Updating of the Entry Control Board (who went in/out and when).
- Check BA 's 'Time of Whistle'. (The cylinders contain roughly 20 minutes of air supply).
- Liaison with other Entry Control Points.
- Liaison with Main Control.
- Having a fully equipped emergency BA team standing by.

2) The (optional) appointment of a BA Main Control Officer
Duties mainly logistics:

- Compose teams of BA wearers.
- Checking, registering etc. of equipment.

Entry by BA wearers: Guideline procedures
Objectives: to enable

- A team of BA wearers in a risk area to retrace their steps to the entry point;
- Subsequent teams to readily locate a team of BA wearers;
- Subsequent teams to locate the scene of operations.

Guideline description:
The exit route on all guidelines is identifiable by touch. Two tabs 150mm apart are fitted at 2.5 m intervals. A knotted tab indicates the exit route and must always be on the "way out" side of the plain (unknotted) tab.

Guideline procedure:
The 'guideline' is a special line which is used to indicate a route between the Entry Control Point and the scene of operations. At larger scenes branch lines [of the same type] may be used. The individual BA wearers attach themselves using a personal line (1.25m) to the guideline or to each other.

The guideline is secured to an object outside the risk area and is under control of the Entry Control Officer. Laying the guideline, the BA team would follow a wall or similar guiding structure, starting either to the left or the right of the point of entry. The guideline is secured at intervals to suitable objects and is kept off the floor, branch lines are connected to the main guideline.

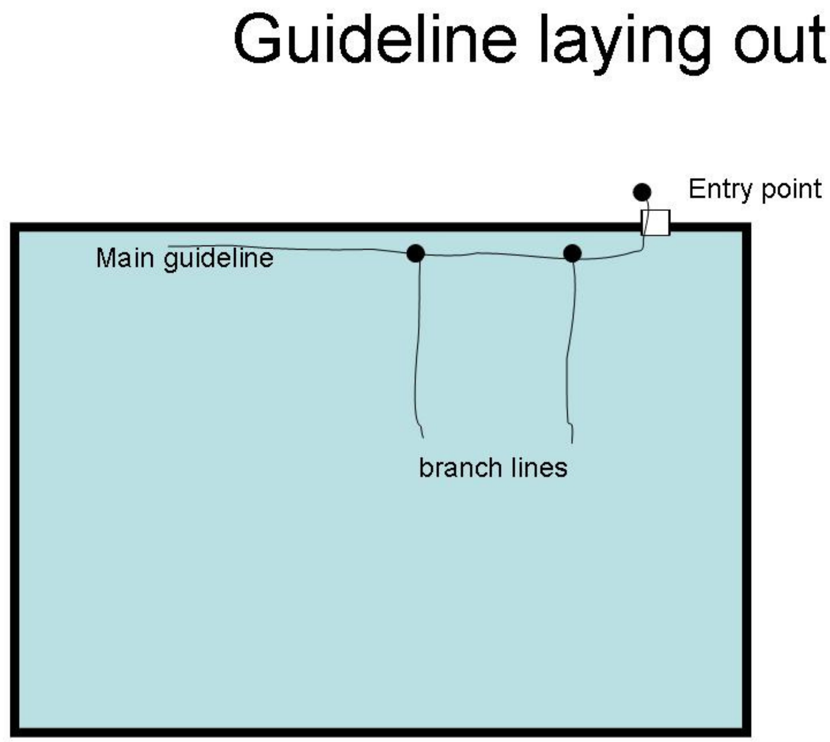

Figure 5, Guideline lay out

Usually a two person squad is deployed. One fire-fighter (the squad leader) moves forward feeling for obstacles/survivors and testing the integrity of the floor as he goes. The other fire-fighter holds on to the leader and communicates with him verbally. His job is to communicate with the base station. At the firetraining (January 2007) we clocked an experienced crew of two firefighters following the guideline, they proceeded about 12 meters in one minute. This means that with full cylinders (20 minutes of air) they can advance 240 meters. Syfire will apply specialised teams who will be provided with extended duration BA.

User requirements:

- One fire-fighter (the squad leader) determines the direction of movement and should not be disturbed by external communications.

- The second fire fighter is in charge of the communication with the entry control officer (ECO).
- Communication is restricted to safety critical information.
- Any system aiming to guide the squad should indicate unambiguously the direction towards the Entry Point (in fact exit point) and the scene of operations. Such a system must be robust and reliable in any unfavourable circumstances.

Section 2 Environment Descriptions

This chapter contains factual descriptions of:

- A warehouse.
- A small factory.
- Gases and toxics relevant for fire fighting.
- Limitations on communication technology.
- Limitations for (navigation) sensors.

Ikea warehouse

NDL (Norbert-Dentressangle Logistics) runs the warehouse for IKEA (so called 'dedicated warehousing').

The warehouse is the largest IKEA distribution centre. Floor space is 330m x 186m (phase 1) and 330m x 224m (phase 2) that is 13.5 ha or 20 full football pitches. It supplies the whole of the U.K. and parts of central Europe.
The main stock items are flat-pack furniture etc. nearly everything is palletized, on either half-Euro, standard Euro and 'IKEA' size (large, 2m length) pallets. When fully operational the warehouse will have 330,000 pallet spaces.

The warehouse does not handle White goods, sofas and beds; though several foam based products (pillows and cushions) are stored.

Personnel work mainly in two shifts, 6.00-14.00 and 14.00-22.00. The maximum personnel onsite is 85 at any one time. The Warehouse has a small nightshift, approximately 3 nights per week, though this is dependant on demand.

Structure

The Warehouse is divided into large functional areas referred to as 'Houses'. Houses 1, 2 and 3 are of sizes: 186m x 108m x 12 m. (The newer ones in phase 2 are slightly larger). The houses are separated by walls (4 hours fire resistant). The large shutters that connect the 'Houses' will close automatically in the event of a fire. The floors consist of smooth concrete; during operations floors are wiped clean with a soft swab. Black and white barcodes on the floor identify areas.

Currently the Houses 1 & 2 are not used. They are awaiting the opening of new stores.
House 1, 3 and House 5 are densely racked 'euro' size pallet storages. House 1 and 3 consist of roughly 10 aisles: a rack (1.05m) and aisle (3.22m) and a rack (1.05m); the racks are about 8m high and 186m long;a manned crane operates in one aisle.

House 5 is a completely computer operated silo with a height close to 35 meters. When in normal operation there are no staff inside the storage space. People are allowed inside only for maintenance or error recovery.

Houses 1, 3 and 5 consist of tight (grid like) metal constructions, refer to the section marked '1' in Figure 7, where the gsm signal reduces very quickly (When we tried a GSM phone 5 meters inside house 1, signal strength had halved).

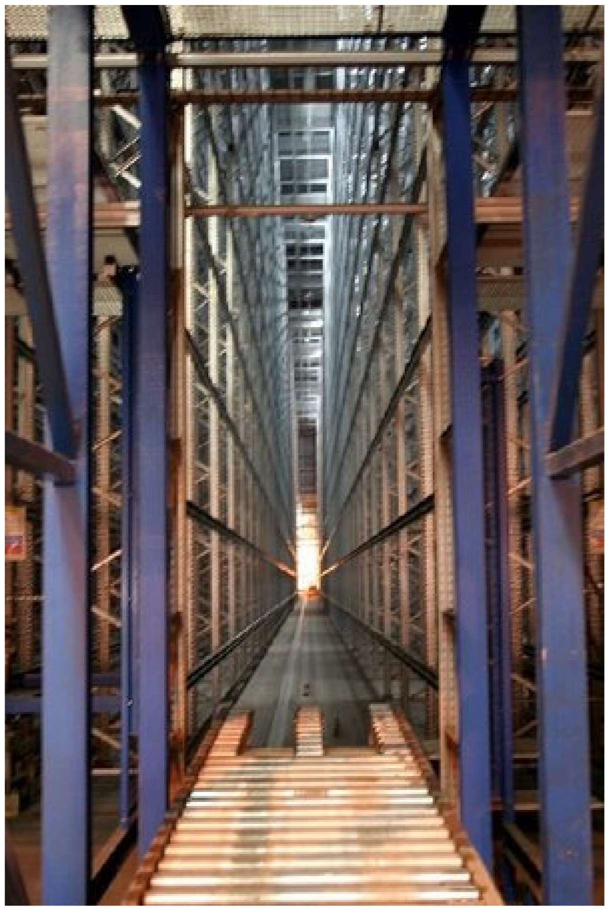

Figure 6, View into an aisle of the IKEA warehouse (house 1).

Goods storage is determined by operational principles/requirements only, and the goods are not ordered according to types of material or products.
The exception is a small group of products, some chemicals e.g. varnishes that are kept in particular sections.

One of the houses contained a traditional pallet storage the section marked '2' in Figure 7, where manually operated forklift trucks are used to store and pick pallets. The aisles in this area are considerably wider than in houses 1,3 and 5.

There is a 'Block stack', which contains fast moving items and items that cannot fit into one of the silos. The arrangement of products in this area is dispersed and random compared to the other storage areas. One area is used for manual order picking (on the level of individual items).

Roughly speaking, goods come in at one side of the building and leave at the other side. The docking bay areas are used for short term storage. The in-docks are used to check deliveries and the out dock areas are used to compose and check full orders before dispatch. In every operational house, most of the staff are working in these areas.

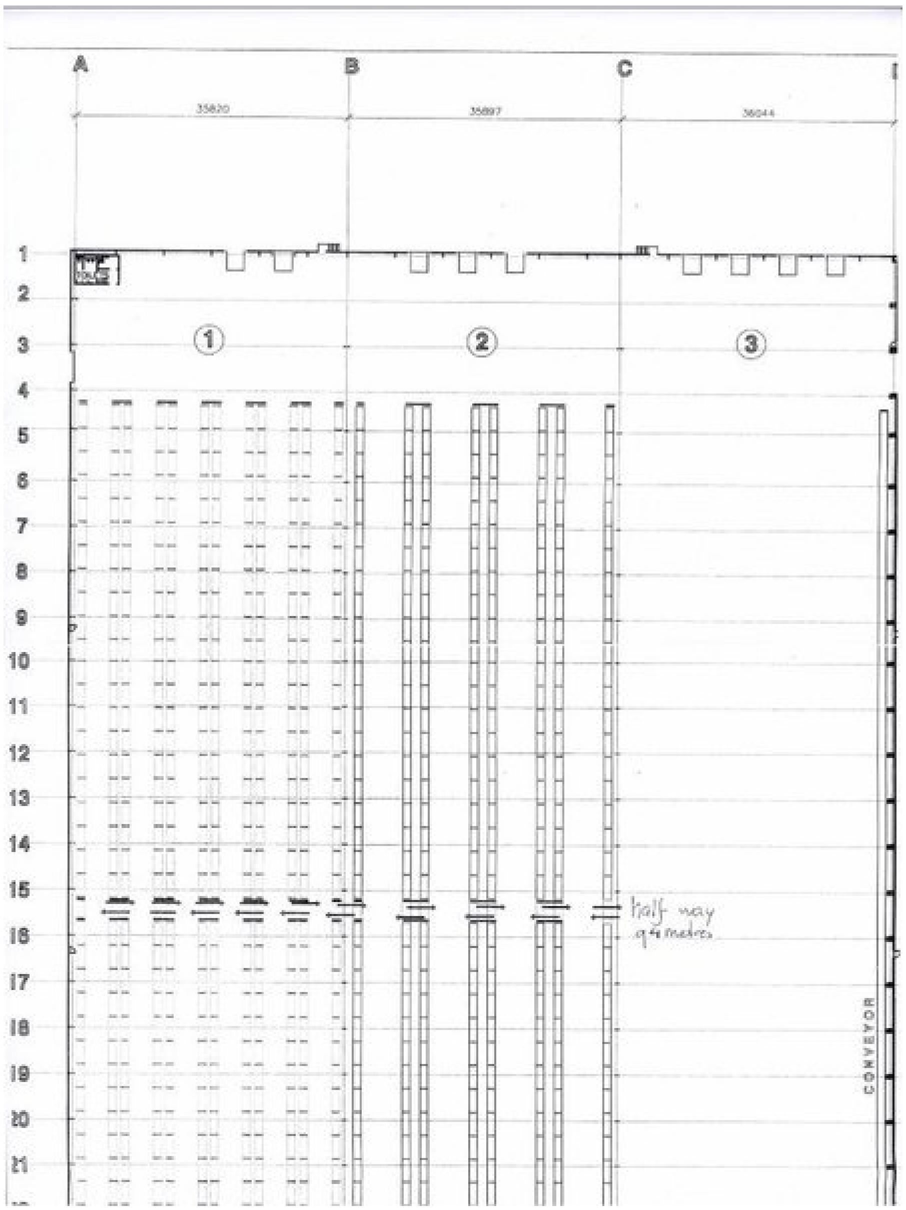

Figure 7, Part of the plan of the IKEA warehouse.

Specific Risks / Features

- IKEA's biggest threat is fire.
- The sprinkler systems are aimed at preventing fire spread damage limitation.

User requirements:

- Attendance at the IKEA warehouse would probably be three standard appliances plus one aerial appliance.
- It would be very useful for fire fighters if robots are able to go into the building to gather information for a first assessment.

Further Questions

- There is a lot of space between the pallets on the ground floor of each row. Can we reliably program the robots to follow 'zones' matching the electronic map so they don't waste time mapping the areas between pallets in each row?

- There were numerous 'Spill Kits' around the warehouse, implying that liquid spills are relatively common. Some liquids could be quite viscous or sticky; is the potential restricted movement for the robots through such spills going to be factored into their behaviour (i.e. if their movement is stopped or slowed will they 'assume' an obstacle is present without confirmation from external sensors?)

Fusion Provida Factory (Dronfield)

The factory is relatively small compared to the Ikea warehouse. The factory manufactures machines, control boxes and ancillary equipment for the jointing of Poly ethylene pipe and also provides storage for the assembled products before shipping.

There are primarily two types of employee based in either offices or on the factory shop floor working hours 8:30 - 17:00 and 6:00 - 16:00 respectively. On average around 50-60 people occupy the building during standard working hours. In periods of high demand a relatively small nightshift of approximately 10 people also operates.

Structure

The main structure of the building is a steel frame clad with sheet metal sitting on a solid smooth concrete base. There are several entry and exit points around the building, two of which are large roller doors providing large goods access.

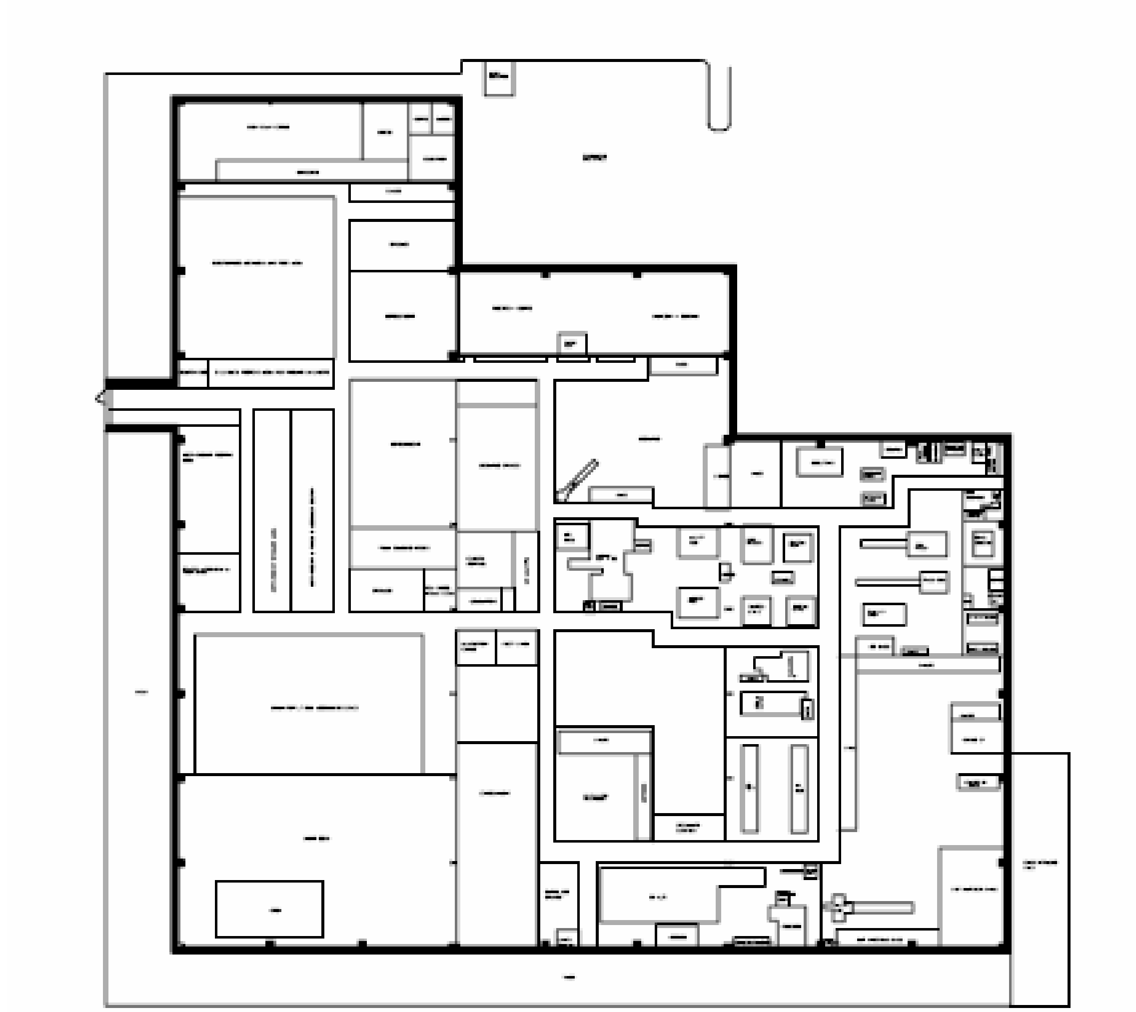

Figure 8, Plan of the Fusion Provida Factory.

The factory is divided into several areas some of which are partitioned using full height walls others simply sectioned by markings on the floor showing designated workspaces and walkthrough/access areas. Storage for the manufactured machines is provided by racking while some is simply placed on the floor in the goods outwards area. The main area comprises of workbenches where assembly and testing of the equipment takes place.

At one end of the factory an internal steel frame supports a second level which is used for storage of packing materials and electronic components.

Of particular note is the spray painting room where several solvents and paints and associated chemicals are stored.

Specific Risks/Features

- The primary risk is threat of fire.
- The risk chemical spillage is also apparent.

List of Gases

After discussions with South Yorkshire Fire and Rescue Services the following gases and vapours were identified as the target analytes to be detected by the sensor arrays. The analytes can be split into two groups called vapours and gases. The first group includes the compounds which exist in both liquid and gaseous forms at room temperature and normal atmospheric pressure. In the thermodynamic equilibrium, the vapours can be characterised with the parameter of saturated vapour pressure. In contrast, gases could be condensed into the liquid form at low temperatures and/or high pressure.

Vapours:

- Hydrocarbons (hexane, cyclohexane, octane, and higher hydrocarbons constituting petrol).
- Alcohols (methanol, ethanol, butanol, propanol).
- Ketones (acetone, ethylmethylketone).
- Ethers.
- Aromatics (benzene, toluene, ethylbenzene, xylene).
- Chlorohydrocarbons (chloroform, dichlormethane, dichlorethane).

The range of concentrations of interest for the above vapours lies between low explosion limit (LEL) and high explosion limit (HEL), which is normally equivalent to several volume percent of the vapour in the atmosphere. Therefore the range of concentrations of the above gases stretches from 0.1 to 10 volume percent.

Gases:

Electronegative (oxidising gases):

- Oxygen.
- Chlorine.
- Hydrogen Chloride.
- Hydrogen Cyanide (cyanide gas).

Electro-positive (reduction gases):

- Hydrogen.
- Carbon Monoxide.
- Ammonia.
- Low hydrocarbons (methane, ethane, butane, propane constituting natural gas).

• Acetylene.

Oxygen is considered a very important analyte since the majority of other vapours (gases) may ignite at certain percentage of oxygen in the mixture. Carbon monoxide is the gas associated with burning of various flammable materials. Chlorine, hydrogen chloride, ammonia, and particularly hydrogen cyanide are released during burning of the majority of polymers (plastics).

The range of concentrations of interest for the above gases stretches from 0.1 to 100 volume percent.

Analyte	**Detection limit** (ppm)
Hexane	22
Toluene	10
Benzene	5
Xylene	2
Cyclohexane	20
Most volatile Organics	>30
Propane	500
Methane	500
Isobutane	500
General combustible gas	500
Hydrogen	50
Acetone	50
Carbon monoxide	50
Ammonia	30
Hydrogen sulfide	5
Carbon dioxide	350
Alcohols (Ethanol)	50
Oxygen	0-100%
Chlorine	To be tested
Hydrogen Cyanide (Cyanide gas)	To be tested
Acetylene	To be tested
Tear gas	To be tested
Chemical warfare agents	To be tested

Table 1, Detection limits for the target analytes.

<u>Sensor limitations and recommendations</u> - From datasheets of the purchased sensors and our own experience with QCM devices the following recommendations and limitations for the sensing elements are advised:

1) Exposure to silicone vapours (MOS devices)

If silicone vapours absorb onto the sensor's surface, the sensing material will be coated, irreversibly inhibiting sensitivity. Avoid exposure where silicone adhesives, hair grooming materials, or silicone rubber/putty may be present.

2) Highly corrosive environment (MOS and QCM devices)
High density exposure to corrosive materials such as H2S, SOx, Cl2, HCl, etc. for extended periods may cause corrosion or breakage of the lead wires or heater material.

3) Contamination by alkaline metals (MOS devices)
Sensor drift may occur when the sensor is contaminated by alkaline metals, especially salt water spray. This may also happen if the sensor is exposed to inorganic elements.

4) Contact with water (MOS and QCM devices)
Sensor drift may occur due to soaking or splashing the sensor with water.

5) Freezing (MOS and QCM devices)
If water freezes on the sensing surface, the sensing material would crack, altering characteristics.

6) Storage for extended periods (MOS and QCM devices)
When stored without powering for a long period, the sensor may show a reversible drift according to the environment in which it was stored.

7) Long term exposure in adverse environment (MOS and QCM devices)
Regardless of powering condition, if the sensor is exposed in extreme conditions such as very high humidity, extreme temperatures, or high contamination levels for a long period of time, sensor performance will be adversely affected.

8) Vibration (MOS and QCM devices)
Excessive vibration may cause the sensor or lead wires and or crystal to resonate and break.

9) Shock (MOS and QCM devices)

Breakage of lead wires and or crystal may occur if the sensor is subjected to a strong shock.

Sensor System requirements

- The sensors require a certain start-up period this is most cases between 60-120 seconds for the MOS devices and up to 10 minutes for the QCM sensors. This is dependant on the atmospheric conditions during storage of the devices.

- The sensors are dependant on the ambient temperature. A compensation circuit to eliminate/reduce the temperature affects shall be incorporated into the sensors circuits. The relative humidity of the atmosphere also affects the sensitivity of the MOS devices.

- Both MOS and QCM devices require a stable power supply for optimum sensitivity, it is imperative that is achieved for relative and accurate operation of the sensors.

- The long term stability of the sensor devices is good and after initial calibration should be stable for an estimated period of 1 year. It is however recommended calibration is undertaken at 6 month intervals.

- There is a potential 10 minute start-up hence fire-fighter's procedures need to take account of this; for example by switching the robots' sensors on/off before arrival at the scene.

<u>Sensor head space and sampling</u>

System requirements:
The sensor devices only give a representation of the analyte(s) present in the direct vicinity of the sensing elements (i.e. the sensor headspace), see figure 6 below. It must therefore be noted under certain conditions detection and quantification of analytes although in close proximity to the sensors may give erroneous readings.

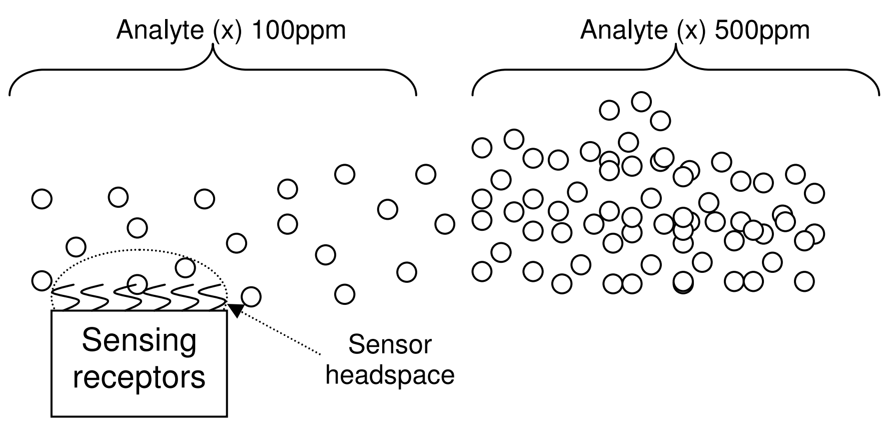

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Figure 9, Sensor Head Space.

Figure 9 shows a diagrammatical representation showing a room with two different concentrations of analyte in the atmosphere. The sensor only samples within its direct headspace and would hence give a reading of 100ppm analyte (x).

Sensor Implications

In general, no single sensor can be used on all environments. In mobile robotics a number of different sensors are utilised for map building and navigation, as well as for Human-Robot interaction based on the Map Building and Navigation inputs. For example, in an environment with optically transparent materials (e.g. glass) laser-based sensors will perform much worse than sonar-based sensors; i.e. laser range scanners will not detect glass but a sonar-array will. Hence the purpose of sensor (data) fusion, whereas readings from different sensors are fused to increase the robot's understanding about its environment.

An inherent problem in fire and rescue operations is visibility due to smoke conditions. This introduces some essential problems regarding applicability of certain technologies predominantly due to loss of incident power (attenuation). That is, a wave of some wavelength attenuates in a medium relative to the attenuation constant (α) of the medium. Loss of power can be explained via absorption in the medium: *smoke, fog, humidity and temperature make air become a 'lossy medium'*.

In general, the attenuation constant is inversely proportional to the wavelength and the power attenuation exhibits an exponential decay with respect to distance from target object (total path length). As a result, the higher the wavelength the lower the power attenuation towards an object is, hence measurement uncertainty decreases. Some commonly used sensors with corresponding operational wavelength can be seen in Table 2 the higher the wavelength is, the measurement uncertainty decreases.

System Type	**Wavelength**
air-borne sonar	3.4 mm
RADAR (GHz)	7 mm
near-IR	750 nm - 1000 nm
optical sensor (red)	650 nm

Table 2, Sensor systems and corresponding wavelengths.

Laser based range scanners can be used for obstacle detection and target object geometric data acquisition in adverse/hazardous environments irrespective of the principle of measurement used. However, this is true as long as there is a 'good visibility' and the reflectivity of an object is at least 10%. Furthermore, absorption from the medium (air) is small: the reflected light pulse is of intensity values that do not fall within a pre-defined uncertainty region. In general, if the concentration of a substance (gas or vapour) becomes too large within the field-of-view of the receiver electronics, then the scattering and (molecular) absorption of a beam becomes so high that no meaningful reading can be made. It should also be noted that scattering and absorption also depends on the particle size distribution and particle density that constitutes the gas / vapour / smoke.

The larger the incident laser beam's intensity the higher the distance (range) that can be detected. However, due to health and safety considerations on humans only Class 1 or 1M lasers can be used, irrespectively of wavelength. This is in accordance to either international or British standards 60825-1, which define the same operational characteristics with minor differences.

Air-borne sonar arrays operate at mm wavelengths through 'echo-detection' of a target object. Many surfaces, which at visible wavelengths appear rough, at millimetre wavelengths appear to be smooth. The amount of radiation returned from the object depends more on its angle and geometry rather than its physical size. Note that in mm wavelengths scattering and absorption is not a vital problem and as result sonar based sensors are not sensitive to increased concentrations of gas or vapour. Finally, smoke does not affect their performance since visibility is not an issue. However, under certain temperature conditions, sonar sensitivity and accuracy decreases due to increased wave spreading.

Vision cameras (CCD or CMOS technologies) are the most representative sensor for providing images in robotics. The reason for CCD technologies (as opposed to CMOS) is due to their being able to operate under low natural light intensity conditions. However, they cannot be used when natural light is limited and smoke conditions result in 'poor visibility' conditions. A possible way of solving this problem is the use of a light source. Some examples are: structured light scanners (natural or laser light), near-IR and line laser scanners. However, the same problems as the ones for laser based range scanners still apply, making their use difficult on increased smoke conditions.

However, we must note the recent advent of true 3D cameras, based on the time-of-flight (TOF) principle and work with a modulated infrared light source. The emitted light pulses are reflected by the objects in the scene and travel back to the camera, where their precise time of arrival is measured locally in each pixel of a custom (CMOS) image sensor. Three-dimensional data acquired from the CSEM SR-3000 (www.swissrange.ch) do not suffer from ‘shadowing’ in the intensity image or other lighting effects. We can only postulate that 'poor visibility' is still an issue even though the TOF principle is used.

The operational characteristics of some of these laser and camera based sensors of different technologies can be seen in Table 3:

Technology	Product	Accuracy	Resolution	Speed	Max Operating Distance	Applicability Problems in conditions
Structured Light	Brueckmann, StereoSCAN-3D	mm: 0.005 - 0.03	mm: .045 - .450 1.4 Megapixel	1,400,000 Points / .9 Seconds	unknown	Poor visibility
Laser (Line)	3DScanners, ModelMaker Z35	n/a	mm: 0.025	30 Lines / Second	unknown	Increased particle density; Poor visibility
Laser (Cross Lines)	Creaform, HandyScan 3d	mm: ±0.05	mm: 0.1	18,000 Measures / Second	mm: 3000	Increased particle density; Poor visibility
Laser (Phase Shift and Interferometry)	FARO Technologies, Laser Tracker	mm: ±0.025	User Defined	350 Points / Second	m: 70	Poor visibility
Laser (Phase Shift)	Hokuyo, URG series	mm: ±10	angular: 0.38 degrees / 240 degree scan	683 Points / 100 msec	m: 4	Increased particle density
Laser (Triangulation and/or TOF)	Riegl, LMS series	mm: ±5	mm: 5	12,000 Points / Second	m: 2 - 200	Poor visibility
Directional Light	LaserDesign, PS series	mm: 0.02 - 0.12	mm: 0.175 - 0.52	7.5 Frames / Second	unknown	Poor visibility

Table 3, Some laser, camera (or fusion of both) based sensors and characteristics. Note the column on applicability problems.

Sensor Limitations

Vibration: Laser Scanners due to their mechanical parts (e.g. revolving mirrors) and precision positioning of optics, have a vibration resistance of 55Hz for duration of 2 hours. For a continuous exposure of 10 -55 Hz vibration exposure it is possible that the scanner will be permanently damaged.

Shock: Laser based sensors can withstand a shock of 120Hz. Sonars can withstand higher shock levels but this may affect their housing.

Temperature and Humidity: Sonar precision is affected by temperature and corrections have to be applied for varying temperature conditions. As a guide, the velocity of sound in air varies linearly with temperature and the time-of-flight estimation of range has to be corrected. Commercial laser scanners can withstand up to 50^{o}C at 85% humidity without frost and dew. Any frost on the protective structure will damage the sensor.

Ambient Light: Natural light interference is a problem in laser scanners because it can interfere with the readings. For example, the Hokuyo laser scanners are designed for indoor environments (outdoor is problematic due to IR radiation) and do not suffer from errors as long as the ambient light is less than 10000 Lx luminance.

Some System requirements for the sensors:

1. The sensors can be mounted with vibration isolation components like silent-block, etc. Provide sensors with some system that eliminates or reduces vibration and protects from shock and impact.
2. Protect sensors against water and frost.
3. Provide robot with environment sensors like humidity sensor, temperature sensor, in order to avoid or temporarily switch-off in problematic for the sensors areas.
4. Develop a device to produce an air flow. Inside this device the different gas sensors must be installed. The measure of the gases are made inside this device.

Communication Technology Issues (wireless)

At any incident a communications log is kept on a database in the fire service control room, via the following procedures:

- The Incident Commander is supposed to send an 'information message' to control every 15-20 minutes including information on e.g. the progress of the fire, whether the fire-fighters are adopting an offensive or defensive stance etc.
- Fire service operators type information into the database.
- The information is constantly updated as the incident progresses.
- A hand written log at the incident itself may also be available.

User requirements

- Information relayed in whatever capacity needs to be brief and succinct.
- Improvements to mobile data services might allow the Incident Commander to access the log.

- There are implications for procedures regarding the relationship between the base station, control room and communications generally.
- Generally overall information goes to the control room. Specific information would be required primarily on site for those involved in the incident, so the base station could focus on this.
- The wireless infrastructure should be available at all times and interruptions avoided. Secrecy is not a priority.
- In Viewfinder, access to a log on the Base Station may be especially useful (e.g. for the dynamic monitoring of gases).
- Structure may be important in communications for instructions to be relayed to the robot(s) (e.g. from a fire-fighter involved in the incident who needs a specific action to be performed by the robot(s)). Therefore we need to understand exactly what kinds of tasks fire-fighters are doing so we can determine where and how robots can assist.

Comments:

- In these projects we are breaking into new territory, SyFire (and other end users) might need to restructure procedures around new technology rather than vice versa (e.g. regarding the structuring of messages etc).

- For the moment it may be better to adapt to already existing command and control protocols rather than creating new ones.

- We need to get further into the projects in order to decide on the types of commands to be sent to the robot(s).

- Communications are a serious problem for SyFire (and other Fire and Rescue services). For example, during the floods in South Yorkshire, most of Neil's communications occurred via a public service mobile phone.

- SyFire can access a privileged mobile network in a state of emergency (though obviously this cannot be relied upon for most standard incidents).

Section 3: Human Interactions

In The Field (Scene of Incident)

When arriving at the incident, fire fighters are briefed with their specific tasks (for example being in control of hoses, water jets and so on). Fire fighters are usually committed into the incident in teams of two. On arriving at the incident fire-fighters are grouped into teams and briefed with a specific task that each team has to perform at the scene of operation. A task could vary from performing the search procedure to explore the incident or to investigate something at the scene of operation (for example investigating the status or contents of some identified cylinder).

Each team coming out of the incident, de-briefs the ECO (Entry Control Officer). The ECOs report back to the sector commander who then feeds back the collected information to the incident commander.

Visibility is one of the major difficulties in any fire incident. Most of the fire incidents have very low visibility (as bad as being blind folded). Fire fighters tend to lose their sense of direction in such a smoky situation. Therefore, as explained in the Warehouse search procedure section, the two high level tasks that fire fighters are trained for are:

- Managing their way in the field to the scene of operation.
- And back to the entry point outside the incident.

To prepare fire-fighters for such environments with low-visibility, fire fighters receive search procedures training and rescue training blind folded. In this training fire fighters only rely on their touch and hearing senses.

The Guardians project aims to provide a swarm of robots in form of a ring around the fire fighters assisting them with their most important task: managing their direction to the scene of operation and the exit point.

When the swarm of robots is assigned to assist a fire fighter team, it stays in a relatively close distance to the team at all times, notifying them of the possible hazards surrounding them (e.g. obstacles, high temperature). The swarm maintain its distance to the fire fighters to give them the maximum flexibility while monitoring the surrounding area for possible hazards.

When committing into the incident the swarm can be set to guide the fire fighters to a location within the incident. The swarm guides the fire fighters though a visual interface. However it will stay with fire fighters if they find it necessary not to follow the direction provided by the swarm. During the whole procedure the swarm keeps fire fighters aware of the possible surrounding hazards through visual and tactile interfaces.

In terms of the priority of the information provided to the fire fighters through the interfaces, those that indicate the hazards should be most noticeable for the fire fighters while the interfaces that provide the direction guidance should be noticeable but not too distracting for the fire fighters if they decide not to follow them due to circumstances.

Therefore, robots should have some level of autonomy which enables them to react based on the fire fighters' actions. In addition to the ability of the swarm to adopt its behaviour and therefore the information that provides to fire fighters based on the team movement and actions, the fire fighters in the field should also be able to interact with the robots in a swarm directly when it is essential.

To enable fire fighters to interact with robots, they should be provided with a tangible interface (large buttons preferably) designed and built in accordance with current standards used for tools and gear used by fire fighters.

Considering fire fighters’ gear, it limits their senses and their ability to interact with complicated interfaces that are used to manage many commands and tasks. Therefore, it is essential to identify the more important tasks that require fire fighters to interact with the robots directly, and incorporate them in the provided interfaces.

Interaction between the fire fighters and the robots can also be facilitated through the base station. One of the fire fighters in each team that is committed in to the incident is in charge of a voice contact with an operator who is placed out side the incident. The operator out side the incident can be the ECO or one of the operators at the base station. This contact channel can assist the fire fighters in assigning more complicated tasks to a robot in the vicinity, or the swarm.

The following table illustrate the fire fighters interaction with the swarm of the robots, specifying possible interaction channels, direction of the interaction, possible tasks and operations that such interaction can be used for, the availability of each of them depending on the visibility of the incident.

Interaction	Type	Priority	Installed	Availability	Possible tasks
Robot → Human	Visual	Mandatory	Fire fighters' helmet	Visual devices (e.g. LED light and small LCD displays) installed on the fire-fighter helmet can be used at any visibility level.	Displaying direction to the fire fighters. Visual warnings, for example when the temperature is extreme or a certain gas has been detected
		Optional	Robots	Devices installed on the robots can become unavailable as the visibility level reduces in an incident.	
	Audio	Optional	Robots	Audio devices are installed on the robots and can become less noticeable in noise polluted incidents.	Alarming fire fighters by using a high frequency siren
	Tactile	Mandatory	Fire fighters' gear	Available	Notifying fire fighters with possible surrounding hazards.
Human → Robot	Passive	Mandatory	Robots	Ultra-sonic and Infrared sensors can be installed on the robots to monitor fire fighter's movements. Such sensors are available for any level of visibility.	Robots have some level of autonomy which enable them to adopt their movement in accordance to the fire fighters
	Visual	Not recommended	Robots	Cameras installed on robots can not be used due to the low visibility of incidents	It could be used in recognising visual gestures made by fire fighters in form of a sign language
	Audio	Optional	Robots	Audio devices on robot can be available in incidents with low level of noises	The audio devices could be used to recognise voices of other possible human beings in the incident. E.g. words such as "help"
	Tactile	Mandatory	Fire fighters' gear	Available in form of a tangible buttons easy to use for fire fighters	Assign the swarm to direct the team to the exit point in event of emergency evacuation
Operator → Human	Audio	Mandatory	Fire fighters' helmet	Available	Briefing fire fighters using voice devices
	Visual	Not recommended	Fire fighters' helmet	Available	Displaying critical information to the fire fighter such as maps,

					however the size of display is an issue considering the limitations that fire fighters' gear has.
	Tactile	Optional	Fire fighters' gear	Available	Instead of using voice the operator can use the vibrators on fire fighter's gear to give directions.
Human → Operator	Audio	Mandatory	Base Station	Available	Fire fighters can use the voice to report back to the station, or ask the station to assign complicated tasks to a robot
	Visual	Optional	Base Station	Not available because of the low visibility	--
	Tactile	Not recommended	Base Station	--	--

Table 4, Human-Robot Interactions.

Base Station

User requirement:

For debriefing and other purposes (i.e. forensic investigations) it will be very useful if the data passing through the base station can be logged. The preference is for data that helps to reconstruct the order of events.

Scope

Below a number of features for the Guardians system are proposed and a list of preliminary System Requirements for the Base Station are specified. We expect some Guardians system end-users to read and to comment on the content, according to their experience and their expectations for the Guardians Base Station. Moreover, some targeted questions are expressed, where inputs from end-users would be welcome too.

Introduction

The Guardians Base Station is a multi-user system that is assumed to provide a client/server architecture. The users will interact with the Guardians Base Station by logging on the system through a client interface. The services available through this interface will be configured according to the user role, a configuration profile associated with the user.

We preliminarily identified the following roles:

Role name	Typical (foreseen) number of users having the role	Role explanation
Robots Operator	1 at least	In charge of controlling some of the robots activities
Sensor Data Specialist	1-2	In charge of supporting decision making through monitoring of science data (and especially chemicals assessment)
Guardians System Coordinator	1	In charge of the robots operator and science data specialists coordination during a mission. He is likely to be also the Guardians Base Station administrator responsible for managing the users role and users registration.
1st circle observer	~3	Users having access to all available monitoring data (for the purposes of observation and communication to a particular extent). Typically: major / local crisis manager, rescue services coordinators such as firemen, etc.
2nd circle observer	?	Users having access to limited / filtered monitoring data (for the purpose of observation only). Typically: press & information media

Table 5, Base Station Roles.

In the following sections we introduce different categories of foreseen features / requirements, related to different aspects of the Guardians Base Station:

- Base Station Features (BSF)
- General H/W Requirements & Constraints (GHW)
- Operational Constraints (OC)
- Setup Procedure and Constraints (SPC)
- Interface to Crisis Management Authorities

For each category, the foreseen features / requirements are prioritized according to 3 levels of importance: M (Mandatory), D (Desirable) and O (Optional). In addition, some justifications are provided to clarify the need for the expressed features / requirements.

Ref.	M/D/O	Requirement statement	Justification
BSF-01	M	The Base Station shall allow the visualization / monitoring of all the robots of the system as a whole.	A global/synthetic view of the whole situation is a basic, essential feature.
BSF-02	D	The Base Station shall allow the visualization of the detail status of any single robot on request.	This feature would be very useful, although the robots' redundancy may make this feature secondary. (To get a focus on particular robot activities and status during operations)
BSF-03	M	The Base Station shall enable any number of users to connect to the station through a number of client stations: operators, scientists, mission coordinator, etc.	A number of different users, with different operational / analytical skills, may have to cooperate during mission execution through different means, i.e. from robot actions control to scientific data analysis and mission supervision… Hence a number of client stations shall be able to connect to the Base Station server. This is a scalability concern.
BSF-04	D	The Base Station shall enable individual control of robots, from locomotion to perception tasks and manipulation (should some robots have manipulation means). The control means shall be reactive enough to perform in a reasonable time (performance criteria to be discussed and provided later on).	The purpose is to enable robot control through a client station connected to the server. The control means can be through a GUI and/or joysticks or other control means, according to further user requirements analysis. However, in the usual scheme, it's likely that robot groups will be operated as a whole team, and not as individuals.
BSF-05	O	Haptics & force feedback capabilities may be considered as possible options, according to further detailed / refined users requirements.	This feature may be relevant in certain operational situations, but requires very stringent TC/TM communication delays, making it hard to design and implement. However, depending on available resources, this requirement may be considered, taking into account the impact and constraints on the

			overall system.
BSF-06	D	The Base Station should offer a number of *individual* robot behaviours such as “stop and wait in stand by”, or “come back to the Base Station”, etc. Detail of the behaviours to be provided later on.	Having the possibility to control a robot at a behaviour level can be very convenient, especially for routine jobs or repetitive (but simple) actions to be performed. This assumes that robots will be endowed with sufficient autonomous capabilities.
BSF-07	M	The Base Station should offer a number of *group* of robots policy options for setting the “behaviour” of sets/subsets of robots, such as “explore an area”, or “observe simultaneously a given target from different points of view”, or “follow the firemen” etc. Detail of the policies to be provided later on.	Having the possibility to control robots at a group level is very convenient, especially for routine jobs or repetitive (but simple) actions to be performed by a group of robots.
BSF-08	M	The Base Station shall offer the possibility to monitor and, in a certain extent, to control *human squad members* activities in the field, as well.	The purpose is to be able to communicate with the human squad members, to be able to send them task requests, and to be able to monitor humans activities: motion, remaining available time (taking into account air tanks capacity, probability of flash over / back-draught, etc.).
BSF-09	M	The Base Station shall allow the selection and visualization, possibly through various modalities, of robots processed data (as available from the robot data processing processes).	Visualization of processed data is a critical requirement: it is indeed an essential objective of the Guardians project. This is the basis for any analysis of risks in terms of chemicals products, victims / injuries assessment, and eventually for decision-making regarding further operations.
BSF-10	M	The Base Station shall provide the means to support mission design at a high level of granularity, as mission profile, and to apply (or re-use) such models in particular operational contexts.	The purpose is to provide tools to support the design of mission in such a way that designed mission profiles can be saved and potentially exploited in multiple operational contexts.
BSF-11	D	A mission profile can be exploited as a coordination support for the different step/phases of a mission, when a number of users with	Exploiting mission profiles for coordinating users and robots activities can drastically increase the operations efficiency and

		different roles are connected to the Base Station through client interfaces.	safety: the aim is to have these mission profiles used as references to be applied / interpreted according to well defined procedures and policy.
BSF-12	D	Applying a mission profile can typically be supervised during the full extent of a mission by a system user having a "coordination" role: this user will follow the progress of the mission, confirm the transitions between major steps, and ensure that the robots coordination is consistent (taking into account that some robots can be working autonomously, while some other robots may be temporarily tele-operated).	A mission is likely to be supervised by a "coordinator" user, who will have some kind of control on the mission progress, validating the completion of steps, while being in contact with other rescue organizations / entities. Hence it makes sense to support this "coordinator's" activities through the Base Station.
BSF-13	O	The supervision of a mission profile could also be performed, to some extent, automatically by the Base Station (autonomous coordination of the system's operations), based on clearly defined coordination policies (to be confirmed).	It may be worth delegating the coordination of some parts of a mission to an automatic process, due to time consuming and/or repetitive, non critical issues. This would help in saving some user (and especially the "supervisor") efforts.
BSF-14	D	Some parts of a mission are likely to be automatically planned and/or scheduled, such as robots path planning to a number of locations and then path following: the Base Station should provide some "intelligent" means for that purpose.	The automatic planning & scheduling of mission tasks represent an efficient, (hopefully) safe and time-effective way to control the robots of the system. It can be used in support of a human-controlled approach, where relevant. The relevance of applying autonomous task planning and scheduling in particular operation schemes will be studied later on with End Users' support.
BSF-15	M	In the Base Station, the mission recorder shall record all transiting data, either TC/request, TM/status, or perception data.	Data recording is an obvious, critical requirement in such a system.
BSF-16	M	The users shall have the	Mission replay is mandatory to

		possibility to replay a previously recorded mission, through a debriefing console system that will enable post mission data processing / analysis. The users shall also have the possibility to dump recorded data (or data tracks / subset of information only) when needed.	support mission debriefing. The purpose is obviously to help users in analyzing and better understanding the mission events, without the real time constraints of the operations.
BSF-17	O	It may be good to have the possibility, for each client, to enable the video recording of the client's display(s), either as a training support feature, or for post-mission analysis purpose. and some synchronization capabilities with the other recorded mission data…	Video recording of the users' display could be an additional useful source for mission debriefing, although maybe not the primary one. It may give a better understanding of the interrelation between user actions and received data & TM.
BSF-18	M	The Base Station shall be able to manage rough video and audio data received from the robots in such a way that these rough data can be directly provided to clients on request (either visualized if camera data, or listened if audio data).	Dedicated channels shall be available for rough data (essentially video and audio data incoming from the robot) transmission. These rough data provide the users with a feeling of what rough information the robots perceive, in the field. Vision and audition are the most straightforward (and maybe important) perception means to relay to the users.

Table 6, Base Station Features

Ref.	M/D /O	Requirement statement	Justification
GHW-01	D	The Base Station H/W components shall be, as far as possible, centralized on a single or a few PCs and required infrastructure, and carryable to the proximity of the operations location.	A centralized solution is obviously easier and faster to setup.
GHW-01	D	The Base Station H/W (server & clients) shall, as far as possible, be connected through a wired network, to avoid RF disturbances and to better protect against intrusion.	Shall the Base Station devices be centralized as previously assumed, then it makes sense to connect local devices with wired connections, which are less communication failure prone than wireless communications, more convenient to setup, and more secured.

Table 7, General H/W Requirements and Constraints (GHW)

Operational Constraints (OC)

Ref.	M/D /O	Requirement statement	Justification
OC-01	M	Users / operators involved in a mission shall be able to communicate adequately and efficiently through their client interfaces. Exact modalities will be detailed later on, according to End Users expectations.	Communication, either aural or visual, is obviously a critical requirement for coordination purposes between robots operators on the one hand, and between robots operators and robot coordinators on the other.
OC-02	D	The loss of a client connection shall never result in unsafely operating the system: backup plans & solutions shall be available to cope with the loss of any number of client connections. As an extreme situation, shall all the clients be disconnected, the Base Station shall be able to put the whole system (and especially the robots) in a safe configuration.	This issue is about ensuring a high level of reliability of the Guardians system, even if severe trouble occurs with robot control. Robots shall not get lost or damage themselves, nor injure people (squad members…) because of control communication hazards.
OC-03	D/O	The client stations shall be able to assess whether or not the user is actually present or alive: for tasks or mission steps considered as critical, the client station shall be able to request a sign of life from the user, and after a timeout, it shall be able to notify the Base Station (where relevant) that the operator is not operational.	It may happen that an operator has a physical issue that makes him/her unable to perform the expected control operations: such a situation shall not jeopardize the mission, neither the robots' (and humans' in the field!) integrity.

Table 8, Operational Constraints.

Setup Procedure and Constraints (SPC)

Ref.	M/D /O	Requirement statement	Justification
SPC-01	M	The setup of the Base Station shall be performed in a time compatible with the time-criticality of the operations. The available setup time will be discussed and decided with End User, taking into account their expectations and foreseen operational constraints (Base Station, robots and communication system deployment, S/W initialization, human organization, etc.)	The setup time of such a Guardians system shall be properly assessed. This can be very important information in order to decide whether or not a Guardians system can be exploited for a particular disaster.
SPC-02	D	Base Station deployment in that time interval shall be possible with a minimal team (2-3 persons? TBC).	The minimal Guardians operational team shall be quite small: this point shall be established clearly with rescue actors.
SPC-03	D	Default, ready-to-use deployment procedures shall be available.	Purpose would be to improve robots setup efficiency.
SPC-04	M	Base Station casing and relocation shall be possible in time compatible with the time criticality of operations.	For safety and efficiency issues, clear time constraints shall be defined in Guardians relocation procedures.

Table 9, Setup Procedure and Constraints (SPC)

Related questions for End-Users:

1. What security range from the disaster should be respected for the setup of the Base Station and the deployment of the robots? (Is there clearly defined data in procedures, regarding the distance between the local coordination centre and the disaster ? Who assesses it, and how is it assessed?)

Interface to Crisis Management Systems and Authorities

What are the interface requirements to higher level of crisis management authorities?

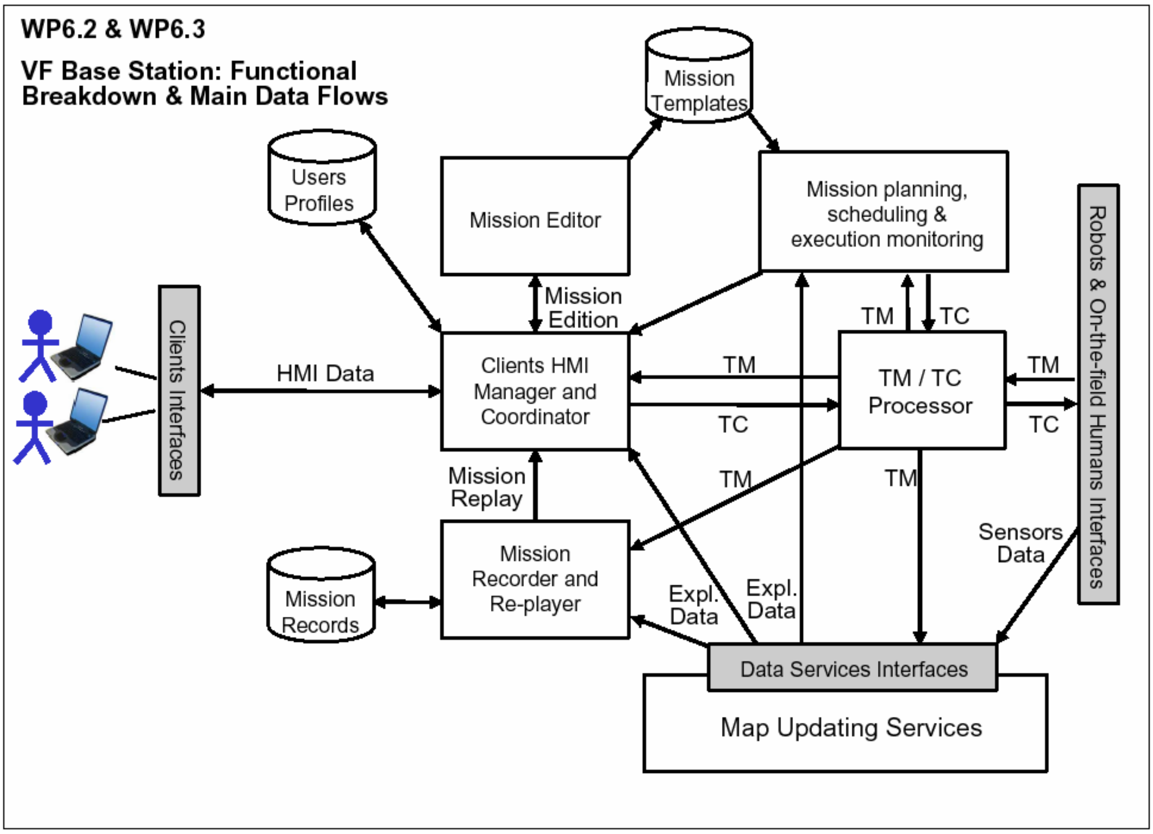

Figure 10, Guardians Base Station Concept

The functions represented on the above figure are supposed to cover all of the features and requirements presented in this document. Should additional requirements be identified (or existing ones be refined/modified), this Base Station concept would be updated accordingly.

On the above picture:

- HMI = “Human Machine Interface”
- TM = “TeleMetry”
- TC = “TeleCommand”

Section 4: Warehouse and Factory Scenarios

Introduction

This section describes possible scenarios to be tested by the Guardians Project. The scenarios are being built on the basis of (parts of) the descriptions given in the previous section.

Figure 11, Worcester Warehouse Fire

Major points from the Worcester Warehouse fire:

- Thick black smoke with no visibility
- Largest dimension 50 metres.
- First crew reported being lost 22 minutes into the incident.
- First and second crews' positions where unclear to themselves as well as to ECO (and others), one didn't know on which floor the first crew got lost.
- Evacuation of the site 1.45 minutes into the incident.

User/system requirements - robots:

The following is based on the user requirements of the USAR (Urban Search and Rescue) robots.

Communication:

- Beyond Line Of Sight: Must be able to ingress specified number of feet in worst-case collapse. Worst case is a reinforced steel structure.
    - Syfire response: definitely required.

- Security: System must be shielded from jamming interference and encrypted. Scale defined: 1=None, 3=Command; 5=Both data and command.
    - Syfire response: not key.

Human System interaction:

- Initial Training:
    - Syfire response: SyFire would train the crew of the special unit.
    - Response from View-Finder: partner PIAP is interested in developing a training programme.

- Operator ratio per robot. Number of operators per robot.
    - Syfire response: we would employ people in shifts so subsequently different operators are active.
    - Syfire response: we would prefer that more then one person could be employed to achieve multi-tasking.

- Acceptable Usability: Percent of tasks users can complete. Effectiveness.

- Auto Notification: System notifies operator when conditions arise that need attention.
    - Syfire response: definitely required.

- Lighting Conditions: Special emphasis on no light and glare.

Display:

– Dashboard: General chassis system health and status.

This requirement captures the responders' expectation to monitor general system health and status (e.g. orientation, communication strength, power level, etc.). They identified two types of information: (A) Display of organic information: 1) system health status, i.e. power, motors, sensors, comms, etc.; 2) robot pose, i.e. absolute (x,y,z) or relative location from a start point; 3) constraints imposed by environment, i.e. inhibitors, manipulator problems, occluded or blocked sensors; (B) display of external information: 1) Hazmat; 2) Temperature; 3) Other payload sensors. In addition to determining if the information is present, it is advisable to perform a series of empirical tests to determine if the operator(s) can accurately interpret the displayed information.

- Mission data Integration: Includes all add-on sensors.
- Interaction - Component controls: To include diagnostics.

Cache packaging-Setup Time: Time from on-site delivery to operation.

- Syfire response: 15-20 minutes maximum. The robot(s) should be operable for hours and especially should include some standby facility where it could be recharged easily and re-deployed.

Operating Environment

1. Max Temperature
2. Water Resistant: Scale: 1=Not water resistant; 2=Wash down; 3=Submersible; 4=Water resistant to 12 meters.
3. Runtime Indicator: Must be able to inform operator of remaining power level (percent).
4. Audio – 2 way: Scale defined: 1=Volume control. Listen all the time, push to talk; 3=Stereo; 5=Directional indication.

Mobility:

The more common scenarios for fire-fighter operations in industrial areas are:
- Single storey buildings, some rubble on the floor perhaps some steep slopes.
- Stairs are not so common on industrial premises.
- Narrow doors, door size is 750 mm minimal.
- The robot should not have to carry a person, though it may be useful for the robot to be able to carry / pull a stretcher.
- Robots extinguishing small fires could be useful in a CBRM risk environment (e.g. if Acetylene cylinders are present).

Sensing

5. Internal: Orientation reporting.

6. Video Pan: Independent of robot mobility.

7. Video Tilt: Independent of robot mobility.

8. Pan/Tilt orientation, Pan/Tilt orientation indicator.

9. Video: Real time remote video system (Near).

Section 5: Trial Scenario

The Guardians project aims to apply the robot swarm in a warehouse in smoke and will trial the robots in an artificial but similar scenario. In anticipation, the consortium decided to make a simplified trial at the end of the first year. This trial has been defined to allow for first experimentations with, in particular, the interface between the robots and a human being.

The trial scenario is described below, insofar as it is aimed at eliciting further user requirements. It draws together the specifications for the scenario and tries to distil from them a list of assumptions that must be fulfilled if the system is to achieve its aims. This includes an assessment of the practical difficulties that would need to be overcome in order to realise the assumptions.

Usually when the fire and rescue service explore a building in smoke a minimal two man squad is deployed. One fire-fighter (the squad leader) moves forward along a wall or other 'fixed' object, feeling for obstacles/survivors and testing the integrity of the floor as he goes. The other fire-fighter holds on to the leader and communicates with him verbally, his job is to communicate with the base station. (Refer to the section: Warehouse search procedure).

In scenario 1 the squad consists of a single fire-fighter assisted by a swarm of six or seven robots (Pioneers in the case of the UJI demonstration). However it is conceivable that the robots could also be used to assist a two man squad, in this case, provided the robots behave reliably, it is acceptable for the two fire fighters to be physically separated and for robots to move about in the space between them.

- Syfire response: If the system is reliable there is no objection to having a robot operating between the human beings.

Based on scenario 1 Amir has described two possible modes of behaviour for the robots. In the robots leading human mode (see storyboard 'Leading.pps') the swarm has a leader which moves towards a known goal, say the exit of the warehouse, and the fire-fighter follows the leader to reach the goal. In the human leading robot mode (see storyboard 'Exploring.pps') the robots follow the fire-fighter and provide him with information about the surroundings so that he may form a mental picture of the area. It is assumed that visibility for the fire-fighters in the warehouse is zero: the sensory information they have about their environment is based on touch alone.

Response - would any person want to be led by robots?

Context:
The swarm is programmed such that obstacle avoidance, robot avoidance and human avoidance is combined with staying in the vicinity of the human and gradually proceeding towards the end point.

The robots are provided with enough sensors to perform avoidance, and determine or estimate the distance to the human. Communication is one-way only, from robots to human being. The major aim is to provide the human being with a first experimental (one way) Robot-swarm to Human communication device.

Objective:
1: Can we develop a device such that the human understands from the signals received from the robots how to proceed?
Additional question:
2: Is the human able to reconstruct a (mental) map of the environment?

Trial-Demonstration floor plan

Below is a section of the floor map at UJI where the demonstration is planned (Figure 12). The scene will consist of one or two human beings (blindfolded) and surrounded by up to 6-7 Pioneer robots.

Task: the robots have to guide the human being through the corridor to position END.
The squad starts from the door of the laboratory (bottom left), then the robots guide the human through the corridors; there are two turns (first left, then right) in a path of 10-12m length. No obstacles yet.

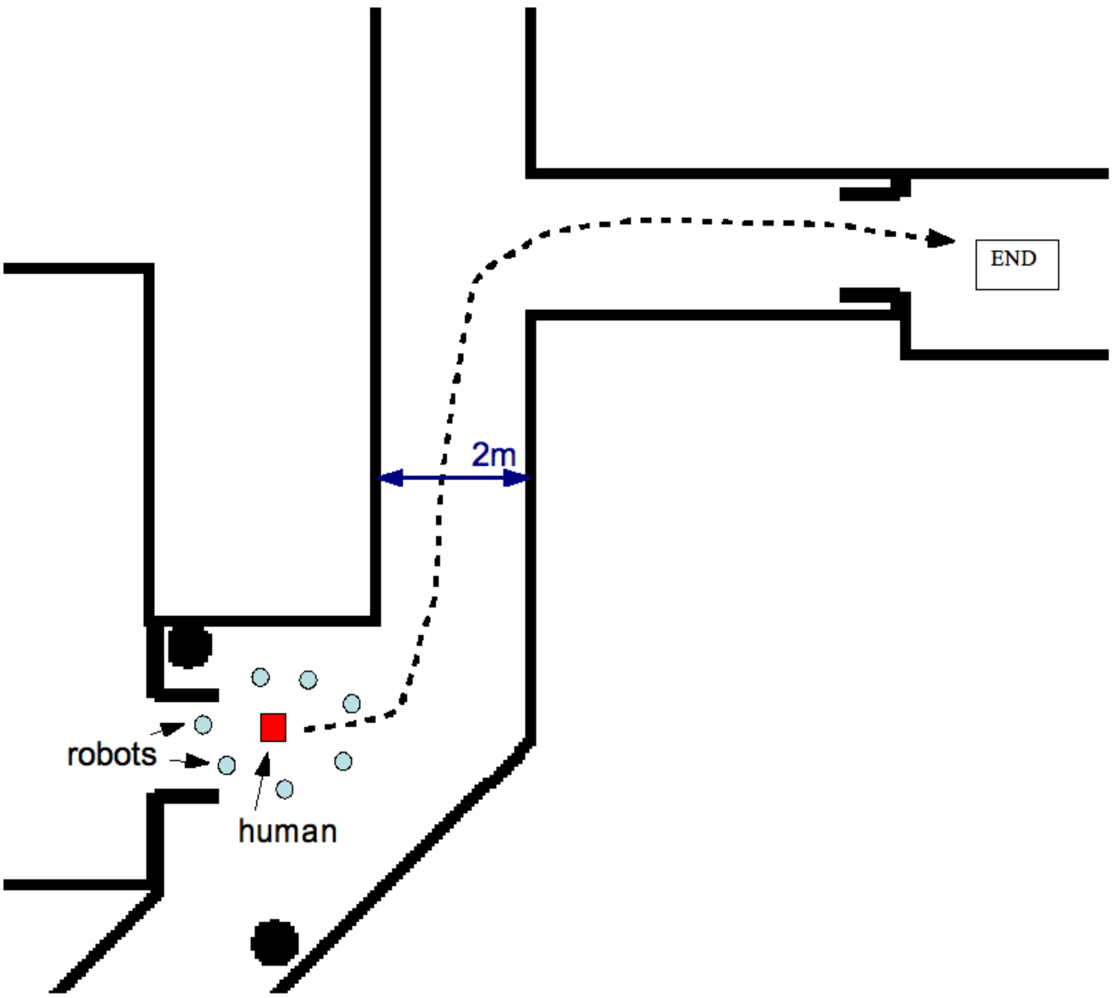

Figure 12, Floor plan of corridor at UJI to be used in physical demonstration of trial scenario

Scenario 0 Minimal configuration for experimental testing:

For first experimentation the following minimal scenario has been defined.

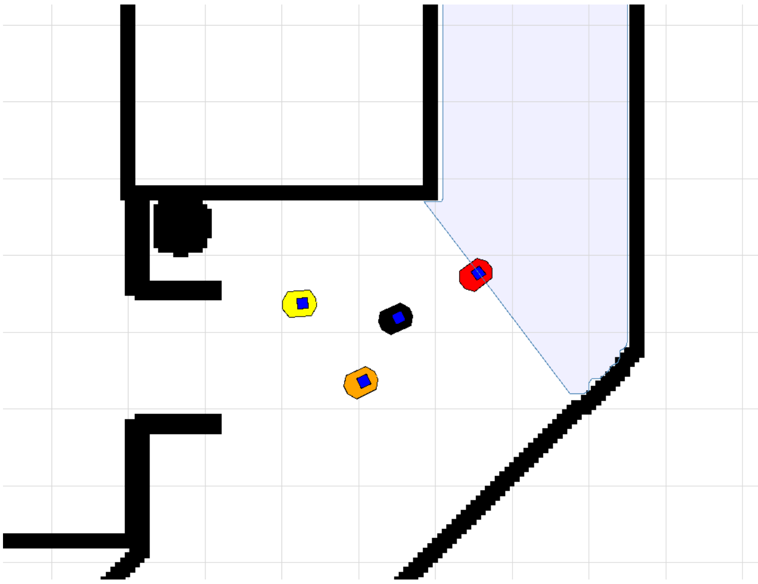

Figure 13, Minimal scenario.

The squad consists of three robots (red, yellow and orange) (Figure 13) surrounding a person (a black robot in the picture). Robots are equipped with laser range finders (need to be tested in smoky conditions – alternatives might be sonar plus inertial, or infra-red vision). Red robot leads the squad according to a given path or a searching strategy.

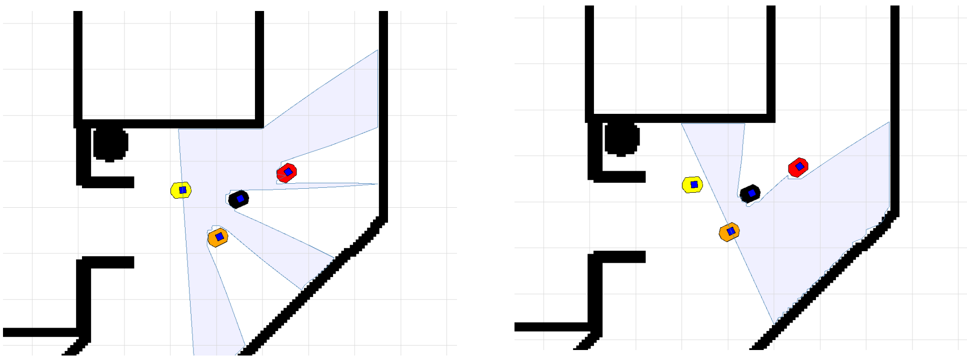

Figure 14, sensing in the minimal scenario

Yellow and orange robots guide the person in-between them. The robots sense the locations of the person and the leading robot with the range finder. Sometimes they can also sense each other. Reflective strips might be used to improve the laser detection. The person is endowed with a motion tracking and orientation sensor, connected to the wireless network. The robots may also carry motion tracking sensors, in order to improve the odometry measurements, and to be robust against failures in the laser range finder.

System questions:

The questions below should be answered for the real case of the warehouse in smoke (in short Smoke-Warehouse) as well as for the trial scenario (in short trial scenario).

Human robot interface: how are motion commands transmitted to the person?

- Answer (SHU): Presentation of robots to the human via both lights in the helmet and vibrations applied to the body.
- Answer (SHU): The direction of the robots with respect to the human could be conveyed via vibrations from actuators on a belt worn around the body or by an array of LEDs built into the fire-fighter's visor.

What information about itself should the robot provide to the Human-swarm interface and/or broadcast to other robots?

- Its relative position to the human?
- Could the human-interface determine the relative location of each robot based on the incoming signals?

What sort of communication is supported on the robot?

- Answer: The Pioneers are currently equipped with wi-fi.

What information can the robots provide to the fire-fighter, details like height and width of an obstacle, how will it fit in with the information gathered by the fire-fighter?

- Answer: A fire-fighter will sweep his arm up and down in the direction in which he moves to feel for obstacles.
- Answer: He will also test the ground to check its integrity as well as detecting objects at foot level.
- Link to Amir's video of fire-fighters at Syfire training centre.

Syfire response: Preferably one person is group leader. The other person is communicating with the base station.

User requirements:
(Syfire) The information flow from the robots to the human being is limited to safety critical information only.

The human wants to know (roughly) where the robots are, what is the source of this information?

Can the human can see the robots? How does the human know the current status of the robot, determining if its active (alive), trapped (about to die) or missing (dead = no signal)?

- Syfire response: The robots need to know where the human is, not vice versa; the human only wants to be confident that the robots are there.

User requirements:
-The human being wants reassuring information from the robots.

System requirement: data gathered by the robot is in general not presented to the Human squad member. Only processed and compact safety critical data (statements) are forwarded to the human squad member.

Where do the robots get (relative) positioning information from?

- 1a: The wireless communication network.
- 1b: Ultra-sonic sensors
- 1c: Vision cameras
- 1d: Infrared sensors

    - Answer: In the trial scenario, the best option is the laser rangefinder.
    - Answer: In the smoke-warehouse a combination of odometry, inertial-magnetic sensors and sonar sensors. The laser rangefinder needs to be tested, but it is unlikely to work.

Factors relevant to identifying the pose of fire fighter

How do the robots distinguish the human being from obstacles?
Can the robot determine the difference between a human, an obstacle and another robot and communicate it across?

System requirement: the robots need to be able to distinguish the human fire-fighter(s).

- The human wears special clothing?
- The human is provided with an RF tag?
- The human is marked with … ?
- UJI response: If the human is in the centre of the squad, robots can distinguish between the external environment, and the inner person. Sonar or rangefinder (if smoke allows) can be used.
- UJI response: a priori knowledge of the human standing in the centre of the squad, and surrounded by the robots and subsequently keep a fix on the fire-fighter as he moves.

- Syfire: As the fire-fighter moves forward his head will be facing more or less in the direction in which he is advancing and he would be looking straight ahead. However the fire-fighter may tend to adopt a slightly sideways stance with the result that, on average, the body will be facing slightly away from the direction of forward movement.

    - Answer: The orientation of the fire-fighter could be defined by the direction his *visor* is facing and we may assume that all movements are in the same direction as this orientation.

Simulation's key assumptions

(1) Robots can distinguish the fire-fighter from all other objects.
(2) Robots avoid getting too close to the fire-fighter whilst keeping the fire-fighter

within sensor range.
(3) Robots can determine the pose of the fire-fighter.
(4) In order to guide the human to a goal, the robots must determine a reliable bearing with reference to the fire-fighters' frame of reference and broadcast that information to the HRI which then conveys the direction to the fire-fighter.
(5) In order to provide the human with an impression of the environment, from which he may form a mental map, the robots must determine the positions of obstacles with reference to the fire-fighters' frame of reference and broadcast that information to the HRI. The HRI would then need to convey the distance and direction of the obstacles to the fire-fighter.

Issues relating to assumptions

Assumption 1 – Robots can distinguish the fire-fighter from all other objects.

Distinguishing the fire fighter from the surroundings is absolutely fundamental to achieving the aims of scenario 1. If the robots cannot distinguish the human they will not be able to stay close to them let alone supply guidance or mapping information expressed in the human reference frame.

One solution that has been suggested is for the robots to have an *a priori* knowledge of the initial position of the human and then subsequently track them as they moved away from that position. The advantage of this approach is that it requires no additional hardware – the robots simply use their existing sensors to track the position. However if one or more of the robots lost sensor contact with the human for a significant period of time, due to the line of sight being broken by an obstacle or another robot, it might not be possible to re-establish contact. The reason for this is that even if the robot subsequently reacquired a line of sight it might well be unable to positively distinguish the echo from the human from those of other surrounding objects, particularly moving ones i.e. the other robots. Also it might be impractical to go through the procedure of getting the robots set up with an initial fix on the fire-fighter at the scene of an incident.

Marking the human with special clothing or an RF tag would allow the robots to immediately lock on to the fire-fighter at the start of the mission as well as giving the robots a much better chance of reacquiring contact should it be subsequently broken. It would be useful to assess the reliability and accuracy of this method and in particular identify whether it is being or has previously been used elsewhere.

Assumption 2 – Robots avoid getting too close to the fire-fighter whilst keeping the fire-fighter within sensor range.

Provided the robots know where the fire-fighter is suitable programming should ensure that they remain within a specified range. However it is always possible that robots may lose sensor contact with the human due to the line of sight being broken by obstacles and not be able to subsequently reacquire due to the fire-fighter having moved on to another part of the warehouse. One might expect this to be common in confined or convoluted environments with sharp turns (see later discussion on formalised scenario for simulation). To reduce the chances of robots becoming separated from the squad, individual robots should be programmed with reacquisition algorithms that come into play as soon as a robot loses sight of the fire-fighter. For example the robot could simply reverse direction to move back to the position at which it last observed the fire-fighter. Also it might be possible to program the robots to try to avoid losing contact in the first place. For example a robot could in principle compute, on the basis of its current velocity and the positions of the fire-fighter and obstacles, if its current course would take it out of sight of the fire-fighter. If so the velocity could be changed to avoid this happening. Reacquisition and compensatory algorithms along these lines could be useful. However they would need to be designed with care otherwise the changes in velocity computed by them might conflict with the other potential functions in operation, perhaps to the extent that the stability of the swarm as a whole was disrupted.

Assumption 3 – Robots can determine the pose of the fire-fighter.

If the fire-fighter is within sensor range in a clear line of sight and a robot can distinguish him from other objects, then it follows that the distance and the angle of the fire-fighter relative to the robots orientation can be determined. However if the robot wishes to determine the distance and angle of objects including itself in the fire-fighter's reference frame it must know what the orientation of the fire-fighter is or, to be more precise, what the orientation of the HRI device the fire-fighter wears is. Otherwise the directions in which objects lie with reference to the fire-fighter cannot be defined.

It difficult to imagine a means by which this could be determined both accurately and reliably in the warehouse scenario given that the visibility is poor and the human is constantly on the move. However the fact that the fire-fighter generally faces in the direction in which they move suggests a crude but possibly quite robust method for determining the pose of the fire-fighter. The robots could simply track the fire fighters trajectory over a given period of time and estimate an orientation vector from it. The problem is slightly complicated by the fact that the robot must take into account its own movement during the interval in which it tracks the fire-fighter to determine the pose therefore odometry over this period would have to be reasonably accurate. Also the ability of the robot to plot the fire-fighter's trajectory naturally depends on the effectiveness of the system used to mark the fire-fighter (see assumption 1).

Assumption 4 – In order to guide the human to a goal, the robots must determine a reliable bearing with reference to the fire-fighters frame of reference and broadcast that information to the HRI which then conveys the direction to the fire-fighter.

To guide the human successfully the lead robot must itself know where its goal is and how to reach it. This is a complex problem which might involve one or more of the following:

- Odometry: gives reliable information on absolute position and orientation relative to an initial pose but only over short distances.
- Global positioning systems: could give the robot accurate knowledge of its absolute position relative to the goal, but the robots orientation in the absolute

frame of reference would also be required in order to compute the correct heading.
- Map building: could help the robot negotiate obstacles between it and its goal.
- Trail following: could the robot leave a trail of scent as it moved into a building and then retrace it when the time came to withdraw?

The robot must also be able to determine the pose of the fire-fighter (assumption 3) to compute its position and or bearing in the fire-fighters reference frame. This information then needs to be passed on to the human via the HRI. Another important issue relating to assumption 4 is how to appoint the lead robot. The most obvious choice for the leader would have to be the one that is closest to the goal. However to make this choice either all the robots would need to know their absolute positions or the base station would need to know the positions of all the robots and appoint the leader via the wireless communication network. Also it might be desirable to reassign the role of leadership to another robot at some point. This might be due to the current leader becoming damaged or losing contact with the fire-fighter or simply because the task of guiding the human may be accomplished more efficiently if the lead robot is changed.

Assumption 5 – In order to provide the human with an impression of the environment, from which they may form a mental map, the robots must determine the positions of obstacles with reference to the fire-fighters' frame of reference and broadcast that information to the HRI. The HRI would then need to convey the distance and direction of the obstacles to the fire-fighter.

To express this information in the fire-fighter reference frame, assumption 3 must be fulfilled. An effective way of displaying the information at the front end of the HRI also needs to be devised.

Additional desirable properties of robots

A robot can distinguish one robot from another especially if the identities of individual robots, particularly the lead robot could be known. This could enhance the ability of the swarm to operate collectively to accomplish a task.

Robot actions are dependant on the positions of other objects relative to a particular robot. In addition logical procedures could be defined for dealing with certain types of situation e.g. what action a robot should take if it loses sight of the rest of the squad.

In the case of the robots leading the human mode, the simulated behaviour of the human could, as a first approximation, be simply to move in the direction of the lead robot. However in general, the response of a real person to more general information about the environment will be highly subjective and therefore not readily circumscribed by mathematical functions or simple sets of rules. For this reason the plan is to include the option for real-time interaction of the user with the simulation, in other words the user can play the part of the fire-fighter and make decisions about which way to move. This could be informed by a 'God's eye' view of the simulation scenario (figure 15a), i.e. the user makes the decision based on a display which shows the complete layout of the warehouse including the current positions of the fire-fighter and all the robots. Alternatively the user could make the decision based on a display of the limited information sent by the robots about the local environment. The latter could therefore be viewed as a first step to simulating the front end of the HRI (figure 15b).

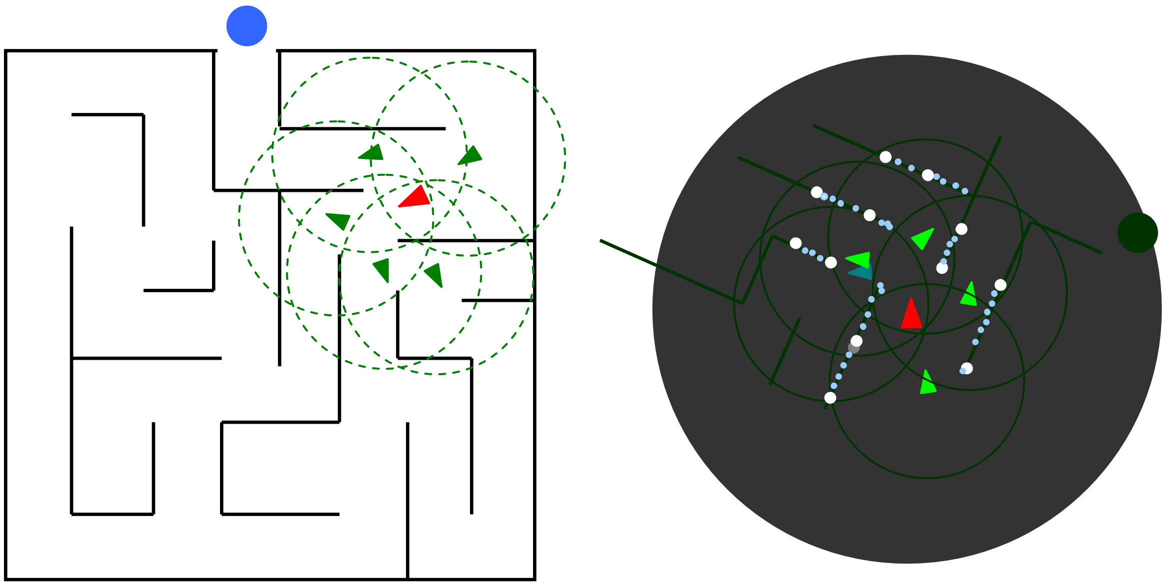

Figure 15, a. global view of environment; b. local environment view

Aside on representation of robot data sent to fire-fighter

Figure 15b shows the local environment in the reference frame of the fire-fighter, who is represented by a red isosceles triangle (the apex of the triangle defines his orientation). The green triangles represent robots; the turquoise triangle marks the last known position of a robot that has lost contact with the fire-fighter. The white dots represent the positions of the closest sensor echoes registered by the robots on the current scan, on their own they don't give much of an impression of the local environment. The blue dots are the echoes registered by previous scans – as the robots move forward, the robots will pick out different closest spots on the surrounding wall.

Perhaps a display of these earlier points would produce a trail that the fire-fighter could interpret as a wall or a recognisable profile of an object? If so the question is then: would it be feasible for the robots to store these co-ordinates, periodically transform them to compensate for the fire-fighters movements and broadcast all these co-ordinates to the fire-fighter? Further: is a HRI capable of receiving, processing and displaying this information a realistic prospect?

Human-obstacle potential function

Due to the fact that the human's only direct sensory data is through touch, we assume that they cannot distinguish robots from static obstacles. The form of the human-obstacle potential is simply a step function with the step position equal to the sensor range, if at any time a forward facing sector encroaches on an object, the fire-fighter must stop and change direction since the way is blocked. A reasonable response on the part of the fire-fighter to such an encounter would be to stop and move in a direction parallel to the edge of the obstacle. Ordinarily, however, the human-obstacle potential should be redundant since the robots should provide the fire-fighter with prior warning of surrounding obstacles, furthermore the robots should always keep out of the way so human-robot collisions should never occur.

Miscellany

Further details that could in principle be included in the simulation

- Differentiate different classes of static obstacle.

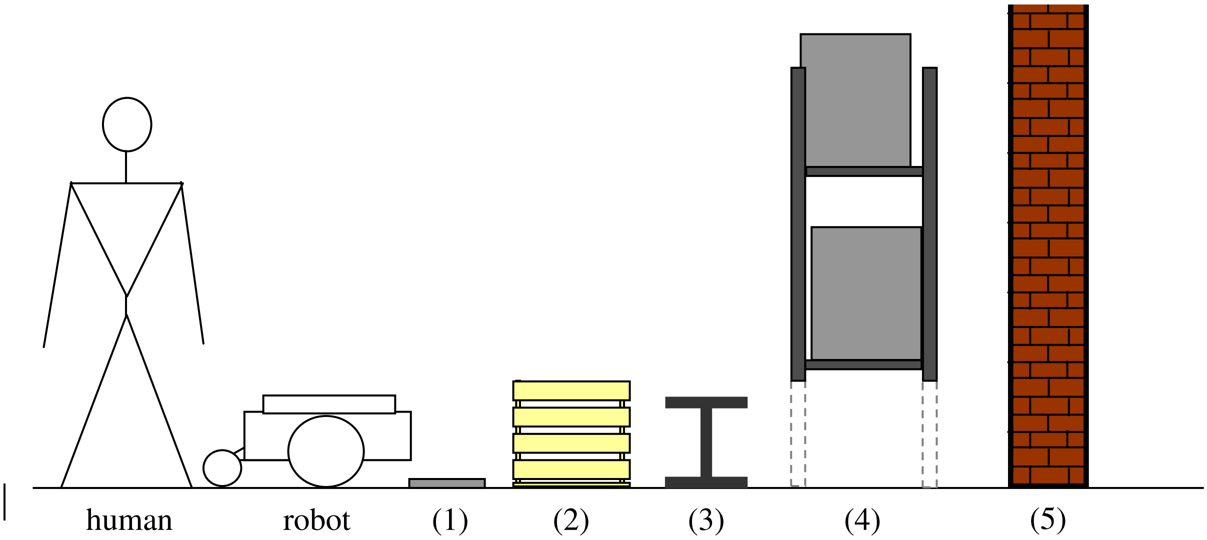

Figure 16, Classes of static obstacle.

A possible scheme for classifying static obstacles is as follows:

(1) Can be negotiated by human and robot (e.g. small fragments of debris).
(2) Block the progress of robot but can be stepped over or moved out of the way by human (e.g. empty wooden crate).
(3) Block the progress of robot but can be stepped over by human (e.g. steel beam).
(4) Can be passed under by robot but block the progress of the human (e.g. underneath a storage rack).
(5) Block the progress of robot and human (e.g. brick wall).

- Uncertainties/failures in sensor response either intrinsic or due to environmental factors.

- Progressive increase in error of odometric data.

- Introduce map-building algorithm.

- Introduce communicative swarming; include communication blocking and delay.

- Introduce plume fields or other environmental factors.

Appendix 1: User requirements table:

Incident Command Structure
• The safety of the fire-fighter can never be negotiated.
• Fast gathering of information in order to determine the seriousness, and scale of the incidents and request adequate resources.
• The command structure is clearly defined and visible.
• Sector commanders stay physically in their sector to provide direct and visible leadership.
• Each commander is given only a limited span of control. Procedures related to deployment and use of the Guardians robots should reflect this.
• Information flows are limited to the essential parts in order to avoid information overflows.
• The chain of command should not be interrupted.
• Crews are employed in the vicinity of their appliances as they use their own equipment etc.
• The Inner cordon is by definition a high hazard zone, access is restricted to the minimum number required to work safely and effectively; personnel should enter only after being fully briefed and allocated a specific task.
• Communications to crews within the inner cordon is restricted to safety critical information passing.
• Risk assessment precedes any operation and is continually reviewed while operations are on-going.
• Robots could assist the Incident Commander in making risk assessments.
Appliances
• First appliances at a scene will generally not be specialist appliances; the assessment of a situation is however dynamic, so the specialist units may be requested at any time.
• New pieces of equipment are either common to all appliances or are only provided to specialised appliances. It is likely that the Guardians robots and base station will be attached to one of the specialist appliances.
• An Incident Command unit is automatically requested at five appliances (though it can be requested earlier).
• The robots will be applied with a specialised unit, crew as well as appliance.
• A specialist rescue facility is to be built in Dearne Valley. It will house 28 staff, all who should be trained to use the robots.
• On a large scale incident such as the recent floods (Sheffield June 2007) every appliance will be deployed and may be dealing with non-specialist incidents, though they could be redeployed to where they are most appropriate.
• During the flood rescue operations Syfire had an officer to prioritise calls for assistance.

Warehouse Search Procedure
• One fire-fighter (the squad leader) determines the direction of movement and should not be disturbed by external communications.
• The second fire fighter is in charge of the communication with the entry control officer (ECO).
• Communication is restricted to safety critical information.
• Any system aiming to guide the squad should indicate unambiguously the direction towards the Entry Point (in fact exit point) and the scene of operations. Such a system must be robust and reliable in any unfavourable circumstances.
IKEA Warehouse
• Attendance at the IKEA warehouse would probably be three standard appliances plus one aerial appliance.
• It would be very useful for fire fighters if robots are able to go into the building to gather information for a first assessment.
Communication Technology
• It would be very useful for fire fighters if robots are able to go into the building to gather information for a first assessment.
• Improvements to mobile data services might allow the Incident Commander to access the log.
• There are implications for procedures regarding the relationship between the base station, control room and communications generally.
• Generally overall information goes to the control room. Specific information would be required primarily on site for those involved in the incident, so the base station could focus on this.
• The wireless infrastructure should be available at all times and interruptions avoided. Secrecy is not a priority.
• In Viewfinder, access to a log on the Base Station may be especially useful (e.g. for the dynamic monitoring of gases).
• Structure may be important in communications for instructions to be relayed to the robot(s) (e.g. from a fire-fighter involved in the incident who needs a specific action to be performed by the robot(s)). Therefore we need to understand exactly what kinds of tasks fire-fighters are doing so we can determine where and how robots can assist.
Interfaces
• In terms of the priority of the information provided to the fire fighters through the interfaces, the interfaces that indicate the hazards should be most noticeable for the fire fighters while the interfaces that provide the direction guidance should be noticeable but not too distracting for the fire fighters if they decide not to follow them due to some circumstances.
• To enable fire fighters to interact with robots, they should be provided with a tangible interface (large buttons preferably) that is designed and built in accordance with current standards used for tools and gear used by fire fighters.
Base Station
• For debriefing and other purposes (i.e. forensic investigations) it will be very useful if the data passing through the base station can be logged. The preference is for data that helps to reconstruct the order of events.

• *See also tables 4 through 9.*
Robots (Comms)
• Beyond Line Of Sight: Must be able to ingress specified number of feet in worst-case collapse. Worst case is a reinforced steel structure. (Syfire response: definitely required).
• Security: System must be shielded from jamming interference and encrypted. Scale defined: 1=None, 3=Command; 5=Both data and command. (Syfire response: not key).
Robots (Human System Interaction)
• *Initial Training:* Syfire response: SyFire would train the crew of the special unit.
• *Initial Training:* Response from View-Finder: partner PIAP is interested in developing a training programme.
• Operator ratio per robot. Number of operators per robot: Syfire response: we would employ people in shifts so subsequently different operators are active.
• Operator ratio per robot. Number of operators per robot: Syfire response: we would prefer that more then one person could be employed to achieve multi-tasking.
• Acceptable Usability: Percent of tasks users can complete. Effectiveness.
• Auto Notification: System notifies operator when conditions arise that need attention. (Syfire response: definitely required).
• Lighting Conditions: Special emphasis on no light and glare.
Display
• Dashboard: General chassis system health and status.
• This requirement captures the responders' expectation to monitor general system health and status (e.g. orientation, communication strength, power level, etc.). They identified two types of information: (A) Display of organic information: 1) system health status, i.e. power, motors, sensors, comms, etc.; 2) robot pose, i.e. absolute (x,y,z) or relative location from a start point; 3) constraints imposed by environment, i.e. inhibitors, manipulator problems, occluded or blocked sensors; (B) display of external information: 1) Hazmat; 2) Temperature; 3) Other payload sensors. In addition to determining if the information is present, it is advisable to perform a series of empirical tests to determine if the operator(s) can accurately interpret the displayed information.
• Mission data Integration: Includes all add-on sensors.
• Interaction - Component controls: To include diagnostics.
• Cache packaging-Setup Time: Time from on-site delivery to operation. (Syfire response: 15-20 minutes maximum. The robot(s) should be operable for hours and especially should include some standby facility where it could be recharged easily and re-deployed).
• Operating Environment: Max Temperature.
• Operating Environment: Water Resistant: Scale: 1=Not water resistant; 2=Wash down; 3=Submersible; 4=Water resistant to 12 meters.
• Operating Environment: Runtime Indicator: Must be able to inform

operator of remaining power level (percent).
• Operating Environment: Audio – 2 way: Scale defined: 1=Volume control. Listen all the time, push to talk; 3=Stereo; 5=Directional indication.
Robots (Mobility)
• The more common scenarios for fire-fighter operations in industrial areas are: Single storey buildings, some rubble on the floor perhaps some steep slopes.
• Stairs are not so common on industrial premises.
• Narrow doors, door size is 750 mm minimal.
• The robot should not have to carry a person, though it may be useful for the robot to be able to carry / pull a stretcher.
• Robots extinguishing small fires could be useful in a CBRM risk environment (e.g. if Acetylene cylinders are present).
Robots (Sensing)
• Internal: Orientation reporting.
• Video Pan: Independent of robot mobility.
• Video Tilt: Independent of robot mobility.
• Pan/Tilt orientation, Pan/Tilt orientation indicator.
• Video: Real time remote video system (Near).
Trial Scenario
• Syfire response: If the system is reliable there is no objection to having a robot operating between the human beings.
• Syfire response: Preferably one person is group leader. The other person is communicating with the base station.
• Syfire response: The information flow from the robots to the human being is limited to safety critical information only.
• Syfire response: The robots need to know where the human is, not vice versa; human only wants to be confident that the robots are there.
• The human being wants reassuring information from the robots.

Appendix 2: System Requirements table

Sensor System Requirements
• The sensors require a certain start-up period this is most cases between 60-120 seconds for the MOS devices and up to 10 minutes for the QCM sensors. This is dependant on the atmospheric conditions during storage of the devices.
• The sensors are dependant on the ambient temperature. A compensation circuit to eliminate/reduce the temperature affects shall be incorporated into the sensors circuits. The relative humidity of the atmosphere also affects the sensitivity of the MOS devices.
• Both MOS and QCM devices require a stable power supply for optimum sensitivity, it is imperative that is achieved for relative and accurate operation of the sensors.
• The long term stability of the sensor devices is good and after initial calibration should be stable for an estimated period of 1 year. It is however recommended calibration is undertaken at 6 month intervals.
• There is a potential 10 minute start-up hence fire-fighter's procedures need to take account of this; for example by switching the robots' sensors on/off before arrival at the scene.
• The sensor devices only give a representation of the analyte(s) present in the direct vicinity of the sensing elements (i.e. the sensor headspace), (see figure 6). It must therefore be noted under certain conditions detection and quantification of analytes although in close proximity to the sensors may give erroneous readings.
• The sensors can be mounted with vibration isolation components like silent-block, etc. Provide sensors with some system that eliminates or reduces vibration and protects from shock and impact.
• Protect sensors against water and frost.
• Provide robot with environment sensors like humidity sensor, temperature sensor, in order to avoid or temporarily switch-off in problematic for the sensors areas.
• Develop a device to produce an air flow. Inside this device the different gas sensors must be installed. The measure of the gases are made inside this device.
Human-Robot interactions
• See Table 3.
• How are motion commands transmitted to the person? Response (SHU): Presentation of robots to the human via both lights in the helmet and vibrations applied to the body.
• Response (SHU): The direction of the robots with respect to the human could be conveyed via vibrations from actuators on a belt worn around the body or by an array of LEDs built into the fire-fighter's visor.
• Data gathered by the robot is in general not presented to the Human squad member. Only processed and compact safety critical data (statements) are forwarded to the human squad member.
• The robots need to be able to distinguish the human fire-fighter(s).

• The human wears special clothing?
• The human is provided with an RF tag?
• The human is marked with … ?
• UJI response: If the human is in the centre of the squad, robots can distinguish between the external environment, and the inner person. Sonar or rangefinder (if smoke allows) can be used.
• UJI response: a priori knowledge of the human standing in the centre of the squad, and surrounded by the robots and subsequently keep a fix on the fire-fighter as he moves.
• The orientation of the fire-fighter could be defined by the direction his *visor* is facing and we may assume that all movements are in the same direction as this orientation.
Positioning Information
• Where do the robots get (relative) positioning information from?
• 1a: The wireless communication network.
• 1b: Ultra-sonic sensors.
• 1c: Vision cameras.
• 1d: Infrared sensors.
• Answer: In the trial scenario, the best option is the laser rangefinder.
• Answer: In the smoke-warehouse a combination of odometry, inertial-magnetic sensors and sonar sensors. Laser rangefinder needs to be tested, but it is unlikely to work.
Base Station
• See Tables 4 through 9.

Appendix 3: Debriefing report of Staniforth Road Fire Incident

South Yorkshire Fire and Rescue Training Centre, Sheffield

May 2007
Amir M Naghsh

Introduction

This is a report of a debriefing session to a fire incident that happened in Sheffield on 01-03-2007. The report gives an overview of the incident and presents the outcome of the debriefing session that took place at South Yorkshire fire and rescue training centre. Finally, it highlights some of the problems and shortcomings of the incident.

Overview

The incident was first reported as a fire in an open tyre yard that later was speeded to alongside premises (The building was used as a tyre fitting workshop, tyre warehouse and MOT garage). In total 11 appliances attended the incident which included eight pumps, two ALP and one incident control unit. Other resources attended the incident were a high volume pump (HVP), police, ambulance, super tram supervisor and gas officers.

A recollection of the incident

The fire incident was reported at 20:44:12 on 01-03-2007. This time is used as the start time for the incident. In three minutes from the call (at incident time 00:03:00) first appliance (called DAR1) attended the incident.

The incident was reported as fire in an open area. DAR1 when attended the incident located outside the car park (see Figure 17). DAR1 reported the condition as big smoke and fire coming out from the containers (believed to be one of them). At the time flames were coming out from the end part of the containers which was away from the rear of the premises (See Figure 17).

In very early minutes of DAR1 attending the incident a fire-fighter was sent to prepare hoses for using the closest hydrant (A) that is indicated with an arrow on Figure 17. However due to the problem with the hydrant, DAR1 crew were forced to use a more distanced hydrant (B) (See Figure 21). During this time the building (the premises) appeared to be clear of any fire. Therefore, the main objective for DAR1 was to control the fire and to stop it from spreading further to other premises alongside.

Meanwhile the second appliance was requested by DAR1 mainly due to the shortage of water at the time and the difficulty with the hydrant (A).

DAR2 attended the incident at 00:14:00 incident time (20:59:01) while DAR1 was in a defensive mode with 2 jets in place. As DAR2 attended the incident, its crew manager became the incident commander while DAR1 became the contact point between the incident and the control room. At this time the smoke had became very intense and the visibility was reduced to a very low level.

The incident commander first examined the fire from where DAR1 was located and did find any visible connection between the containers and the premises. Although the building behind the containers still appeared to not be involved with the fire, the incident commander sent couple of fire fighters to assess the fire from the other side of containers which also had a better view to the premises.

As a result they detected some smoke coming out from the edge of the building's roof however it was not still possible to confirm if the building was connected to the containers or not and therefore if fire had spread into it or not?

Therefore, it became essential to examine inside of the premises as quick as possible. Consequently, the request for the key holder of the premises was made at 00:20:00 incident time and in few minutes the key holder was available at the incident (00:23:00 incident time). The key holder confirmed that containers are connected to the premises and are used for storing tyres.

As it was confirmed that rear of the premises was connected to the containers that were on fire, DAR2 re located itself to location B as it can be seen on Figure 17 and one more appliance was requested (CEN1).

Due to very low visibility arriving appliances had difficulty in finding the right location to park their trucks and making their way to the incident. The arriving crew managers didn't have the facility or could not use the facility such as radios to contact the incident commander in charge to be informed of the situation. They had to find the commander by walking around.

Control room had informed the station manager in charge (BM01) when the third appliance was requested. At 00:54:00 incident time (21:38:38) the incident commander was changed to (BM01) who immediately asked for two additional appliances (one pump and one ALP).

Three requested appliances arrived at 00:53:58, 00:56:55, and 0059:00 incident times. (See Figure 19, blue [dark] squares indicate the appliances at this point) In addition the incident commander requested the incident support control unit at 00:55:00 incident time (21:40:54) which arrived at the incident at 1:26:15.

At this stage the incident commander decided it is important to examine inside of the premises for any possible spread of fire. Therefore it was decided to send two fire fighters inside the premises. It was not possible to access the building through the main gate (marked with the 5 point star in Figure 18) and the fire fighters had to use next building's gate (marked with the 4 point star in Figure 18) for access.

Due to the safety reasons the fire fighters were asked to commit into the building without making any turn and only go as far as they could maintain a vocal communication (see Figure 22). The fire fighters committed into the building did not detect any sign of fire or a high level of smoke which could indicate that fire had spread to the premises.

Since the incident commander was informed that containers were connected to the building, therefore it was essential to be able to commit the fire fighters into the building to deal with the fire before it spreads into the premises. However, because access through the side building had safety issues for fire fighters who could not commit any further than a limited distance in to the premises, the incident commander made the decision to open the main gate (five point star gate) of the building which would provide a safer access to the premises.

Once the front gate was opened, instantly the whole building went on fire. In less than a minute the premises roof was on a very intense fire. Incident state became offensive and in seconds it changed into an emergency state. All the appliances were commanded to evacuate to a safe location.

Immediately more appliances were requested at this stage and number of the pumps was increased to 7. Due to water shortage more pumps were requested which increased the number of pumps to 9 over all. The incident commander changed to a higher rank officer which attended the incident at 4:00:00 incident time. High volume pump (HVP) was also requested to maintain the water due to the size of the water.

At this stage the main objective was to not allow the fire to spread to the surrounding buildings and the open tyre yard at the rear of the premises. Jets were in place to control the fire and also spray water on to the tyre yard. Once enough number of pumps was in place and fire was under control some of the fire fighters were released or replaced with fresh crews. Finally, the fire fighters managed to put the fire out and limit the damage to containers, tyre warehouse and side building next to it.

Problems and Inadequacies

During the whole incident fire fighters experienced water shortage and problem with hydrants which caused for a higher number of appliances to be requested which were not from the local fire station. Apart from DAR1 and DAR2 other appliances were requested from stations which were located at other areas of the city. One of the main concerns of the incident commander was not to put other part of the city at risk by asking for too many appliances.

In addition to the water problem, there was a serious break down in fire fighters communication. The only equipment used for the communication was radio devices which did not working properly at all. Because of a very low visibility of the incident and poor communication, the incident commander had to physically walk around the incident to talk to each of the sector commanders face to face. This mainly was a problem when the incident commander changed. The incident commander changed three times and each time to get the sense of what's happening he had to walk around the incident and meet the sector commanders to be updated of what's going on. From that point further the operation commander would facilitate the communication to the sector commanders and report back to the incident commander.

The poor communication also made it difficult for the control unit to know how the resources were positioned and to be able to make the most out of the resources. This mainly was a problem since some of the resources were not involved when or where they were needed to be. It also made some difficulty when it had to be decided which crew had to be released.

There was another problem in regards to the communication and that was the control room contacting the fire fighters in charge on mobiles. Apart from being too difficult to reach for mobile when fire fighters are in full gear, it was also a disruption at the time that they were involved on the field. The fire fighters in charge such as operation commander and incident commander were contacted through their mobiles.

Conclusion

Overall it was a successful operation and South Yorkshire fire fighters managed to put the fire out without any casualty or spread of fire to other surrounding buildings.
One of the main conclusions of this report is the need for reliable and advance communication devices that can easily be used by fire fighters.

One of the areas that could have been improved was the command control unit. Providing a command control unit equipped with technologies that can provide detailed information about the incident and resources certainly would have a noticeable impact on the incident.

Another important area is providing assistance to fire fighters when examining a warehouse. Possibility of having any sort of robot or swarm of robots that can extend the level of information available to fire fighters could have major impact in the way that decisions were made.

For example, robots could have assisted fire fighters by committing into the premises and provide detailed information that possibly was covering a bigger area of the premises.

Therefore, it was highly likely for the incident commander to make a different decision instead of opening the front gate which caused the premises goes on fire in less than a minute. However, it is important to note that the decision made was purely based on the information available at that time and would be exactly same as long the information was the same.

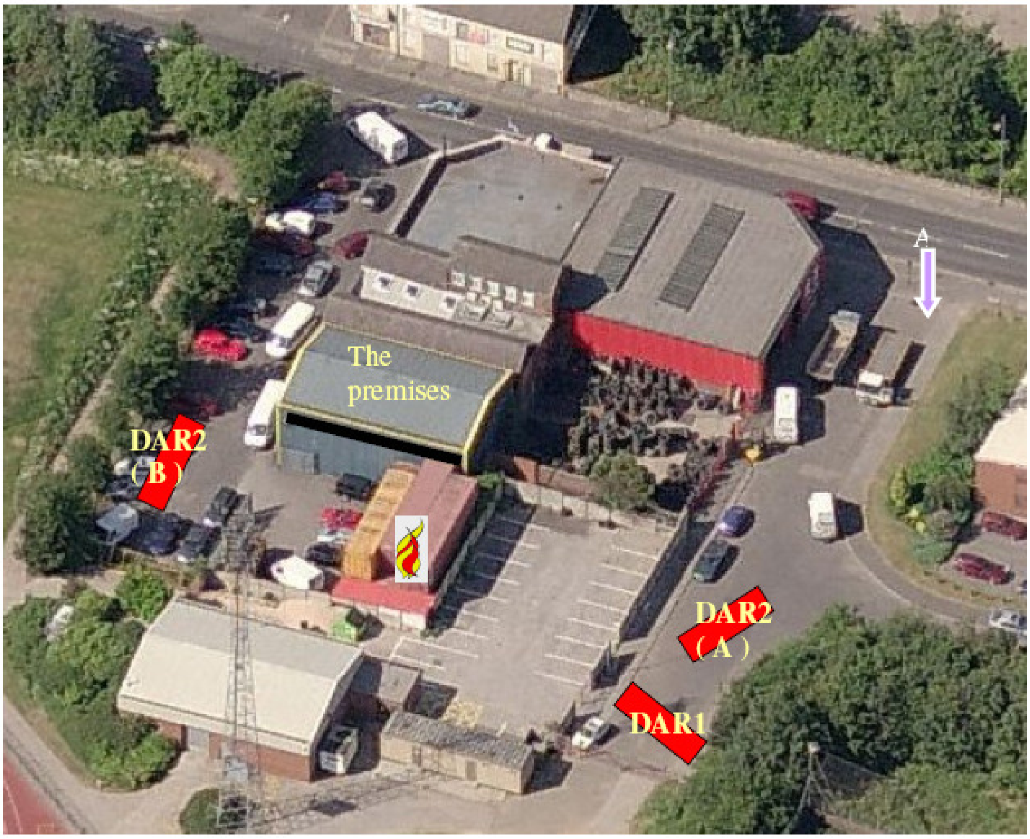

Figure 17 - Map of the Incident A


Figure 18 - Map of the Incident B

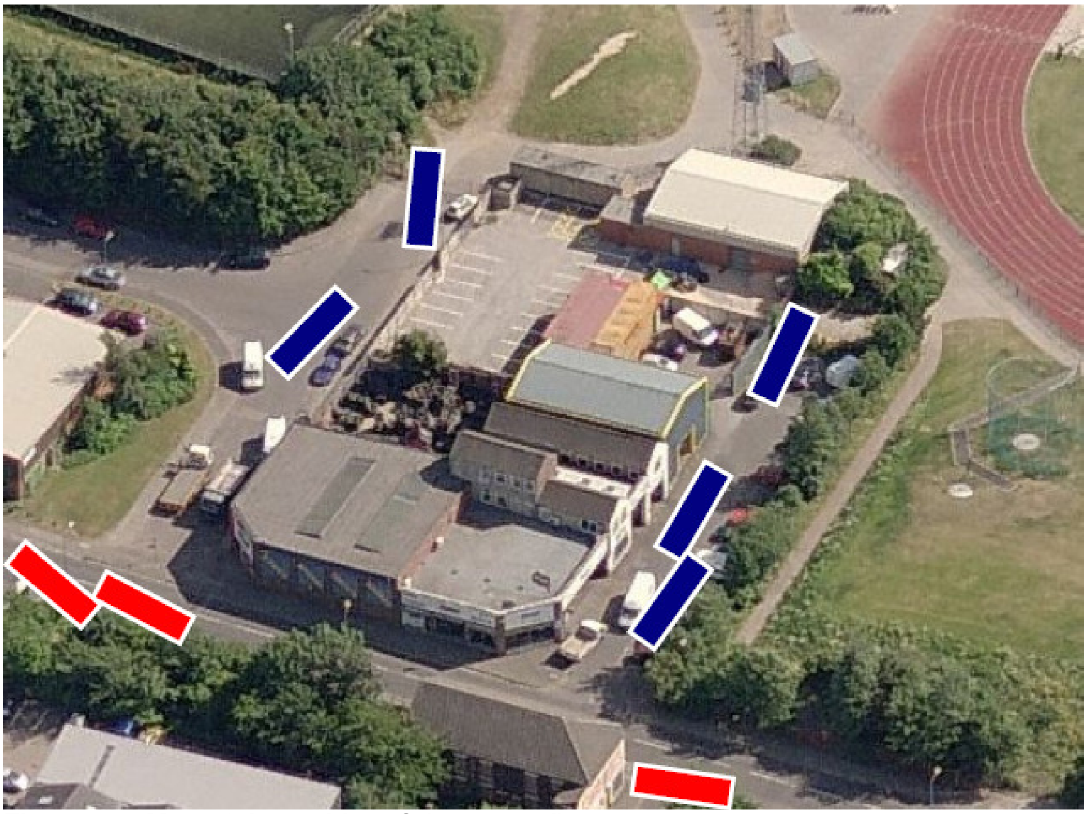
Figure 19 - Map of the Incident C (front road)


Figure 20 - Map of the Incident D

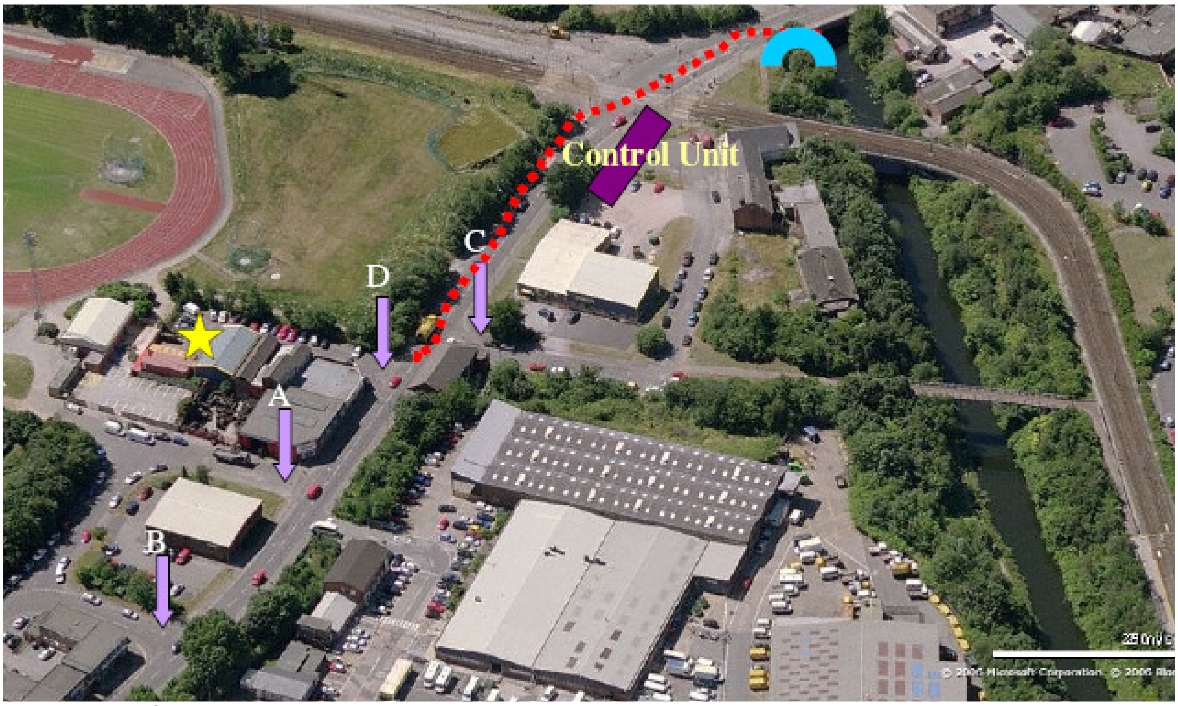

Figure 21 - Overview of the area

(Incident is indicated by a yellow star. Location of High Volume Pump (HVP) indicated by blue semi-circle).

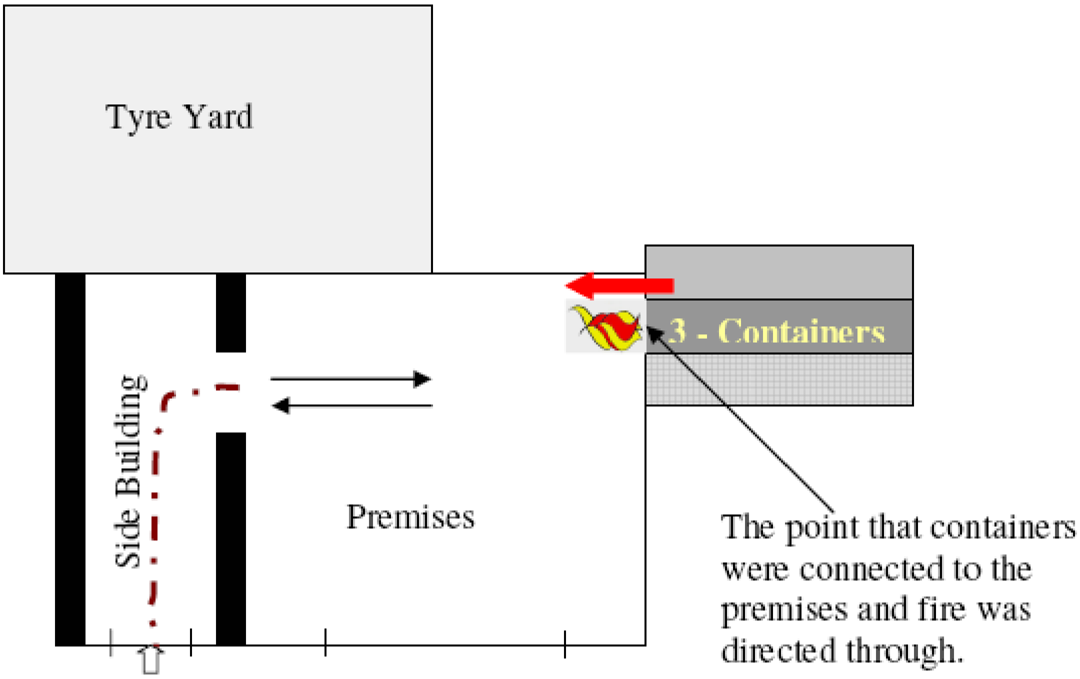

Figure 22 - Premises layout