12
Protective clothing for firefighters and rescue workers

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Abstract: With the emergence of smart textiles, research into developing more sophisticated equipment and garments for firefighters and rescue workers has evolved. The European Commission has invested in establishing a platform of new technologies to actively monitor operators during their work. This has resulted in several research projects of which the PROeTEX project was the first and this is extensively described in this chapter. Other textile-related research projects to enhance the safety of firefighters are included in this chapter. The result of all this research will be integrated into the protective clothing market in the coming years.

Keywords: smart textiles, wearable sensors, protective clothing for firefighters, PROeTEX.

12.1 Introduction

The main purpose of clothing is to protect the human body against environmental conditions such as rain and cold or sun. So all clothing has a protective function to some extent. For professional workers, however clothing contributes to their personal health and safety as it protects them from the hazardous environment in which they operate. According to the European Standard, EN 340, protective clothing is 'clothing including protectors which cover or replace personal clothing, and which is designed to provide protection against one or more hazards', a hazard being 'a situation which can be the cause of harm or damage to the health of the human body'.

There are many occupations that require specific activities and thus various types and levels of protection. Occupational exposure of the skin to toxic chemicals, for example, will be prevented by wearing appropriate chemical protective clothing; micro-organisms are stopped by protective clothing against biohazards; and firefighters are protected from heat by wearing thermal protective clothing.

Continuous, intensive research and development in the area of personal protective equipment (PPE) has led to considerable improvements over the last few decades. Scientific developments, such as the introduction of high-performance fibres in the 1960s, have thoroughly changed and improved the level of protection. The biggest revolution for firefighter protection was the use of flame-retardant polymer fibres such as the aromatic polyamides (aramids) and polybenzimidazole (PBI). Meta-aramids (e.g. Nomex by DuPont) and para-aramids (e.g. Kevlar by DuPont, and Technora and Twaron by Teijin) are nowadays widely used fibres. Meta-aramids are known for their good thermal tolerance and long-time stability at high temperatures, and are therefore broadly applied in thermal protective clothing. Para-aramids, on the other hand, are valued for their high tenacity, high modulus and also have good thermal stability at high temperatures, making them suitable for ballistic applications. The introduction of these lightweight fibres has not only increased the level of protection but also the level of (thermal) comfort.

Next to introducing new high-performance fibres, the level of protection can be increased by changing clothing structure, e.g. by using multi-layered fabrics. Firefighter outer garments and trousers consist of an assembly of three layers: flame retardant fabrics are used as an *outer shell* material for the outer garment and the trousers; underneath there is a *vapour barrier* and an *inner thermal barrier*. Firefighter clothes are designed to protect the wearer against heat and flames in the first place, but also against moisture and to some degree against mechanical hazards such as cuts and abrasion.

All these functionalities can be considered as passive methods of protection. But the emergence of new materials and technologies, such as smart textiles and wearable electronics, opens possibilities to further increase the level of protection, this time in an active way. They can be enabled by integrating sensors into the garment for monitoring the firefighter and his close environment, and by setting up a real-time communication with a command post to monitor possible health or other threats.

This chapter mainly describes the work that has been done to merge textiles and electronics into a garment for firefighters and rescue workers within the framework of the European project PROeTEX. Other European projects deal with enhancing the safety of firefighters and their goals are briefly described in what follows. Finally, two commercially available sensorised firefighter garments are described. Also a simulation of the firefighter market for sensorised garments is given.

12.2 The Protection e-Textiles (PROeTEX) project

The perception of a new generation of PPE for firefighters and for rescue workers was framed in the European Integrated Project PROeTEX (Protection e-Textiles): Micro/nano-structured fibre systems for emergency disaster wear. Research into smart textiles and wearable electronics will play a key role in these developments. So far, the main focus of smart textiles had been in the medical field, for monitoring physiological parameters such as heart and respiration rate in a continuous way and on a daily basis. However, the potential of smart textiles has been further exploited in the field of protective clothing, and PROeTEX was one of the first projects of its kind. The project started in February 2006 and lasted 4 and a half years, until July 2010. The expertise of 23 partners from eight different countries was brought together to achieve the objectives of the project (see Table 12.1). Partners were universities, research institutes, industry and organisations operating in the field of emergency management.

An incremental set of prototype garments was built and tested during the 4 and a half years. A first set of prototypes was ready in July 2007, a second set in December 2008, and a third set in April 2010. Each of the three sets was tested either on a laboratory scale or in field tests.

Apart from developing a successive set of prototypes, also different types of garments were targeted, not only for the rescue workers involved in an

Table 12.1 The PROeTEX project partners

	Partner	Acronym	Country
1	National Institute of Physics of Matter	INFM	Italy
2	Technical University of Lodz	UniLodz	Poland
3	Ghent University	UGent	Belgium
4	Smartex S.r.l.	Smartex	Italy
5	Milior S.p.a.	Milior	Italy
6	Sofileta	Sofileta	France
7	Thuasne France	Thuasne	France
8	University of Pisa	UniPi	Italy
9	Dublin City University	DCU	Ireland
10	Commissariat a l'Energie Atomique	CEA	France
11	Centre Suisse de Electronique et de Microtechnique SA	CSEM	Switzerland
12	Sensor Technology & Device Ltd	STD	UK
13	Steiger	Steiger	Switzerland
14	Philips Research	Philips	Germany
15	Ciba Specialty Chemicals	CIBA	Switzerland
16	Diadora/Invicta Group	Diadora	Italy
17	iXscient Ltd	iXscient	UK
18	Zarlink Semiconductor	Zarlink	UK
19	Brunet-Lion	Brunet	France
20	Brigade de Sapeurs-Pompiers Paris	BSPP	France
21	INSA-Lyon-CNRS	INSA	France
22	EUCENTRE Italian Civil Protection	EUCENTRE	Italy
23	Dept de la Defense et de a Securité Civile	DDSC	France

operation but also for possible victims of an incident. The project involved the development of three types of garments:

- garments for firefighters (urban and forest),
- garments for civil protection rescuers,
- garments for victims (a patch).

The sensorised garments were a combination of available technologies and newly developed textile-based components.

The uniform for the firefighter comprised an outer jacket, an inner jacket and boots. The development was done in close collaboration with the project partner BSPP (Brigade de Sapeurs-Pompiers de Paris, France). EUCentre Italian Civil Protection and DDSC (Dept de la Defense et de la Sécurité Civile, France) were involved in the development of garments for civil protection rescue workers.

12.2.1 The needs of PROeTEX end-users

The PROeTEX project started with interviewing the end-users involved in the project, coordinators from the Italian and French civil protection agencies and managers of the Brigade de Sapeurs-Pompiers de Paris to determine the needs of the firefighters in terms of enhanced safety. Five scenarios in which intervention is critical were hypothesised as follows:

- three for civil protection intervention: violent earthquake and volcano activity in a highly populated area, heavy rain or flooding, and earthquake in a mountain area during winter;
- one for urban firefighter intervention: a large industrial fire;
- one for forest firefighter activity: wild-land fire near populated areas.

The needs could be mainly categorised into two areas, depending on the type of rescue worker:

- monitoring of health status of the wearer and of hazards in the environment;
- localisation of rescue workers when working on an extensive area.

Civil protection workers mainly need to locate all rescue workers when operating in large numbers in a spacious area. The same functionality is important for forest firefighters. In addition, health monitoring is of interest to all firefighters. One of the known types of health failure for firefighters is heat stress. It is caused by the many layers of textiles in their garments. They give the firefighter a very good level of protection; however, they hinder heat dissipation from his body and limit the evaporation of sweat. Actually, the jacket works as a thermal barrier in two ways: from outside to inside but also from inside to outside (Havenith, 1999). When the body is overheated, a condition of heat stress can occur, which reduces mental performance and slows down the reaction and decision time of the person. The danger can be minimised by measuring some body- and environment-related parameters:

- heart rate, respiration rate, body temperature, etc. from the wearer;
- toxic gases such as CO and CO_2, outside temperature, heat flux through the garment, etc. from the environment.

12.2.2 The PROeTEX integrated system

Nowadays, a typical firefighter uniform comprises a helmet, an outer garment, gloves, trousers and boots. PROeTEX focussed on integrating the major part of the system in only one part of the uniform, the most suitable candidate being the outer jacket. Most of the components of the integrated system can be located there. However, to measure the presence of some toxic gases such as CO_2, the sensor needs to be near to the ground; therefore, some components were integrated into the boots. On the other hand, to measure some physiological data such as heart rate, respiration rate and body temperature, it is obvious that a close contact with the skin is required. For this reason, it was soon clear that the PROeTEX uniform should include an inner garment, next to an outer garment and a pair of boots.

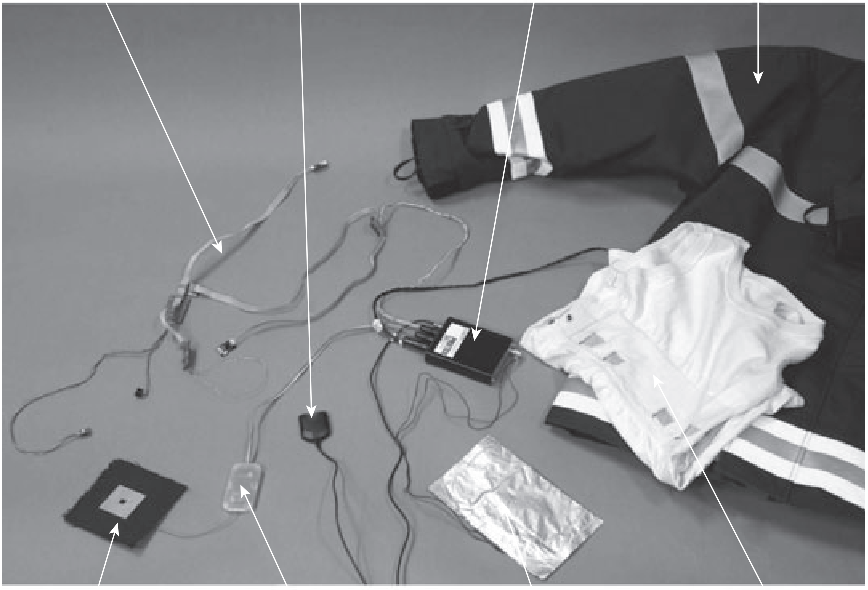
In most cases, a T-shirt or some kind of inner garment is not part of the uniform of a firefighter. However, BSPP; being part of the French military makes an exception: their uniform includes a cotton T-shirt. This means that for these firefighters, the inner garment of the PROeTEX uniform was not an unusual extra piece of uniform.

The outer garment of a firefighter is typically made out of several layers of textiles with distinct functionalities:

- the outer shell is the first level of protection for the firefighter and needs to give flame, thermal and even mechanical resistance;
- a moisture barrier is meant to keep the firefighter dry, or at least to protect him from water or from other liquids approaching him from the outside;
- the thermal liner prevents the transfer of heat from the environment to the body.

In order not to perforate the different layers, all components of the PROeTEX system were integrated between the second and the third layer of this assembly. In this way, the electronics are also protected by the moisture barrier from water coming from the environment.

The first set of prototype uniforms (Fig. 12.1) were delivered 18 months after the start of the project. They were based mainly on commercially



12.1 The first PROeTEXfirefighter prototype with all its sensors and components.

available components, completed with technologies already developed by the project partners in former projects and some new components that had been developed during the first project period.

During the following months, the uniforms were comprehensively tested both in laboratory and in field conditions organised in the specific training centres such as the Firefighter training centre of Paris in St Denis, France, for the urban fire scenario and in the Research Centre of the French Civil Protection (CEREN) in Gardanne, France for the forest fire scenario. The latter was done by the end-users themselves, the Italian and French civil protection and the firefighter department of Paris BSPP. The tests are fully described in Curone *et al*. (2008). The outcomes of the tests were used to improve the second set of uniforms that were delivered at the end of 2008. Again, the system was validated from a technological point of view and from a usability point of view by the researchers and by the end users (Curone *et al*., 2010). Improvements and adaptations were done and led to a third and final set of prototype uniforms, which were delivered in April 2010.The last months of the projects were dedicated to their testing, both in laboratories and in simulated firefighter scenarios (Magenes *et al*., 2010). (Fig. 12.2)

12.2 During field testing of the PROeTEXfirefighter prototypes.

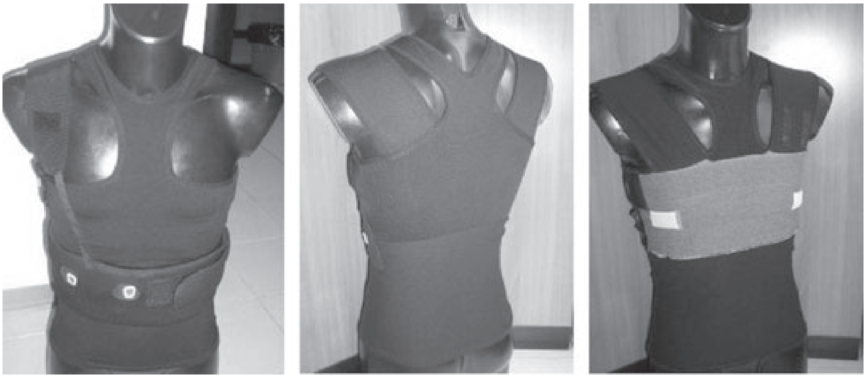
A more detailed description of the PROeTEX garments and their integrated components is given in the following section.

The inner garment

The inner garment (IG) (Fig. 12.3) incorporates the physiological sensors that are needed to monitor the health status of the wearer. To do so, a close contact with the skin is essential. In order to achieve this, the region around the torso is manufactured in a highly elastic material. The close contact with the skin also means that attention needs to be given to the sensation of comfort because this will be a key factor in the acceptance of wearing the system. The first T-shirt was based on cotton; however, to increase the protection level, a blended yarn of aramid and cotton was the basis for the following prototypes (Fig. 12.4). The first shirt comprised sensors for heart rate, respiration rate and body temperature but, during the project, additional sensors were developed and integrated into the garment. They are listed in Table 12.2.

The *heart rate (HR) electrodes* are textile electrodes based on electroconductive stainless steel yarn that is knitted into the inner garment by using

12.3 The first PROeTEX inner garment with: I1 – textile electrode for measuring heart rate; I2 – piezoresistive sensor for measuring breathing rate; I3 – thermocouple for measuring body temperature.



(a) (b) (c)

12.4 Examples of prototypes of the inner garments for Italian and French civil protection employees.

Table 12.2 Components in the inner garment for the three successive prototypes

First	Second	Third
Cotton-based T-shirt	Aramid-based T-shirt	Aramid-based T-shirt
Heart rate electrode	Heart rate electrode	Heart rate electrode
Breathing rate sensor (piezoresistive)	Breathing rate sensor (piezoresistive and piezoelectric)	Breathing rate sensor (piezoresistive and piezoelectric)
Body temperature sensor	Body temperature sensor	Body temperature sensor
	SpO_2 sensor	SpO_2 sensor
		Dehydration detector
	Vital signs board (VSB)	VSB
	Wired (bus) connection between VSB and Personal Electronic Box (PEB)	Wireless connection between VSB and PEB

a tubular intarsia technique. The electrodes are knitted double face and the outer part of the electrode does not contain electroconductive yarn so that it is insulated from the environment. These two knitted layers do not touch, so they create a kind of pocket. The insulating side of the electrode is made out of a blended yarn: 50% meta-aramid Nomex® from DuPont and 50% flame-retardant viscose. To maximise the contact between the electrode and the skin, a hydrogel membrane was used in the first prototype (Loriga *et al.*, 2005). For the next prototypes, the electrode fabrication method was improved and a Neoprene filler was inserted into the aforementioned pocket to guarantee a good contact with the skin without using the hydrogel.

The *breathing rate (BR) sensor* is based on two different technologies. The first one is a *piezoresistive* textile sensor, positioned around the chest and integrated into the inner garment. Slight variations in length and shape because of thoracic and abdominal circumference changes during breathing alter the resistance of the sensor (Pacelli *et al.*, 2006). The second approach assures a more reliable breathing signal because it is based on *a piezoelectric transducer* in wire form. In the third set of prototypes, this piezoelectric polyvinylidene fluoride (PVDF) sensor was integrated, together with the electronics, as *the Vital Signs Board (VSB)* in a detachable belt (Fig. 12.5) that is carried around the chest. It easily opens and closes with a Velcro strip and it has an adjustable strip over one shoulder. In this elastic sensing region, *the interconnections* between the sensors and the electronics have been achieved with two specially designed elastic conductive yarns, integrated during the knitting process. The elasticity is obtained through an elastic core material (Lycra®) and the conductivity comes from a stainless

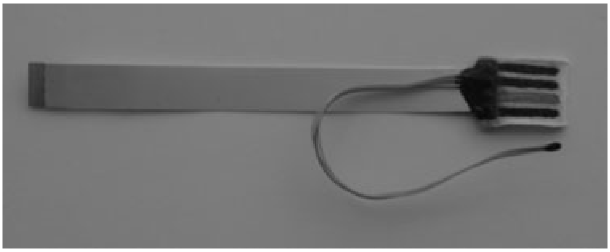
12.5 Belt with piezoelectric sensor and vital signs board (VSB), wirelessly connected to the Personal Electronic Box (PEB).

steel monofilament that is twisted around the core. Electrical insulation is obtained by covering the yarns with polyester.

The *skin temperature* is measured with a commercially available thermocouple (LM92, by National Semiconductor) placed at the armpit. Different packaging has been tried to minimise the interference with the environmental temperature. Good skin contact is ensured by the elastic belt.

The *dehydration sensor* measures the sodium concentration in sweat. During an intervention, the emergency personnel can be exposed to extreme physical action, with dehydration as an important consequence. An abnormal loss of sodium in the sweat can lead to a hypo- or hyper-natremia. To be wearable and integratable into the inner garment, a textile-based electrochemical sensor (Fig. 12.6) was developed. A metallic coating was chemically deposited on a 95/5% cotton/elastane fabric. The electrochemical cell is made of four electrodes of which three are working electrodes and one is a reference electrode. The cell is coupled to a temperature sensor to enhance the reliability because electrochemical measurements are temperature dependent.

The working electrodes carry a host molecule which is able to selectively trap Na^+ ions. This functionalised electrode is an Ionic Selective Electrode.



12.6 Electrochemical cell made of three working electrodes and one reference electrode. The temperature probe is attached to it.

The electrochemical cell is connected to a portable electronic board which drives the sensing part and achieves the signal processing to convert the electrical information into sodium ion concentration (Marchand *et al.*, 2009).

The SpO_2 sensor measures the amount of oxygen carried by blood cells in the arterial blood. To do this, a non-invasive technique involving pulse oximetry (i.e. SpO_2) is used. Commonly, this technique requires the use of an optical sensor placed around the fingertip of the patient. CSEM have developed a reflectance pulse oximeter that can be placed at body locations such as the breastbone. This allows integration of the sensor into the inner garment. The sensor is an optical transducer based on controlled-source electromagnetics technology. A unit with several pairs of optical emitters and receivers is integrated at the breastbone level of the inner garment. There, a processor selects the best signals and stores the values in a memory.

During the project, the architecture of the inner garment evolved, in terms of materials and in terms of design. Finally, two different inner garments were developed,

The outer garment

The outer garment (OG) comprises a different set of sensors and other electronic components (Table 12.3).

The system is entirely integrated under the moisture barrier of the garment. As such, all components are also protected against liquids from the environment. Because the different components are interconnected with electroconductive wires, all components are fixed between the same fabric layers so that the fabrics do not need to be perforated.

A modified platinum sensor array is integrated into the outer garment to simultaneously monitor the *environmental temperature* and the *heat flux* through the jacket. The sensors used are Pt1000 platinum resistors (temperature sensors to the Pt 1000 Ω standard from Atexis), which have a

Table 12.3 Components in the outer garment for the three successive prototypes

First	Second	Third
External temperature sensor	External temperature sensor	External temperature sensor
	CO sensor	CO sensor
	Heat flux sensor	Heat flux sensor
GPS module	GPS module	GPS module
	Visual alarm	Visual alarm
	Acoustic alarm	Acoustic alarm
Accelerometers (in collar and wrist)	Accelerometers (in collar and wrist)	Accelerometers (in collar and wrist)
	Motion sensor (textile)	Motion sensor (textile)
	ZigBee module	ZigBee module
Personal Electronic Box (PEB)	PEB	PEB
Textile antenna, one	Textile antenna, one	Textile antenna, two

positive temperature coefficient, i.e. the resistance value increases when the temperature rises (Oliveira *et al.*, 2010).

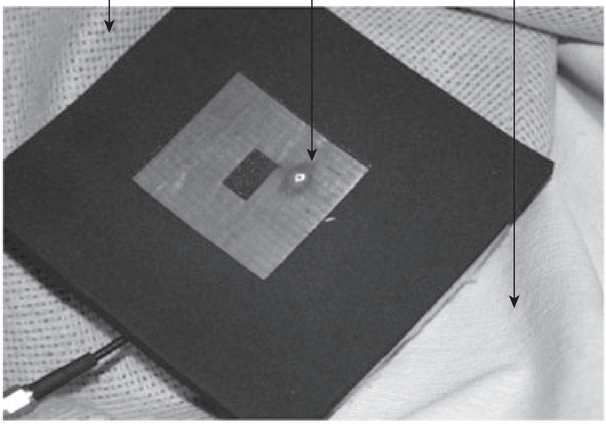
A heat flux sensor gives information about how heat propagates from the environment through the garment. When heat escapes from the body, a positive heat flux is measured. This is the normal situation. The human body removes over-production of metabolic heat to avoid an increase of the internal temperature. Consequently, a negative heat flux means that heat is entering the body from the environment. This results in an increase of the core temperature. An increase of 1.5 °C in relation to the core temperature of the firefighter at the beginning of the intervention, triggers an order to leave the fire (Oliveira *et al.*, 2009).

The *user's activity* is measured by means of two tri-axial accelerometers, one of which is placed in the collar of the jacket and the other in the left sleeve. Different activities, such as standing, walking or running, can be distinguished. An alarm is generated when the firefighter is 'down'.

The *GPS module* is meant to be able to locate the rescue worker in an outdoor environment such as a forest. It does not function when the rescuers approach high buildings or other kinds of dense obstacles such as thick vegetation in a forest.

The electronic heart of the system is *the professional electronic box (PEB)*, which collects the data from all the sensors both in the IG and in the OG.

A *planar textile-based antenna* (Fig. 12.7) is connected to a Bluetooth module and transmits the data collected by the PEB to a remote monitoring station. The first prototype incorporated only one antenna, which was in the front of the garment; however, to ensure optimal data communication, a



12.7 Textile antenna integrated between the moisture barrier and the liner.

second antenna was later added in the back of the garment. The antenna operates in the 2.45 GHz ISM band and is a microstrip patch antenna (Hertleer *et al.*, 2009). The size of the antenna patch is about 5 cm by 5 cm and it is made of an electroconductive material, which can be a textile or a printed surface (screen printed with silver-based electroconductive ink). Several substrate materials were explored during the project, but flexible foam seemed to be most suited. Bending the antenna, and the presence of the human body or of moisture had no adverse effects on the antenna characteristics (Hertleer *et al.*, 2010).

The prototypes were equipped with a lithium ion-polymer *battery* which was effective for up to 7 hours to power the garment's electronics. Within the project, CEA developed and delivered flexible textile compatible batteries that were able to power all electronic devices embedded in the firefighter outer garment during a period of two hours, with a maximum useful capacity of about 900 mAh for 360 cm^2 surface.

The *visual and acoustic alarms* integrated into the garment are to warn the wearer if something goes wrong.

The boots

The boots have been manufactured by one of the project partners. In the final arrangement they comprise two types of sensors (Table 12.4): to measure the presence of toxic gases, such as CO_2, that are heavier than air

Table 12.4 Components in the boots for the three successive prototypes

First	Second	Third
CO_2 sensor	CO_2 sensor ZigBee module housing	CO_2 sensor ZigBee module housing

and are found near the ground, and to measure the activity of the wearer. The module is based on a CO_2-D_1 Alphasense sensor, together with a processor for data acquisition and processing, and a ZigBee module to communicate wirelessly with the PEB in the outer garment.

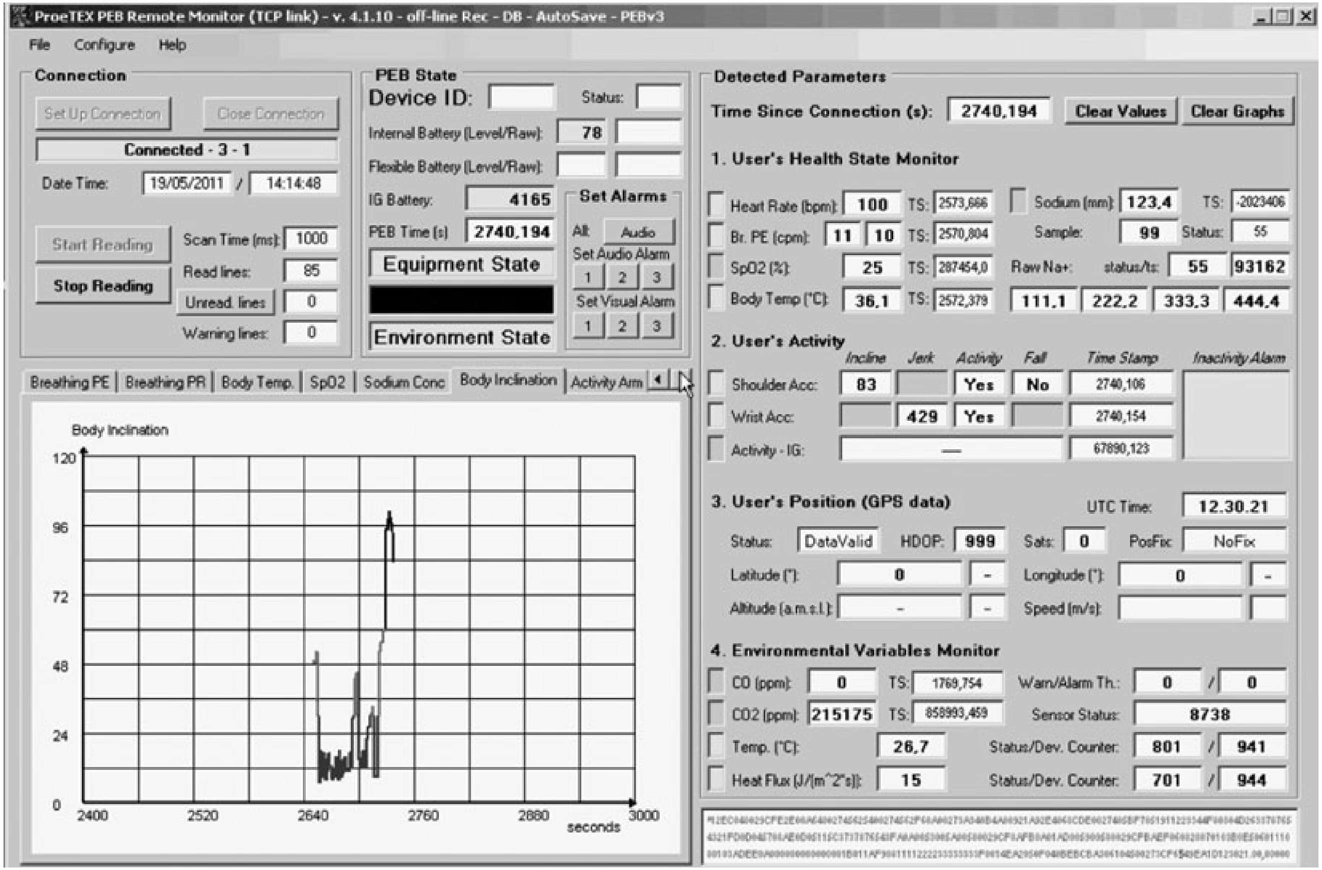
The PROeTEX monitoring software

The data recorded by the sensors in the wearable system are transmitted through a long-range communication system (Magenes *et al.*, 2009) to a computer in the command post. The monitoring software produces a visual representation of the data measured by the PEB, as shown in Fig. 12.8. A colour code red draws attention to things that are going wrong. Detailed information is given in four groups: about the user's health status, about the user's activity, about the user's position and about the environment. For each of the group of sensor data, a graph shows how the values change over time. In Fig. 12.8, the body inclination is in a dangerous zone, meaning that the firefighter might be lying down. The 'User State' flashes red to get the attention of the commander.

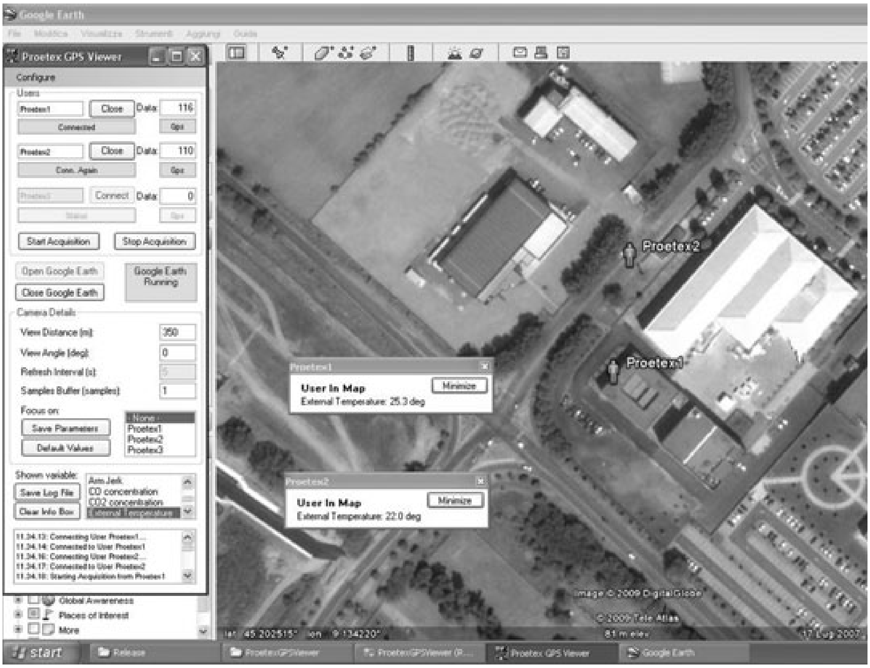
The position of the PROeTEX firefighter is visualised on a graphic interface based on Google Earth software and is shown in Fig. 12.9. A small icon follows the track of the wearer as he moves around the disaster area.

The victim patch

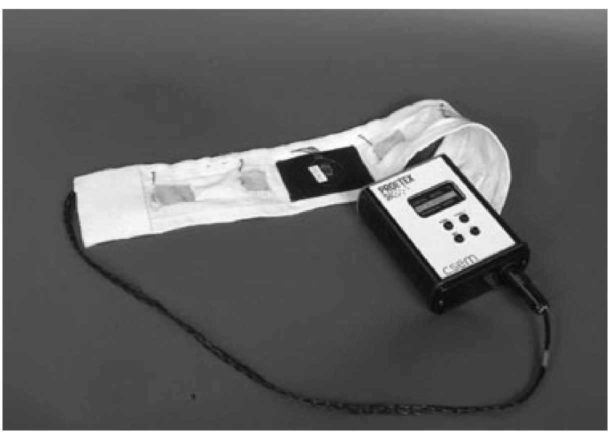
In addition to monitoring the health status of rescue personnel, victims should be monitored. Therefore, a victim patch (Fig. 12.10) has been developed within the PROeTEX project, using the same technologies but integrated in a different way. The victim patch is a textile belt that can easily be put around the chest of a victim to monitor vital signs. Therefore, it contains sensors to measure heart rate, breathing rate and body temperature. The sensors that are used here are the same as those of the firefighter inner garment. A dedicated *victim electronic box (VEB)* processes the sensor's data and transmits them to the monitoring station by means of an integrated Bluetooth module.



12.8 Window of monitoring software providing information on the status of the wearer and his environment; data provided by the sensors.



12.9 Window of monitoring software showing the position of the wearer.



12.10 Textile victim patch with VEB.

12.3 Other firefighter-related European projects

12.3.1 I-Protect

The I-Protect project (EU FP7-NMP Project I-Protect, 2009–2013) for PPE was launched on 1st October 2009. It ends in November 2013. The PPE will ensure active protection and provision of useful information. It is most applicable to high-risk and complex environments such as firefighting, mining and chemical operations. The main risks include explosions, high temperatures, dangerous chemicals released, smoke, dust, high humidity and limitation of breathable fresh air. The project aims at integrating advanced materials with sensors for real-time monitoring of exposure to risk in the surroundings e.g. temperatures, gas and oxygen levels. The sensors will also measure changes in protection aspects, such as air pressure in compressed units. Materials used for the sensors will be optical fibres and micro-sensors, integrated with textiles. Carbon nanotubes will be incorporated into materials for functionalisation and achieving aspects such as conductivity of the material.

Partners

There are a total of 16 partners involved in this project (Table 12.5), with about seven institutions, the rest being either industries or a network of industries having a common interest.

Table 12.5 I-Protect partners

	Partner	Country
1	Institute of Biomechanica Valencia	Spain
2	Central Institute for Labour Protection	Poland
3	Finnish Institute of Occupational Health	Finland
4	Institute of Mining Technology	Poland
5	Federal Institute for Materials Research and Testing	Germany
6	Centralna Stacja Ratownictwa Górniczego S.A	Poland
7	NeoVision Sławomir Zwolenik	Poland
8	Fundacion LEILA	Spain
9	Gruppo Colorobbia	Italy
10	Sperian Respiratory Protection	France
11	German Fire Protection Association	Germany
12	Safibra	Czech Republic
13	Orneule Company	Finland
14	Aero Sekur	UK, Italy
15	Coalesenses Gmbh	Germany
16	Orlene Company	Poland

Project expected results

The results of the project are to address the safety of firefighters, miners and rescue squads. Special sensors will be developed and combined with a wireless system for detection and communicating on hazardous gases and temperature changes during rescue operations. Both physiological and working environment parameters will be transmitted via a dedicated wireless system to the rescue coordination centre in order to allow the supervision of the rescue activities and health of different members of the rescue team. Utilising nanomaterials will allow the development of sensors that will measure the amount of toxic gas in the environment.

12.3.2 ProFiTex

The project ProFiTex started on 1st October 2009 and has a duration of 36 months (EU FP7-NMP Project ProFiTex 2009–2012).This project also deals with improving the safety of the firefighters. The approach of the project is based on professional user (firefighter) involvement in designing and evaluating the safety of their equipment. The design will be adopted from the European wearIT@work project (EU FP6-IST Project wearIT@work, 2004–2008) and improved further by creating innovative systems for data transmission and tactical navigation. This will enhance the communication between the firefighters' front line, their group leaders and the commander hierarchy.

Prototype

The ProFiTex system to be developed comprises two main components: a fire fighting jacket with integrated sensors, electronics, and a *'Smart LifeLine'*, which is a braided rope with a double function: as a security rope and as a medium to transmit data and energy. Inside the *Smart LifeLine,* several beacons will be embedded. These beacons enable the navigation of the firefighters in smoky environments and the exchange of information with the group commander. One firefighter is physically connected to the rope; he also wears an infrared camera on his helmet. The other firefighters wear electronics that can pick up the signals emitted by the beacons. A helmet-mounted display shows the firefighter where the beacons are and thus the way back, out of the fire. The navigation system has been tested successfully at a workshop in December 2010, where professional firefighters were deployed.

The ProFiTex system comprises electronic devices such as localisation sensors, communication devices and a human–computer interface device integrated into the firefighters' jackets. Since wireless communication is

Table 12.6 Project ProFiTex partners

	Partners	Country
1	Active Photonics AG, visualisierungs-kommunikationssysteme	Austria
2	D'Appolonia S.p.A.	Italy
3	Texport Funktionsbekleidung GmbH	Austria
4	Centro Tecnológico Leitat (Lei), Leitat	Spain
5	The Fraunhofer Institute for Applied Information Technology	Germany
6	Sabine Gross (Heat)	Germany
7	LABOR S.r.l. (Lab)	Italy
8	RWTH Aachen University	Germany
9	The Swiss Federal Institute of Technology, Zurich	Switzerland
10	TexClubTec	Italy
11	Vienna University of Technology	Austria

difficult over long distances and through several walls of a building, an innovative method to transmit information will be applied.

Partners

There are a total of 11 partners, comprising 3 industries and 8 institutions, (Table 12.6).

12.3.3 Safeprotex

The project started on 1st April 2010 and it is to run for 42 months, up to October 2013 (EU FP7 NMP Project Safeprotex, 2010–2013). The Safeprotex project is concerned with research on highly protective clothing worn during complex operations. The main idea of the project is to address the problems that current protective garments are facing – such as new risks, due to advances in technology and climate change – by innovative solutions. The Safeprotex clothing is designed for rescue teams and emergency operators.

The scope of the research is limited to three areas:

- emergency operations under extreme weather conditions (e.g. floods, hail),
- operations under the risk of wild land fires,
- first aid medical personnel potentially exposed to any type of risk.

Partners

There are 18 participants (Table 12.7) in this project.

Table 12.7 Project Safeprotex partners

	Partners	Country
1	Clothing Textile and Fibres Technological Development SA	Greece
2	Inotex S.R.O., DVUR Kralove Nad Labem	Czech Republic
3	SARL SCIC Rescoll	France
4	TDV Industries	France
5	De Montfort University Textile Engineering and Materials (Team) Research Group	United Kingdom
6	TUT – Tampere University of Technology	Finland
7	Fundacion Gaiker	Spain
8	Swerea Ivf Ab	Sweden
9	Next Technology Tecnotessile Societa Nazionale Di Ricerca R.L.	Italy
10	Acondicionamiento Tarrasense Leitat	Spain
11	Lenzi Egisto S.P.A.	Italy
12	VUCHV – Vyskumny Ustav Chemickych Vlakien, A.S.	Slovak Republic
13	Calsta Workwear SA	Greece
14	Nanothinx SA – Research and Development of Carbon Nanotubes S.A.	Greece
15	Suministros Irunako, S.C.	Spain
16	Fundacio Privada Cetemmsa	Spain
17	ONGD SAR Espana	Spain

Expected project outputs

The goal of Safeprotex is to develop highly effective PPE for people who operate under complex emergency situations. The garments aim to provide protection against multiple hazards, present extended useful lifetime and ensure physiological comfort of the wearer. The research will take a bottom up approach, where possibilities of developing new fibres with different functionalities are investigated. Among these are bicomponent fibres, chitosan fibres, and fibres that incorporate multiwall carbon nanotubes (MWCNTs). The project will look into the entire value chain (spinning, weaving, surface treatment technologies and design), up to the prototyping of the actual protective uniforms. The approach will be based on user requirements. Other established safety level requirements are against foul weather conditions, microbial contamination, and protection against low temperatures, poor visibility, mechanical instability and chemical attack.

12.3.4 Prospie

This project was launched in September 2009 and it is to run for three years. The Prospie project aims at improving the comfort of firefighters by

Table 12.8 Project Prospie partners

	Partner	Country
1	Bel-confect	Belgium
2	Capzo	Netherlands
3	D'Appolonia	Italy
4	Empa – Eidgenössische Materialprüfungs- und Forschungsanstalt	Switzerland
5	ErgonSim	Germany
6	Foritas	Lithuania
7	Humanikin	Switzerland
8	HVC – Henk Vanhoutte Consulting	Belgium
9	ICOP	Italy
10	ifak system	Germany
11	LU – Loughborough University	UK
12	LTI – Lithuanian Textile Institute	Lithuania
13	Merford Cabins	Netherlands
14	Pakaita JSC	Lithuania
15	Palemonokeramika	Lithuania
16	TNO	Netherlands

absorbing or removing the excess heat that the firefighter is exposed to. This will enable him or her to work longer wearing protective clothing, feeling less discomfort. In addition to sensors in the PPE that will alert the worker, innovative cooling methods will be investigated (cooling salts, phase-change materials and ventilation cooling). These will be incorporated into the PPE.

Prospie aims at developing an improved PPE, disseminating the results to standardisation organisations, industry and public procurement organisations. It also aims at developing a training programme for SMEs and end-users for acceptability of the system.

Partners

This project involves 16 partners (Table 12.8) located within European countries.

Prototype

The Prospie system demonstrator, Protective Responsive Outer Shell for People in Industrial Environments and Multi-Layer Sensor Array, is provided by ifak system GmbH (http://www.youtube.com/watch?v=syBXs51aEic).

12.4 Simulation of the firefighter market

Within the European Coordination Action project Systex (EU FP7 ICT Project Systex 2008–2011), a simulation tool was developed to estimate the value of market growth. The firefighter market was selected to work with because it is a mature market. The total market value is determined by:

- the number of potential users,
- the fraction of those users actually buying the product,
- the price of the product.

The models start from estimates of the above mentioned factors, as well as their expected evolution in time.

For the firefighter market, a distinction has to be made between large fire brigades operating in cities (mainly professionals) and small brigades operating in rural areas (usually volunteers). The bigger brigades replace their equipment more often (every five years) and are able to afford more high-tech suits. This is in contrast to the equipment of volunteers, which serves considerably longer; up to 10 years or even more.

In Europe there are:

- 385 000 professional firefighters,
- 2 200 000 volunteers.

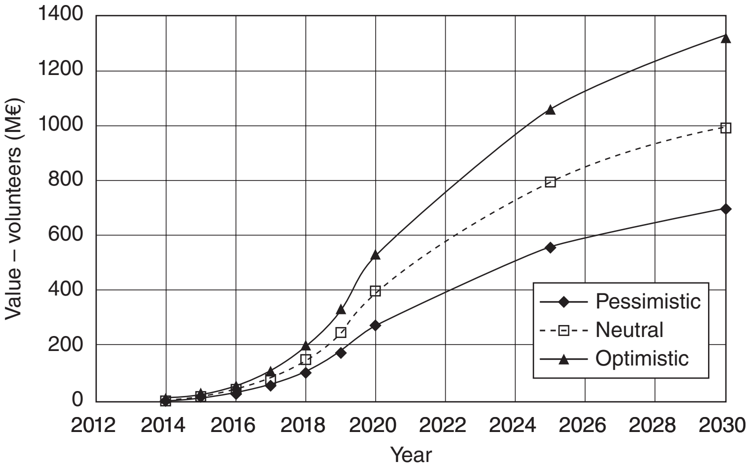
These numbers are not expected to change significantly over the next few years. So the market is mature. The price of a high-tech suit is thought to be €1000. A 'lighter' version with some basic functions, such as heart and respiration rate sensors and a basic alarm function, could have a lower price of *ca*. €600. The price will slowly decrease because of the scale factor. On the other hand the decrease will be limited because the level of complexity and intelligence will increase.

Simulations have been made for forecasting the market value for smart firefighter suits. They take into account the number of firefighters and the fraction wearing the smart suit as well as price evolution. The simulation for the market evolution in Europe for PPE for volunteer firefighters is shown in Fig.12.11 and that for professionals in Fig. 12.12. The graphs show three lines: one considering a pessimistic, one a neutral and one an optimistic scenario.

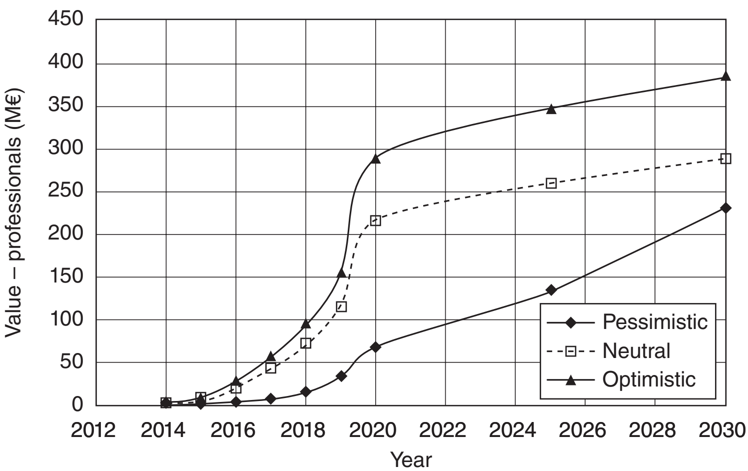
The conclusion of these simplified simulations is that, in spite of the lower price of the product and the lower replace rate, the total market value is considerably higher for volunteers.

12.5 The Viking fire protection suit with built-in thermal sensor technology

The Danish company Viking has introduced a suit with in-built thermal sensor technology (TST) (Fig. 12.13). 'Integrated thermal sensors in the inner and outer layers of the coat monitor heat near the fire-fighter, as well as inside the coat close to the body. Sensors are attached via a conductive ribbon to LED displays on the sleeve and back of the left shoulder. The

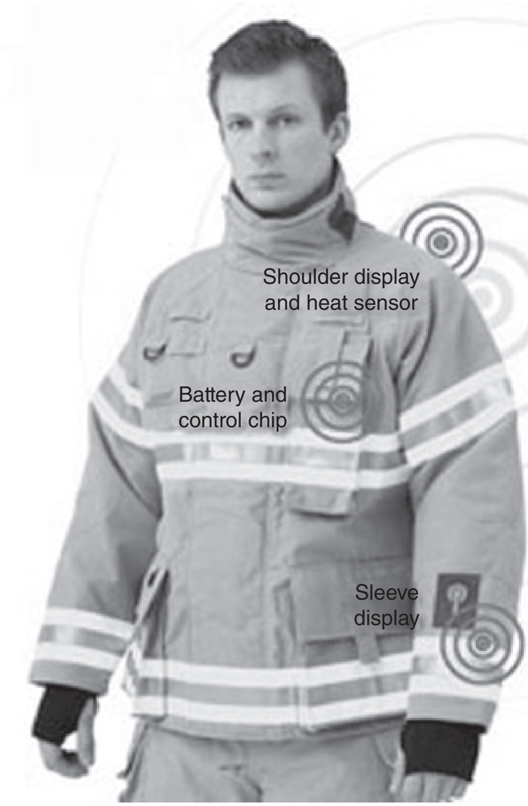


12.11 Market evolution in Europe for PPE for volunteer firefighters.



12.12 Market evolution in Europe for PPE for professional firefighters.

shoulder LED display is visible to other fire-fighters, indicating to them potentially dangerous situations. The LED on the lower sleeve indicates elevated heat levels both inside and outside their fire suit. As an indication, the display's outer circle flashes slowly when external temperatures reach about 250 °C. Indicating the precious seconds between safety and injury, at 350 °C, it flashes rapidly. When the temperature inside the garment reaches about 50 °C, the long line on the display flashes slowly. At 68 °C it flashes rapidly. A small box in the inner liner of the coat contains a battery and an innovative control chip that calculates temperature and activates the LED



12.13 Viking firefighter suit with built-in thermal sensor technology.

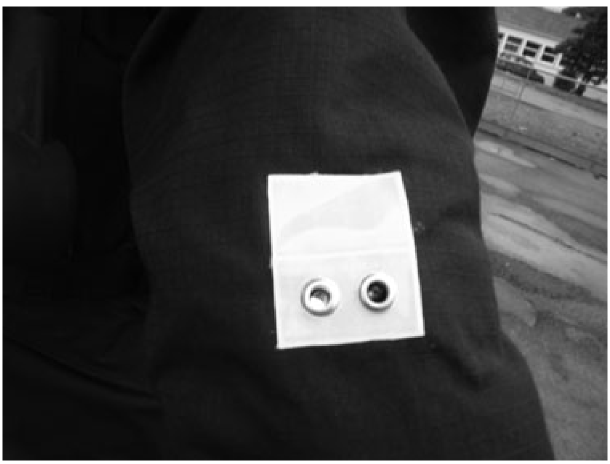
displays. Sensors are protected by a flexible waterproof and heat resistant thermo plastic material. No maintenance is required, only the battery needs to be changed. The durable fire suit with built-in TST microelectronics can withstand at least 25 wash cycles.' (Viking, 2007).

12.6 The Tecknisolar firefighter garment

The French company Tecknisolar Seni (Tecknisolar, 2011) located in Saint-Malo, France, has introduced a sensorised firefighter garment (Fig. 12.14). On the outside of the jacket, a temperature sensor measures the environmental temperature; inside the jacket, the internal temperature is measured. A 'man down' detector is integrated, together with a gas sensor (Fig. 12.15). A thermographic camera indicates the environmental temperature in real time and is built into the helmet.

The purpose of the system is to avoid heat stress for the firefighter. The system warns him in extreme situations to withdraw from the fire. The

12.14 Integrated gas sensor.



12.15 Tecknisolar sensorised firefighter suit.

jacket has proven its efficacy in a marine training centre in Brest, France and is being further tested.

12.7 Conclusion

This chapter has made clear that in Europe a lot of research effort is put into elaborating the safety of firefighters and rescue workers. Much of this is done by integrating sensors for monitoring the wearers' health status and their environment into the high-performance garments they are already equipped with. The PROeTEX project was the first in its kind, and many