Accident Analysis and Smart Management Model of Metro Safety

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ABSTRACT

An increasing number of developing countries step into the new underground network traffic era, where metro safety management faces great challenges. This paper collects 243 metro safety incidents in 48 cities around the world. The statistical results show that the number of metro safety accidents does not decrease with the development of society, and there is a positive correlation between the number of accidents and the number of people injured in the accidents. Interrupted train operation accidents are the main type of metro safety accidents, followed by fire accidents, train derailment and impact accidents, and terrorist attacks. As a major component of smart city development, metro safety management is an important part of the healthy development of large cities. The expansion of big data and the development of the IoT technology play an important role in the feasibility of smart metro safety management. In this paper, the prospect of big data applications to smart metro safety management is described. A new development direction of smart metro safety management is discussed, and a system structure model of smart metro safety management is proposed. In the context of big data, this study provides a reference for researchers and industry to the research on and development of smart metro safety management in the future.

KEYWORDS: metro; safety accident; smart management; big data; IoT

INTRODUCTION

Metro railways exist since the mid-1860s in all major cities all over the world. With the rapid growth of population and economy in Asia and South America, new metros began to be built. For example, by 2020, more than 40 Chinese cities are planned to have more than 6000 kilometers of metro lines, bearing 40-50% of the total urban public transportation (Figure 1) [1].

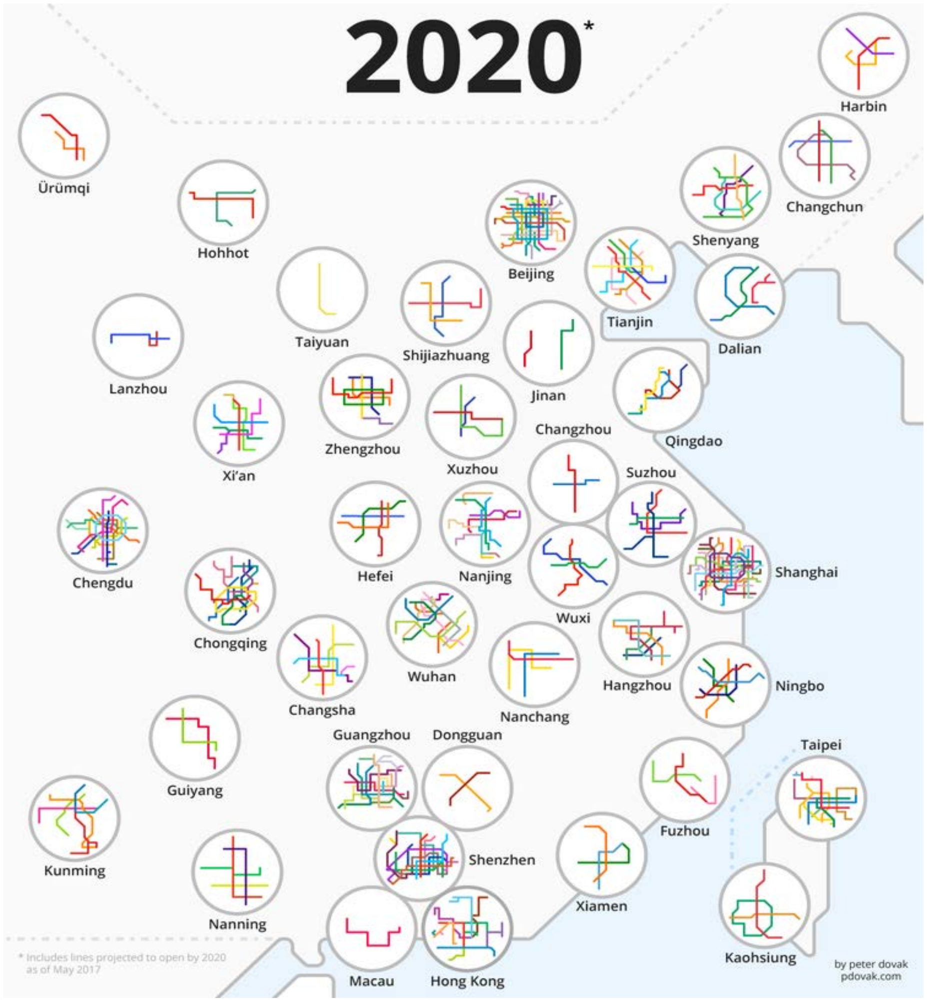

Figure 1: Sketch map of Chinese urban metro in 2020

Metro is considered the safest type of urban transportation. The safety accident rate of metro is much smaller than that of urban road traffic. But metro operates in an underground confined and narrow space, and carries a larger number of passengers, so, in an event of a safety accident, the death toll and property losses are often higher than those in a road traffic incident. The main influencing factors of metro safety accidents include electrical equipment and train failures, management defects, natural disasters, passenger unsafe behavior, terrorist attacks, and operational errors. Metro safety accidents caused by these factors have the characteristics of being sudden, destructive, hidden and dynamic.

The emergence of metro accidents has made people pay more attention to safety management. Metro operation safety management has important influence on all aspects of society, such as social and economic development. The operation safety management of metro can reduce the occurrence of safety accidents to a certain extent. In order to solve the problem of population growth, great efforts have been made to build more metro tunnels in Asia and South America. Many countries have entered the new era of underground network traffic. With the development of metro networks, the difficulty of metro safety management has been greatly increased. Accordingly, many organizations and researchers try to identify the potential risk factors of accidents, and carry out in-depth research on metro safety management. Tsukahara et al. [2] study largescale fire emergency evacuations in metro stations, which is a significant factor in minimizing damage and avoiding loss of life in an emergency. Zhang et al. [3] investigate metro topological characteristics with network theory to assess the extent to which a metro network is robust against random and malicious attacks, independent of differences among metro stations and passenger flows. Kyriakidis et al. [4] proposed a safety maturity model to address behavioral and attitudinal culture, technical and methodological elements, and actual achievements in accordance with safety outcomes. Yan et al. [5], for example, use Data Envelopment Analysis (DEA) to assess the risk of being crushed by crowds and trampling accidents according to the risk characteristics involved. Lu et al.[6], on the other hand, analyze safety risk in metro operations using Case-Based Reasoning (CBR), including case representation and retrieval, noting that the precision by which the similarity of the input and stored cases can be determined has a big impact on the result. Zhang and Hu [7] present a multi-objective maintenance model of cost effectiveness, aiming to optimize the maintenance strategy of metro vehicles, as the maintenance level of all kinds of equipment is a crucial factor in reducing failure frequency. Wan et al. [8] explore the classification and effects of passenger behaviors and their relations to incident involvement, and the results might help in understanding passenger behaviors and targeting metro safety interventions in ways that promote safer operations. Zhang et al. [9] presents an adaptable metro operation incident database (MOID) for containing details of all incidents that have occurred in metro, whilst the MOID can be used to identify trends in the incidents that have occurred and to anticipate and prevent future accidents. LI et al. [10] establish metro operation hazard network (MOHN) for making beforehand strategies prior to metro accident and contributes to elevate system safety of metro operation.

At present, the existing studies play an important role in the prevention, prediction and safety management of metro safety accidents. However, few studies address metro safety management modes. The emergence of new technologies is expected to break the current research status, and gradually promote the development of smart metro safety management models. Technologies, such as big data methods, cloud computing, and the Internet of Things (IoT), are already in our lives, affecting jobs and minds. Hashem [11] pointed out that big data can provide great potential for cities to obtain valuable information, and plays an important role in the development of urban intelligence. Bilal [12] discusses the current state of the adoption of big data in the construction industry, and the future potential of such technologies across the multiple domain-specific sub-areas of the construction industry. As an important sub-area of the urban construction industry, new technologies play an important role in future metro safety management applications.

The main content of this paper is divided into two parts. Section 2 describes the statistics of accident types, the number of injuries and deaths, the distribution of accident grades, and the causes of accidents, based on 243 metro safety incidents in 48 cities around the world. Section 3 describes the prospect of big data applications in smart metro safety management, and proposes a system structural model of a smart metro safety management. Section 4 concludes.

METRO SAFETY ACCIDENT ANALYSIS

Accident statistic

The statistics on 243 metro safety incidents in 48 cities around the world (Figure 2) consists of 55 incidents (22.63%) obtained from literature and 188 (77.37%) from media. In order to distinguish the characteristics of accidents, the metro safety accidents are divided into fire accidents, terrorist attacks, train derailment and impact, train operation interruptions and other accidents. Figure 3 summarizes the numbers and the time periods of occurrence of these accident types. It can clearly be seen that the number of train interruption accidents is largest, followed by fire accidents.

Figure 2: National and regional distribution map of metro safety accidents (48 cities)

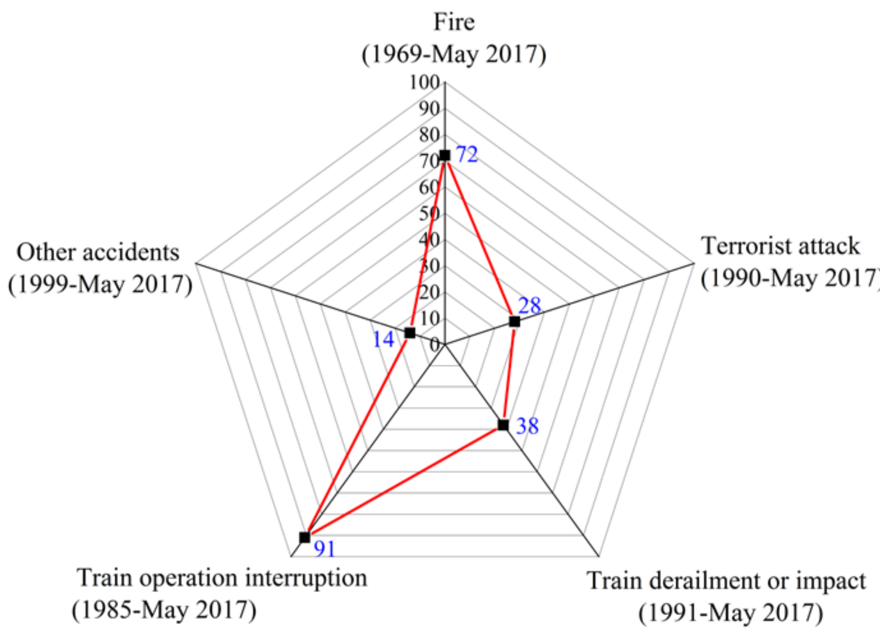

Figure 3: Types, quantities and timeline of safety incidents

Figure 4 shows the numbers and the distribution of types, and the numbers of injuries and deaths in metro safety incidents in 2005-2016. It can clearly be seen from the figure that the number of metro safety accidents does not decrease with the development of society, and that the largest proportion of accidents is train operation interruptions. Fire accidents, terrorist attacks, and train derailment and impact accidents happen almost every year. There is a positive correlation between the number of people injured in metro safety accidents and the number of accidents, whilst the number of deaths caused by metro accidents is more uniform. This analysis indicates that metro safety management still faces great challenges. It is necessary to pay attention to the development of metro safety management to reduce the number of metro safety accidents.

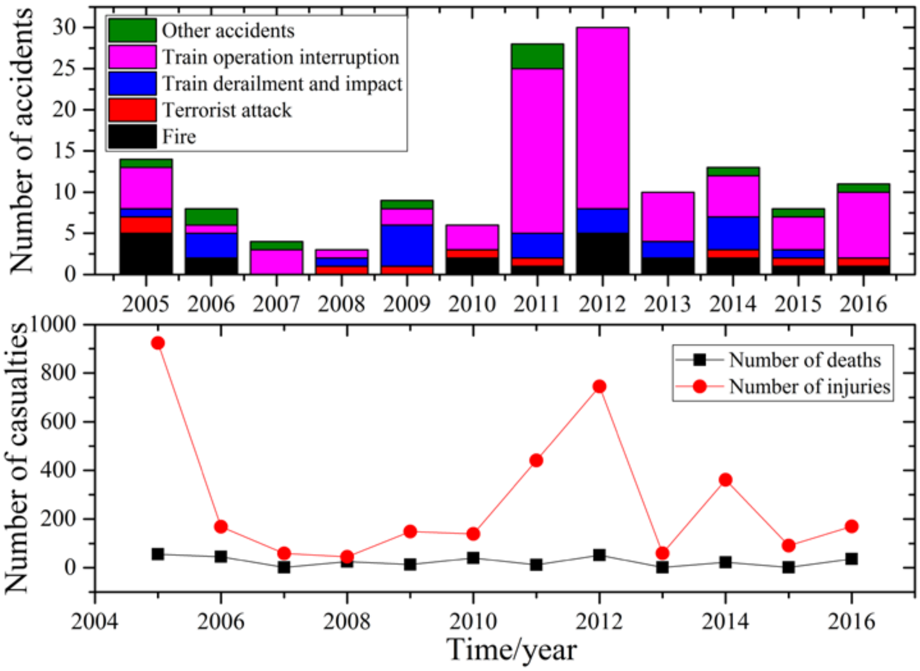

Figure 4: Distribution map of safety accident types, and the number of injuries and deaths in 2005-2016

Accident grades

According to the casualty numbers, direct economic losses and interruption times, the severity of metro safety accidents is divided into extraordinarily serious, serious, major and general accidents (Table 1).

Table 1: Grades and standards of metro safety accidents

Accident grade	Number of casualties	Direct economic loss	Interruption time
Extraordinarily serious accident	Number of deaths ≥30	≥10 million RMB	/
Serious accident	Number of deaths ≥3 or number of serious injured ≥5	≥5 million RMB	t≥180min
Major accident	Number of deaths ≥1-3 or 5＞number of serious injured ≥3	1-5 million RMB	60≤t＜180min
General accident	Number of serious injured ＜3	10 thousand - 1 million RMB	0≤t＜60min

Note: The extent of damage meets two or more of two conditions at the same time, taking the most serious conditions as the basis for the classification of accidents.

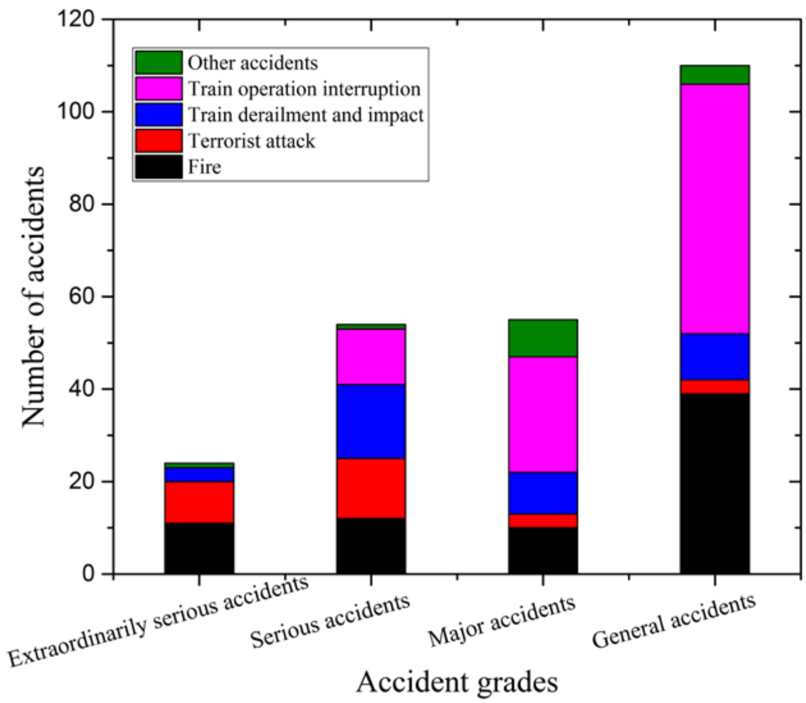

Figure 5: Grade distribution of accident types

According to the accident classification standard presented in Table 1, the investigated metro safety accidents are graded, as shown in Figure 5. The accident grade distribution fits the general law of accidents, where the proportion of extraordinarily serious accidents to serious accidents to major accidents to general accidents is 9.88%:22.22%:22.63%:45.27%. Extraordinary serious accidents are mainly caused by fire accidents (45.83%) and terrorist attacks (37.5%). Serious accidents are mainly caused by fire accidents (22.22%), terrorist attacks (24.07%), train derailment and impact (29.63%), and train operation interruptions (22.22%). Major accidents are mainly caused by fire accidents (18.18%), train derailment and impact (16.36%), and train operation interruptions (45.45%). General accidents are mainly caused by fire accidents (35.45%) and train operation interruptions (49.09%).

Causes of accidents

Serious metro safety accidents may lead to deaths and injuries. The causes of such accidents mainly include natural factors, human factors and equipment factors. For example, an earthquake causes a running train to derail or impact, and a typhoon causes a train to stop. An explosion or fire accident caused by a terrorist attack or a train dispatching error results in a train rear collision accident. A brake failure or signal failure results in a train rear collision. The risk factors of metro safety accidents are various, and same risk factors can cause many safety accidents.

Circuit failures (31.94%), equipment failures (20.83%), and unsafe behavior (12.5%) are the most frequent causes of fire accidents in metro (Figure 6). Circuit failures include short circuit and transformer faults, and equipment failures mainly refer to circuit fires caused by the malfunction of train equipment. For example, air conditioning equipment can caught fire due to a circuit fault. Unsafe behavior includes passengers throwing away cigarette butts, or carrying flammable materials. In addition, arson (9.72%) and improper human operations (5.56%) are also important factors of fire 7accidents. The cause of fire accidents is unknown (19.45%).

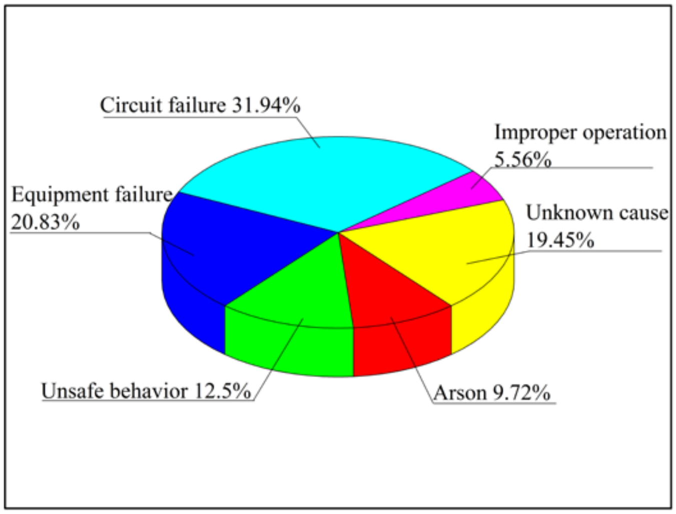

Figure 6: Cause distribution of fire

As shown in Figure 7, explosions (60.71%) and arson (21.45%) are the most frequent consequences of terrorist attacks. Poison gas (7.14%), stabbing (7.14%) and shooting (3.57%) are also important incidents caused by terrorist attacks.

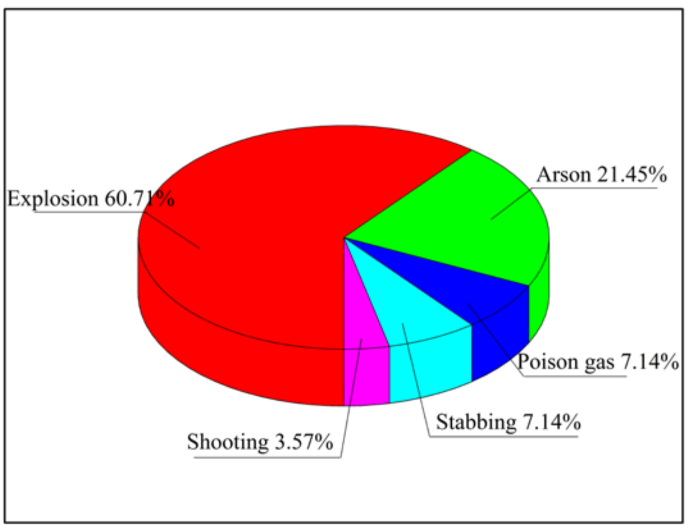

Figure 7: Cause distribution of terrorist attacks

Figure 8 shows the causes of train derailment (55.26%) and train impact (44.74%). Among them, equipment failures (47.62%), unsuitable operations (23.81%), and brake system failures (19.05%) are the main reasons of train derailment. Equipment failures usually include rail damages, train equipment failures, and brake failures. Unsuitable operations include the loss of the driver's concentration, the sudden death of the driver, the speeding of the train, and the lack of driving experience.

The causes of train impact mainly include management defects (35.29%), train system failures (23.53%), improper human operations (23.53%), and signal failures (17.65%). Management deficiencies include scheduling errors and violations of management. Improper human behavior includes drivers playing mobile phones, sleeping or speeding.

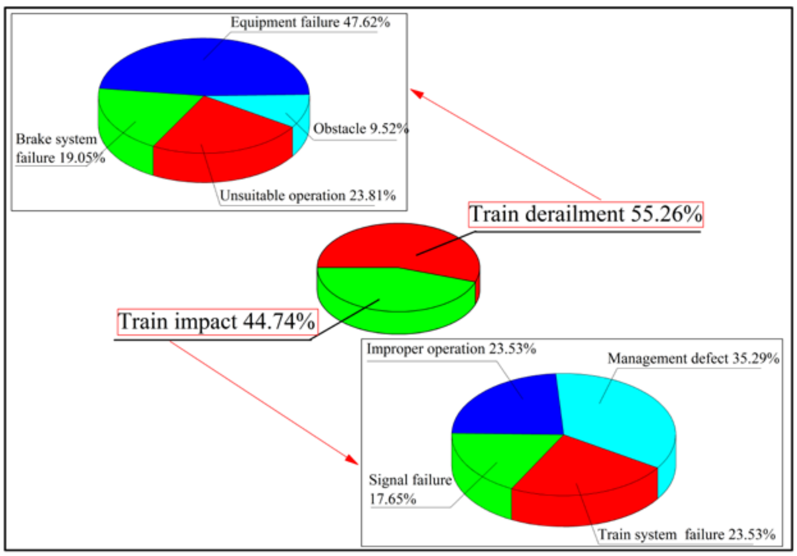

Figure 8: Cause distribution of train derailment and impact

Figure 9 shows the causes of train operation interruptions. Train equipment and auxiliary equipment failures (48.35%) and natural disasters (39.56%) are the main reasons of metro operation interruptions. Human factors (5.49%), power failures (4.4%) and tunnel structure damages (2.2%) are the secondary causes of metro outage accidents. Natural disasters include hurricanes, rainstorms, earthquakes, lightning, snow and ice. Human factors include scheduling, communication failures, management deficiency, hitting people, suicidal behavior, passenger congestions and passenger flow surges.

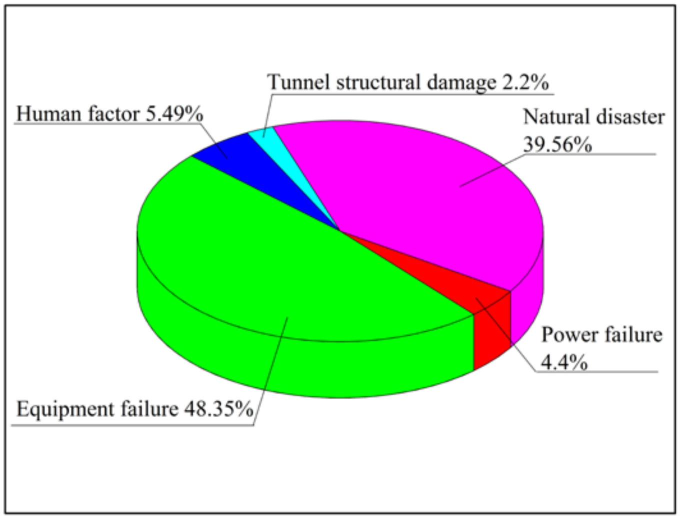

Figure 9: Cause distribution of train operation interruptions

Figure 10 shows the cause distribution of other accidents, mainly falling rail events (57.15%), stampede (28.57%), hitting people (7.14%), and explosions of electrical equipment (7.14%). Falling rail events mainly include suicides, accidental falls, crowding and other factors. Stampede is mainly caused by congestions and elevator failures.

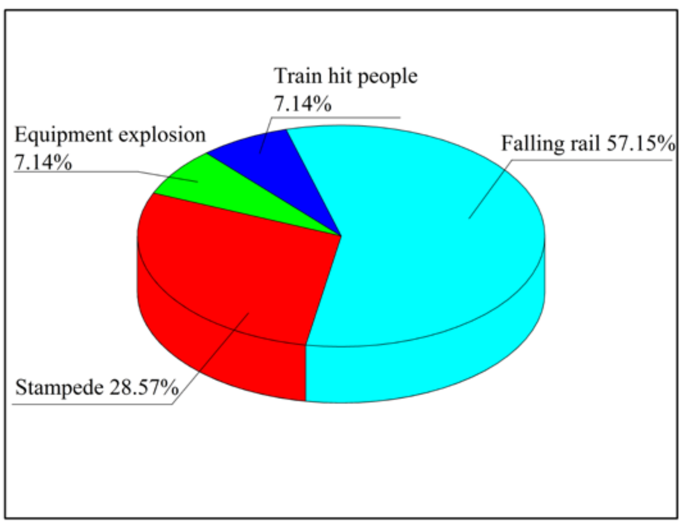

Figure 10: Cause distribution of other accidents

SMART METRO SAFETY MANAGEMENT MODE

The Internet of Things (IoT) is an important part of the new generation of information technologies, and also an important stage of development in the era of information technologies. Using an Internet or local network communication technology, as well as sensors, controllers and machines, people and objects are linked together to realize informatization, remote management control and smart networks. The emergence of the IoT has promoted the development of smart cities. Several applications of smart environments have been introduced recently, including smart homes [13], smart transportation [14], smart grids [15], smart healthcare [16], and smart cities [17-18], due to the growth of urban population and rapid urbanization. At present, urban performance depends not only on the physical infrastructure but also on the availability and quality of knowledge communication and the social infrastructure. As an important component of smart city development, metro safety management is a prerequisite for the healthy development of large cities.

After the completion of urban metro construction, metro safety management becomes very extensive, and management data increases significantly. Such huge data is a key to the services provided by the Internet of Things. Big data has long been characterized by its volume, velocity, and the variety of data types created at ever-increasing rates [19-20]. Big data offers cities the potential to obtain valuable insights based on a considerable amount of data collected through various sources. Figure 11 illustrates the prospect of the smart management technologies of metro safety using big data and cloud computing, where various smart applications exchange information using embedded sensor devices and other devices integrated within the cloud-computing infrastructure to generate large amounts of unstructured data. This unstructured data is collected and stored in a cloud, which is shared among various services, and is used to improve services and applications[21].

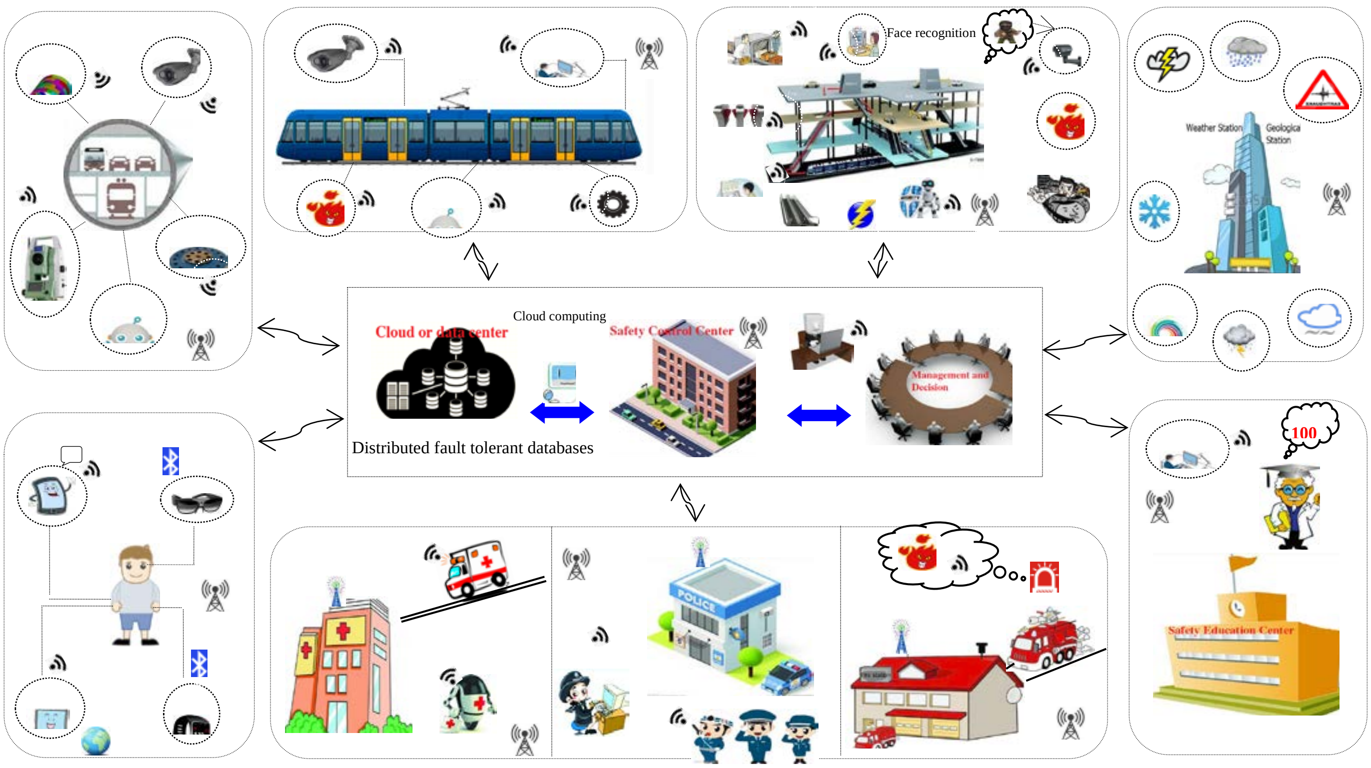

Figure 11: Prospect of the smart management technologies of metro safety using big data and cloud computing

Currently, large data analysis for smart environments is still in its infancy. New technologies provide great development potential for city metro safety smart management [22]. There are many types of metro safety related data, such as the information about the weather, train system, train operation, terrorists, tunnel structure monitoring, safety culture education and urban human flows. Such data grows exponentially, and efficient data storage and processing equipment has become a challenge for data analysis and mining. One of the possible means to get the benefits of this information is the reliance on cloud computing services and IoT technologies.

The IoT provides a platform for sensors and actuator devices to communicate seamlessly within smart city environments, and enables increasingly convenient information shared across platforms. The IoT, as a revolutionary technology, has witnessed its recent implementation in smart city systems, such as smart grids, smart retail stores, smart homes, smart traffic, smart healthcare and smart energy [23]. However, smart metro safety management, as an important component of smart city systems, has not yet been defined. The key of smart metro safety management is a new technology applied in all management departments. Embedded sensors, equipment and information acquisition equipment in metro stations, trains, tunnels, bridges, power grids, meteorological stations, fire departments, hospitals, police stations, metro operation centers and so on, form the IoT of metro safety.

The system storage technology, processing technology and information collection technology of large data can improve the level of the smart management of metro safety. In addition, big data can also help metro safety managers to make correct management decisions.

Cloud computing provides services for large complex computational tasks, such as mining large network data using smart devices. Cloud computing services can be combined with the IoT to achieve large data processing, including platform services, software services, and infrastructure services. Moreover, cloud computing can provide a virtual infrastructure for utility computing that integrates monitoring devices, storage devices, analytics tools, and visualization platforms [24]. For example, metro safety management large data is transmitted to a cloud storage system by sensing equipment and information acquisition equipment, where cloud computing is used to deal with large data to identify metro safety hazards and reduce safety incidents.

Figure 12 shows the system structure of the smart management of metro safety. The structure can be divided into 3 layers, each of which represents a potential function of the smart metro safety management system. The first layer represents a dynamic data information set related to metro safety, where the information set is collected using embedded sensing devices and other devices connected to Local Area Networks (LANs) and Wide Area Networks (WANs). These devices collect large amounts of unstructured data. The second layer is to store all unstructured data in a metro safety management database, such as cloud databases and various large data storage systems. The stored data is processed in batches by a programming model, which combines smart identification, smart monitoring, smart statistics, smart judgment, smart tracking and other smart modes to analyze the data stream intelligently. The third layer is to realize the direct function between managers and intelligent machines for making informed decisions by applying the smart analysis results to the metro safety management center, finally, the purpose of preventing the occurrence of metro safety accidents and reducing casualties and property losses in accidents is achieved.

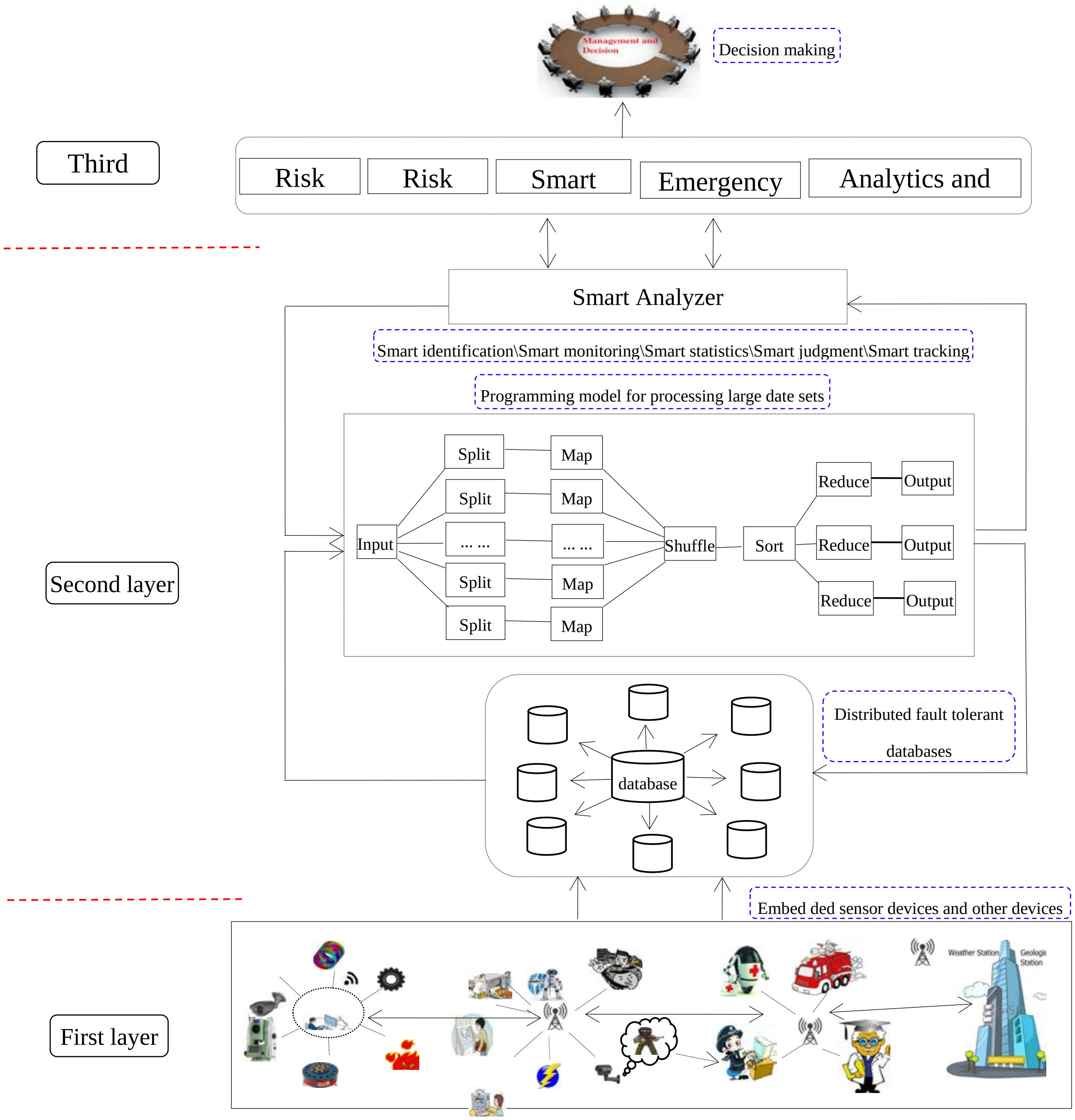

Figure 12: System structure of the smart management of metro safety

CONCLUSION

An increased number of developing countries step into the new underground network traffic era. In general, metro operates in a complex urban environment, and metro safety is easily affected by various factors, such as human factors, management defects, natural factors, equipment failures and so on. Metro safety management faces great challenges.

This paper collects 243 metro safety incidents in 48 cities around the world, and reveals the statistics on metro safety incident distributions by types, injuries and deaths, grades and causes, which provides useful information related to metro safety. The results show that the number of metro safety accidents does not decrease with the development of society, and there is a positive correlation between the number of accidents and the number of people injured in accidents. The accident grade distribution corresponds to the general law of accidents, where the proportion of extraordinarily serious accidents to serious accidents to major accidents to general accidents is 9.88%:22.22%:22.63%:45.27%. Train operation interruptions are the main type of metro safety accidents, mainly caused by train equipment and auxiliary equipment failures (48.35%) and natural disasters (39.56%). Fire accidents are the second major type of metro safety accidents. Circuit faults (31.94%), equipment failures (20.83%) and unsafe behavior (12.5%) are the causes of metro fire accidents. Train derailment and impact accidents are the third major type of metro safety accidents, mainly caused, respectively, by equipment failures (47.62%), unsuitable operations (23.81%) and brake system failures (19.05%), and defective management (35.29%), train system faults (23.53%), improper operation (23.53%) and signal faults (17.65%). Terrorist attacks are the fourth major type of metro safety incidents, where explosions (60.71%) and arson (21.45%) are the most frequent causes.

The emergence of new technologies, such as the IoT, big data and cloud computing technologies, promotes the development of smart cities. As a major component of smart city development, metro safety management is an important part of the healthy development of large cities. At present, all kinds of sensors and connecting devices are frequently used in many aspects of life, resulting in the rapid growth of data, causing the concern of many researchers in different research areas. The purpose of this paper is to provide a new model for the applications of big data to metro safety management. We explore the development prospects of smart metro safety management, and propose a system structural model of smart metro safety management to prevent metro safety accidents and reduce accident casualties and property losses. However, large data research on smart metro safety management still faces many challenges, providing new directions for future research.

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