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Home Office
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AN INVESTIGATION INTO A HIGH TECHNOLOGY ALTERNATIVE TO BREATHING APPARATUS GUIDELINES

by

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ABSTRACT

The Fire Experimental Unit undertook an investigation into high technology alternatives to guidelines in an effort to overcome problems that have been encountered when using rope guidelines. The high technologies considered were infra-red beams, radio frequency tags, electroluminescent lighting strips, leaky feeder cables, thermal imaging cameras and geographical and inertial navigation systems.

None were considered to have sufficient advantages over the current procedures to warrant their use.

MANAGEMENT SUMMARY

Introduction

The FEU was asked to investigate the possibility of high technology alternatives to guidelines. The alternatives explored in this report would offer a fundamentally different system to fulfil the requirements of guidelines. In some cases detailed potential solutions were developed and considered, in others a more general approach was taken to establish any possible application of the technology in question. Adaptations and improvements on the current guideline procedures and equipment are not considered here, although they are the subject of other on-going work.

The Technologies

The alternative technologies were broadly divided into the following systems:

continuous way marking,
intermittent way marking
external guidance systems.

In the continuous way marking category, electroluminescent lighting strips and leaky feeders were considered. Intermittent way marking systems included an infra-red system, a radio frequency identification system and a system using thermal imaging cameras. The two external guidance systems were a geographical navigation system and an inertial navigation system.

Conclusions

During the course of the investigation, no existing applications of high technology were encountered that could directly replace guidelines were encountered. Therefore, any new system would have to be developed from basic principles, with all of the cost and time penalties that would incur.

Although there are recognised problems with guideline procedures, the system itself has a lot to recommend it: the line is light, flexible, low-cost and easily replaced. Physical contact with the line provides security for a disorientated firefighter. For any high technology system to replace rope guidelines there must be positive advantages to the new system. In the technologies explored, it was felt that the drawbacks outweighed the advantages offered.

After studying the options described in this report, it was felt that none could offer a fundamentally new system with significant improvements on the current system.

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1. INTRODUCTION

When it is necessary to search a large or complex, smoke logged building, the UK fire service uses a guideline. A line (rope) is tied off outside the entrance and at intervals throughout the route. Teams of firefighters in BA (breathing apparatus) keep in physical contact with the line and with each other. Procedures for the safe use of guidelines have been developed, but problems still remain.

The FEU was asked to investigate the possibility of high technology alternatives to guidelines. The alternatives explored in this report were to offer a fundamentally different solution to the requirements of guidelines. In some cases detailed potential solutions were developed and considered, in others a more general approach was taken to establish any possible application of the technology in question. Adaptations and improvements on the current guideline procedures and equipment are not considered in this report, although they are the subject of other on-going work.

The various technologies that were investigated are set out in individual sections below. The technology is briefly described and examples of its current use outlined. The possible application of the technology to a guideline system, along with the advantages and disadvantages, is explored. Where possible, approximate costs of the system (without VAT unless stated otherwise) are given. These are often only 'ball park' figures, since the equipment does not exist in the form described. Where costs are available, they are compared as directly as possible with current guideline specifications (see Reference 1). For comparative purposes in July 1994 the cost of a standard hemp BA guideline was given as £50.79[1].

2. REQUIREMENTS OF A GUIDELINE ALTERNATIVE

The guideline alternative must have the following capabilities:

To mark a route which has been traversed such that a firefighter can follow it. It must mark only the route that has been followed and not cut corners.

To distinguish the entry and exit directions.

To enable firefighters to be located should something happen to them.

To distinguish between the main path and separate paths branching off it.

To enable firefighters to relocate the path if they lose contact with it.

To fail safely. Should an element of the guideline system fail to function, the firefighter should at least be able to leave the building safely, and preferably be able to continue the search.

To provide a reference for searching.

To be simple in operation.

To be light and portable - firefighters will already be wearing BA sets, the extra equipment should not significantly add to their load.

To be low cost. The guideline, or any alternative, may have to be abandoned after a search. For this reason, any part of the equipment to be left in the building should not be expensive.

In a situation where a guideline is used, there are a number of restrictions on the firefighters sensory perceptions which must be considered. Smoke logging will severely reduce visibility. Noise levels may be high. Firefighters will be wearing gloves which restrict manual dexterity and make recognition by touch difficult. This is a significant drawback with current guideline techniques which rely upon the ability of the firefighter to identify different lengths of tag on the guideline to denote path direction. The firefighter is also required to carry out tasks such as tying knots and clipping and unclipping connectors.

With these restrictions in mind it is important that any high technology solution should present information to the firefighter in a clear and simple format.

During the course of this work the presentation of information to the firefighter was not considered in any great detail. It was felt that this could be achieved in a variety of ways with relative ease.

3. HIGH TECHNOLOGY SOLUTIONS

The possible high technology alternative systems explored in this report fell into three categories:

Continuous route marking, in a similar manner to laying a conventional guideline.

Intermittent route marking, searching from one point to the next.

External guidance systems, where the details of a firefighter's movements can be fixed in space.

Continuous route marking can be regarded as a development of the rope guideline. The rope provides physical contact to indicate the route and different length tabs to indicate directional information. The alternative systems in this report use an electroluminescent lighting (EL) strip (Section 4.3) or a leaky feeder cable (Section 4.4) as the continuous marker.

Intermittent route marking involves laying occasional way markers at critical points along the route. The markers send out some kind of signal which aids a firefighter to find, and stay on, a given route. Section 5.1 explores infra red emitters and Section 5.2 considers radio frequency emitters.

Thermal imaging (TI) cameras (Section 5.3) are included in the intermittent route marking category, with mention of a system which uses a TI camera to locate markers on a route. However the TI camera should not be regarded as only a part of an alternative guideline package, it could be used in conjunction with other methods to improve or facilitate their use.

External guidance systems enable anyone outside the building to know the whereabouts of a firefighter searching it. Using the same technology as is used in missile navigation, the movements of a firefighter can be calculated and transmitted to build a record of the searched path. Section 6.1 describes geographical navigation systems, while Section 6.2 describes inertial navigation systems.

4. CONTINUOUS WAY MARKING SOLUTIONS

4.1 Electroluminescent Lighting

4.1.1 Background

Electroluminescent (EL) lighting[2] consists of a broad flat strip of extruded polycarbonate containing long EL lamps at intervals along it. Each EL lamp consists of a phosphor layer sandwiched between aluminium foil and a transparent electrode sealed in a high density polymer. A low AC current is used to excite the phosphor which produces a glow. Systems sold commercially are designed to run primarily on a mains supply with an option of switching to an emergency back up supply, i.e. a battery. The nominal operating temperature of the system is 20°C, although it has been tested to 75°- 80°C.

EL lighting is currently used as emergency lighting along the floor of aircraft aisles. Here, the lights are at low level and so they remain visible under the smoke in the event of a fire.

A system using EL strips as a part of a guideline replacement system has been proposed by Harper (Reference 5). Each member of the search team would carry a battery powered lighting unit. The unit would consist of a reel of EL lighting strip and a battery. A battery would be laid at each turning point encountered and the EL strip laid out from that point to the next turning point. The path would then be extended with another unit.

4.1.2 Advantages of an EL system

It employs existing technology.

It is visible under the smoke layer and can be continuous. Visible arrows and possibly tactile direction markers could be included in the lighting strip design.

EL lamps are a cold light source with a low power consumption.

Manufacturers figures suggest that a back up battery will last for up to three hours, although this is dependent on the conditions in which it is used.

No tie off points are required.

EL strip stowed on a reel would be easily deployed and re-stowed and unlikely to tangle or snag.

4.1.3 Disadvantages of an EL system

A power source is required. The life of a battery cannot be guaranteed in severe conditions.

The complete system would be very heavy and bulky.

The original proposal suggests starting a new reel of EL strip at each turning point. This allows the possibility of starting a large number of reels, but not using much EL strip off each, effectively wasting the strip that had been carried. If the strip could be fixed in position at each turning point, in much the same way that guidelines are tied off, fewer reels would be necessary and the strip would be used more efficiently. However, EL strips are not very flexible. They would be laid around complex buildings requiring many turns, some of them very tight.

There are doubts about the robustness of EL strips. The manufacturers are confident of its performance when exposed to knocks (they quote its resistance to 'hard knocks and scratches from carts, trolleys, mobile cleaning and maintenance equipment'), but in an operational situation it may be bent, folded or buckled, and will not necessarily have a smooth, flat surface underneath it for support.

The use of guidelines is recommended when premises are flooded, or likely to be flooded. In this situation it is important to have the EL strips raised off the ground for it to remain visible (it is tested under 'deluge' conditions). The system described above does not provide for this eventuality. In fact the reverse is true, that part of the benefit of the system is in letting the EL strip lie on the ground.

The maintenance of a system such as the EL system must be taken into account. The lights, batteries and EL strip would all need regular checking, maintenance and repair.

An EL strip would only be visible from a low level. The BA team would be upright in most cases.

4.1.4 Alternatives

The system described by Harper includes the use of a sodium fog-lamp at each turning point. The EL strip unit would contain a fog-lamp and battery at the reel. The fog-lamp would provide a flat 90° beam under the smoke layer illuminating the path ahead. The addition of the fog-lamp would improve visibility between turning points and provide a securing point for the EL strips. It would however considerably increase the weight, bulk and power requirement of the unit to be carried and therefore the weight of the power unit required.

It may be possible to connect a personal line to the EL strip to provide physical contact with the route. This would give firefighters the option of following the EL strip physically or visually.

4.1.5 Fail Safe Mechanisms

Each unit (fog-lamp, EL strip and power unit) is a self contained entity, so in the event of equipment failure, only one unit would be affected. If an entire unit were to fail, the path up to the failed unit would be marked by the previous fog lamp beam, as far as that beam could penetrate, and beyond the failed unit the subsequent EL strip would start. In a situation where the search has continued for a long period, it would be conceivable for a number of units to fail due to battery exhaustion. In this case the EL strip would still provide a physical link which could be followed as a guideline.

4.1.6 Cost

The costs of a system based on EL lighting have been given by Form Product Design Consultants[3]. They are based on the following system:

The guideline would consist of 100 m of cable in 10 m lengths. Each length to carry 10 lamps at 1 m intervals, each lamp to be detachable. A power unit (12 volt DC supply) would give 8 or more hours continuous use. Custom connectors would connect the lamps to the cable and cable to cable.

Each lamp would produce a green light equal to 58cm^2 of lit area. Colour coding could be adopted for branchline turns, for example, red for right turn and white for left hand turn. Arrows or a numbering sequence could be used to give a firefighter directional information.

The costs are approximate since a number of factors are unknown (e.g. optimum distance between lamps, size of area to be lit, method of attachment etc); also, in order to achieve the flexibility required of the line, new manufacturing techniques would need to be developed. However as a broad estimate the following figures were supplied:

10 x 10 m cable	£162
90 x green lamps	£900
10 x red lamps	£150
10 x white lamps	£150
1 x power unit	£200
1 x storage case	£100
TOTAL	£1,662

4.2 Leaky Feeders

4.2.1 Background

Leaky feeder systems are used to improve radio communications in poor environments. In the early 1980s, Merseyside Fire Brigade reported that they had carried out trials of the system in a tube station[4].

Originally developed by the mining industry, leaky feeders are aerial feeders (co-axial cables) with gaps in the screening. The gaps allow bursts of the signal to escape throughout the length of the cable, thereby maintaining good communications in otherwise difficult situations.

4.2.2 Advantages of a Leaky Feeder System

They were originally hoped to directly replace the line or rope.

Radio contact could be improved without extra equipment.

4.2.3 Disadvantages of a Leaky Feeder System

They are more costly, bulkier and heavier than the standard line that is currently used.

They are less flexible and more prone to breaking.

They don't solve the problems encountered with current guidelines; for example tying off points are still needed, the line may still drop to floor level between tying off points and the procedure is still complex.

The standard, coaxial, leaky feeder cable that could be used for VHF transmissions is lighter and more flexible than that which is required for UHF transmissions. The leaky feeder for UHF has been described as a structure like a copper pipe with gaps along it. This would obviously be unacceptable for a guideline. Fireground radios work on UHF frequencies.

4.2.4 Fail Safe Mechanisms

If a portable leaky feeder line were to be used as a guideline and it ceased to function as a leaky feeder, it would still be usable as a standard guideline. Only if the leaky feeder line broke would it fail as a guideline, and in this case the two ends of the line would remain in close proximity. The failure would be no worse than if a rope guideline broke.

4.2.5 Alternatives

London Fire Brigade[5] are developing a guideline which was to have a leaky feeder element included within it. However their current construction has used a communication line as the basis for a guideline[6]. Previous systems have used the standard communication cable as the guideline, but in that situation radio contact is made only when the firefighters are in contact with the end of the cable. In this latest development, inductive coils are located between the guideline tabs, when the firefighter is in physical contact with these coils, simple inductive amplifiers and receivers can be used. Communications are then possible between the firefighter and the BAECO, or between teams of firefighters. It should be possible to connect extra branchlines or extend the main guideline as often as required with no appreciable loss in signal strength.

Using this system, the guideline procedures are maintained as previously (London Fire Brigade have already introduced new aspects to guideline procedure that can be used with this system) and radio transmission is improved. However the system is still being developed and is undergoing changes during that process. No costs are available for this system.

5. INTERMITTENT WAY MARKER SOLUTIONS

5.1 Infra-red

5.1.1 Background

An infra-red (IR) guideline system was considered by the FEU. It was discussed with various authorities in the field of IR technology[7,8].

The system was to comprise IR emitting beacons placed at intervals to denote a safe path. The firefighter would carry a torch-like detector which was to give an audible signal and show a flashing light when it received an IR signal from a beacon.

One side of the IR beacon was required to emit a long pulse (a dash) to denote the entry direction. The other side would emit short pulses (dots) to denote the exit direction. Branch lines would emit pulses in groups (for example, two dots and a pause, two dots and a pause) to differentiate between the branch and main guidelines.

5.1.2 Advantages of an IR System

The use of an IR source modulated for the Khz frequencies (wavelengths of 850 - 950 nm) will allow transmission through dense smoke over a distance of 10 m. These frequencies will help to avoid hot spot interference.

A torch-like detector with a 5° field of view was discussed. In this way the fire fighter could sweep an area with side to side movements. When the detector emitted an audible tone, the firefighter would know that the marker lay in the direction that it was pointing.

It was felt that the detector could be increased in range to give a much wider field of view, but with a central target of 5°. A wide array of detectors would be able to identify the area in which the marker was located, leading the firefighter into the central target. For example, a detector with an array covering a 90° field could emit a tone when the marker was in range. When the detector was moved towards the marker the tone could increase in frequency and/or volume, peaking when the marker was within the central target.

IR technology does allow a two way link to be set up between the transmitting beacon and the detector. This can extend to provide a full 2-way communications link, although this much sophistication is unlikely to be of benefit in this situation.

5.1.3 Disadvantages of an IR System

Although IR waves travel through smoke well, the presence of water spray (as there may be from a sprinkler system) would increase transmission losses.

Powering the beacons within the building could cause problems. The operating life of a battery in a hot environment can be unpredictable and the batteries could be potentially dangerous.

Because of the number of beacons and their power units that may be required on a search, their weight and bulk could become unacceptable.

The beacons would have to be positioned correctly to give the correct directional information, but IR transmissions scatter, which may make it difficult to discriminate between the entry (dot) and exit (dash) signals. It could be possible to pick up both the exit and entry signals from a single source. However, if the detector was to read only the strongest signal (with the largest amplitude), the lesser, scattered signals could be ignored. Alternatively, the beacon could indicate the exit direction with a constant output and the entry direction with a modulated output of perhaps 1 Hz (1 dot per second).

There is likely to be significant interference between signals from different beacons. The use of pulse repetition to distinguish between transmissions would help to reduce the interference. However, in early discussions, pulse repetition was to be used to differentiate between the main guideline and branch lines.

A detector may be able to detect more than one beacon, for example if there are a number of corridors leading off a central corridor, each with beacons close to the junctions. However a combination of a tight central target on the detector, and only reading from the strongest signal should overcome the problem. Additionally, the lines leading down a side corridor may be branch lines with beacons transmitting at a different pulse repetition rate.

5.1.4 Fail Safe Mechanisms

In the event of equipment failure, the system becomes very difficult to operate safely. If, for example, the detector fails to operate, the firefighter is left to follow a visible light on the beacon. The smoke density will make this hard to find.

If a single beacon fails to operate, the firefighter does have some chance of locating the next beacon by scanning the area. However the possibility of several beacons failing may also arise as the batteries run down. In this case the firefighter has no means of finding the entry or egress routes.

5.1.5 Alternatives

Alternative systems, based on different approaches to the problem could be developed. The possible avenues considered were:

A passive IR system may overcome the problems of powering an IR beacon in a severe environment. In this case, rather than using separate beacons and detectors, the firefighter could carry a combined transmitter/detector and place reflectors as markers along the route. Thus the only power required is within the transmitter/detector. This has the advantages that only one power unit is needed; its working temperature will be governed by acceptable conditions for a firefighter and it would be a considerably cheaper solution than providing numerous, powered beacons.

A passive system would, however, create its own problems. For example the strength of signals reflecting back to the detector would be greatly reduced, therefore stronger transmissions would be necessary. There may be many reflective surfaces in a building so that there would be no guarantee that the returning signal was reflecting off a route marker.

As a compromise, the IR transmitter, on the beacon, could be stimulated to light up by another beam contained within the detector. This would reduce the power requirements of the beacon because it would only transmit when stimulated.

In order to reduce the interference and direction problems, a combined system using IR beams and radio frequency identification (RFID) tags (see next section) could be developed. The RFID is a small, low cost tag capable of holding information which could be interrogated by a handheld reader. An IR beam could be used to mark the path between points. The information required of the marker (exit, entry, branch or main line) could then be held on an RFID tag. This would use the transmission benefits of IR beams and the information carrying ability of the RFID tags. However it does not overcome the power supply problems of installing an IR beacon in a hot building.

A system where a route is marked with large bar codes which can be read with an IR reader was discussed[9]. It is under development as a system for guiding robots around a factory floor. As a guideline system, the problems involved in carrying sufficiently large bar codes to be able to locate them, combined with the problems of fixing them to any surface, outweigh any advantages that may be gained.

Marconi Electronics[2] are developing IR technology in an area which may be applicable to guideline alternatives. If IR was considered to be a desirable guideline option, the existence of applicable technology could significantly reduce development costs, for example by adapting the existing technology for use in one of the systems described above.

5.1.6 Cost

Marconi give a 'ball park figure' for the cost of IR beacons as approximately £20 - £25 (including VAT) for each beacon. Added to this cost should be the cost of the reader and all associated electronics.

5.2 Radio Frequency Identification Tags

5.2.1 Background

Radio Frequency Identification (RFID)[10] tags have been developed to detect, track and control items in various applications. For example they have been used in production processes to provide reliable, automatic identification of batches of bottles being sterilised by autoclaving. They can also be used to operate a car park barrier when a correctly tagged car is recognised.

Each tag is a battery free, low frequency transponder that uses FM transmission techniques. To interrogate the tag, a reader sends an energy burst to the transponder via an antenna. The power burst charges up the tag in about 50 milliseconds. The tag then returns a signal which carries the data that is stored within it. The total read cycle lasts about 120 milliseconds. The tags carry a digital code up to 1024 bits. Read/write or read only tags are available.

RFID tags could be adapted for use in a guideline system where the tag would be used as a way marker. The tags could be provided in a body which would provide fixing options. For example, cable ties or hooks could be a part of the RFID container. The tags would then be fixed at intervals along a searched route. Using read only tags, they would be left in a predetermined order. The tags would be available only one at a time and only in the right order. Each would bear a numerical code, so that, with zero as the entry point, an increasing value would denote the entry route and a decrease would denote the exit.

Branch lines could bear an extra digit or letter. Extra tags, to denote areas that had been searched and were not a part of a continuing route, could also be coded. The reader would be responsible for decoding all of the information and for communicating it to the firefighter in whatever form was required (audible, visible, VDU screen etc).

In a more sophisticated system, read/write tags could be used. The tags could then be used in any order and the code would be determined by the firefighter. The reader would then have to incorporate a programming facility to write data to the tag. The tag could then be interrogated by a reader carried by the firefighter.

For example, the BAECO (BA Entry Control Officer) could set up one team's reader (and incorporated writer) to automatically write a letter or code to indicate whether the main guideline or a branchline is being marked. After that the reader could add a sequential code to indicate the route direction (zero for the route start and increasing into the building). A separate key could be used to write a 'Room searched' code on to a tag, where it was deemed unnecessary to continue the search around the room. The tag could be coded by passing it over a writing face on the reader.

5.2.2 Advantages of RFID Tags

They can be coded to give information on direction, branchline or mainline, whether the area has been searched, and so on. Read only tags could be used provided they were used in the correct order. Branch lines could be identified by an extra letter or digit.

They are passive, requiring no integral power source. The power would be supplied by the handheld reader carried by the firefighter.

They can withstand temperatures of -40°C to 120°C.

They cost in the region of £5 to £10 per tag.

There is, already developed, a detection system called 'signal capture' which only reads from the tag closest to the reader. This system could be used to ensure that a reader is not confused by tags further along the search path.

Tags can be mounted within protective casings without affecting the signal. The casing could include options for fixing the RFID to a surface. For example cable ties or nails could be included.

5.2.3 Disadvantages of RFID Tags

The most important drawback to RFID tags is the range of the transmissions. Currently their typical range is approximately 0.5 metres, with a maximum of 3-4 metres. In order to achieve the maximum range a large antenna is required and the reader is no longer portable.

The tags are orientation sensitive; that is their range is dependent on the position of the reader in relation to them. In order to overcome this, the tag should be correctly oriented when it is used. However, for specification purposes, only the lowest transmission, in the worst orientation, could be assumed.

The radio frequencies transmitted by RFID tags can travel through solid objects. Although this means that smoke, dust, water spray etc, cause no interference, it does mean that signals will travel through walls. This is obviously a major drawback when only a clear, safe path should be marked.

There may be interference with the RFID transmissions from other radio frequency sources.

The tag may be affected by close proximity to metal objects; this can be overcome by providing a plastic casing to keep it sufficiently distant from the metal.

The need to use read only tags in the correct order would add to the complexity already involved in guideline procedures. The need to code read/write tags as they were used would require the user to know how to code tags and what to code them with. It could be possible to code the tags automatically as they were removed for use. The initial coding (for example the team identity or branch line code) could be carried out by the BAECO, with the reader programming in the individual tags' increased codes automatically. Keying in any information would be impractical for firefighters in gloves, although a single 'Room searched' key may be feasible. However the tags were written to would need to be a simple and non-time consuming task.

The tags themselves are relatively cheap, but readers are also required. The cost of developing the system must also be taken into consideration.

The tags that have not yet been deployed would have to be suppressed prior to their use, otherwise the energy burst from the reader would detect responses from all of the tags.

5.2.4 Fail Safe Mechanisms

The fail safe mechanisms of a system using RFID tags would be broadly similar to those of IR systems. If the reader failed the system would be useless and the firefighter stranded. With passive markers there would be no way of relocating them in thick smoke and the coded information would not be available.

If a single tag failed to respond, the next tag would provide an adequate response since the firefighter would only be searching for a higher (or lower) value. This would however be dependent on the signal being sufficiently strong to be detected.

With read/write tags, the added sophistication allows scope for a wrong value to be programmed in. This may create confusion by repeating values, or by leaving a firefighter searching for a non-existent value. If it was only the programming element of the reader that failed, the firefighter would be able to follow the existing tags but would not be able to extend the route.

5.2.5 Alternatives

The tags are currently used for identification purposes rather than route marking or direction finding. The drawbacks are such that a system using only RFID tags is unlikely to provide a guideline solution. For this reason the combined RFID and IR system outlined at the end of Section 3.1 was considered.

5.2.6 Cost

If RFID tags were to be placed at 5 m intervals throughout a 60 m route (the length of a guideline) the cost of tags would be £60 - £120. The cost of a reader or a read/writer would vary depending on the sophistication required of it, but a typical hand-held read/writer could be in the region of £1,000. The cost of any maintenance that would be required is not included..

5.3 Thermal Imaging Camera

5.3.1 Background

In 1992 a survey by the Fire Research and Development Group

(Reference 2) found that 66% of brigades owned thermal imaging (TI) cameras. They work on the principle of converting IR energy into a visible image, where different temperatures are represented by various shades of grey on a screen (Reference 3).

Some brigades routinely use a TI camera whenever a guideline is used. They can be used to identify branch and main guidelines, to identify tying off points and aid tying off, they can aid the identification of direction tags and branchline tallies. In more broad firefighting terms, they are useful for locating hot spots and assessing the success of firefighting operations.

5.3.2 Advantages of TI Cameras

The camera gives firefighters a degree of vision in dense smoke, allowing them to find a path and to gather other visual information.

This equipment is widely available, well established technology.

5.3.3 Disadvantages of TI Cameras

Using a TI camera alone, the firefighter must rely on only vision to identify a route.

It does not mark the route or the area that has been searched.

No directional information is provided.

A TI camera is an expensive piece of equipment. In order to use it routinely in guideline work, it would be necessary to provide one camera per BA team. Therefore more than one camera would need to be available at an incident where guidelines were deployed.

The operator of the TI camera is completely occupied in holding the camera; they have no ability to search or follow a guideline manually. A head up display would allow more flexibility for the firefighter than a handheld camera.

5.3.4 Fail Safe Mechanisms

If the TI camera failed when used with the current guidelines, the standard procedures would still enable the firefighter to find the way out of a building.

5.3.5 Alternatives

It may be possible to develop a system of 'cold markers' (made of a low emissivity material) that would show up on the TI camera screen as dense black spots. Branch line and directional information could be coded on to these. For example the marker could be an arrow shape to indicate direction and two or more arrowheads to indicate the branch line. However the firefighter would have to be able to ensure that the markers followed were the correct ones and not some other cold object.

If cold markers were used, without a TI camera they would not be visible, and therefore the firefighter would be left without any information. The markers themselves could not fail, but they could fall or become hidden. In this case the next marker would have to be sought and the route could no longer be assumed to be safe.

5.3.6 Cost

EEV[11] manufactures the TI camera most commonly used by UK fire brigades; it is currently (July 1994) selling for £7,420. In December 1994 or January 1995 a new camera will be launched and it is anticipated that it will cost around £4,990. These cameras are both hand-held, but Sonic[12] produce a helmet with an integral TI camera and BA capability (Reference 4). This helmet has a head-up display of the thermal image on the visor, the firefighter can either focus on the display or look through the visor as normal. The Soltic helmet, with camera and BA capability have a list price of £12,300 (July 1994).

The TI camera provides a valuable aid to guideline work, but, used alone, is unlikely to replace the current system.

6. EXTERNAL GUIDANCE SOLUTIONS

6.1 Geographical Navigation Systems

Geographical direction finders[13] use satellites to pinpoint locations. They rely on line of sight with the satellite and are therefore only useful outdoors.

6.2 Inertial Navigation Systems

6.2.1 Background

Inertial navigation systems involve the use of pairs of accelerometers to provide positional information by measuring movement. These accelerometers are used in missile guidance systems. Navigation systems are currently being developed for use with robots[4] (Reference 6). Given a plan of the area, and a communications link, the inertial navigation system can transmit information about the movements of the robot so that its position can be tracked.

An inertial navigation system would need to be initialised to establish orientation with respect to the building and the start point of the search. Then the movements of the firefighter in each plane are measured using an accelerometer and the turning movements are measured with the gyroscope. Constant monitoring of these movements will give the position of the firefighter at any given time.

There is a potential for these navigational systems to be used in conjunction with the telemetry system currently under consideration by the Joint Committee on Fire Brigade Operations (JCFBO)[14]. The telemetry system is intended to provide improved information about a firefighter working in BA. The current draft specification (Reference 7) sets out standards to which future telemetry systems should conform. This section gives a brief summary of the main points of the draft specification.

A base station located outside the risk area would be controlled by the BAECO. Each BA wearer would carry a portable unit which could be initialised on to the base station when the wearer was in the risk area. The BAECO would then have information on the number and identity of firefighters in the risk area and would be able to send and receive evacuation and distress signals. Options in the draft specification allow the BA cylinder pressure to be read, or to be read and then the duration estimated, or to be continuously monitored. The latter two options would give a warning when the cylinder pressure was low. Other options include the display of the BA wearers name and the auto transmission of a contact signal to confirm communications links.

The signals would be transmitted on a Home Office managed frequency band between 862 and 863 Mhz. The channel would be dedicated to data transmission using FM techniques. The BAECO could choose to transmit to and from all initialised firefighters, or specific initialised firefighters.

All communications would be logged, along with identities and times to provide a complete record of events throughout an incident.

The bandwidth of the link is such that the transmission of extra data, such as the position, or movements, of the firefighter, would be feasible. If the base station were a standard portable personal computer (PC), the PC could also contain fire safety (FS) plans of the building. If these plans were combined with the details of the movement of the firefighters within the building, the BAECO would be able to trace their search routes on the plan. The BAECO could then relay necessary information back to the firefighters, for example how to leave the building, which areas had been searched and so on.

6.2.2 Advantages of Inertial Navigation Systems

The position of the firefighter in relation to the building is known (there have been situations where firefighters have become trapped within metres of an external door).

The BAECO and later search teams waiting outside the building can see the progress made by the teams inside.

A telemetry system for the fire service is already under development.

6.2.3 Disadvantages of Inertial Navigation Systems

The inertial navigation systems currently under development are subject to significant drift errors and need to be corrected at regular intervals. There are more reliable robotic navigational systems but they rely on measuring distance by sensing the robot's wheels turning. The guideline system would have to use inertial navigation.

The telemetry system is not intended to transmit to a PC. If it were possible to transmit positional data to a floor plan contained on a computer, the scale of the plan could be of concern. To provide enough detail to be useful, only a very small area could be viewed on a portable PC screen.

The status of FS plans for complex buildings is not always accurate and up to date. It would be essential to hold a copy of all FS plans in a computerised form compatible with the software on the portable PC.

The information transmission, to and from firefighters, must be fast, firstly in order to provide useful information and secondly, so that it doesn't tie up communications lines needed for other purposes.

The information provided by this system would not be directly available to the firefighter making the search. Safety crew outside the building could keep track of their progress, but instructions on where they were and how to return safely would have to be relayed by radio. This would involve more personnel outside the building monitoring and directing the teams inside.

More than one entry point into the building would mean that more than one transmission frequency would be required to avoid telemetry interference.

6.2.4 Fail Safe Mechanisms

There are three main areas where equipment could fail: the navigation system, the communications link or the receiving PC. In any of these circumstances the failure would be catastrophic. The firefighter would be left with no method of finding the exit and with no positional information. The complexity of the system results in far more scope for equipment failure than a simple system.

6.2.5 Cost

The inertial navigation system would need information for three directions (up/down, left/right, backwards/forwards). This would involve the use of three transducers, each with its own amplifier and low voltage power supply. Each transducer package would cost £1,008[15], an equivalent of £3,024 per firefighter for the accelerometers alone. In addition it would be necessary to identify rotations in order to establish when the firefighter is crawling. The cost of the telemetry system would not be totally attributable to the inertial navigation system.

7. DISCUSSION

In an effort to improve guideline procedures, this study was required to consider fundamentally new techniques. Certain requirements were vital, but the methods of achieving them remained open.

Continuous route marking methods (EL lighting and leaky feeders), have an obvious advantage in that the firefighter is able to make some kind of contact (physical or visual) at any point along the route. They also fail safely.

Leaky feeder cables were considered because they could be dual purpose. They could be laid as guidelines, and also provide improved radio communication. However a leaky feeder construction for UHF frequencies is too bulky and inflexible for use as a guideline. Systems incorporating inductive communications into a standard guideline provide some of the benefits of leaky feeders without the drawbacks.

Electroluminescent lighting is a heavy, bulky system. It is hoped that it could be stowed on a reel so that it could be deployed quickly without snagging. It would aid a firefighters vision slightly, would be visible under the smoke and, in the event of a total equipment failure, would provide a physical line to mark the route. Although there are advantages to this system, the power required and the volume and weight of the light strip count against it.

Intermittent route marking systems cannot provide a constant confirmation of a route. In some of the systems described the markers are only discernible when a specialised reader is used, increasing the problems that arise in the event of equipment failure. An additional feature could be added to the marker in case of failure (such as the visible light on the IR beacons) but this involves duplication of effort and increases the power requirement of the system.

Infra-red technology could provide a straight line of light capable of transmitting from one beacon to the next, even through thick smoke. Handheld detectors could be developed to guide the firefighter along the path of the beam and to interrogate the beam for directional information. However the beacons would require an integral power source; adding to the weight and bulk of the unit and possibly not reliable under the conditions likely to be encountered. Some existing commercial systems could be used towards the development of an IR guideline, but considerable work would be required to produce a working system.

The placing of the IR beacons would require care and precision to ensure that the information they gave was accurate. The problem of where and how to place them would be as much a problem for IR beacons as it now is to find, or create, tying off points for a line.

From the point of view of the firefighter, a beam of light offers less security than a tangible line. If the route was lost for any reason, scanning for a beam allows too much scope for potential failure; the beacon may fail or be blocked, numerous beacons may be within range and so on.

Infra-red technology then, could be developed to produce some kind of guideline system. The development would be likely to be long and costly. The system as described would not fail safely. The procedures needed to use an IR system would not be any simpler, and may be more complex, than those already in use with the current rope guidelines.

Radio frequency identification tags (RFID tags) could not currently provide a complete solution for a guideline replacement. The restricted range and requirement for careful orientation make them unsuitable. They also transmit through solid objects and are affected by other radio signals.

It may be possible to develop an RFID system in combination with IR technology to provide an improved solution, but the disadvantages of IR technology, discussed above, still apply.

TI cameras could supply valuable visual information to the firefighter and in some brigades their use is advised wherever possible. However they could only be used as an aid to other guideline systems. The handheld TI camera, currently most popular with the UK fire service, completely commits the faculties of the firefighter using it. A head up display, or helmet mounted camera would give more flexibility, for example enabling the firefighter to tie off with the benefit of the thermal image.

Geographical navigation systems could not be used within a building. Inertial navigation systems could be used to transmit positional and search information to an outside monitor. However this removes control from the firefighter. It implies that the BA entry control officer, outside the building, must keep a record of where the search crew are and where they have been, and be able to communicate to them how to proceed from there. Any area of equipment failure, of the navigation system, the communications link or the receiving equipment would result in a complete loss of the firefighters information.

The current state of inertial navigation technology would not be sufficiently accurate for Fire Service needs. Large amounts of time and money would be needed to produce a working system. If inertial navigation were to be considered for the fire service, it would more likely be as an addition to guideline procedures than as a replacement for them.

Many of the guideline alternatives will mark a path that has been searched, but allow the possibility of straying from that path. In particular, the failure of a single marker, for example an IR beacon or RFID tag, can be overcome by searching for the next marker. However, in this way an entirely new path, that has not been searched, may be used. This failure of a marker is not an unlikely event, since they may fall, be hidden or cease to function and so this aspect of high technology alternatives could cause great concern.

If a firefighter needs to be rescued from a building, a system with no physical contact between guideline and firefighter will reduce their chances of a speedy rescue.

8. CONCLUSIONS

The initial intention of this project was to establish the physical and economic feasibility of replacing traditional rope guidelines with a system making use of high technology. As each area of high technology was investigated the advantages and drawbacks of a system using that technology became apparent. For some areas the drawbacks were such that the idea was not pursued further, for others, avenues for further investigation are possible - if it was considered desirable to pursue that course. For example, the use of TI cameras could be included in current guideline procedures; the progress of inertial navigation systems could be monitored, as could RFID and IR technologies.

In making decisions about continuing an investigation into any technology, the current state of the art of that technology should be considered. Some technologies that could potentially be of benefit to the fire service are at an early stage of development. A great deal of investment would be required before it was clear whether they might work.

During the course of this investigation, no applications of high technology that were directly applicable to guidelines were encountered.

The capital costs of some of the guideline systems were included. It was felt that a higher cost, with increased maintenance costs could be accepted if the improvements warranted it. The broad estimates of costs varied between being slightly higher than a standard guideline to being very expensive (but possibly having applications in different areas e.g. TI cameras).

Because guideline procedures are slow and quite involved, they are infrequently used. However, the system itself has a lot to recommend it: the line is light, flexible, low-cost and easily replaced. Physical contact with the line provides security for a disorientated firefighter. For any high technology system to replace rope guidelines there must be positive advantages to the new system.

After studying the high technology options described in this report, no area of high technology has been found that could offer a fundamentally new system with significant improvements on the current system.

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