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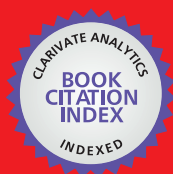
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Integrated and Personalised Risk Management in the Sensing Enterprise

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1. Introduction

Due to its impact on economy, resources, environment and society, manufacturing is of strategic value to Europe. European manufacturing has to embrace a new logic of global socio-economic sustainability, in which it addresses not only the welfare of its population, but also of emerging economies, contributing at the same time to the preservation of the environment and the resources. Megatrends that have a considerable impact on European manufacturing are:

- Ageing,
- Individualism,
- Advanced and emerging technologies / knowledge,
- Globalization,
- Urbanization,
- Sustainability,
- Finance and Public debt.

Under the influence of these megatrends, manufacturing sectors are undergoing structural changes in view of increasing their competitiveness through intelligent and sustainable solutions. The move from eco efficiency to resource efficiency is related to the need for building "citizen centred systems". This will require further improving the socio economic dimension of future metropolitan areas and factories by addressing the quality of life of the citizens living and working there.

This new perception of the worker in the manufacturing environments requires that a new approach is made available to manage risks and hazards in the manufacturing environment.

Worker's safety and health is observed jointly by legislation, knowledge generation and technology development to enable a full risk management focused on the employee (paradigm "factory worker first"). When the personalized risk management will be achieved, the European Strategy for Safety and Health at Work 2007 – 2012 will be able to reach the objective of 25% reduction in workplace accidents and then a yearly reduction of 5% to finally achieve the ambitious objective of zero-accidents.

So far, most efforts in work safety have been focused on improving work equipment features and definition of more secure tasks. Machine manufacturers have worked hard to provide security devices to eliminate or mitigate the risk, but success lies in considering security by design. Big gaps are detected in the process of establishment of security systems in industrial environments focused on the worker. The worker needs to be introduced as an active element in the risk management equation and proactive measures need to be facilitated to increase the effectiveness of the solutions in place.

All working environment variables and conditions in risk management require the challenge of finding technologies to monitor and manage the human factor in manufacturing processes. The reason is that the human factor is the main responsible for incidents and accidents in factories nowadays. The expected risk management system must incorporate proactive capabilities understood as the ability to detect the confluence of several risk factors with potential likelihood to cause an accident.
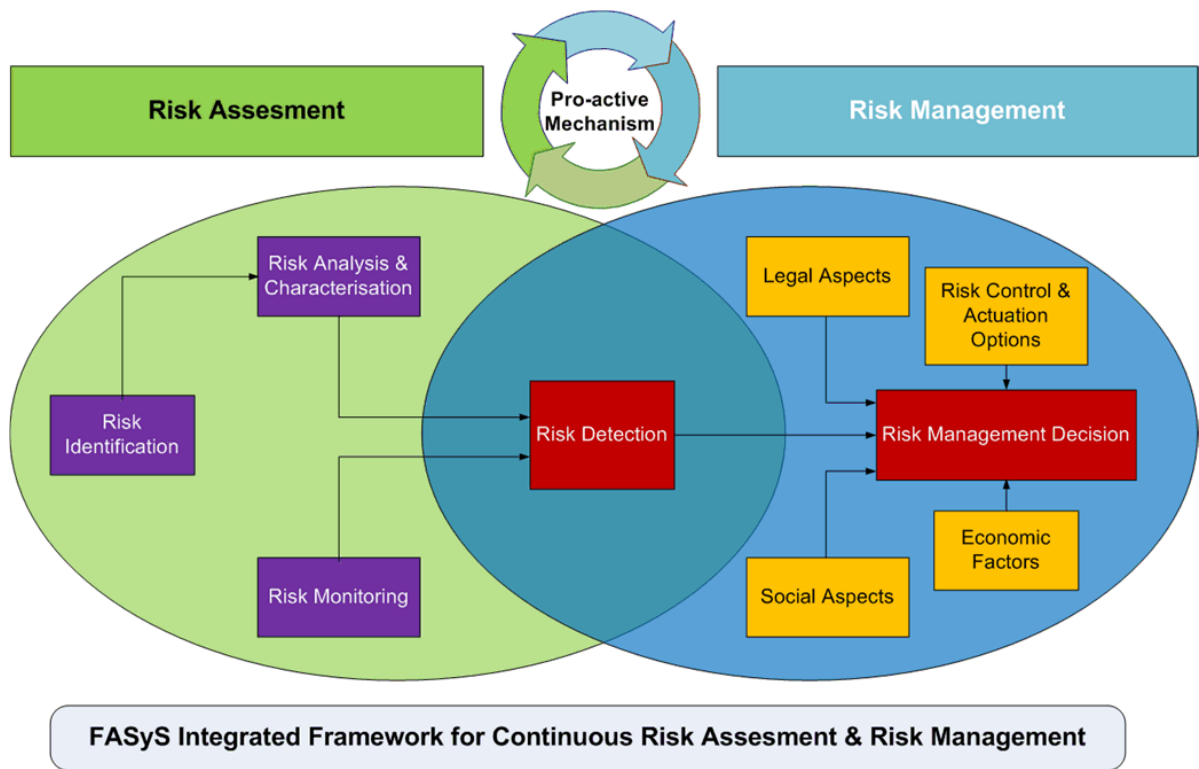

Figure 1. FASyS proactive risk management reference framework.

The best starting point is the general framework of proactive risk management provided by the ISO 31000:2009: Risk management – Principles and guidelines, see Figure 1. This standard has been suggested by the European Technology Platform on Industrial Safety

(ETPIS) as the framework for managing future manufacturing environments. To meet these challenges, technical, organizational and human resources are considered, in order to identify, detect, monitor and manage, on a continuous and effective manner, risks related to health and safety throughout the complete life cycle of the factory. For such solution to become fully effective, risk management system should be developed holistically taking into account an integrated view from sensing devices to reasoning mechanisms and intelligence, capable of reacting to extremely dynamic conditions.

The chapter is organized as follows. First a brief overview on the concept of Sensing Enterprise and Future Internet technologies, where the FASyS system will operate is provided. Then, Section 3 presents the FASyS model for proactive health and safety risk management. Subsequently, a more in depth discussion on key technological foundations of the FASyS model is presented in Section 4 to Section 6. Finally, the main conclusions and observations are summarized in Section 7.

2. The sensing enterprise concept

The Sensing Enterprise is a concept created by the FInES community in the context of the advent of the Augmented Internet. It refers to an enterprise anticipating future decisions by using multi-dimensional information captured through physical and virtual objects and providing added value information to enhance its global context awareness [1]. The enterprise will no longer be composed of and defined solely by atoms, but also by bits and kilobits.

The Sensing Enterprise concept is shifting boundaries – towards a borderless enterprise, where collaboration and continuous interactions among smart objects are central to the new scenario. Beyond the push and pull model, the sensing enterprise concept goes further to a direct presence, « sensing » data and transforming it into knowledge for business operation. The concept of sensing enterprise shifts the focus on the interaction among objects and systems.

The Sensing enterprise concept supports the notion of smart dust in the clouds as a new form and evolution of current state of the art computing systems. Thus, decentralised and delocalised computing and data storage resources provide dynamically scalable capacities to exploit linked open data that facilitate the exploitation of internal and external data systems. This highly flexible computing and sensing environment is the basis for a new generation of cross-cutting horizontal enterprise application areas. The Sensing enterprise concept leverages the power of sensor networks and decentralised intelligence to perform analysis and decision making both in synchronised real and virtual worlds.

3. The absolutely health and safety factory (fasys) model

The development of any excellence model should be based on a thorough analysis of the risks that can be faced in a particular working environment. However, the development of a proactive model demands that the very same approach can be used to completely manage in an integrated, proactive and continuous manner well-known as well as emerging hazards.

Figure 2. FASyS 13 prevalent hazards

This is the reason why the FASyS model has consolidated the vast diversity of incidents and accidents that can potentially take place in handling, machining and assembly factories into 13 prevalent hazards; such as trapping, falls on a level, awkward postures or repetitive and forceful movements, as illustrated byFig. 2. These 13 hazards have been used as reference in the development of the FASyS excellence model.

In the current regulatory framework, both legal and technical and having health damage prevention as the ultimate goal, the employer must "ensure" the maintenance and improvement of health, supported prevention services, which, through performances in R & D have to improve and evolve the performance and services provided. FASyS provides an integrated model for Continuous Risk Assessment, Monitoring and Management, that has to exhibit the following unique features:

- Integrated medical and technical risk management disciplines.
- Act as a single health model (mixed and integral)
- It is based and actions scientific knowledge for active risk prevention – technical
- Provides a "uniform" and universal framework for data and information management
- It can be "embedded" within the company's control and management system

3.1. FASyS excellence model

FASyS is the first integrated solution providing a coherent view to the 4 main dimensions that drive risk management i.e. methodology, technology, functionality and normative.

- **Methodological dimension** suggests that the risk model should be taken into account in the factory of the future; this model must establish the worker as the central point of health and safety management, thereby providing the missing link between occupational health, hygiene, ergonomics and psychosocial risks that current practices

exhibit. This dimension of the model advocates for 4 different approaches to risk management so that proactive measures can be supported. FASyS methodological dimension combines safety performance based, risk based, incident and resilience based combined approaches as the means to address effective risk management. Moreover, this dimension increases traditional risk modelling functions on the assumption that risk should and will be monitored and therefore a suitable description should be made available.

- **Technological dimension** establishes the technological fabric needed to support the functional requirements of the risk management model. The technological dimension provides the technology blocks leveraging the concept of sensing enterprise. The FASyS approach to technology lies increasing interest and a prevailing role of ICT in the context of factory environment. In parallel with increased sensing and actuating capabilities, the improvement in backhaul communications present a new factory scenario where more autonomous intelligent reasoning mechanisms could be envisaged. The Internet of Things (IoT) scenario that needs to be handled is characterized by highly variable spatial and temporal contexts that should be effectively managed. FASyS combines the concept of autonomous systems with sensing and actuating capabilities with semantic-based distributed reasoning approaches to complex system operation. The technological dimension defines the reference architecture, where the risk management system will be integrated.

Figure 3. Three-level FASyS risk management reference architecture for sensing enterprises.

- **Functional dimension** includes all accesses to functional requirements needed to assure that the risk management cycle is complete and effective. The FASyS model defines 10 different modules that encapsulate the required functionalities to leverage ISO 3100:2009. The modules mainly deal with risk modelling and risk management strategy configuration, business impact analysis and system configuration, health and safety monitoring, autonomous actuation, decision support, personalised information and augmented training functions. Such scheme deals with a holistic and adaptive, evolving view on risk management.
- **Normative dimension** is based on the ISO 31000:2009 and establishes the five stages in risk management life cycle, which should include the previously described features to meet the requirements of each stage: Context, Organization, Monitoring, Intervention and Communication.

3.2. FASyS technological dimension

The implementation and demonstration of the FASyS model demands that coordinated progress is made in particular technology fields. FASyS has identified and prototyped technology at communication, complex event processing, human behaviour analysis, activity monitoring and reasoning level.

As depicted by the Figure below, FASyS technological fabric relies in 5 major components :

- **IoT Networking.** (a) Wireless sensor networks and activity monitoring (b) Communication security and privacy systems (c) Wireless communications in industrial environments.
- **Mixed Virtual and Physical World Detection and Evaluation:** (a) Industrial safety ontologies and reasoning engines. (b) Smart ergonomic characterisation solutions (c) Functional workplace adaptation models (d) Human error identification systems (e) Models for detecting psycho-social indicators and profiles (f) Adapted learning solutions (g) Chemical sensors for pollutant detection
- **Personal Health Systems:** (a) Applications for intelligent video analysis (b) Real-time risk detection tools (c) Automatic medical alert notification system (d) Occupational pathology assessment/diagnosis protocols
- **Machine Tool Active Security Systems:** (a) Part manipulation and part feeding systems (b) Volumetric protection systems (c) Auto-calibration and auto-compensation systems for large units (d) Intelligent part movement guiding systems (e) Visualisation systems for part/tool referencing
- **Comprehensive Real-Time Risk Management Systems: (a)** Personalized risk prevention strategies (b) Personalized decision support systems (c) Semantic solutions for services coordination (d) Emotional interfaces for effective risk communication.

All 5 technologic enablers are supported by a specific information distribution (acquisition and delivery) platform depicted by the Figure below. The FASyS services, provided by the functional dimension of the model, are leveraged in the FASyS plane based on the smart object system plane information and external information sources linked through the FASyS information gateway.
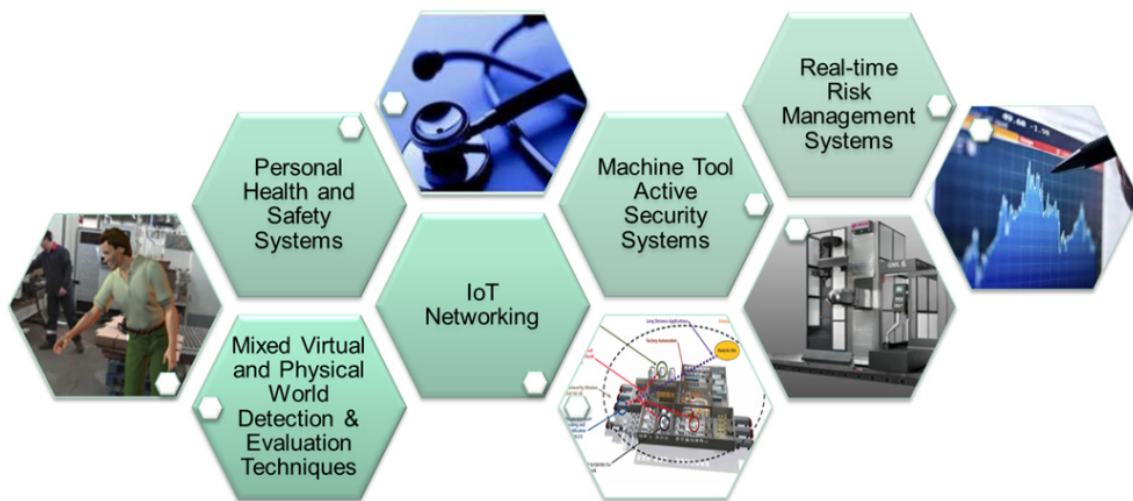
Figure 4. FASyS technological components

3.3. FASyS functional dimension

Ten modules are included in the functional dimension that are directly related to the health and safety services leveraged by FASyS:

1. **Risk assessment**. This module provides to safety managers many tools to access and manage the identified risks, their factors, values and relations. The management of these risks demands worker information, machine and device data and environment values related to each risk that could be monitored. In addition, this module interoperates with factory data stores.
2. **Preventive measures design**. In this module, the prevention responsible is able to design and establish the prevention measures catalogue to be used for each personalized risk identified. The preventive measure design use technical measures, medical protocols, data collection, affected users, execution managers and assessment agents.
3. **Economic impact evaluation**. In this module infrastructure and equipment implementation costs related to preventive measures are quantified. In addition, it is able to estimate the costs of non-prevention, in order to provide quantitative information about the integral risk management.
4. **Preventive measures configuration and management.** This module is used by safety and health managers. They use the complete prevention plan designed in the second module and associates devices (smart objects) to each action. In addition, this module monitors the correct operation of the devices and it alerts from any malfunction.
5. **Environment description module**. This module is used by safety managers and it monitors the real-time factory situation and its related actors, using visual tools to adapt the risk visualization through many filters.
6. **Personal health module**. This module is able to show to the health responsible a real-time monitoring of conducts, indicators and benchmarks to determine the evolution of the worker's health status and to provide early alarms related to health.

7. **Intelligent and automatic remote operation module**. This module provides tools to automate critical functions in manufacturing equipments. So, the equipment is able to adapt its operating parameters to the factory conditions, task values and worker status.

8. **Decision making automatic assistant module**. In this module, the safety responsible interacts with the decision support model, performing informed decision in multiple choice situations or in contradictory situations. In addition, it could be preventive strategies that need some personal interaction to validate a non-automatic event or decision.

9. **Emotional communication module.** This module empowers the prevention responsible to coordinate communication strategies on health and safety messages and to deliver them effectively, individually or massively. The messages could be sent on automatic or supervised manner. The module will also modulate the content of messages adapted to the emotional and psychosocial profile of the receiver.

10. **Continuous training module**. This module allows workers to be trained on prevention through "training pills", that are sent at the right time through the best channel. The safety responsible designs the protocols to assign the most suitable pills to a particular prevention strategy. The pills are training actions or mass reminders to one or many employees and with a predifined periodicity that respects emotional and congnitive constrains.
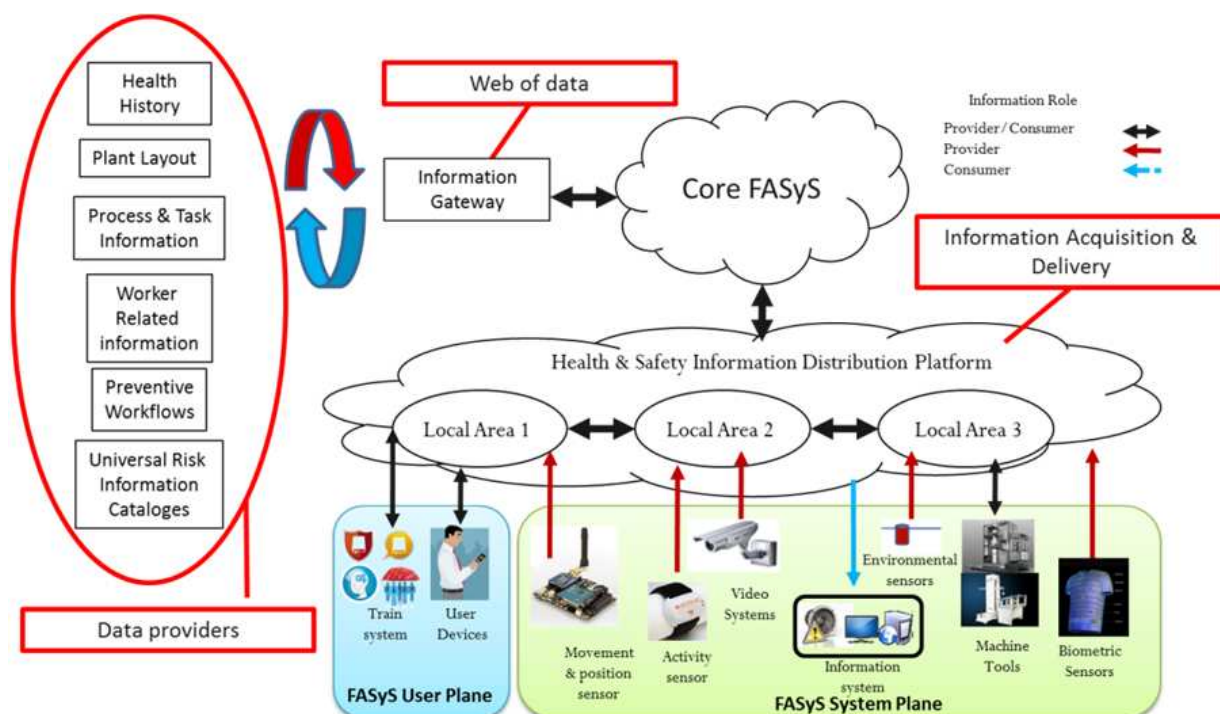

Figure 5. FASyS information data distribution architecture for the sensing enterprise.

4. Industrial wireless communications and Internet of Things (IoT) networking

The concept of sensing enterprise capabilities provided by FASYS are built at the smart object level leveraging on one hand enhanced industrial wireless sensing & communications and on the other hand, facilitating a semantic plane representation of the sensor information provided by smart objects. From a health & safety perspective, the major challenges faced by the wireless communication and IoT networking modules in the implementation of the sensing enterprise concept relate to (a) provision of a common architecture for secure heterogeneous communications (b) reliable wireless sensor network connectivity (c) universal object & sensor semantic representation. This section is devoted to describe how FASyS has addressed each of those fundamental challenges.

FASyS activities with respect to sensor and communication technologies are aimed at guaranteeing the desired levels of safety and health at work with the use of non-intrusive sensor systems (both personalized bio-medical and image sensors) to monitor the worker's physical conditions and the working environment, including environmental conditions and the state of the machinery interacting with the worker. The introduction of wireless communications in the factory of the future will also facilitate the deployment of distributed and mobile sensing applications to improve the factory's productivity and worker's health and safety.

4.1. Industrial wireless sensing and communications architecture

The deployment of heterogeneous wireless communications in industrial environments presents significant challenges [2]. On one hand, industrial environments are usually characterized by challenging propagation conditions (obstructions, interferences, etc.) that difficult the establishment of robust wireless links [3]. On the other hand, hybrid network architectures pose significant challenges to design a system platform efficiently managing data, in particular when real-time connectivity needs to be ensured across multiple wireless technologies [4]　to support the reliable risk management. However, ubiquitously monitoring the worker's conditions requires a reliable mobile sensing and communications platform that ensures the wireless connectivity among the Wireless Sensor Network (WSN) nodes. FASyS has designed an end-to-end heterogeneous wireless solution that enables the continuous sensing of the working environment and the worker's health and physiological conditions in order to detect in advance any potential risks. Fig. 6. depicts FASyS's heterogeneous communications architecture for industrial environments.

To transmit the sensed data to a control centre, a wireless backhaul including medium range technologies for communications within the factory and long range technologies for the transfer of the aggregated data to the control centre has been proposed. The medium range technologies (IEEE 802.11/WiFi and IEEE 802.16/WiMAX) transmit locally sensed data (including video) from different areas of the factory towards a factory's gateway. The gateway can then transmit the received data using WiMAX and/or cellular HSDPA to a

remote control centre. This architecture efficiently and reliably satisfies the requirements imposed by the industrial environment in general, and by the identified FASyS hazards in particular. The proposed architecture takes into account, not only radio propagation and communication aspects, but also semantics and security planes.
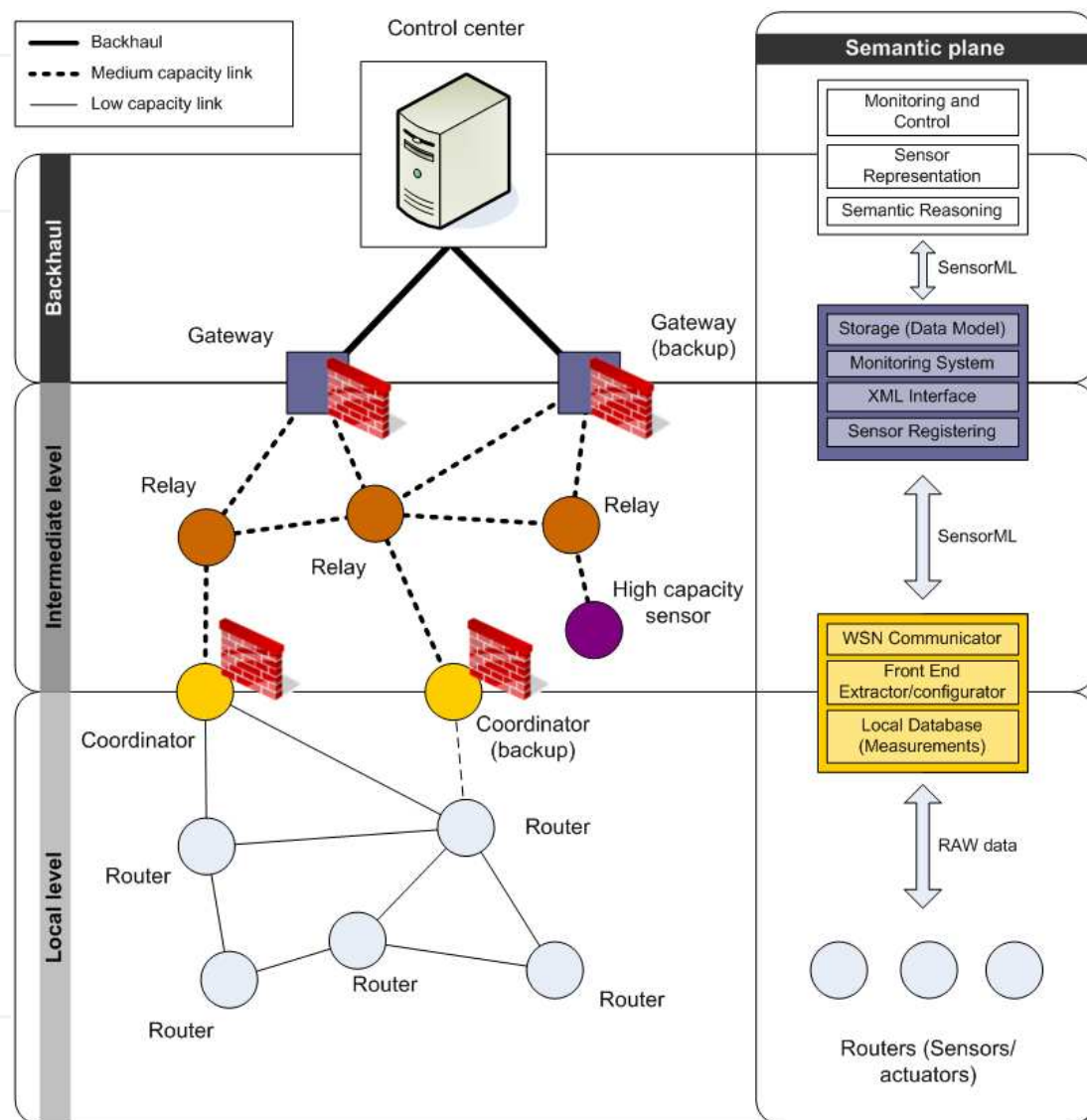

Figure 6. FASyS heterogeneous communications architecture

4.2. Industrial wireless communications and sensing connectivity

To evaluate the performance and connectivity levels of mobile IEEE 802.15.4/ZigBee [3] sensing communications, as well as the quality of service that IEEE 802.11/WiFi, IEEE 802.16/WiMAX and HSDPA technologies [4] can provide in industrial environments, a large field testing campaign has been conducted. This field testing campaign was conducted in GORATU covering a surface area of more than 10.000m² – see Figure 7a. As illustrated in Figure 7b, the plant is characterized by the presence of a large number of potential metallic obstacles that influence the radio propagation and thereby the wireless connectivity.
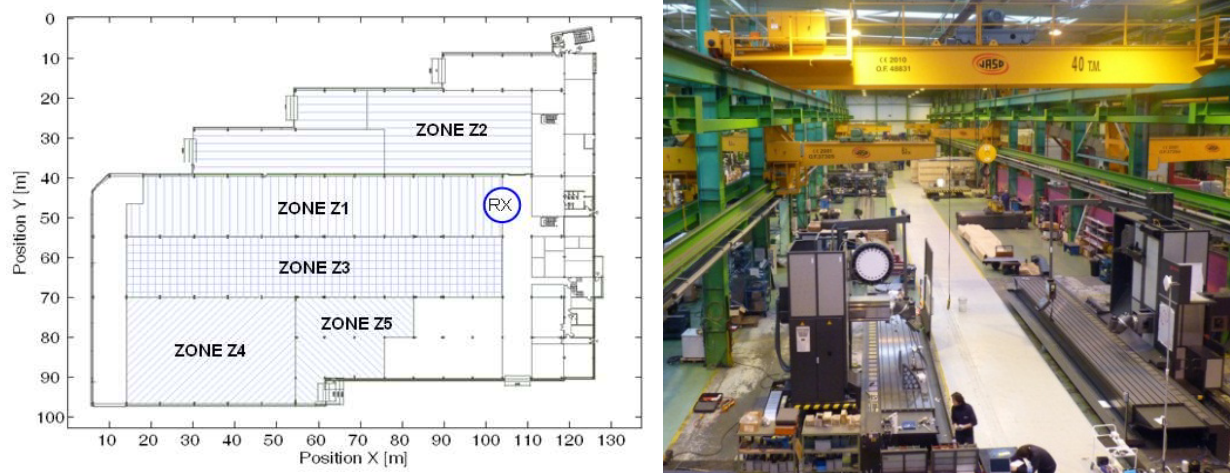
(a) Plan of GORATU's main factory (axis in meters)   (b) View of one of the factory's corridors (Z1)

Figure 7. GORATU's main factory of machine tools.

An example, the results of one of the experiments conducted to analyse the connectivity between a TX mobile sensing mote (e.g. a mote attached to a worker or industrial vehicle) and a stationary RX base station using the MEMSIC Iris WSN motes are presented in Figure 7. In this experiment, the base station was strategically deployed with relatively good propagation conditions with the different areas of the factory (the RX base station was located at position RX in Figure 7.with an antenna height of h_{RX}=5m). During the experiments, the TX mobile node (antenna height of h_{TX}=1.2m) moved across different areas of the factory at pedestrian speed. This node was configured to periodically transmit a data packet every T seconds with a payload of 50bytes excluding headers, emulating the data transmissions of a body sensor device. Along its path, the TX mobile node experienced different propagation conditions with the RX fixed node: LOS (Line of Sight) with reduced obstructions (Z1); partial NLOS (Non LOS) due to cranes, pillars, and machinery (Z2 and Z3); NLOS due to multiple obstructing elements and high distance (Z4); and NLOS and heavy obstruction (Z5, the warehouse). The Figure below depicts the PER (Packet Error Rate) levels measured as the mobile TX mote moves around the factory. The figure shows the average PER levels experienced during time intervals of T_p=5s and the distance between the TX and RX nodes along the path; this figure differentiates the different zones of the factory (Z1, Z2,…, Z5). Additional experiments were conducted with different transceivers, antenna heights and transmission powers. The obtained results show that IEEE 802.15.4/Zigbee can provide the connectivity requirements of industrial applications, even for mobile applications. However, the transceiver, deployment conditions and locations must be carefully selected.
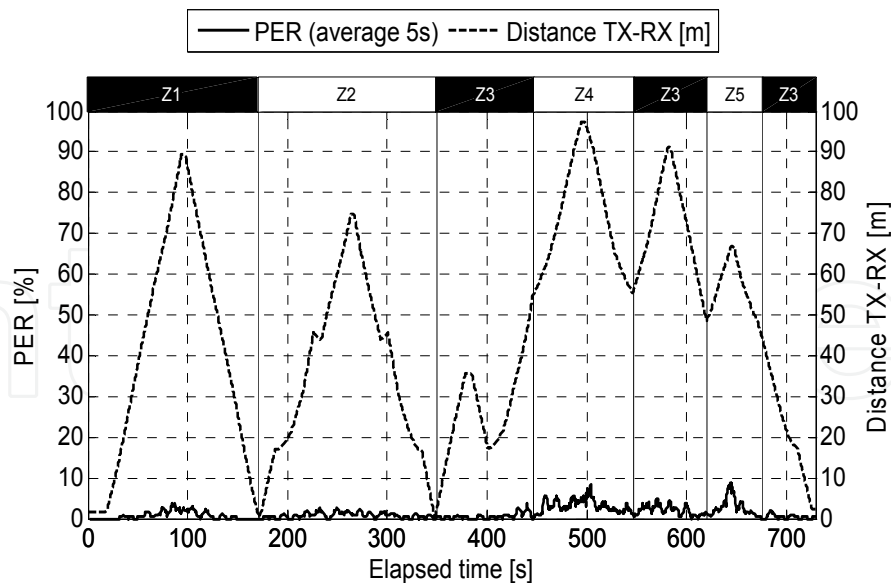
Figure 8. PER performance as a Memsic IRIS WSN mote with Pt=3dBm moves around the factory (h_{TX}=1.2m, h_{RX}=5m, T=200ms, payload=50Bytes).

4.3. Smart object semantic representation

Regarding semantics, a traversal control plane has been included in the architecture. Semantics are based in the Semantic Sensor Web paradigm, [5] and on a specific abstraction for virtual objects. Semantics, interoperability and exchange of relevant sensor configuration and information are based on Service Oriented Architecture. The key components of the FASYS semantic sensor environment are the Sensor Observation Server (SOS), a standard from OGC [6], and the HMI located in the command and control location of the risk management architecture.

The concept of semantic sensor network is used to organize, manage, interrogate, understand and control the different components of the data gathering process (i.e. network, sensors and the resulting data using high-level specifications). If semantics are introduced in the reasoning process of a FASyS subsystem, it is important to design properly the various steps of communication and interfaces if sensors and sensor networks are involved, as they impose various kinds of restrictions and limitations, such as power constraints, finite and limited memory, unreliable communication network and the quality and variability of data received.

The Semantic Sensor Web (SSW) or the Semantic Sensor Networks (SSN) base their operation on the existence of a sensor network that implements a physical layer (PHY), a sub-level medium access (MAC) and network layer (NET), usually implemented by standard protocols (e.g. Zigbee and 6LowPAN), but considering mechanisms and proprietary systems. The contribution of this type of mechanism is the addition to the data measured / generated by sensors in the form of metadata annotations of semantic information of a temporal, spatial and thematic, accessible through a Service Oriented Architecture.

The technology used in FASYS has been standardized by the OGC [6] and has been extended and specially applied to factory automation by the research team [10][7]. The concept of SSW, is based on the use of a special type of information infrastructure for web-centric collection, modelling, storage, subsequent withdrawal, sharing, manipulation, analysis and visualization of information on sensors and observation of phenomena from them. The definition of SSW by OGC is: "*Networks of sensors and sensor data storage accessible via the web, which can be discovered and accessed using protocols and application interfaces standards*"[6]. The standard and components of the SWE SOA are: Observations & Measurements (O&M); Sensor Model Language (SensorML); Transducer Model Language (TransducerML or TML); Sensor Observation Service (SOS); Sensor Planning Service (SPS); Sensor Alert Service (SAS) and Web Notification Services (WNS) [8]. FASYS considers the use of different SOS located in strategic points in the Communication Architecture in order to provide homogeneous access in the heterogeneous network to the different control applications.

FASYS semantic sensor system is based in the use of SOS and Sensor ML, it provides access to the data generated by the sensors so as the metadata to configure and customize each individual component (sensor) of the network. The main benefits of using semantic sensor networks in FASYS are: (i) Platform independence as practically any sensor or modelling system can be supported (even simulated sensors); (ii) easy development of services allowing dynamic connectivity between resources; (iii) Liaison with semantic environments, adding semantic information to the basic SWE paradigm; (iv) Traceability and support to the implementation and management of real-time measurements; (v) Flexibility in implementation: container capacity and existing sensors, implementing and processing services; and (vi) Scalability from a single sensor to a collection, individual, group or cluster of sensors. [9]

Regarding the design architecture, it is important to consider the location of the SOS within the network. Basically, there are two main approaches. The first approach considers locating the SOS in the coordinator node, as near as possible to the physical sensor. The second approach considers locating the SOS in the gateway node, as near as possible to the control center. In order to determine the most appropriate place for the SOS, it is important to consider the data flows that are envisioned between sensors and the SOS and between applications and the SOS in order to minimize data traffic. As the FASyS system uses a Complex Event Processing (CEP) system as key component of the Control Center that continuously issues requests to the SOS, the data flow is considered to be significantly higher than the data between sensors and the SOS. Therefore, the second approach has been selected in FASyS. Once the SOS has been set up in the gateway node, all sensors have to register with the SOS from each gateway to have controlled all data sources [10][11].

Regarding interoperability of systems and applications, the use of SOS provides syntactic and semantic interoperability. Interoperability is a property referring to the ability of diverse systems and organizations to work together (inter-operate). The term is often used in a technical systems engineering sense, or alternatively in a broad sense, taking into account social, political, and organizational factors that impact system to system performance. Interoperability may also be understood as the ability of two or more systems or components to exchange information and to use the information that has been exchanged. [12].

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Regarding Interoperability we can distinguish two different possibilities syntactical and semantics interoperability [13]. FASYS provides both kinds of interoperability starting from the correct use of a SOS as support for merging and concentrating the information generated by sensors and distributed devices. Though strictly speaking the SOS provides syntactical interoperability, it is relatively easy to incorporate simple semantic support as temporal, spatial and thematic filtering are natively supported by SensorML and O&M, the two standard interfaces used by the SOS. Additionally, SensorML supports extensibility through annotations. If such annotations are part of a semantic vocabulary, then more complex semantic operations can be supported. SOS has been extended with a database based on a specific FASYS data model that includes some specific features not included in the OGC standard and are required to integrate the SSN in the FASYS HMI.

4.4. Mobile sensing applications

FASyS advanced IoT networking paves the ground for advanced monitoring functions that can be exploited by other parts of the FASyS risk management system to perform advanced health and safety prevention. Mobile sensing applications facilitated by FASyS include among other collision avoidance and continuous physiological monitoring.

4.4.1. Collision avoidance

Collisions between workers and fork-lift trucks, or between any type of vehicles, have been identified as one of the most common accidents in factories. Such collisions could be prevented if workers and vehicles would be equipped with WSN (Wireless Sensor Network) motes so that they can dynamically exchange information about their position and speed in real time. With this information, they could be able to detect in advance, and avoid, potential dangerous situations, such as the intersection shown in the Figure below. Robust and reliable wireless communication links should be established between any two nodes with a risk of collision, despite the potentially challenging propagation conditions, represented in the intersection by a wall, and large metallic machinery and obstructing elements placed within a large wood container at the intersection.
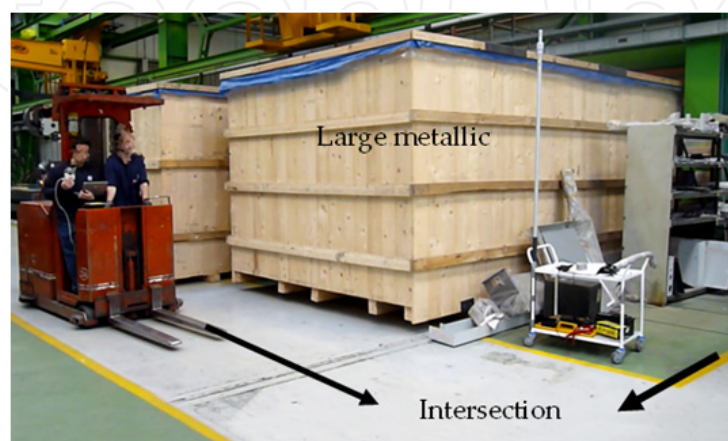

Figure 9. Collision avoidance use case: testing intersection

4.4.2. Continuous physiological monitoring module

A second example of mobile sensing application leveraged by FASyS is an innovative monitoring platform built up by up to six sensors following the HealthAlliance interface that arranges the worker physiological follow up in two strategies: (a) **intensive monitoring**, for those workers on health risk approaching minimum invasiveness as well as maximum ergonomics. (b) **preventive monitoring**, to check periodically main health indicators. FASyS is capable of integrating data coming from different sensors, working with different communication protocols and interfaces. This is done implementing Health Alliance 11073 standard logic communication and manufacturer protocol for the sensing devices. After the acknowledgment, the values are packed into HL7 standard messages and transmitted through secure pathways to the factory DPC (data processing centre), where the personalized health management module can access to it – see next Section on Occupational Personal Health Systems.

5. Occupational Personal Health Systems (O-PHS)

Most developed countries include within their basic welfare policies the right of citizens, as workers, to be protected from sickness, disease and injury arising from their employment. Despite this intention, the International Labour Organization (ILO) estimates that 160 million workers are victims of occupational accidents and diseases every year [14] and over two million of people lose their lives from work-related accidents and diseases. The standards on occupational safety and health provide necessary tools for governments, employers, and workers to establish such practices and to provide for full safety at work. In 2003, ILO assumed a global strategy to improve occupational safety and health, which included the introduction of a preventive safety and health culture, the promotion and development of relevant instruments, and technical assistance [14].

One of the European objectives set for 2020 is the 25% reduction in the number of industrial accidents [15][16]. In order to reduce accidents it is essential to pay attention to the workers, their single workplaces and to their working conditions. In addition, favourable environments make workers feel more comfortable while they are in the factories, and thus the efficiency is increased. As a consequence, it is possible to obtain the maximum efficiency in the factory as a whole, which also produces economic benefit for the company. From a healthcare point of view, factories lack normally in an amount of enough information to allow a holistic care of the worker. Health data stored by companies are only a small amount of data, usually stored once a year, and referred to the physical condition of a person just in a particular moment [17].

5.1. Proactive paradigm for Occupational Health Systems

For these reason, future factories and enterprises need to do an effort in focusing resources and strategic planning towards making the workplace safer, healthier and to significantly reduce the number of accidents and the work related diseases in their population. In order

for this to happen, it's necessary to anticipate and predict the occurrence of risk scenarios that can lead to a damaging situation, either by accident or health threat. This need generates a change of paradigm, moving from a reactive system providing management solutions to problems that have already happened and basic preventive measures, to a much more proactive model, where risk management is understood as a mostly preventive tool. To achieve this, it's important to collect, measure and analyze data during a continuous period of time, in order to evaluate the risks and their evolution.

In this line, future enterprise risk management solution should turn punctual monitoring into a more frequent and personalized vigilance, including individual and collective data. However, collecting information of many people during a long period of time requires collecting a big amount of data. People are not able to process so much information, so intelligent systems for massive data processing are needed. These intelligent systems classify data and generate alarms associated to the worker. Thanks to these alerts and all the other environmental and personal data stored, it is possible to predict health threats. Thus, it is possible to act in the most appropriate way for each worker in particular.

Nowadays, the number of sensors for monitoring personal health data is increasing. In addition, sensors that collect environmental parameters in industrial factories are being introduced more and more. The problem encountered so far, besides a reduced frequency of monitoring, is that these data are usually not thoroughly connected. The information is only collected in order to produce isolated diagnosis or identify single risks, but not common results, and the collected data become less relevant if they are not treated together. The final decision, in a dynamic environment like a factory, could be more precise if results came from a comprehensive study of a diverse set of parameters. However, once the data is collected and stored, a significant effort must be done in processing it in order to identify and highlight those elements that are directly related to present or future risks. This identification becomes more and more difficult as the amount of data analyzed increases and rage of risks augments. Therefore, it seems logical to state that, in parallel to the data collection efforts, new solutions for clustering, prioritizing and filtering information need to be put in place, to generate the most appropriate alarms in the right moment and in the right place. Risks nature can vary from emergency situations to predictive probabilities and Risk Management systems have to be able to discriminate between the two (and the whole range in between) and provide adequate communication of the contextual information so that the reaction to the risk matches the risk characteristics. Finally, once the information has been monitored and classified, the next point is focused on the intervention. With the aim of representing prevention protocols for this intervention, workflows are developed. Given the workers singularity, the adaptation of the prevention protocols is needed for each one of them. In this way, the elimination of the occupational hazard is much more effective

The Health model established in FASyS, is based on the "Ecological Concept of Disease", in which, the environment (Physical, Social, Economic and Biology, among others) is a set of external conditions and influences affecting the life and development of an organism, human behaviour or society, acting on the balance between the so-called "disease agents"

and "human host", even capable of altering it and causing a potential disease situation where such agents exceed the capabilities of the host response and adaptation. This allows to establish, in accordance with the main risk factors (physical, chemical, biological, social and psychological), a pre pathogenic state or period, which we have called susceptibility stage, on which a primary prevention action is required, and other state or pathogenic period, which we called the disease, which holds the secondary and tertiary preventive actions and care actions where necessary.

From here, setting up standard profiles (comparable to health profiles), and pathogenic and pre-pathogenic profiles with abnormality parameters, becomes   much more simple and affordable and allows to introduce these profiles in the system. The development and implementation of a comprehensive and interrelated system of identification and control of the elements participating in the working environment through sensory and monitoring systems, can establish and develop what we have called the SATSE or System to Aid Decision Making in Occupational Medicine. This system consists of multiple modules that collect data and information about the company, the job (Identification of potential risks, protocols to be applied, pathobiological profiles to be determined, potential limitations, referrals ...), the worker (background, demographics and psychosocial factors, medical history at work,...), extra-clinical data (organizational profile, demographic profile, psychological profile...) and additional data (diagnostic algorithms, performance algorithms, medical knowledge data bases...) The use of physiological sensors that help us to determine both in the workplace and outside it, the physiological status or health of a worker at a given time at work or outside work (whenever necessary), complements the sensor system module, that is one of the basic elements of the project.

5.2. Personal Health Records (PHR)

Health data has been traditionally produced and owned by the Healthcare Systems and stored in Electronic Healthcare Records (EHR), focusing mainly in describing clinical procedures, tests and values. However, with the purpose of improving the characterization of the person and his environment, EHR data needs to be extended. This new information is stored, together with the EHR information, in other repositories. These repositories are known as PHR (Personal Health Record) [19] and collect data such as habits, preferences, information about the family, work, moods or nutritional profile. These repositories are, in opposition to the EHR, owned by the person, who has the option to share it with whoever he chooses.

The usage of PHRs in occupational health could enable that when an employee goes to work in a company for the first time, the enterprise's health professionals can ask him to share his relevant PHR data, in order to have his personal file more complete and enable a more complete and accurate health risk management. Of course, this situation would require enhanced methods for privacy and data protection, ensuring no unauthorized and adequate usage of the health information is made. In general, current PHRs contain a summarized version of the EHR adapted to the patient's knowledge and needs and, in some cases, home

monitoring data. Future PHRs covering the area of occupational health should be based in the following aspects:

- Includes relevant health hearths and risks linked to the work conditions.
- It allows patient to introduce data (automatically or manually).
- It allows an exchange of information with the healthcare system (HER).
- It includes an option to generate summaries to share information with other PHRs.

One of the advantages, for example, would be when a worker goes to work in other factory. If the new factory is enabled, his PHR could be downloaded in the system of the new factory in order to have a more complete file and ensure continuity in the management of the risks for that particular worker. Stored Data can also be extracted for consultations and referrals in case health professionals need to, of course under the corresponding access control that prevents unauthorized sharing of the data. Data can be easily anonymized to be used for statistical and epidemiological studies in order to detect population based health problems.

5.3. Care plans, workflows and medical guidance

The normalization of processes is more and more present in current society. The formal definitions of procedures that are usually deployed in enterprises and factories are considered the best practices in order to support the management. This normalization allows not only predefine which is expected in the organization procedures but also allows a continuous monitoring of the processes that is crucial for their correct management and continuous improving. Moving these ideas to Health Care, Care Plans or Clinical Pathways [20] there are protocols for standardization of health processes. Nevertheless, the standardization of those processes is more complicated than usual enterprise processes. First of all, the Health processes are very complex. The high number of variables that are taken into account in a care process, the pluripatological patients and the wide quantity of different treatments that can be applied to them requires a special expressivity in the process definition. In addition, the processes standardized should be designed by health professionals. This requires that the specification language should be legible by those experts in order to ensure that the process can be understood and repeated. Moreover, the specification of the process should be non-ambiguous. This is a key problem in the specification of protocols. It is said that a protocol is ambiguous when more than one interpretation possible for the same specification exists. The presence of ambiguity in Care plans is a great problem that prevents that the process will be deterministic.

Usually, care plans are described as great manuals, free text written, that explain the care processes in a whole. Those manuals are available through big medical libraries like the Cochrane [21] or PubMed [22]. Although those manuals have the expressivity of natural language, they are often ambiguous and the high quantity of data is tedious to read. Other approaches are based on specific formal languages like GLIF [23] that provide tools to avoid ambiguity and to ensure the completeness of the protocols defined. Nevertheless, the use of rule based systems can difficult the creation of legible and controllable frameworks because

the high number of rules to be taken into account. In enterprise environments, processes are usually defined as workflows. Workflows [24][12] are formal specifications of processes designed to be automatized. The main advantage of using workflows is that they usually have a graphical interface that makes easier their design and understandability to non-programming experts like doctors. In Care Plans environment there are works, available in the literature, which faces this problem using workflows technology [25][26]. The main problem of workflows against other approach like GLIF or traditional techniques is that workflows have less expressivity than them. Nevertheless, there are available workflows approaches in literature [26] that ensures a high expressivity for defining very complex workflows and even for the design of clinical pathways [27].

In addition to graphical design, Workflow has more advantages that can be useful for the design and deployment of care plans. Current workflow systems usually have associated an engine able to automatically execute the processes defined in the graphical way. That means that the formally defined processes can be automatically used for deploying the process by using automatic deploying systems. In addition, Process mining [27] technologies allows the application of pattern recognition technologies to support the iterative design of Care Plans. Furthermore, thanks to the low grammatical complexity of some workflow approaches [27] is possible to apply a great quantity of algorithms and tools for ensuring the completeness, the non- ambiguity and the simulation of processes in order to detect problems in their design before their deployment. In the Figure below is presented a basic specification of a Care Plan using a workflow based approach.
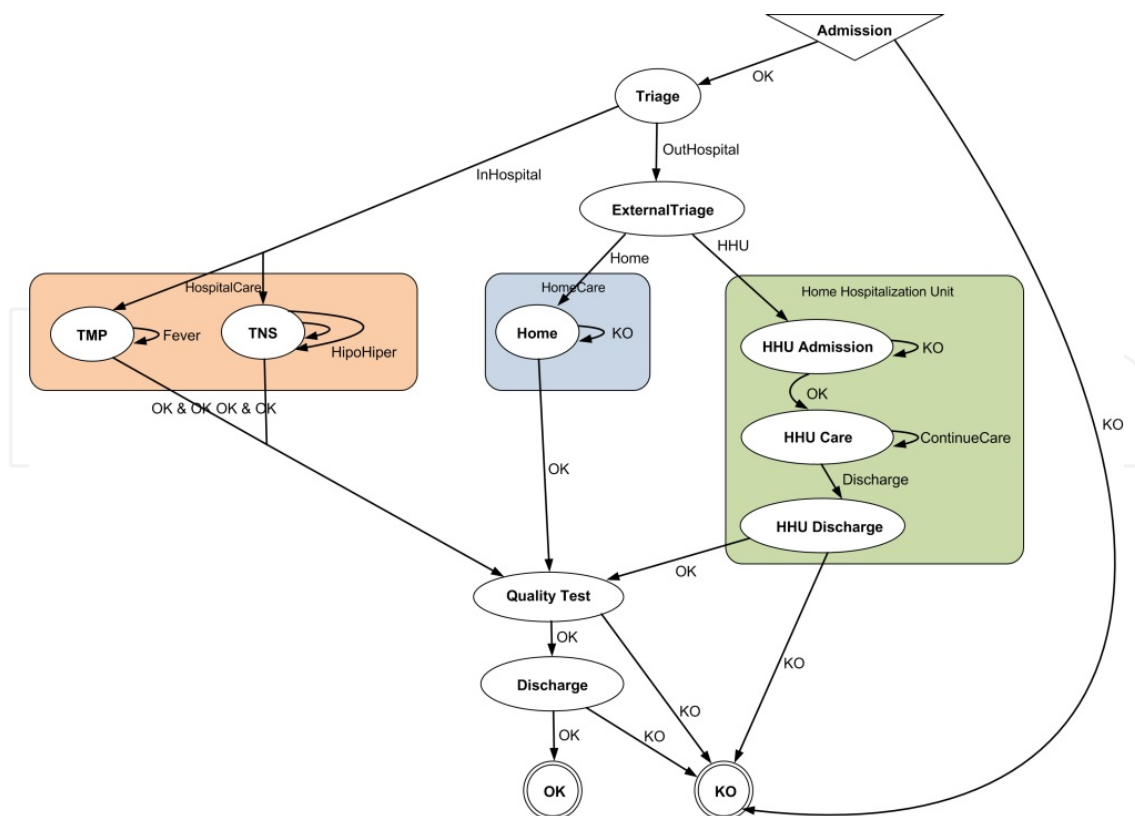

Figure 10. Example of Workflow Based Clinical Pathway

The continuous assessment of processes is critical for ensuring an efficient execution of the enterprise procedures. In this way, there are more and more business intelligence systems available to empower and support the management providing important information about the processes filtered by using Data Mining technologies. Usually those systems, present information about static or evolution of numeric data according to parameters that can, indirectly, help managers to detect inefficiencies or bottlenecks in the processes. In this scenario, an emerging technology is growing in order to enrich those business intelligence systems providing a more directly view about the process execution. This technology is called Process Mining (A.K.A Workflow Mining) [28]. Process Mining technology is research field, based on pattern recognition paradigm, that uses the events or activities of the process logs in order to automatically infer a graphical workflow that explains the actual execution of the process. There are many process mining algorithms in the literature, based on Events like Alpha [16] or Genetic Process Miner [29], or based on activities like PALIA algorithm [27]. Those algorithms are able to create workflows from samples and present graphically in order to know exactly how processes behave in real implementations. Comparing the results of those algorithms with the designed processes, it is possible to directly know what are the most usual paths followed by the processes within the designed workflows, what are the differences and exceptions to the designed processes that are occurring in the implantation of them, etc. In this way, there are available algorithms that allows the comparison between the designed workflows and their real implantation [27].

6. Real-time risk management solutions

The implementation of proactive risk management in a sensing enterprise demands that distributed reasoning capabilities are provided as a means for intelligence and analytics. FASyS should therefore not stop simply at the data collection and distribution level, but on the contrary, it should be able to analyse the vast amount of available information in the presence of data unavailability, ambiguity, imprecision and error. Therefore, for being able to detect, decide and act in real-time to dynamic risk levels various challenges need to ba addressed in the areas of (a) iindustrial safety reasoning engines (b) Real-time risk detection tools (c) Personalized decision support tools and (d) Semantic solutions for services coordination

6.1. Industrial safety ontologies and reasoning engines

To deal with safety in a quite heterogeneous environment in terms of information sources, it is required to create a formal data specification that will be used within ontologies structures that support risk management and context. The ontologies are used as a knowledge base for reasoning engines that are responsible for the detection of risk and responsible of the implementation of relevant actions committed in any situation [30].
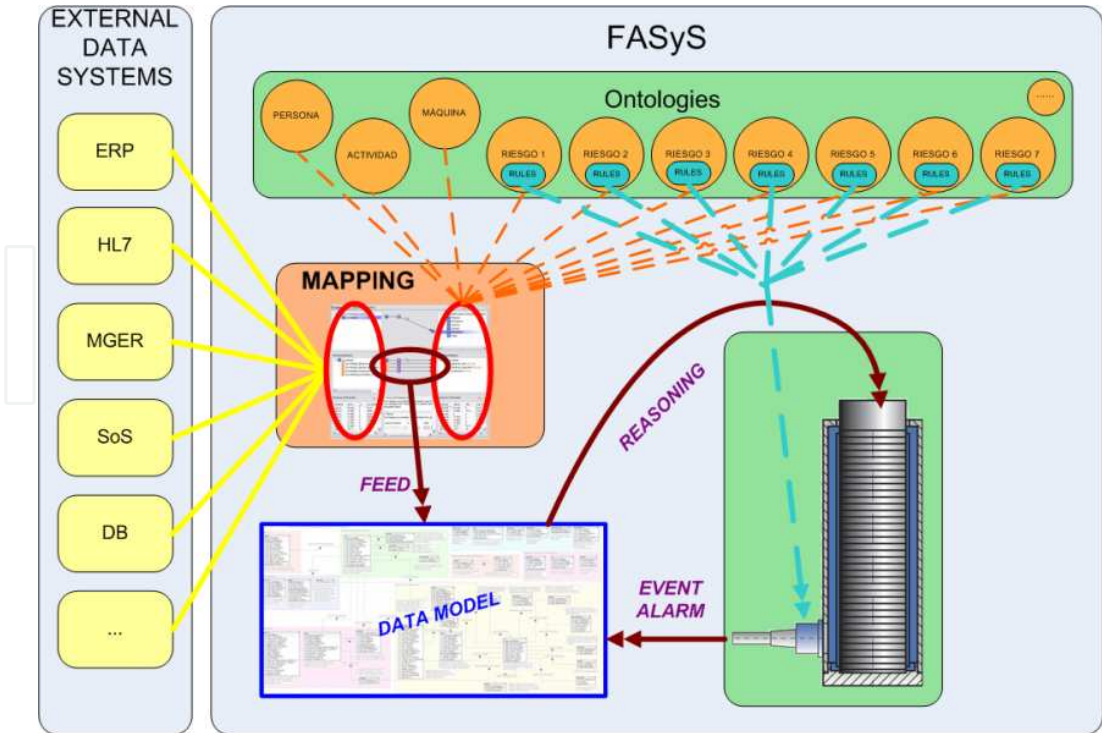
Figure 11. Ontology-based reasoning

As depicted by the Figure above, the selected architecture is based on a distributed multi-ontology structure. This way, there is an ontology for each risk and a set of context ontologies related to different existing and influent entities in each cycle of risk management in the factory. The context ontology properties might be source of different risk ontologies properties. Thus, risk can be defined through different entities or actors of the company.
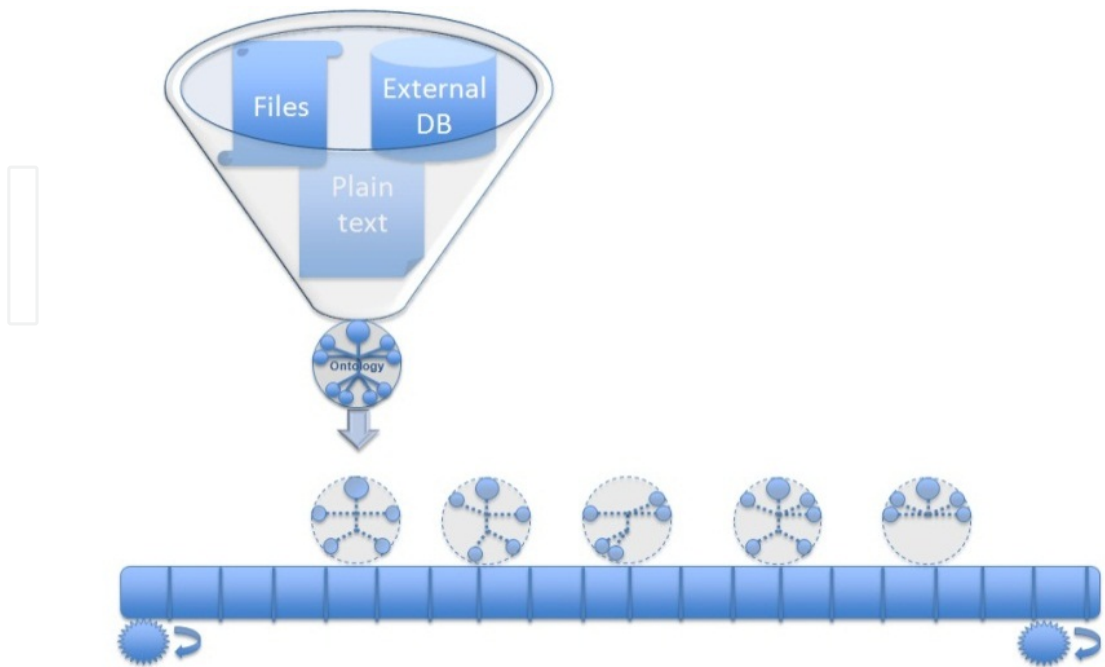

Figure 12. Mapping process results

The use of ontologies is related to the introduction of intelligence and reasoning on the information processing and the relation established between concepts that increase the relevance of such intelligence. Furthermore, this structures will be used for mapping data with information systems of the own company or potential external information systems [31]. The ontologies are considered therefore as the bridge between the heterogeneous information ecosystem and the actual services implementing the FASyS system logic.

6.2. Real-time risk detection tools

Inherent to the concept of proactive prevention is the aim of the system to predict a particular risk by evaluating all the variables of the worker, the working place and the environment. For being able to perform such evaluation the first requirement is to have tools that are able to process all the information in a complete, efficient and, at the same time, very light way. Currently, risk management is focused on monitoring the proposed actions after an evaluation process is periodically; e.g. yearly, performed in the companies. With nowadays facilities, there is no way to propose a 'real time' evaluation of the situation, due to the fact that the safety manager cannot control all the time what is happening in the shop-floor, the data of all the machines involved in the process and the information referred to the state of workers that are moving around the factory. This is inconceivable.
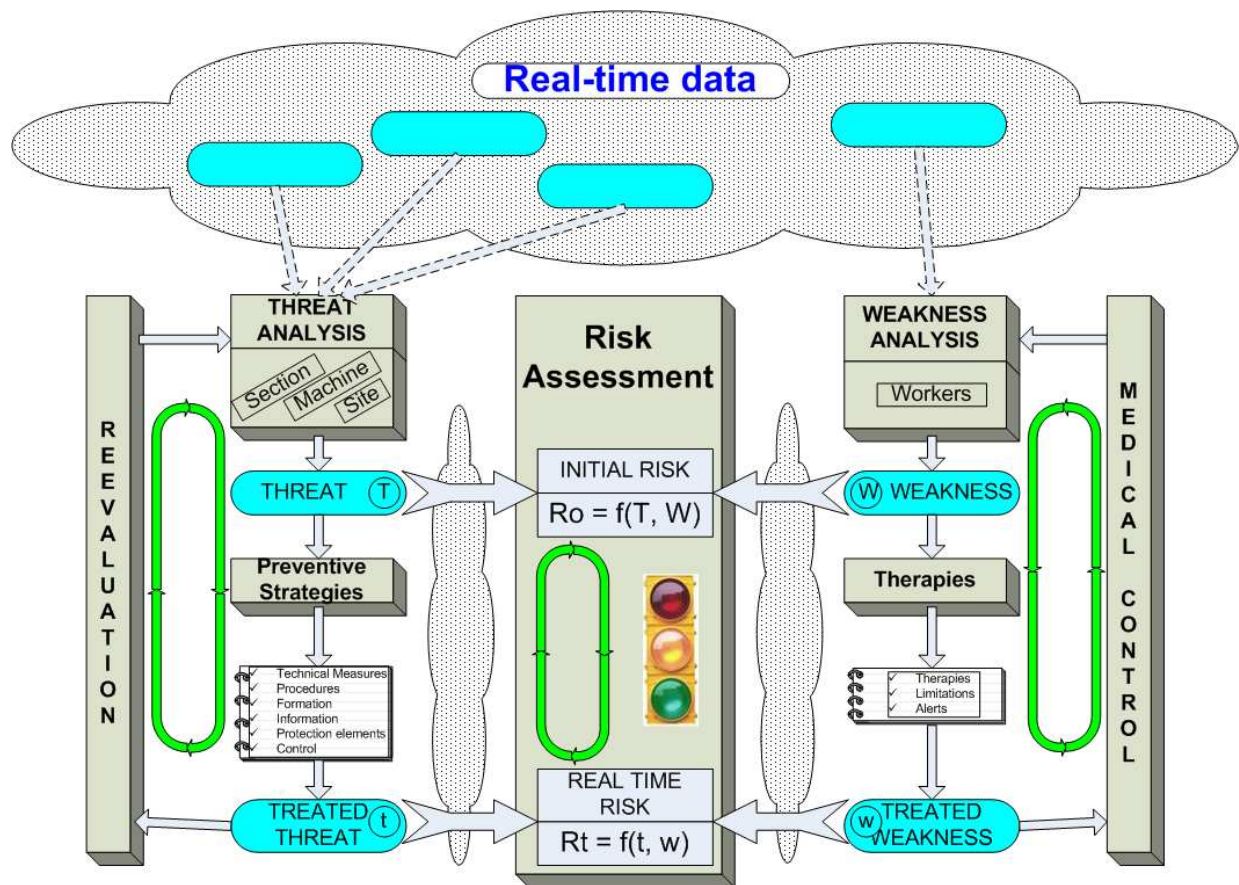

Figure 13. Continuous real-time risk management based on Complex Event Processing Technology

However, in the context of the sensing enterprise, ubiqutous smart object deployment and the availability of suitable universal virtual object abstractions make such control possible. Thus, a new risk management cycle can be designed based on the capability to master big data stream technologies in a scalable manner. FASyS has designed a consolidated framework for risk detection. FASyS does not only leverages effective data management but also consolidates an integrated approach to health (medical) and safety (security) risk management. The consolidated approach is shown below.

FASyS has proposed a complex event processing (CEP) [32] unit network that through a number of pre-set patterns, in the form of a complex formula compound by an undetermined number of factors, will feed and evaluate the patterns in a continuous way, creating alerts based on particular thresholds that have been previously defined and particular set of actions taken concurrently or sequentially place. These tools allow for big data volumes processing with really low computing infrastructure requirements.

However, FASyS data processing solutions go beyond big data volume. FASyS looks for flexible solutions that can create complex feedback and feedforward loops across CEP units to ensure that the time variable, the event frequency or event correlations-workflow can be processed at high speed.

6.3. Personalised decision support tools

As it has become apparent from the previous sections FASyS provides the tools and models for being able to process as much as information in less time as possible. Thus, the enterprise safety and healthy manager can work with relevant information to make informed decisions. The aim of FASyS personalised decision support tools is not just to warn and make apparent a particular risk level but also to ease the decision process based on strong knowledge support. FASyS Monitoring and Control Human Macine Interface (HMI) has therefore being designed to provide highly visual interfaces about risk levels. Moreover, the system also makes suggestions of the most suitable procedures to be aplied when a risk situation is detected, so that the reaction time can be hugely reduced and the user can send a highly effective execution action plan immediately.

The decision support system works with risk patterns that require a human interaction, either to provide additional information or to select preferred option in front of a multiple selection.

6.4. Semantic solutions for services coordination

In the context of the sensing enterprise, FASyS has to deal not only with the detection of risks but also has to support the actuation and deployment of the preventive actions selected by the safety and healthy manager through the personalised decision suppport tools. This implies that FASyS has envisaged a service oriented scenario, where the factory is populated by a large amount of services that exchange messages and perform

are coregraphed or orchestrated to perform the designed actions by means of smart objects.

Therefore, in the FASyS platform, there is a huge amount of available services involved in risk management life cycle. In addition, those services have heterogeneous sources; they can become available, temporarely unavailable or even disappear suddenly; the availability of them can change anytime. In order to solve these situations, FASyS has proposed a highly effective service messaging and service management and coordination semantic solution that would use choreography techniques focused on browsing FASyS service topology [33], which is made using an ontology definition; e.g. through WSDL or USDL descriptions. With this solution, FASyS is able to adapt its reactions to available services at any time and ensure the best possible service performance based on the precedence of the risk to be addressed and the service load in the enterprise bus. Clustering techniques allow for optimum selection of services to be orchestrated otr coreographed to servce a particular aplication in the prevention workflow. Those services could be previously known or even configured at run-time.

All of FASyS technological developments and systems have a semantic service library that would ensure the availability of its own functionalities to the rest of systems. The access to those functionalities will be assured continuously [34].
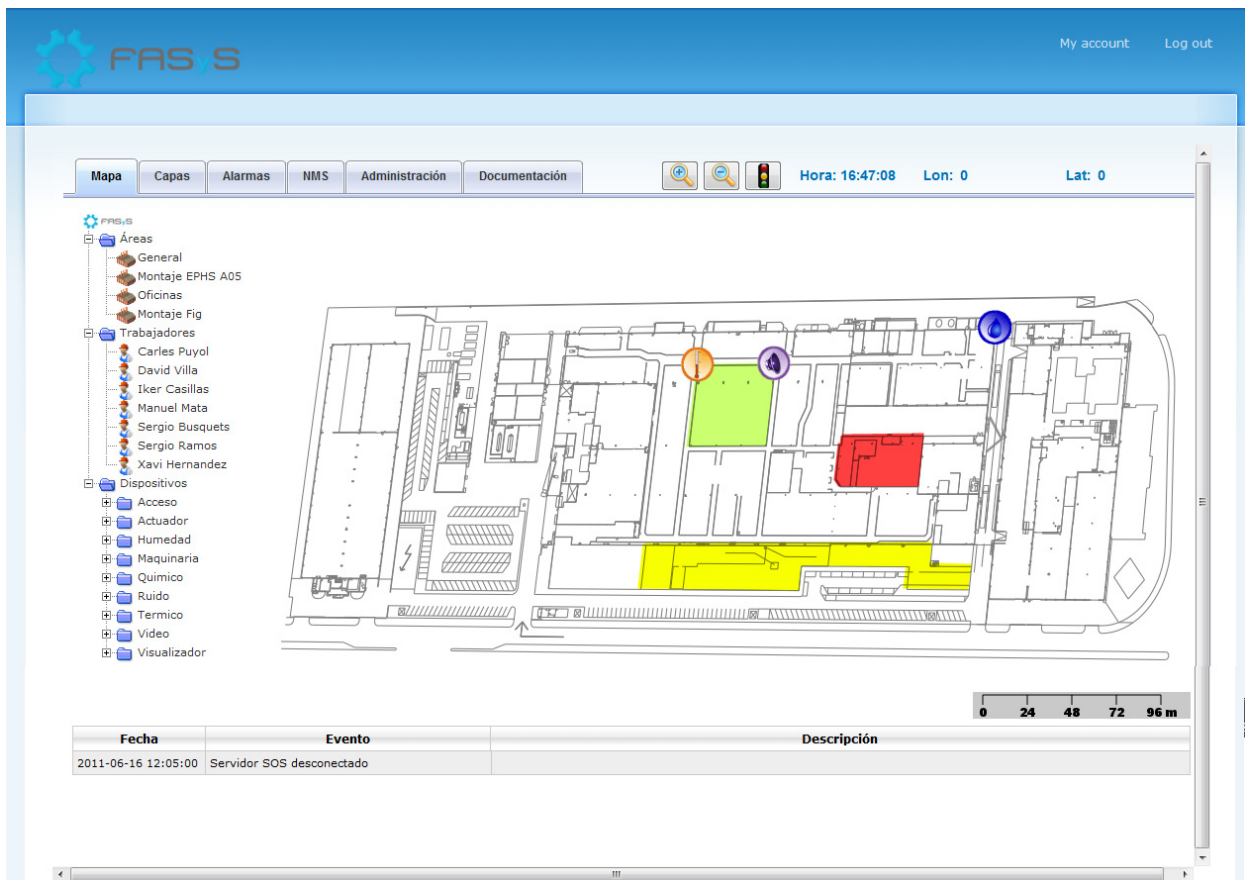

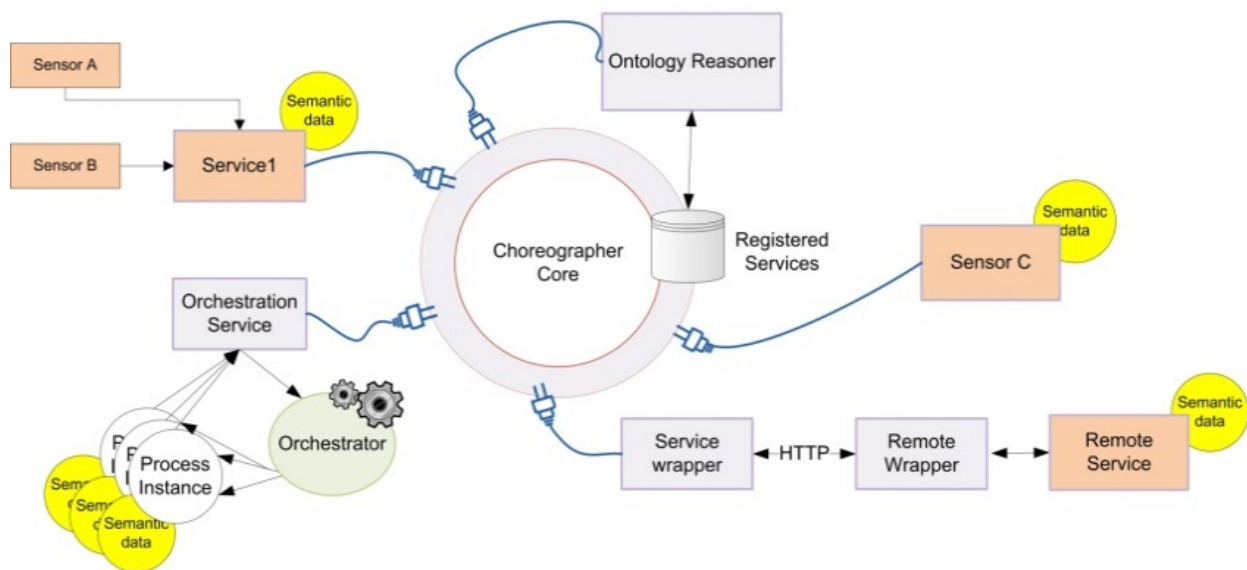**Figure 14.** FASyS Monitoring and Control Human-Machine Interface (HMI)

Figure 15. FASyS processes choreographer

7. Conclusions

This paper has presented the rationale behind the development of a risk management framework for personalised risk management in the context of the sensing enterprise. The paper has presented the main dimensions proposed for the model and it has presented the main technical components.

The paper has introduced the reference architecture and it has argued how this reference architecture is in complete alignment with European IoT movement currently under development. Moreover, the paper has provided evidence in terms of how the FASyS system is capable of providing a personalized and intelligent management of all the factors related, directly or indirectly, to the worker and its environment, in order to identify and detect warning situations, alerts and propose immediate actions required upon a worker, a machine or an area.

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