Safety Science 157 (2023) 105931

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

Precision safety management (PSM): A novel and promising approach to safety management in the precision era

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ARTICLE INFO

Keywords:
Precision
Safety management
precision safety management (PSM)
Safety information
Safety risk

ABSTRACT

Precision is the ultimate goal of safety management. Over the past few decades, technological advances and applications (e.g., advances and applications of information technology) in safety management and its research have given safety managers the ability to pursue and realize relatively precise safety management based on sufficient and precise safety information. It can be said that safety management has entered the precision era. Therefore, in the present and future, developing novel approaches to precise prevention and control of safety risks is an inevitable safety management trend. This paper proposed a new and promising approach to safety management called precision safety management (PSM). The main objective of this paper was to answer the following five basic questions regarding PSM from a theoretical perspective: (i) What is PSM? (ii) Why is it necessary to develop PSM? (iii) What are the relationships between PSM and other concepts? (iv) What does PSM do? (v) How does an organization use PSM? Additionally, this paper presented the application of the PSM approach to the precise prevention and control of safety risks in a chemical industrial park as a case study. The main contributions of this paper are a theoretical framework for PSM, and a practical case for PSM. This study can help researchers and practitioners understand PSM and lay the foundation for its future research and practice.

1. Introduction

Accidents and disasters can lead to personal injury, social unrest, environmental pollution, and other negative effects (Rajeev et al., 2019). Safety is the bottom line that cannot be ignored in any industry. Safety management is a critical element of organizational management that effectively prevents and defuses safety risks (Wang et al., 2017). Therefore, safety management is a basic premise and necessary guarantee for social development.

With the advent of the era of precision (Wang, 2018), the concept of precision has penetrated several fields and achieved significant results. Applications of precision include precision agriculture, precision governance, precision management, and precision medicine (Melgar-García et al., 2021; Wang, 2018; Allegaert and Simons, 2021). As an indispensable component of the social governance system, safety management should be considered from the perspective of precision. The rising challenges faced by safety management have become complex and diverse in the information age and place society at risk (Huang et al., 2018). Therefore, there has been significant discussion over the past few decades about how to improve safety management models based on traditional safety management concepts. The era of digital intelligence requires smart management and a smart society should attempt to improve safety risk governance. Therefore, traditional safety management concepts no longer meet the current development needs of the safety field. What safety management urgently requires in the era of precision is to develop an intelligent and precise prevention and control model for safety risks.

With the rapid development of information technology and its widespread application in the field of safety science, it has contributed to the gradual trend of precision in safety risk governance. For example, in the context of "safety 4.0", digital intelligence technologies (e.g., big data, blockchain, and visualization technology) have been widely used in safety management (Wang and Wu, 2020). Additionally, new changes have occurred in safety management and computational governance has

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https://doi.org/10.1016/j.ssci.2022.105931
Received 5 February 2022; Received in revised form 22 July 2022; Accepted 13 September 2022
Available online 23 September 2022
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enabled safety management to advance in the direction of precision (Que and Lv, 2021). Digital intelligence technology provides more effective and precise prediction, sensing, and error correction guarantees for safety risk prevention and control (Irving and Askell, 2019). It can be applied in multiple phases of engineering projects, including design, construction, and acceptance, to identify safety risks in different areas precisely (Gambatese et al., 2005). Furthermore, it can provide reliable information for location tracking, augmented reality, and building information models to improve the identification of safety risk factors and hazards in management systems (Park and Kim, 2013). One can see that the essence of these studies is to apply advanced digital intelligence technology to capture sufficient safety information to prevent and defuse safety risks to improve the precision, accuracy, and validity of safety management. Precision in safety management does not aim for absolute precision, but rather a precise pursuit and goals aimed at the precise prevention and control of safety risks. Technological advances and their applications have empowered safety managers to pursue and achieve relatively precise safety management paradigms based on adequate and accurate safety information. Safety management has the technical basis for advancement and the development of a new safety management paradigm to handle multi-level safety challenges in the present and future is an important requirement for the development of safety science.

Since precision is the ultimate goal of safety management, precision safety management (PSM) is the inevitable trend of safety management research (the PSM discussed in this paper focuses on production safety management). As safety management transitions from approximate to precise, it is necessary to develop simple and efficient management modes with the support of digital intelligence technology and management theories. It should be noted that intelligence is emphasized in smart management, but intelligence is not equivalent to precision. PSM focuses on the degree of fitting between resource bottlenecks and decision solutions to promote the integration (i.e., integration of safety and development), differentiation, economy, science, and efficiency of safety management, which is a topic worthy of in-depth discussion in academia. Based on these goals, we proposed PSM as a novel concept to promote the research and practice of safety management. This paper presented the relevant concepts and systematically answered some basic questions about PSM. Additionally, as a case study, the PSM approach was applied to the intelligent and precise prevention and control of safety risks in an urban chemical industry park.

2. What is PSM?

To understand a management approach such as PSM, it is helpful to start with a definition that people can understand. This section presents our findings regarding the definition of PSM. To define PSM precisely, we must elaborate on its connotations from a precise perspective based on definitions from other fields.

With the advent of the era of precision (Wang, 2018), the phrase "precision" has become one of the most commonly used terms in different fields. To clarify the essence of the concept of precision and define PSM, we selected certain fields with broad social influence as references. The relevant content is summarized in Table 1.

Engels once said that thinking is the guide to behavior and precision thinking (Zhang and Yu, 2021) is an important means of understanding objective targets and solving practical problems. Precision thinking has been promoted, developed, and maturely applied to several fields, but it has not yet been extended to the field of safety management. Although the overall trend of safety management has developed in the direction of precision, PSM is an emerging trend and field of safety management, and specialized research on PSM is rare. The academic community has not formed a consistent view on PSM and lacks theoretical guidance. Research on PSM is emergent and there have been few reports on specialized research in this area, so existing relevant literature is rare.

PSM is a combination of precision and safety management.

Table 1
Some representative connotations of precision.

Authors	Concept	Specific connotation	Salient features
Luo and Chen, (2017)	Precision medicine	A patient's genetic information and individual characteristics are considered to design a suitable disease treatment plan.	Individualization
Zhan, (2017)	Precision treatment	Precisely classify and diagnose a disease according to the individual characteristics of a patient, tailor a solution, and implement the solution within an effective timeframe.	Pertinence
Khoury et al., (2016)	Precision public health	Provide the correct intervention to the correct person within a prescribed timeframe.	Timeliness
Mahlein, (2016)	Precision agriculture	Combine advanced information technology with agricultural management, monitor changes in the agricultural environment in real time, and collect crop status information to control the supply of water and nutrients precisely to realize the rational use of resources.	Refinement
Wang, (2016)	Precision governance	Target social problems and social needs, and use established social management tools to resolve social conflicts and provide public services through multiple avenues.	Target
Liu et al., (2022)	Precision management	Apply advanced science and technology to predict changes in environmental conditions so that corresponding measures can be taken in advance according to the environmental changes, thereby mitigating the impact of sudden weather changes on agriculture.	Validity

Therefore, clarifying the basic definition of precision is a prerequisite for accurately defining PSM. According to the content summarized above, we can understand that the essence of precision is to grasp precision, accuracy, and validity in the process of promoting management. The specific definitions of these terms are provided below. First, precision entails carrying out management work based on key problems and pursuing differentiated management, particularly in the field of safety. Second, accuracy refers to problem-oriented (i.e., the problem to be solved) approaches to risk classification and control to identify the correct hazard and apply targeted treatment. Final, validity indicates that the solution to a problem is implemented strictly within the required control time. Therefore, the key to precision is to identify key points for solving a problem and implement measures according to these key points to promote management work in an organized, scientific, and efficient manner. Additionally, precision thinking can effectively locate the key issues facing national and social governance, ensure the scientific rigor of the safety governance process, and express the reality of the need for effective safety management. Safety management is an important component of the social governance system that must incorporate the core concepts of precision thinking.

The degree of precise prevention and control of safety risks in the areas of natural disasters, accidents, human-caused disasters, public health, and social safety directly affects the effectiveness of safety management for resolving safety risks and resilience against safety risks (Zhang and Liu, 2021). By building upon the existing foundation, the introduction of precision into safety management can yield the new approach of PSM. Safety management is a set of processes or specific activities that can protect systems from consequences beyond their control (Li and Guldenmund, 2018). Its focus lies on prevention and resolution of safety risks, as well as accident prevention. Therefore, precise safety is the core of safety management in the era of precision and the precise prevention and control of safety risks is the entry point of PSM research. It is worth mentioning that PSM is an intelligent safety management mode and its goal is the same as that of safety management.

PSM is defined as the process of applying the best evidence and basic tools to control safety management objects using safety management subjects. PSM entails achieving intelligent and precise prevention and control of safety risks, where risk control requires clear actions performed by subjects on control targets. Therefore, in PSM, the safety management subjects are precisely identified as the managers who prevent and resolve safety risks. Safety management objects are precisely defined as the safety risks faced by the people, material, environment, and management in a system, which is the control target of the safety management objects.

i. The best evidence for PSM refers to safety information, safety intelligence, and safety intelligence products obtained through data, facts, analysis and demonstration approaches, rather than one-side management experience. Safety information is the foundation and basis of safety management (Wang and Wu, 2020). Safety intelligence is defined as safety information that is directly useful for safety management and can be analyzed and refined from a large amount of safety information (Wang et al., 2022). Safety intelligence plays the role of precise support for safety management. In general, safety management subjects explore the meaningful value of data (e.g., objective facts, analytical methods, and scientific theories) with the help of digital intelligence technology to obtain safety information (i.e., safety intelligence) with a high degree of correctness and relevance to safety management objectives. They then make the most appropriate safety decisions based on their knowledge perceptions (Wu and Wang, 2019) considered safety decisions as a safety intelligence product) to control safety risks.
ii. PSM focuses on the application of digital intelligence technologies (i.e., basic tools). Digital intelligence technologies include digital technology, intelligent technology, communication technology, and multimedia technology (Kohli and Melville, 2019), which support the analysis and processing of safety information and the PSM process. Digital intelligence technologies not only enable the digitization and visualization of safety information, but also comprehensively and precisely describe the safety management environment and process. Therefore, safety management subjects can fully explain safety management objects with the help of digital intelligence technologies. On this basis, they can implement various avoidance measures (e.g., strengthening the protection of vulnerable links, hierarchical control of safety risks, and developing emergency plans) to eliminate or transfer potential risk sources to optimize safety management. With the help of digital intelligence technologies, the management process can be made more precise, targeted, and effective.
iii. As shown in Fig. 1, from source of dangers to hazards and then to accidents, safety risks evolve through a process (Hu and Dong, 2022) and taking early safety measures are critical. The essence of preventing accidents lies in the prevention and control of safety risks. The purpose of PSM is to achieve early safety risk identification and danger points (i.e., points with high accident rates or points with significant and frequent consequences of accidents) searching using the best evidence and basic tools, allowing safety management subjects to control safety management objects in effective timeframes to prevent or reduce the occurrence of accidents.

PSM not only applies digital intelligence technology for real-time data collection, information analysis, and intelligent applications to improve the ability to predict safety risks, but also to adjust and control safety management targets in a timely manner in an effort to handle hazards that may pose significant safety risks in the embryonic stage. In summary, PSM is a vital manifestation of safety science entering the precision era (Wang and Wu, 2020) and it is an essential requirement for the development of computational safety science. PSM emphasizes the application of real-time valuable safety information to the entire process of safety management. First, safety management subjects fully grasp the nature and change laws of safety management objects (mainly their safety risks) based on the comprehensive collection of safety information. Second, they obtain safety intelligence through safety information analysis with the goal of identifying danger points. Finally, the dynamic and graded control of safety risks is realized with the support of safety intelligence.

3. Why is it necessary to develop PSM?

As discussed in the previous section, there is an urgent need to seek novel approaches to safety management and the main factors motivating new safety management approaches from a precision perspective are outlined below.

Technical advancement is the main driving force of PSM. A review of

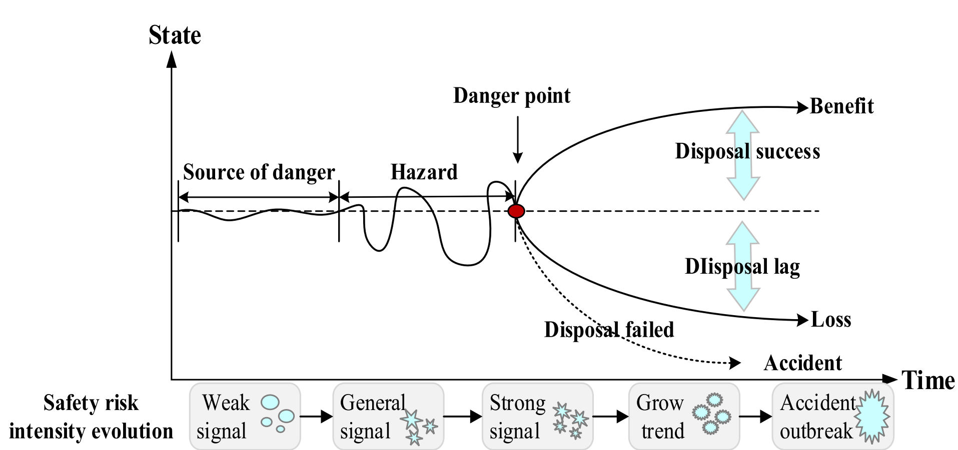

Fig. 1. Evolution of the relationship between risk, hazard, and accident.

recent relevant studies revealed that the evolution and application of digital intelligence technology has led to the development of safety management in the direction of precision and has introduced several significant benefits. For example, big data technologies can be used to predict where components are moving to eliminate potential hazards before they appear (Wang and Wang, 2021a) to prevent the occurrence of accidents. Safety sensors can provide safety managers with real-time safety information so that they can take safety actions before a crisis occurs (Chen et al., 2020). Intelligent fire safety early warning system optimization and reasonable linkage configuration can be implemented to identify electrical hazards in a building (Mu and Wang, 2021). Additionally, managers are paying increased attention to the position of new technologies for safety management. For example, the Ministry of Emergency Management of China proposed a pilot construction program called "industrial internet + danger and safe production" in 2021, indicating that digital intelligence technology is an effective means to improve the precise investigation and management of safety risks. This program emphasizes the promotion of deep integration of industrial internet, big data, artificial intelligence (AI), and other information technology and safety management tools in the field of hazardous chemicals. At both the policy and application levels, the greatest advantage of applying digital intelligence technology to safety management is cost reduction for eliminating hazards and significantly enhanced precision of safety management.

The contradiction between unlimited safety requirements and limited safety resources is the fundamental driving force behind the proposed PSM. It is understood that safety risks are ubiquitous in several fields (Pidgeon, 1991). The universality of safety risks makes safety requirements appear to be infinite. However, while the human pursuit of safety is infinite, the resources required to avoid and prevent safety risks are limited and the utilization of safety resources is often restricted by objective factors (Cheung et al., 2021), such as the safety information circulation degree, safety technology research and development level, and safety manager cognitive level and management ability. Based on dialectical thinking (Dowling, 2020) regarding this contradiction, it is clear that keeping pace with the times, innovative safety management is the intrinsic motivation to resolve the contradiction between safety pursuits and safety resources to promote safety development. The PSM aims to achieve the optimal use of safety resources (Chen et al., 2019) by focusing on precision matching between safety problems and solutions, safety needs and service supplies, and safety objectives and means of implementation, and strive to reduce safety risks to an acceptable level, rather than pursuing zero safety risks indefinitely.

4. What are the relationships between PSM and other concepts?

This section explains why we conducted research on PSM from a safety information chain perspective and discusses the relationships between PSM and safety information and safety risks.

4.1. Safety information chain and PSM

All systems are composed of information, energy, and matter, and the interrelationship between them, and information plays a key role in transmission and connection (Wu and Huang, 2019). From the system safety perspective, safety information is a representation of a system's safety state and change modes (Wang and Wu, 2020), and runs through a safety management system. Additionally, it is the best type of evidence for helping safety management subjects understand changes in the status of the system. Since safety information is an objective representation of a system's safety status and the manner in which it changes, it often contains redundant or useless safety information. Therefore, identifying useful safety information is the key to performing safety management work. It follows that safety information is the foundation of safety management (i.e., when safety management subjects obtain more precise safety information, they can make more correct safety decisions and achieve more effective safety management results). Therefore, the key to precision safety lies in identifying the evolution laws of safety information and processing safety information in a timely manner.

Liang (2003) stated that "information is a continuous concept in English and an 'information chain' is composed of five blocks, namely facts, information, knowledge, intelligence, and wisdom, which are logically related to each other in a cascading manner." Based on this description, Ma (2013) proposed that "achieving the transformation of data into information, then into knowledge, and finally into intelligence (wisdom) requires human subjective awareness and cognitive ability." Specifically, a safety information chain belongs to the information chain branch. This can be inferred based on the evolution of safety information, namely the acquisition of safety facts → collection of safety data → analysis of safety information → formation of safety knowledge → application of safety intelligence → realization of safety wisdom (as shown in Fig. 2). The end result of this evolution is achieving safety wisdom based on safety intelligence.

Safety facts are objective reflections of human thoughts and behaviors when conducting safety activities. Safety data do not automatically evolve into safety intelligence, the key to the evolution of safety information is people (i.e., safety management subjects). Safety data are physical symbols (e.g., numerical graphics and text codes) derived from safety facts, which cover a wide range of content and can only be accessed through the interpretation of safety data by safety management subjects in a specific context. According to safety goal requirements, safety management subjects utilize various effective approaches to analyze information in combination with human wisdom such that the structure and function of safety information is changed (Gersh et al., 2006) and transformed into safety intelligence to realize safety wisdom. It is important to note that the direct source of safety intelligence is safety information, rather than safety knowledge. The process of safety information analysis by safety management subjects cannot be supported by safety knowledge and the essence of safety intelligence is the ability to apply safety knowledge to solve safety problems. Safety intelligence can not only realize prediction in advance, judgment during an event, and perfection afterward, but can also realize the safety management concepts of "anticipatory guidance," "seeing and hearing better," and "precise policy execution." It is conducive to the development of safety management from local safety to overall safety and is an important concept for achieving the precise prevention and control of safety risks.

One can see that the safety information chain plays a comprehensive guiding role for PSM and its ultimate purpose is to achieve precise safety risk prevention and control through the application of safety intelligence. The realization of PSM is the ultimate goal of safety intelligence and it is the inevitable trend of safety wisdom. Therefore, research on PSM should be conducted based on the safety information chain (i.e., law of safety information evolution).

4.2. Safety risk and PSM

A safety risk is an objectively existing unsafe element that arises with the application of technical systems. Such risks are ubiquitous in most applications. From the perspective of risk science, safety risks cannot be completely avoided and prevented. Therefore, safety risk prevention is a constant phenomenon that determines the need for precise safety risk prevention and control. As shown in Fig. 3, accidents occur as a result of safety risk control failures. In other words, accidents are direct products of safety risks (Luo, 2020). Safety risk control failures are the root cause of hazards becoming accidents and unsafe factors require safety risk prevention to prevent control failures. Therefore, eliminating unsafe factors and hindering the formation of accident chains is the main focus of safety work.

Unsafe factors exist objectively, hence, if a certain component of a process is neglected, then there is a possibility that unsafe factors will continue to spread sources of danger or magnify hazards. If the critical

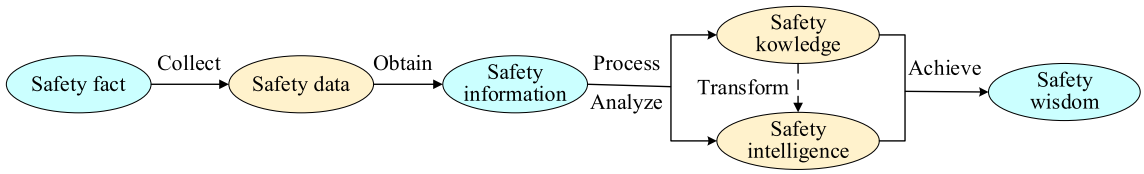

Fig. 2. The evolution law of safety information chains.

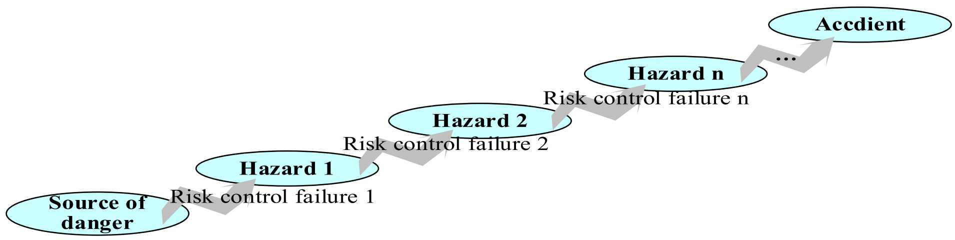

Fig. 3. Evolution from the source of danger to accident.

links of unsafe factors are not eliminated and controlled in a timely manner, then accidents are inevitable. The goal of all safety management work is to minimize safety risks to acceptable levels. Therefore, safety management must realize the differentiation and integration of safety risk prevention and control, and determine the commonality and individuality of safety risk laws to realize the specific analysis and solution of specific safety problems.

It is clear from the literature that allowing the evolution of unsafe conditions will lead to accidents. Therefore, the prevention of accidents begins with the prevention and control of safety risks. According to the risk law of the safety theorem (Chen and Cheng, 2021), the key to safety risk control is to reduce the possibility of accidents and control the severity of the consequences of accidents. Traced back to their essence, it is not difficult to determine that the danger points emphasized by PSM serve as the basis for safety risk control work. PSM applies the best evidence and basic tools to judge safety risks precisely to identify danger points and effectively respond to major risks, minimize safety risks, and keep unsafe conditions within an acceptable range.

5. What does PSM do?

5.1. What is its core?

PSM operates through the entire process of safety management, which relies on the four basic approaches presented in Fig. 4, namely the precise positioning of management subjects, precise research and judgment of safety risks, precise identification of scientific means, and dynamic guarantee of precise processes, to achieve early identification, timely prevention and control, and feedback tracking and dynamic monitoring of the entire process of safety risks to promote the formation of smart and precise safety risk prevention and control modes.

First, one must achieve the precise positioning of management subjects. Typically, safety management can be divided into normal safety management and abnormal safety management (Elliott, 2016). Compared to normal safety management, more emphasis is placed on the management of multiple subjects in abnormal safety management. Based on the higher demand for resource mobilization in the event of extraordinary accidents, a single entity is unable to take sole responsibility. In the face of complex safety problems, collaboration of experts from various related fields is required. For the prevention and resolution of safety risks using multiple managers, precise positioning refers to the functional positioning of multiple subjects for safety management work to achieve collaborative governance.

Second, one must achieve the precise research and judgment of safety risks. PSM objects are the safety risks faced by people, material, environment, and management during the management process. Specifically, we consider uncertain risk factors that induce unsafe human behaviors (Wang and Wang, 2021b), unsafe material conditions, unsafe environmental conditions, and management defects, which cause work to deviate from the normal state. The intensity of safety risk signals

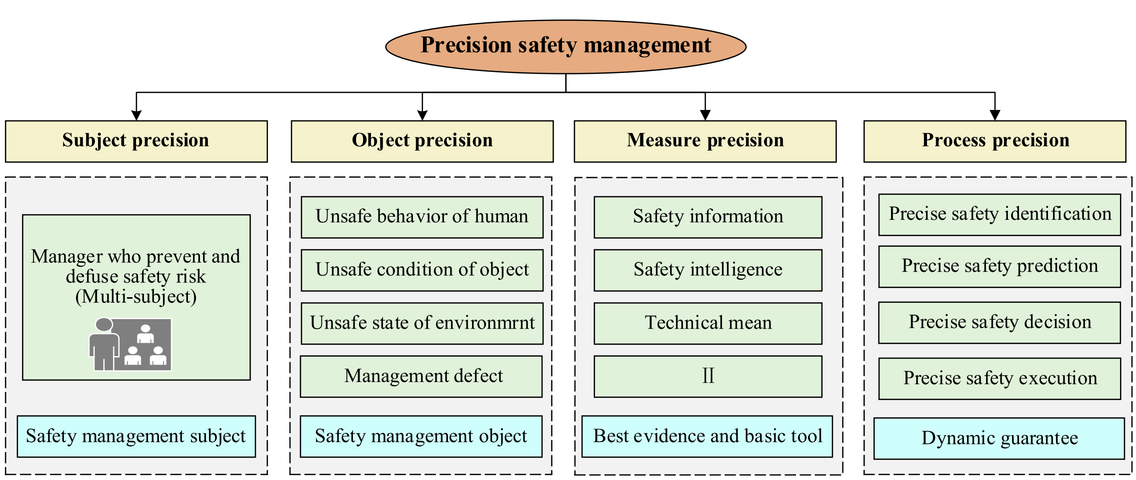

Fig. 4. Theoretical framework for PSM.

throughout the management process (see Fig. 2) and most of the early stages of risk prevention and control failure are traceable with scattered weak signals and early warning signals. Unfortunately, the fragmented, weak, and ambiguous nature of these signals causes them to be mixed with background noise, and hence, they may be ignored or delayed. Therefore, the precise research and judgment of safety risks refers to the comprehensive and precise description of the safety management process with the help of safety intelligence and digital intelligence technology. This process integrates various unsafe factors to explore and predict the laws of safety risk changes, focuses safety management on prevention and source management in advance (Jain et al., 2018), and strengthens essential safety.

Third, one must achieve the precise identification of scientific means. Digital intelligence technology provides advantageous conditions for safety management, but also introduces certain challenges and problems. The massive amount of information provided by the internet and real-time data transmitted by devices lead to a flood of safety information. The openness, diversity, and complexity of these data lead to stricter requirements for information processing in safety management work. The application of digital intelligence technology can not only digitize and visualize safety information, but also comprehensively and precisely describe the safety management environment and process. The application of digital intelligence technology is a quantitative analysis aiming to reduce or eliminate the subjective deviation in analyzing objective facts. While digital intelligence technology attempts to imitate and analyze human beings based on computational algorithms and big data analysis, it cannot precisely predict people's minds. Thus, the key to achieving PSM is that managers complete the safety management process based on their thinking, cognition, and motivation by using digital intelligence technology. Therefore, the precise identification of scientific means refers to safety management subjects apply digital intelligence technology to broaden safety information collection channels and improve the quality of safety information. It captures the behavioral characteristics of management objects at the micro level and grasps the changes and data updates of safety management objects in real time with the goal of better analyzing and researching safety risk points.

Finally, one must achieve the dynamic guaranteeing of precise processes. Precise safety requires both a comprehensive grasp of the tasks of safety management and identification of key issues to identify major contradictions precisely because key work drives the promotion of all types of work. PSM implements the process of safety management through four functions, namely precise safety identification, precise safety prediction, precise safety decision, and precise safety execution to achieve the precise prevention and control of safety risks. Specifically, the dynamic guaranteeing of precise processes indicates that safety management subjects should use precise safety identification as a basis for pinpointing safety problems and control priorities. It utilizes precise safety forecasting as the focus point, precise safety decision as the key point, and precise safety execution as the power point to identify all the main points of safety problems to solve them and realize the dynamic guaranteeing of safety management.

5.2. What are its functions?

Specifically, PSM aims to obtain safety intelligence through safety information processing and analysis with the support of digital intelligence technology. PSM performs precise safety identification, precise safety prediction, precise safety decision, and precise safety execution activities based on safety intelligence to achieve the safety management goals of integration (i.e., integration of safety and development), differentiation, economy, science, and efficiency (as show in Fig. 5).

i. Precise safety identification with comprehensive monitoring and focal point. Safety management subjects apply digital intelligence technology to monitor safety risk changes comprehensively and obtain safety data information, as well as complete safety data information correlation analysis and law mining. Based on multi-source safety data information collection and safety risk perception, safety management subjects must clarify the concepts of precise safety risk prevention and control, and then conduct the coarse screening of data and filtering of irrelevant information to achieve the precise identification of safety risks.
ii. Precise safety prediction with risk classification and intelligent warn. Based on the safety information extracted from safety risk identification links, zoning classification of safety risks is implemented. By relying on the computing power of digital intelligence technology (i.e., applying various model algorithms and multi-source heterogeneous big data for computational analysis) to achieve efficient data governance, one can perform precise diagnosis and grasp the evolution of safety risk laws and development trends. In this manner, one can realize the precise positioning and early warning of major safety risk points, prevent the formation of safety risk clusters (i.e., clustering of safety risks in the spatial and temporal dimensions), and avoid the occurrence of systemic safety risks.
iii. Precise safety decision with target decomposition and dynamic analysis. Based on the safety intelligence obtained from precise safety prediction combined with digital intelligence technology to deeply analyze safety management objects (Sorokin et al., 2019), one can fully grasp the real-time changes in safety management objects and their environments. Safety management subjects define the degree of hazards and assess the level of safety

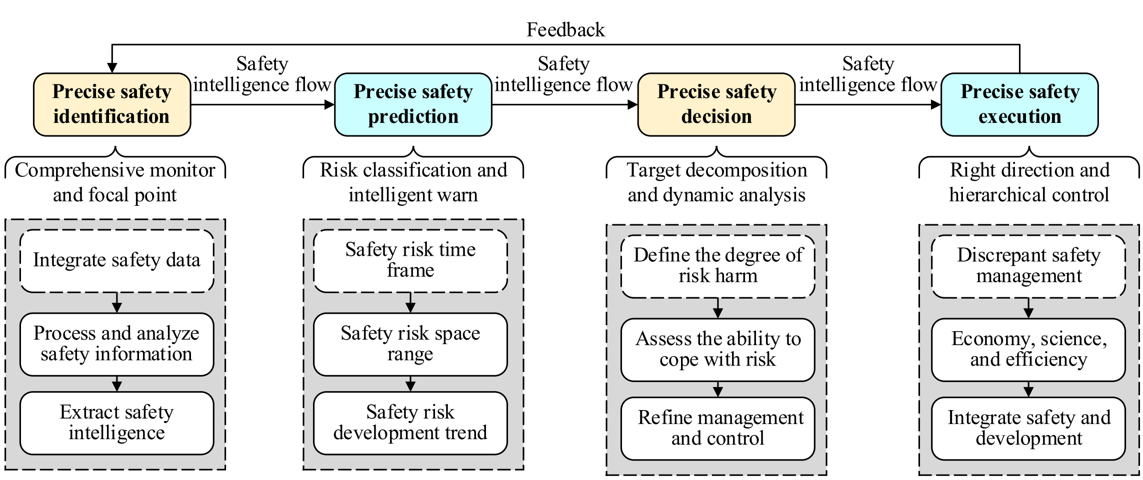

Fig. 5. Main functions of PSM.

risk, and then make practical safety decisions for safety problems, which serve as safety intelligence products. Links maximize the elimination of information asymmetry and ensure the flow of valuable information.

iv. Precise safety execution in the right direction through hierarchical control. According to the goals and focus of safety management, safety management subjects attach importance to the individualized and differentiated needs of control targets. They solve different safety problems and eliminate safety risks based on the commonality and individuality of safety risk laws and their flexibility, and implement differentiated safety management and the precise deployment of safety resources. Additionally, they can clarify the applicable areas of security decision programs and specific security measures, strictly implement decisions and specific measures, and realize the hierarchical control of safety risks.

6. How does an organization utilize PSM?

6.1. The PSM model

The essence of PSM is the process of collecting, analyzing, and processing safety information to obtain safety intelligence, and applying safety intelligence to identify and control safety risks. According to the above analysis, safety risk is defined as an objective unsafe state in a system that exists during the entire process of safety management. PSM is a process for protecting a system from uncontrollable consequences. The evolution of the regular laws of safety risks is closely related to the occurrence of accidents. Most early failures of risk prevention and control measures have traces that can be followed and there are scattered early warning signals.

A signal (Mallat, 2010) is a carrier for information transmission (e.g., sound, light, and electricity) that first appeared in the field of communication and gradually expanded to other fields. In intelligence research, signals include a variety of signs, indications, and clues before an event occurs. Signal analysis is the interpretation of the signs, symptoms, and clues of an accident for predicting future development trends to provide timely warning for possible risks and crises. Therefore, it is important to be proactive in handling the signals generated by the evolution of safety risks and collecting various early signs, data, and information. Safety management subjects find warning information through signal analysis and quickly transform it into valuable safety intelligence. Then, with the help of digital intelligence technology and safety intelligence, they can prevent safety risks from developing into accidents.

Therefore, based on the safety information chain, we constructed a PSM model and designed an intelligent and precise safety risk prevention and control pattern based on the concepts of "digital intelligence empowerment + signal analysis," as shown in Fig. 6.

As shown in Fig. 6, the model follows precise safety identification, precise safety prediction, precise safety decision, and precise safety execution as the main research line, which consists of four major sections, namely monitoring perception, data process, information service, and intelligence application.

i. Monitoring perception is the basis for the precise identification of safety risks and safety risk signal discovery. Early in their development, most accidents are traceable and there are corresponding scattered weak signals (Guillaume, 2009). Before an accident occurs, safety risks in the system are in a continuous process of progress and change and emit weak warning signals. Safety management subjects should capture and analyze these weak safety risk signals before they become strong. Weak signals exhibit fragmentation and weakness before evolving into strong signals, making them difficult to detect. Therefore, based on specialized equipment associated with digital intelligence technology, such as remote monitoring, environmental sensing, and automatic alarm equipment, safety management subjects can connect the real-time statuses of management objects and their environments through the internet. They can then actively collect and scan for signs, symptoms, and clues that exist in a system to detect (the key is the safety management subject's alertness and attention to "anomalies") weak warning signals generated by safety risks.

ii. Data process is key to the precise prediction of safety risks and safety risk signal identification. Signals are scattered, fragmented, and incomplete system data or environmental data with no clear meaning (Guillaume, 2009). Early safety risk signals tend to be weak and only when they accumulate to a certain amount can they be integrated and mined by safety management subjects (i.e., intelligence personnel). Signal recognition is subjective in nature and different intelligence personnel have differences in terms of their perception of signal recognition. Therefore, based on the concepts of cognitive completion and safety information piecing, subjects can use digital intelligence technology to determine the authenticity of weak signals. Intelligence personnel use big data technology to process multi-source heterogeneous data (Wang et al., 2021) and use suitable analysis approaches (e.g., model calculations) to integrate data with the goal of removing redundant information and outputting safety information in a visual form (e.g., graphical mapping and knowledge reports) that facilitates the sequential processing of safety risk signals and elimination of false safety risk signals.

iii. Information service act as the bridge to precise decision regarding safety risks and the interpretation of risk signals. Safety management subjects process and analyze safety information from which false risk signals have been eliminated to extract safety

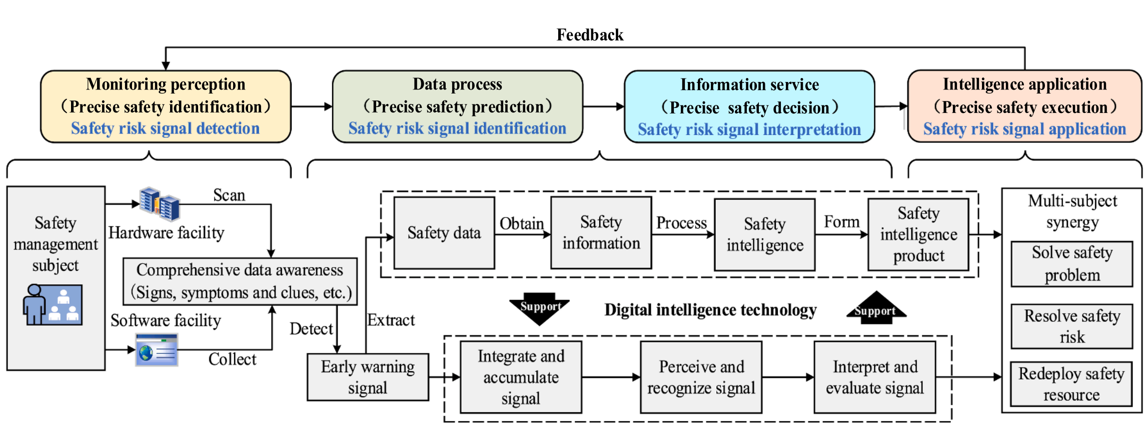

Fig. 6. A model for PSM.

intelligence, and then classify, organize, and interpret the collected safety risk signals to identify potential disadvantages and clarify the safety defects of a system. First, with the aid of digital intelligence technology (e.g., using "private keys" in blockchain to enhance the security of safety information and ensure the quality of safety data, using AI "automated processing" to deeply analyze the intelligence value contained in safety information, and using cloud computing to measure the development trends of accidents), they can interpret safety problems and confirm the precision of information. Second, based on past experience and an organization's risk index system, subjects can predict the existence of safety risks, impact levels, outbreaks, and major characteristics. Finally, possible safety risks are graded to perform scientific decision making and promote safety management overall.

iv. Intelligence application is the core of precisely handling safety risks and achieving safety risk signal application. Safety risks are not static and there are certain correlations between different categories of safety risks. When one type of safety risk arises, other safety risks may arise in conjunction or even overlap with each other to create or expand different types of safety risks (Verbano and Venturini, 2013). Therefore, we identify risk factors based on safety risk signals, comprehensively analyze changes in the internal and external environment (e.g., human, material, environmental, and management factors), perceive changes in safety risks in a timely manner, form different safety intelligence products, and transmit them to subordinate departments. By utilizing multiple resources, diversified entities can implement safety programs by following the common law of safety risks, pinpointing common safety problems, and formulating one or a set of safety measures to solve multiple safety problems. Simultaneously, based on the individual laws of safety risks, they can precisely study and evaluate specific safety problems covered by specific or similar major safety risks to achieve economic, scientific, and efficient differentiated safety management. Most importantly, the results of safety risk signal analysis and intelligence application effect are archived to optimize precise safety risk prevention and system control.

6.2. Case study

Fig. 7 presents a longitudinal view of the control of hazardous chemicals in a chemical park based on the establishment of an intelligent and precise safety risk prevention and control model to verify the effectiveness of the PSM model.

The overall architecture of the chemical park is designed in accordance with the multi-layer layout of a perception layer, operation layer, management layer, and control layer to collaborate with enterprises, the park, and government subjects related to safety management. The chemical park assembles several petrochemical and chemical enterprises that handle a large number of dangerous chemicals, complex production processes, and numerous sources of danger. Therefore, the chemical park applies digital intelligence technology to create an industrial Internet platform to construct full-factor networked connections with rapid response times. The platform covers the entire industrial chain of hazardous chemicals in production, storage, utilization, operation, and transportation to achieve comprehensive and precise information acquisition. It is mainly applied in the perception layer and supports the safety supervision of the park.

The perception layer realizes the comprehensive perception of data

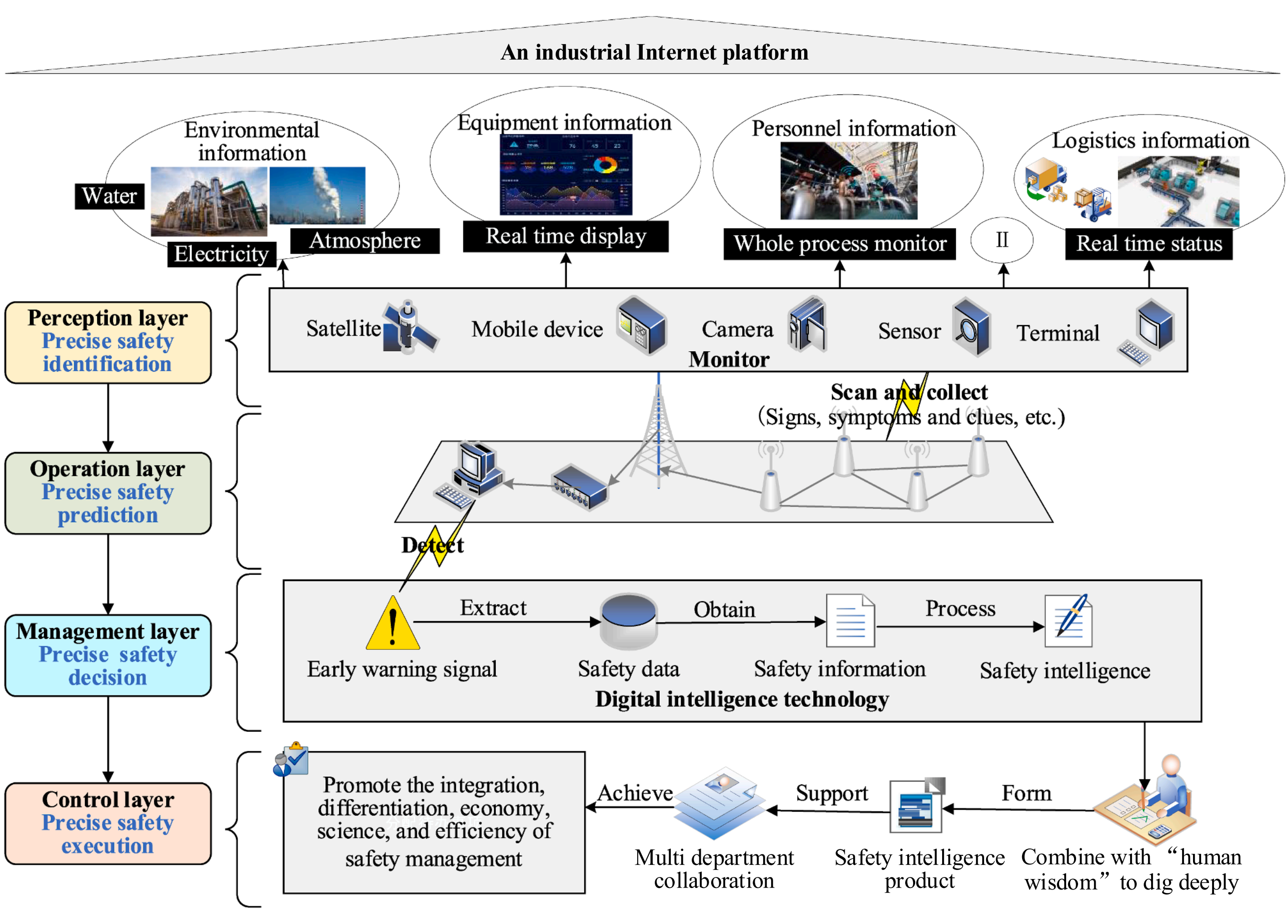

Fig. 7. PSM in a chemical park.

from multi-source equipment, heterogeneous systems, operating environments, personnel, and inventory with the support of intelligent technology and displays the real-time statuses and operation modes of devices to enhance the monitoring of hazardous processes. The operation layer is combined with digital intelligence technology to scan and collect signs, symptoms, and clues in the system to detect early warning signals. Based on thinking and cognition, management-layer intelligence personnel analyze safety information pieced together with the aid of digital intelligence technology to identify the authenticity of weak signals and realize the interpretation of safety risk signals. Specifically, based on big data, satellite remote sensing monitoring, and other intelligent technologies, they can collect water, electricity, fire, security, and other data of key devices. Signals are scattered system data with no special meaning. Therefore, advanced algorithmic technology (e.g., machine learning is utilized to identify and screen data sets by scanning signs, symptoms, and clues, as well as interpret early warning signals combined with existing knowledge to predict the evolution trend of safety risks. Cluster analysis is utilized to classify data and information with various similarities and output by visual map to help find closely related risk factors) is applied to mine valuable information to process the safety risk signals of each link sequentially to obtain safety information, which is then combined with human wisdom for refinement into safety intelligence.

With the support of safety intelligence, the management layer comprehensively analyzes changes in the internal and external environment of the park and accelerates the analysis and prediction of safety risks to understand and systematically grasp changes in the progression from safety risks to disaster-causing accidents in the park, which facilitates safety decision (i.e., safety intelligence products). The control level classifies and grades the risk list according to the possibility and severity of consequences, refines the safety risk responsibility lists of safety managers and operators at each level, and combines them with the operator inspection system. Through intelligent inspection, we can construct a differentiated management system for safety risk classification and control (Yuan et al., 2022), and hazard investigation and management to realize intelligent early warning.

According to this analysis, it is clear that the application of digital intelligence technologies (e.g., information technology and computational analysis technology) to the control of chemical parks significantly improves operational efficiency, precise prevention, and control ability of all aspects of safety management, and enhances the management path of chemical parks. Overall, it can strengthen the synergy of the park management department linkage to focus on prevention and control, management subjects at the government level participating in multiple collaborative transfer, management of fragmentation and systematic transformation, and prevention and resolution of safety risks at their source.

7. Limitations and future directions

This article provided new insights into the fundamental issues of PSM and discussed the application of the best evidence and basic tools in the process of intelligent and precise prevention and control of safety risks from both theoretical and practical perspectives.

However, our study has some clear limitations. For example, the basic questions and determinants of PSM were not detailed exhaustively in this study. We only focused on discussing the primary issues and related model development of the PSM approach at the theoretical level. The proposed model and approach are still incomplete and need to be improved further through additional experimental studies and quantitative analysis.

Additionally, practical research on PSM is urgently required from members of the industrial sector to achieve intelligence and precision in safety management. Therefore, some future research directions that deserve attention are listed below. (i) The application and effectiveness of digital intelligence technology in PSM should be analyzed. (ii) Precise matching between safety problems and solutions, safety demand and service supplies, and safety objectives and execution means is required. (iii) Effective communication among safety management subjects in PSM is necessary. (iv) Influencing factors in the implementation of PSM in an organization should be studied. (v) The specific influence of PSM on safety science should be evaluated, and precise safety science as a new safety science area should be established. (vi) PSM and traditional safety management paradigms should be combined. (vii) The integration between PSM and some new safety management approaches (such as smart safety management (Lyu et al., 2022) and evidence-based safety management (Wang, 2022)) should be elaborated.

8. Conclusions

The term "precision" is popular in several fields, including medicine, agriculture, and management. Since safety is the basic guarantee of social and national stability, safety management must progress rapidly and safety risk control must be developed in the direction of precision. This paper identified the current challenges and problems associated with safety management to motivate the urgent transformation of safety management modes. Inspired by the concept of precision, we proposed a novel effective safety management paradigm for the information age called PSM. We analyzed the definition, core, and main functions of PSM and other basic issues. Finally, a PSM model was developed to provide a clear operation framework and detailed research was conducted through a case study to promote the integration of theory and practice.

From the perspective of safety information, PSM is the process of obtaining safety intelligence by collecting, analyzing, and processing safety information, and using safety intelligence to identify and control safety risks with a focus on improving the precision, accuracy, and validity of safety management work. The era of digital intelligence has introduced changes in thinking and technology related to safety management. PSM breaks out of the traditional safety management paradigm, broadens the vision and depth of safety management, and promotes the formation of intelligent and precise safety risk prevention and control through precise safety identification, precise safety prediction, precise safety decision, and precise safety execution to complement and improve upon traditional safety management systems. Overall, this study puts forward the concept of PSM and further improves the theory and practice of safety management by establishing a theoretical framework for PSM and providing a case study for its practice.

CRediT authorship contribution statement

Bing Wang: Writing – review & editing, Supervision, Funding acquisition. **Miaoting Yun:** Writing – original draft. **Qiong Liu:** Writing – review & editing, Supervision. **Yuanjie Wang:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the reviewers and editors for their positive and constructive comments and suggestions. This study is supported by the National Social Science Fund of China (No. 22ZDA121).

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