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Widespread Sensors and Artificial Intelligence for a Novel Safety Management System at the Seveso sites

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Sensors may be pervasively distributed throughout the plant, in the workplace and also worn by workers. They offer, coupled with Artificial Intelligence, a great opportunity to make safety management at Seveso sites much more dynamic and participatory. The article discusses how it is possible to exploit innovative systems based on pervasive sensors and AI to introduce important elements of flexibility and resilience in the SMS-MAH, while maintaining the consolidated structure envisaged by the Seveso legislation.

1. Introduction

Safety Management System SMS for the control of major accident hazard MAH is a pillar of the Seveso legislation. This legislation, over the last 30 years, has contributed to reduce definitely the number and severity of chemical accidents in Europe. At Seveso establishments, the adoption of a formalized SMS-MAH is mandatory and is subject to a program of periodical inspections, carried out on behalf of the Competent Authorities. The development of technologies poses new challenges and new opportunities for safety management, which the Seveso industries can seize in advance, as they already trust in a good safety organization. The widespread use of information and communication technologies makes much easier to record all minimal events and enlarge the base of information useful for SMS-MAH improvement. The location sensors, for instance, may be useful, to have the actual position of the event. Ambient sensors may provide further relevant information as well as sensors plugged in the equipment. By exponentially increasing the number of events, the analysis is more and more difficult and time wasting. The use of AI artificial intelligence techniques, including text mining and machine learning techniques can be valuable in expanding the number of events studied and increasing the ability to extract information, hidden within the event reports. The procedures and operating instructions should be practical, brief, lean and effective; they should include different formats such as diagrams, drawings, photos, videos. Information sheets and training material are further elements, and their dynamic updating is essential to have a staff at the highest level. The paper proposes a new model of SMS-MAH, featuring just a few formal procedures, constant over time and many dynamic resources easy to adapt to the changing environment, thanks to the enabling technology of industry 4.0, namely Sensors and AI. The basic idea of the proposed architecture is the following: the management system is very dynamic in the operational part, but needs a reasonable stability in its regulatory core, which is important because in Seveso contexts the management system also has a legal weight.

2. Safety management system for controlling major accident hazards

SMS-MAH is divided, according to Seveso legislation, into a Policy for the prevention of accidents and seven points, including: Resources and Leadership (including Training), Risk Assessment, Operating Control, Management of Change, Emergency Planning and Management, Performances (including Near Miss Management), Control and Review (including Audit). There is no international standard for controlling MAH; but, in Italy, there is a national standard, UNI 10616: 2019, which complies with the ISO 31000 framework standard. These recent developments have brought coherence and uniformity between the management systems. Thus, safety management becomes a single system in which the various aspects are then detailed. Further refinements of the management system are still possible but no further advantages in reducing accidents may

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be imagined. The science of safety has advanced far ahead of recognized standards and has been proposing more dynamic and flexible approaches for ten years: there are the Safety II and Safety III approaches, which integrate, to varying degrees, the concepts of organizational resilience in the management system.
Resilience is defined as the intrinsic capability of a system to modify its functioning before, during and following a disturbance, to continue operating both in expected and unexpected conditions. As reported by (Hollnagel et al. 2006), resilience has four aspects: ANTICIPATE, MONITOR, REACT and LEARN. Anticipate has the capability to prevent hazards and modify functioning to adapt to changes. Monitor is the control and supervise the system performance and its operating status by searching for potential weak signals. React is the capability to immediately respond to changes, regulate operations and avoid major damage. Learn is the capability to learn from past events in order to increase the level of safety. There is also the HRO High Reliability Organization approach which has a certain number of followers and which contains many points close to resilience approach, including Anticipation, Learning, Just Culture and Mindful Leadership. These are much more flexible and dynamic approaches than conventional ones. Their implementation requires a great deal of effort from the manager, by balancing preventative control, mindful action, performance optimization and adaptive innovation, as well as managing the tensions inherent to these distinct perspectives. The Seveso context has some peculiarities, which must be carefully considered, before experimenting with innovative ways:

i. SMS-MAH has a binding legal value and is subject to inspections by the authorities. These controls are in practice audits carried out according to established protocols. Inspectors are often key actors for the safety of the Seveso sector and not mere verifiers.
ii. SMS-MAH is mandatory at all Seveso plants, both upper and lower level. Establishments include complex plants, such as refineries and petrochemicals, but also simpler industries, such as oil terminals, factories and specialty chemical warehouses, for which a disproportionate effort cannot be demanded.
iii. The "real" approach to the management system by many national regulators is actually already more flexible than required by the standards. In inspections, two approaches can be followed: one systematic, based on very detailed and meticulous checklists, and one more systemic that starts from the discussion of operational experience (including near misses and anomalies) to identify the weak points in preventive or protective barriers, according to the bow-tie pattern (Bragatto et al. 2017). This favours a dynamic approach to safety management.
iv. Over the years, thanks also to the commitment of managers and inspectors, the management system in many plants has become very robust, although not resilient in the strictest sense of the term. This feature has proved very important in addressing the pandemic crisis (Bragatto et al. 2021).

Thus, the proposal is to maintain the formal scheme of the Seveso SMS-MAH, which is well tested and accepted by all stakeholders. Within the classic scheme, elements of flexibility, dynamism and adaptation may be introduced, drawing inspiration from the most modern approaches, including that of resilience. This avoids revolutionizing a well-functioning system. To do this, the potential of technology is used, especially sensors and artificial intelligence.

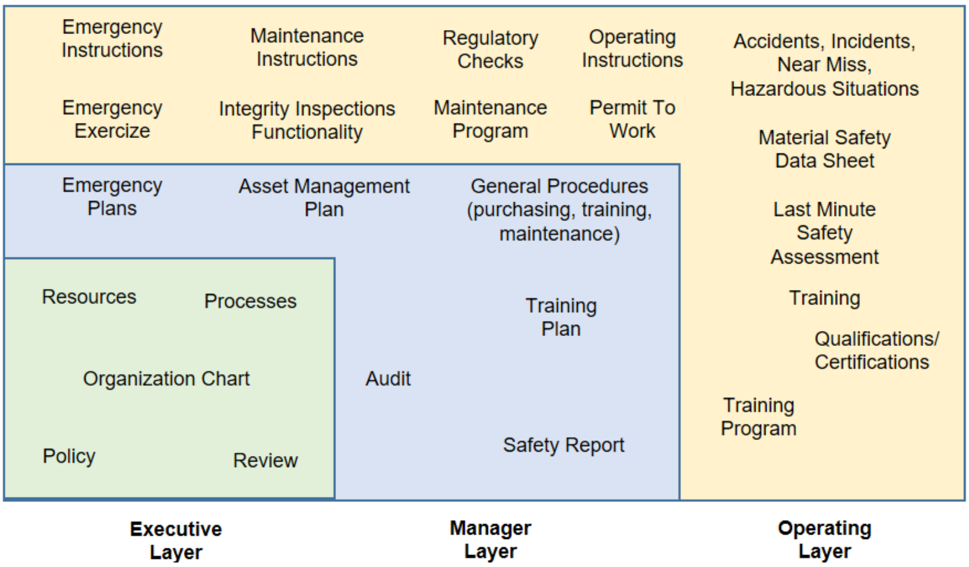

Figure 1: Safety management system

3. How to change SMS-MAH

The proposal represents the safety management system made up of at least three layers, one on top of the other. At the first layer, there are policy, resources, and the organization chart. All matters for top management, who make strategic decisions and set resources and budgets. The second layer contains the main processes (purchases, modifications, operation, etc.) with the related plans (training, maintenance, emergency). At this level, there is also the risk analysis and the safety report, updated every five years according to the law. This is the level of managers and, in particular, of the safety managers. At the most concrete and operational level, there is the implementation of general plans and procedures, i.e. verification activities, maintenance programs, individual permits to work, instructions for operating the plants, in normal and emergency conditions, accidents and near misses. This is the level of workers and heads of department. Figure 1 summarizes this view in a simplified way.

3.1 Executive layer

The “executive” core remains the same and rightly so, because there are the greatest responsibilities, there are the most binding legal obligations. Even if the scheme remains the consolidated one, it is essential that the policy, adopted by the higher decision-making level, includes at least an awareness of the variability of the context. In general, it is not possible to predict all external threats, but executive management must always be ready to anticipate in a timely manner the changes that could adversely affect the SMS. This means including in the policy the commitment to address any external crises, guaranteeing resources for maintaining minimum levels of safety in the crisis and for the rapid restoration of normal conditions.

3.2 Managerial layer

The managerial level is a little more flexible, but even there are mandatory obligations, including safety reports, inspections, communications to the authorities of plant and organizational changes. At that level, the general plans and guidelines are also defined which fall as obligations within the operational level. Even if not too many changes are made at this level, in planning the various activities managers will take into account the elements of resilience that can be introduced at the operational level. In training plans, which is one of the things set up at a managerial level, it is essential to include non-technical skills as well.
The risk analysis also involves formal obligations, in particular for upper-tier establishments, which include the risk analysis in the safety report to be submitted to the authorities, as well as emergency planning. Dynamic risk assessment is valuable for making last-minute assessments and adjustments in operation. The challenge is to harmonize it with formal documents (e.g. safety reports). Among the possible methods of risk analysis, the bow-tie has significant advantages to have an immediate understanding of preventive and protective barriers. The redundancy of the barriers is also fundamental to allow safe operations even in the event of a barrier failure due to unexpected changes in the external context. As part of operational control, there is the need to define the aging management plans, which takes into account the innovative resources used for the purpose, leaving their implementation at the operational level.

3.3 Operational level

The third level is the operational one, where many innovations may be introduced, without questioning the general model. The following sub-sections discuss a number of elements in the “operational” layer and point out what is needed to make it more dynamic and what technological solution can help. The list is not exhaustive, but gives the feeling of how to introduce elements of resilience or at least of robustness within the SMS-MAH. The discussion follows the eight-point scheme of SMS-MAH defined in the Seveso legislation.

3.3.1 Training and information

At the operational level, training already makes use of e-learning tools and, with the pandemic, this method is now consolidated in most Seveso plants. Instead, it is important to understand that the interaction and cooperation between the different levels of staff is growing to levels never done before.
The Industrial Internet of Things (IIoT) are providing new ways to integrate and deliver information. This is important, as newer workers are much more comfortable using portable devices than bulky paperwork and terminals. Thus, it is possible to provide the worker with the necessary information when they are needed, revive what they have learned with training and also receiving feedback. The gap between training and operations can become increasingly narrow (Agnello et al. 2012).
Location Awareness. The Location Awareness technology helps implement compelling solutions to protect workers. Using the wearable position sensor anchors, these solutions enable safety-oriented monitoring. Additional benefits better safety collection and management of physical or virtual fences. The privacy issue could be an obstacle to the application of these useful technologies. As discussed by (Bragatto et al. 2018), it

is therefore essential to study solutions that prevent the storage of sensitive data, except in the event that the reports may be relevant to safety or health (e.g. in the event of an accident).

3.3.2 Hazard identification and risk assessment

Material Safety Data Sheet. The Material safety data sheets (MSDS) are essential for knowing the hazards of substances and managing them in the best possible way during normal and emergency operations. The computerization of MSDS and the combined use of the IIoT, including smart tags, can be of great help, as discussed by (Tseng et al. 2009).
Digital Twin and Machine Learning. Even if the safety analysis is done at a higher level, the identification of hazards is still an operational activity, which benefits from the pervasive sensors present everywhere in the plant. Digital Twin solutions help to determine which process adjustments will improve performance by creating digital plant replicas. These virtual copies simulate plant data, automation systems and process resources in real time and allow providing modeling data of the predictive process for analysis in order to anticipate the emergence of new problems. Machine Learning can also be helpful in identifying risks. (Peng et al. 2019) applied the principle of machine learning from plant data and maintenance reports to provide effective measures and suggestions for users to complete the risk assessment process and ensure safety for personnel and facilities. As mentioned in the previous paragraph, these things are valuable for immediate evaluations and last-minute interventions.
Augmented Reality. (Nakai and Suzuki 2016) showed that Augmented Reality (AR) may also provide workers on field with the information they need in that situation. In this way too, knowledge is revived and training is integrated.
Confined spaces. Working in confined or suspected polluted spaces continues to cause fatal accidents and injuries, despite the strengthening of global regulations and standards. Confined spaces are defined as limited areas not designed for continuous occupation where employees enter and perform a specific task. In Seveso establishments, there are many areas known as confined, but also maintenance can create areas that have similar characteristics. (Botti et al. 2016) discussed the potential contribution of IIoT technologies to identify hazards and control the hazards of working in confined spaces.

3.3.3 Operative control

IIoT sensing and connectivity technologies are essential for safe and continuous monitoring of asset health and performance. Potential equipment failures may be detected before they affect operation, bringing together data from predictive intelligence applications and analytical tools to create an overall view of asset health. Moving from a reactive operations and maintenance approach to a predictive or prognostic strategy helps to extend equipment life and reduce overall costs while increasing plant safety, reliability and availability.
Corrosion monitoring. Wireless corrosion and erosion monitoring solutions provide continuous visibility of those deterioration mechanisms trends in real time by continuously checking the risk and impact of metal leakage in pipelines without having to touch inside and contact the process fluid. It is important to monitor the corrosion of static containment systems. A data-driven corrosion and integrity management program will ensure that the condition of the assets is known. As a result, maintenance and repair strategies may be optimized in terms of timing and scope, and unexpected outages can be avoided.
Vibration monitoring. By Smart Wireless Vibration Monitoring solutions, operators monitor machinery without having to enter a potentially hazardous area. With permanent installation, data are available more often than before. In general, connecting sensors to critical, remote, dangerous and hard-to-reach resources automates supervision and enables predictive and prescriptive maintenance.
IIoT to make operations safer. As discussed by (Gnoni et al. 2020) with the IIoT sensors interact in a work environment through a digital platform for the management of different types of hazards, e.g. involving plant and worker safety, usually affecting safety levels especially in the process industry. The fields of application of the system include the remote monitoring of the dangerous conditions of workers.
Permit to Work. The purposes of the “Permit to Work” (PTW) System are to ensure that work is carried out in safe conditions, inform workers of potential dangers and of the rules for working safely, check authorization and delegation of responsibility. For some time, these systems have been largely computerized (Tolba 2014). (Pika et al. 2021) wanted to extend the potential of the PTW. They studied process-mining tools, which analyze process execution big data, to derive a visualization. They used these tools to highlight the underlying complexity of the organization's work permit process, reveal compliance and performance issues.

3.3.4 Emergency

Many IIoT solutions allow to report and intervene quickly and effectively. The reports on the spot by the workers concerned are made available in the control room and at the other levels concerned. This speeds up the activation of emergency teams and the gathering of others at the collection points.

IIoT support for rescuers. Among the many solutions available, the automatic recognition and reporting of anomalous situations (e.g. person down). Rescuers entering smoke-cluttered plant areas can be equipped with inertial sensors combined with fixed anchors. This makes rescue more efficient and also protects the rescuer (De Cillis et al 2014). Thus, the rescuer is never left alone.

3.3.5 Near miss

Recording and discussion of incidents and near misses has been a pillar of the SMS for years. Learning from experience is essential to improve the SMS and adapt it to changes in the context. Including anomalies in the management of near misses allows personnel to increase attention to weak signals, anticipating potential weaknesses, which could compromise the SMS. The workers are encouraged to detect anomalies and near misses; those events are analyzed, with the support of supervisor or safety managers, for pointing out the critical points in the SMS-MAH, they represent an opportunity to recognize unsafe conditions and prevent incidents.
Near miss (NM) management with Artificial Intelligence (AI) techniques. Seveso establishments collect and analyze near misses and, the most virtuous ones, manage them into document archives. The challenge in developing near miss management system is to extract information and knowledge contained into the document repositories (Ansaldi et al. 2019). Thus, it is first necessary to have tools capable of managing texts in natural language, through text mining techniques that automatically recognize the parts of speech. Recently, more advanced techniques of artificial intelligence (AI), including the machine learning (ML) processes, greatly improve the automation of analyzing large amounts of data, including text data. (Ansaldi et al. 2021) discuss a methodology based on ML techniques for preprocessing the reports and extracting the concepts organized into an entity-relation model.

3.3.6 Review

Safety Walk. A safety walk is an "advanced" inspection of one or more logic units or the entire factory. It can be invaluable for an internal audit that allows having the control of the situation and perhaps updating the SMS-MAH. For each element of the equipment and machinery, through the data provided by a network of sensors, the inspector determines the information on aging, in the form of the probability of failure, as well as the expected residual life. The use of virtual reality techniques presents the data effectively to the auditor (Milazzo et al. 2019); through the walk, it is possible to understand the actual conditions and reported them to the highest levels of managers and executives.

4. Discussion

A Seveso establishment is always quite complex and cannot be entirely framed through the procedures and instructions encoded in the management system. Furthermore, the plant is never a closed system and is also affected by changes in the external context. In particular, the ongoing transition to low-carbon or carbon-free products and processes are inducing rapid changes throughout the oil supply chain, with inevitable repercussions also on the organization of safety.

Table 1: SMS with innovations and their resilience peculiarities

SMS points	Section §	Innovations	Resilience
Training and Information	3.3.1	Location Awareness	ANTICIPATE - MONITOR
Risk Assessment	3.3.2	Material Safety Data Sheet	ANTICIPATE
	3.3.2	Digital Twin	ANTICIPATE
	3.3.2	Augmented Reality	ANTICIPATE - LEARN
	3.3.2	Confined Spaces	MONITOR
Operative Control	3.3.3	Corrosion Monitoring	MONITOR
	3.3.3	Vibration Monitoring	MONITOR
	3.3.3	IIoT for safer operations	MONITOR
	3.3.3	Permit To Work	ANTICIPATE
Management of Change			
Emergency	3.3.4	IIoT support for rescuers	REACT
Near Miss	3.3.5	NM management with AI	LEARN
Performance			
Review	3.3.6	Safety Walk	MONITOR

Surely, the safety management system must evolve to include elements of resilience, in order to better adhere to the rapidly changing real world. In summary, to anticipate, data and information are not enough, basic knowledge is needed, phenomena and mechanisms must be studied a priori, technology serves to feed any modelling, but if there are no a priori scientific bases, it is possible do very little. The sensors spread pervasively on plants, in environments and even on workers allows continuous monitoring and makes a rapid reaction possible. Collected data and information are not lost and allow learning from experience and strengthen the SMS-MAH. Table 1 shows the summary of the previous discussions. For each SMS point (first column), the innovations, described in the referring section, are listed (third column) with their characteristic of resilience (fourth column).

5. Conclusions

The development of industrial security solutions based on industry 4.0 technologies has been very rapid in recent years. In the Seveso context, however, the effort of researchers and practitioners is important to channel this into the SMS-MAH, making it more effective, flexible and possibly resilient. This is also a challenge for Seveso legislators and regulators, who have to define the lines of development for the future.

Nomenclature

AI – Artificial Intelligence
HRO – High Reliability Organization
IIoT – Industrial Internet of Things
MAH – Major Accident Hazard
ML – Machine Learning
MSDS – Material Safety Data Sheet
NM – Near Miss
SMS – Safety Management System

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