An incident database for improving metro safety: The case of shanghai

Zhang, Xiaoling; Deng, Yongliang; Li, Qiming; Skitmore, Martin; Zhou, Zhipeng

Published in:
Safety Science

DOI:
10.1016/j.ssci.2015.11.023

An incident database for improving metro safety: the case of Shanghai

Xiaoling Zhang [a], Yongliang Deng [b,*], Qiming Li [b], Martin Skitmore[c], Zhipeng Zhou [d]

([a] Department of Public Policy, City University of Hong Kong, Hong Kong, China)

([b] Department of Construction and Real Estate, Southeast University, Nanjing, China)

([c] School of Civil Engineering and Built Environment, Queensland University of Technology, Brisbane, Australia)

([d] College of Economic and Management, Nanjing University of Aeronautics and Astronautics, Nanjing, China)

Abstract: Large cities depend heavily on their metro systems to reduce traffic congestion, which is particularly the case with Shanghai, the largest and most developed city in China. For the purposes of enhancing the possibility in quantitative risk assessment and promoting the safety management level in Shanghai metro, an adaptable metro operation incident database (MOID) is therefore presented for containing details of all incidents that have occurred in metro operation. Taking compatibility and simplicity into consideration, Microsoft Access 2010 software is used for the comprehensive and thorough design of the MOID. Based on MOID, statistical characteristics of incident, such as types, causes, time, and severity, are discovered and 24 accident precursors are identified in Shanghai metro. The processes are demonstrated to show how the MOID can be used to identify trends in the incidents that have occurred and to anticipate and prevent future accidents. In order to promote the application of MOID, an organizational structure is proposed from the four aspects of supervision, research, implementation, and manufacturer. This research would be conducive to safety risk analysis in identifying relevant precursors in safety management and assessing safety level as a qualitative tool.

Keywords: Metro safety; Incident classification; Database; Accident precursor.

1. Introduction

Increasing numbers of people in China live in cities and the size of cities is expanding rapidly with the growth in urbanization. Taken together with the massive increase to over 250 million motor cars (Edelman, 2009), this has resulted in a major traffic congestion problem and associated atmospheric pollution. The metro is the most effective means of solving this problem in major cities. According to recent statistics, metro network systems are expanding at a rate of 30-50 km per year in such big cities as Beijing, Shanghai and Guangzhou. Additionally, up to December 31, 2014, 36 cities in China had been approved to construct metro system, and 22 cities had already been operating metro. As a result of this extensive and rapid development, metros are entering a new era of operations in China and with an increased need for more sophisticated operating systems.

Of particular concern is the serious consequences of metro accidents, such as the Baku metro accident in the Azerbaijan Republic (in 1995, more than 340 casualties) and Daegu, Korea (in 2003, more than 189 casualties), making their management and prevention a very important issue. Crucially though, most metro accidents can be predicted and prevented by the proper utilization of existing knowledge (Wang and Fang, 2014). From a safety science perspective, this takes the form of a figurative iceberg of which serious accidents are the tip (Yang, et al., 2012). As shown in Fig. 1, this points to a broadening base of serious accidents, non-serious accidents and near misses. Preventing accidents, therefore, involves focusing on the lower levels, or precursors, and paying more attention to near misses.

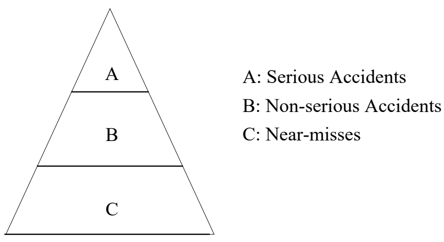

Fig. 1 Incident pyramid

Near misses have been studied in many fields, such as aviation, petrochemical and medicine. These studies show that the frequency of accidents can be reduced through effective near miss management (Van der Schaaf, 1992; Jones, et al., 1999; Cambraia, et al., 2010; Zhou, et al., 2011). The direct comparison between accidents and near misses is shown in Table 1. This can be analyzed from the perspectives of frequency, loss and recovery.

Table 1: The difference between accidents and near misses

Incident type	Frequency	Loss	Recover
Accident	Low	Obvious properties or casualties	Difficult to return to be normal operation
Near-miss	High	Almost no loss	Easy to return to be normal operation

For such an analysis to be carried out in practice involves the collection of data in the form of 'incident' cases, comprising both accidents and near misses. In safety research, accident case analysis has been extensively applied in such fields as nuclear engineering (Choi et al., 2008), construction engineering (Goh and Chua, 2010), medical engineering (Andersen, et al., 2010) and chemical engineering (Tauseef, et al., 2011). Despite being well known that quantitative risk assessment in metro operation safety cannot be practiced effectively without adequate information of previous incidents (Shin, et al., 2009), there are no professional metro operations incident databases in existence in any metro operation company in China. The purpose of this paper, therefore, is to develop such a database and demonstrate its use in a city such as Shanghai.

The paper is organized as follows. Following the literature review in section 2, section 3 describes the metro operation incident database (MOID). Its use is then demonstrated by collecting and analyzing Shanghai metro incident data from different viewpoints in section 4. Sections 5 and 6 provide an initial precursor analysis of the Shanghai data and offer some suggestions for its use in improving safety management. Conclusions and suggestions concerning possible implementation issues and future study are provided in the final section 7.

2. Literature review

2.1 Definitions

There has been some substantive theoretical development of the concepts involved in safety management and notable criteria have been introduced. For example, Cavalieri and Ghislandi (2010) have developed a widely accepted classification method based on set theory. This model enables the identification of events as errors, incidents, operational interruptions, accidents or near misses. They also explicate relationships and differences between incidents, accidents and near misses.

Three main definitions exist in the literature: Labelle (2000) define an incident as an event that does not affect the completion of an activity ; Cavalieri and Ghislandi (2010) define an accident as an unplanned incident that causes injury to persons and/or harm to property, the environment or a third party; Zhou et al. (2009) define a near-miss as an incident that does not develop into an accident . In this paper, a serious accident is defined according to metro operation safety evaluation standards (Ministry of Construction P. R. China, 2007) as having caused serious consequences, such as fatalities, serious injuries, or interrupted operations for at least 60 minutes. An accident that just causes minor injuries or interrupts operations for less than 60 minutes is identified as a non-serious accident.

2.2 Current state of safety management in metro operations

Safety management in metro operations has a significant impact on society in many aspects, such as social and economic development. Due to the rapid development of metro construction in China, more and more metro lines have been put into n service, and many cities have entered a new era of networking operation. In general, the development of metro network size and its capacity will increase the difficulty of metro safety management.

In metro operations, organizations try to identify the risks of potential accidents and many studies have been conducted of their safety management. (Kyriakidis, et al. (2012) 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. (2012), 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. Tsukahara et al. (2011) also study large-scale fire emergency evacuations in metro stations, which is a significant factor in minimizing damage and avoiding loss of life in an emergency, while Zhang and Hu (2014) 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. Lu et al. (2013), 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 et al. (2011) 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.

Most previous studies are therefore concerned with the cause and propagation of accidents, topological analysis, and emergencies. In contrast, this paper is mainly focused on risk identification, precursor analysis, and equipment maintenance in the safety management of metro operations.

2.3 Incident management

Various models and methods have been adopted in studying incident management. Jain and Mclean focus on simulation-based training systems, which have a significant impact on incident management (Jain and McLean, 2005). McLennan et al. (2006) study the decision-making processes relating to the Incident Management Team (IMT), with findings that are a useful in creating, training, managing and providing decision support for IMTs. Runciman et al. (2006) develop an integrated framework for establishing an information and incident management system based on a universal patient safety classification. Travaglia et al. (2009) evaluate an existing electronic incident management system and identify specific problems that need to be targeted for ongoing modifications. A dynamic agent-based model of flood incident management processes has been developed to improve policy analysis and other practical aspects (Dawson, et al., 2011), and Liu et al.

(2013) present a generalized diversion control model for freeway incident management that can optimize detour rates and arterial signal timing.

These studies mainly focus on the how to deal with safety incidents. However, the use of incident analysis is also very important as it provides a valuable means of improving safety management by learning from past safety-related incidents. The incident databases involved are also very useful tools for managing large amounts of raw data. Such databases have been developed for various applications. The European Commission Joint Research Centre (Institute for Energy) and Det Norske Veritas (DNV), for example, have established an international hydrogen incident and accident database (HIAD) (Kirchsteiger, et al., 2007); the U.S. Center for Chemical Process Safety (CCPS) has developed an incident database (Sepeda, 2006); a Danish patient safety database had been developed based on the Danish Act on Patient Safety (Andersen et al. 2010); Zhou et al. (2011) have developed a versatile metro construction incident database for the safety management of construction workers; and bias in incident reporting databases has been the subject of an empirical study in the chemical process industry (Van der Schaaf and Kanse, 2004).

It is apparent that incident databases have significant influence in promoting safety management in various industries, metro safety management is no expection.. It will be valuable to construct such a metro operation incident database for precursor analysis to help prevent the reoccurrence of accidents from similar causes in every urban metro.

2.4 Accident precursors

Accident precursors are defined by the National Academy of Engineering as “conditions, events and sequences that precede and lead up to an accident” (Phimister, 2004). Many accident investigation reports have indicated that the occurrence of an accident usually follows a series of precursors (Zhou, et al., 2011). Accident precursor analysis can provide crucial information concerning failure mechanisms, and the probability of accidents occurring may be reduced by lowering precursor frequency (Kyriakidis, et al., 2012).

Accident precursor analysis is a useful method for improving safety management in various applications. Vinnem (2012), for example, analyze 45 major accident precursor investigations for understanding major potential hazard risks in the Norwegian offshore industry - also demonstrating the importance of learning from major accident precursors. Groen et al. (2010) develop an accident precursor analysis process specifically for NASA’s Earth-to-Orbit space systems, aiming to identify and characterize potential sources of system risks to indicate the unknown or insufficiently understood risk-significant conditions existing in the system. Skogdalen and Vinnem (2012) combine precursor investigation and quantitative risk analysis (QRA) to identify hazards, probabilities, safety barriers and possible consequences in the oil and gas industry. This combined method draws a more complete cause and risk picture in complex systems by using well-known hazard analysis techniques. In another more general study, probabilistic risk assessment (PRA) is used as a fundamental tool to identify potential precursors for optimizing a warning threshold to minimize risks and losses (Paté-Cornell, 2011), showing that precursory signals can be used to update the probability of failure of a system.

For metro systems, Lu et al. (2011), for example, have studied safety risk events in order to identify precursors and find similar precursors that often result in similar accidents. Recent research by the U.S. National Academy of Sciences also pays close attention to the signals or conditions that precede and result in accidents, finding that some institutions have already tried to identify precursors in order to benefit from precursory information of accidents (Phimister, 2004). Precursor analysis, therefore, appears to have considerable potential for use in the safety management of metro operations. To do this involves the analysis of many accident cases, and hence the necessity to design a suitable database for their storage and access.

3. Metro operation incident database (MOID)

In general, every database should contain several types of objects, such as ‘table’, ‘query’, ‘form’ and ‘report’. Taking conciseness and compatibility into consideration, these are devised as modules in Microsoft Access 2010. Several visual functions are also provided based on the Visual Basic for Application.

3.1 Tables

The ‘table’ is the crucial object in any database, as it is the most basic element in which the original data of all objects is contained. There are two principle involved in designing the tables: information classification principle and normal form principle, the information indicates that one table is only pertinent to one subject, and there should not be repetitious information in one table or between tables. The second principle is normal forms (NF) principle. There are several NFs, including first NF, second NF, third NF, fifth NF, sixth NF, Boyce-Codd NF, fourth NF, domain/key NF. In general, the first three NFs should be followed. (Codd, 1970; Fagin, 1981; Kent, 1983). For the MOID, there are 19 such tables as shown in Table 2. The tables contain several fields, with the first field being designed as the foremost component in every table. The first field in each is set as the primary key, and the content of each table is different. The relationships are defined carefully according to the difference and relevance of the content of each table. For example, table "information of near-miss" contains "degree of near-miss", then, there is a relationship between these two tables. The tables are interrelated as shown in detail in Fig. 2.

Table 2: Basic information of tables

Table	Name	Brief Description
1	Casualty information	General information of the casualties in an accident
2	Degree of near-miss	Severity of adverse impact from a near-miss
3	Degree of non-serious accident	Severity of adverse impact from an non-serious accident
4	Degree of serious accident	Severity of adverse impact from a serious accident
5	Education	Education of relevant personal
6	Experience	The experience of the incident
7	Incident cause	The reasons for the incident
8	Information of near-miss	The general information relating to a near-miss
9	Information of non-serious accident	The general information relating to an non-serious accident
10	Information of serious accident	The general information relating to a serious accident
11	Near-miss potential consequence	Description of injury, property loss, environmental damage, etc., resulting from a near miss.

12	Near-miss relevancy index	Description of proximity, learning value, visibility, utility, etc.
13	Professional title	Degree of profession
14	Reporter information	Main information concerning the near miss reporter
15	Reponses to incident	The action taken to reduce the impact of the incident
16	Source of incident	The channel to obtain incident
17	Type of casualty	Death or injury
18	Type of incident	Incident classification based on relevant standards
19	Type of staff	Role a person plays in the metro operations

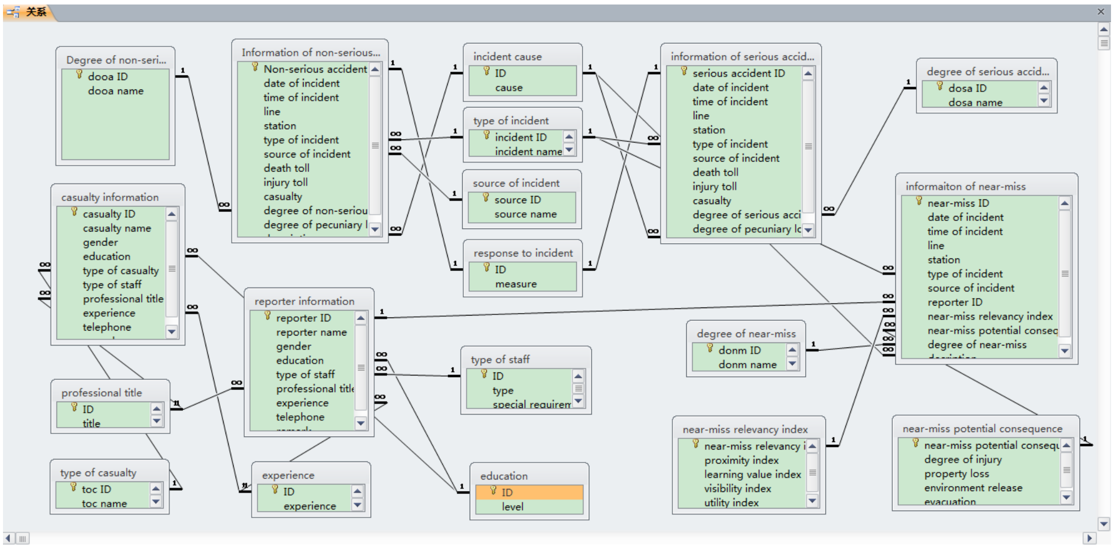

Fig. 2. Relationships between the 19 tables in the MOID

3.2 Forms

Forms play a very important part in an accessible database because they provide a convenient means for carrying out data operations such as input, search, maintain and delete. Based on the tables and the query and report facilities in the MOID, 10 basic functions are designed by forms, including start, management, query, report and exit. Some functions are necessary, for instance, "start", "exit". The other functions are designed to make the database user-friendly and convenient. Length limitations of the journal preclude a detailed description. Fig. 3 simply represents the software interface, which is an available form in the MOID. Several option group controls are designed, which are the key components in the main form and contain the serious accidents, non-serious accidents and near misses. There are several commands in every part, which provide the necessary links between different forms. Additionally, the relative Visual Basic for Application code has been edited for better operation of the system.

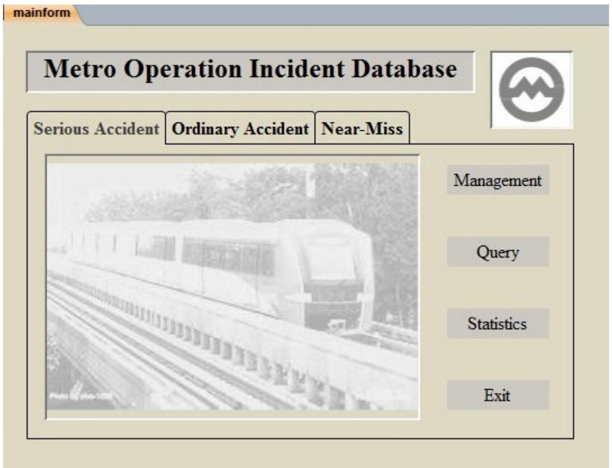

Fig. 3. The main MOID form

3.3 Basic functions

In general, a database has two basic functions - query and report. Queries help to quickly find the data needed and have to be designed to easily access data in tables. According to the general information of three kinds of incidents, which may be frequently-used, these queries were constructed to help to find required records quickly. In total, there are 35 queries in the MOID, including 11 types of accident/near miss information queries created from tables. 54 corresponding reports are provided, 19 of which are in detail, to satisfy the daily use requirements of the MOID.

4. System demonstration

4.1 Data and characteristics

Shanghai is an international metropolis, and is committed to building an international financial and shipping center. As one of the most developed cities in China, Shanghai established the first metro line, put into operation on 28 May 1993. 14 metro lines have been operating until the present time. These contain 332 stations and 567 kilometers mileage. In 2013, the Shanghai metro handled an average of approximate 8 million passengers per day - one of the busiest metros in the world. In this sense, the Shanghai metro tops the global rankings, bigger even than the London Tube and New

York Underground.

4.2 Data collection

In order to collect the metro incidents in Shanghai metro, the MOID was populated by a three-stage process. Firstly, some keywords, such as 'Shanghai metro/subway/underground' AND 'near misses' OR 'safety' OR 'accident' OR 'incident', were used to search for incidents on the internet, including Google Scholar and media websites. Many documents and webpages were downloaded and their contents are sorted and coded for content analysis. In the second stage, interviews were carried out to gain further information about the collected cases and obtain additional incident cases. In doing this, the collected data was further discussed with many stakeholders, and more data was generated from 12 face-to-face interviews at the interviewee's offices, meeting rooms and tea bars. Between April 2014 to July 2014, we met with a high ranking senior officer of the Shanghai metro operation company, five high or middle ranked managers and officers in five departments and two station staff. The manager and officer may have more knowledge and experience due to they have worked for a long period of time. Among the interviewees, there is an officer and a manager working in vehicle department who can represent the opinion of drivers in a large part. In order to maximize interviewee freedom, the interviews involved mostly open-ended questions. For instance, interviewees were asked "what are the existing barriers to improving metro safety management level and thus what should be done to minimize these barriers". The causes/precursors of the incidents were also discussed and investigated. The interviews lasted from 30 to 60 minutes and were transcribed into subsequent memoranda or research reports (Table 3).

Table 3: List of interviews

	Venues	Data	Interviewees	Contents
1	Office	Apr-2014	Senior manager of Shanghai metro company	Safety status and the previous accidents
2	Office	Apr-2014	Manager in vehicle department	vehicle incidents and precursors
3	Office	Apr-2014	officer in vehicle department	Vehicle incidents
4	Office	May-2014	Manager in signal department	Signal incidents and precursors
5	Office	May-2014	Officer in signal department	Signal incidents
6	Meeting room	May-2014	Manager in power department	Power incidents and precursors
7	Office	May-2014	Officer in power department	Power incidents

8	Office	May-2014	Manager in maintenance department	Equipment maintenance level
9	Tea bar	Jun-2014	Officer in maintenance department	Equipment maintenance level
10	Office	Jun-2014	Manager in control department	Operation level and incidents
11	Station	Jul-2014	Station staff	Station incidents and precursors
12	Station	Jul-2014	Station staff	Station incidents and precursors

In the third stage, a special meeting on the theme of metro incident precursors was held in August 2014. Participating in the meeting were leaders from the Shanghai metro operation company, experts in metro safety, university professors, and all the members of the research team. The precursors of the incidents were analyzed in-depth and coded in accordance with the type and nature of the incidents. The potential means of improving safety management levels were also discussed.

4.3 Analysis of incident characteristics

A total of 249 incidents that occurred between January 2005 to May 2013 were collected, comprising 64 (25.7%) incidents from the literature and the remaining 182 (74.3%) from the media. Fig. 4 summarizes these, showing the ratio of near misses to non-serious accidents to serious accidents to be approximately 6.4:2.1:1. It is apparent that the proportion may depend on sample size and the classification standard used.

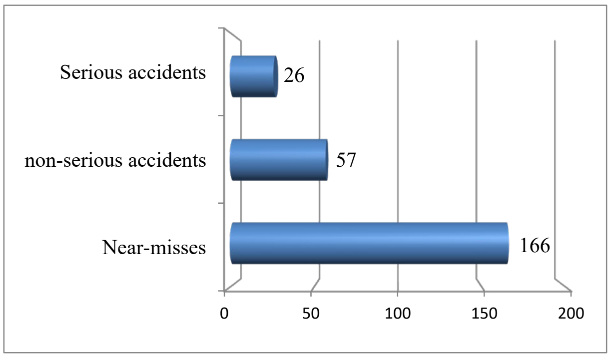

Fig. 4. Frequency of incidents by type

Fig. 5 indicates the frequency of incident occurrences in daily time intervals over the period. It is apparent that most incidents happen in the morning and afternoon rush hours. The number of incidents fluctuates with the number of passengers. The metro system may also not meet traffic needs during rush hours, eventually leading to overloading, platform overcrowding, channel congestion, fully loaded escalators, etc., as the entire metro system is overworked at these times. This suggests the need to strengthen the level of safety management during rush hours, and to carefully examine and repair equipment and facilities at the end of each day.

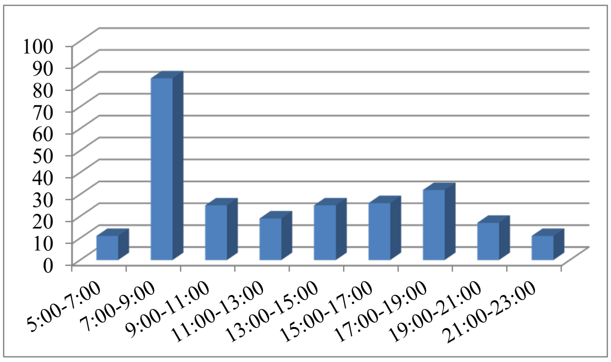

Fig. 5. Frequency of incidents during the day

As Fig. 6 indicates, train failure (29.32%), signal failure (21.29%), and screen door failure (10.44%) are the most frequent causes of incidents. In this part, the cause analysis is a primary analysis, and the human errors are summarized as "Dangerous Behavior". These causes are interdependent, as some cause others – a relationship termed *primary-secondary*. For instance, an accident that happened on 22 December 2009 started with a power problem, which then led to signal failure, and finally resulted in a collision accident.

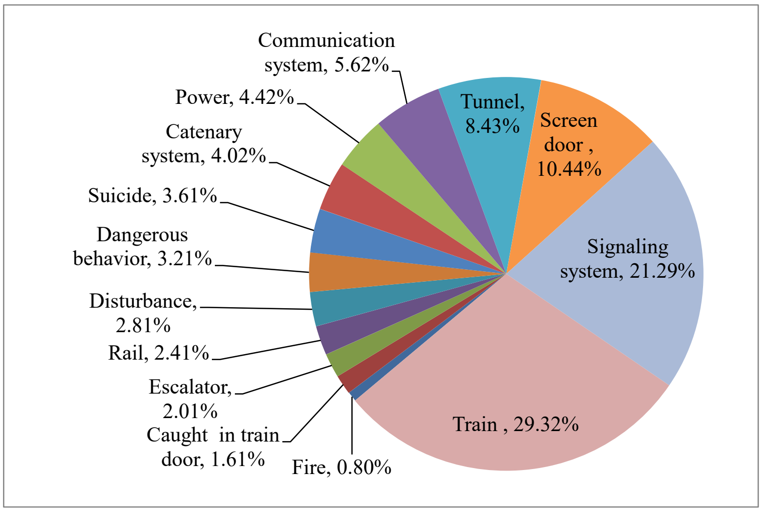

Fig. 6. Frequency of incidents by causes

A final statistic is that the proportion of lethal accidents to nonlethal accidents is approximately 1:3.4, as shown in Fig. 7.

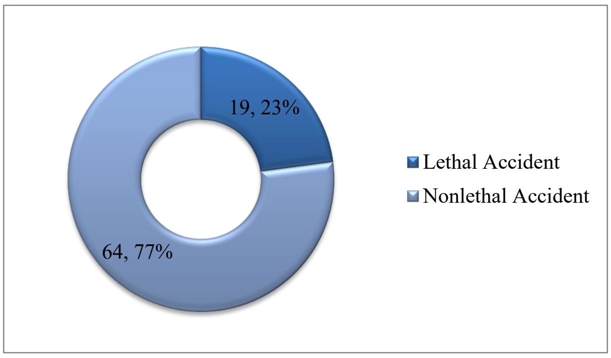

Fig. 7. Frequency of incidents by severity

4.4 Precursor analysis

A better and less subjective understanding of why accidents occur is very beneficial in preventing future ones (Leveson, 2004) and identifying precursors is an important aspect of this in practice. The MOID provides an important source of supporting information. For example, take this metro accident case in Shanghai:

On 27 September 2011, two trains collided on metro line 10 near Yuyuan Garden in Shanghai, which resulted in 284 people being injured, and paralyzing parts of China's financial capital. The processes leading up to accident are elaborated in Table 4.

Table 4: The process of accident

Behavior Subject	Incident	Time	Reason	Consequence
Automation instrument company	Signal interruption at Xintiandi station	13:58	Wrong operation procedure causes partial lack of power supply	Automatic monitoring panel blank screen, signal failure
Dispatcher; equipment	Train no. 1016 shows no speed code after depart Yuyuan station	/	The metro operation transferred to the manual control system	Dispatcher commands train no. 1016 to continue running with limited speed
Dispatcher; vehicle precursor	Train no. 1016 stops in tunnel between Yuyuan and Laoximen station	14:00	Red light signal	Dispatcher commands train no. 1016 to stop and wait
Dispatcher	Releases dispatching order	14:08	Releases incorrect command by telephone system	Train no. 1005 departs from Yuyuan station
Driver	Train no. 1005 takes braking measures to stop	14:35	Train no. 1005 finds train no. 1016 stopped ahead on a bend	Train no. 1005 reduced speed from 54 km/h to 35 km/h
Vehicle	The two trains collide	14:37	Insufficient braking distance; inertia	Heavy casualties and loss of trust

The accident involved three critical steps. First, the signal system failed at 13:58 due to a wrong operation procedure causing a partial failure in power supply. Next, the metro operation was transferred to manual control due to the signal failure. Then, the dispatcher released an incorrect command through the telephone block system that directly resulted in the collision. This suggests three main precursors to be faulty maintenance, signal failure and scheduling violation. The correspondence between the precursors and the accident is shown in Fig. 8. Faulty maintenance and the scheduling violation belong to human factors, while the signal failure is an equipment factor.

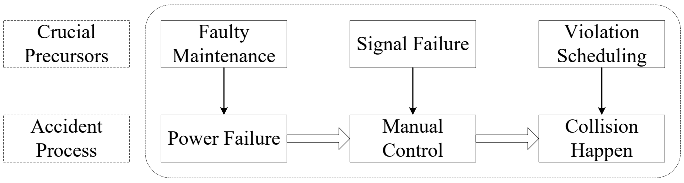

Fig. 8. Correspondence between precursor and accident

A complete metro system includes all the staff and equipment needed for it to function, which is to transport passengers in a specific environment. The incident precursors can therefore be grouped into three categories of human, equipment and environment. The precursory information obtained from the Shanghai MOID grouped in this way is listed in Table 5. In fact, there may many kinds of human errors, but it may not applicable to list all the kinds of human errors. Therefore, the most dangerous error of drivers is select to represent the driver errors, for instance, "Exceeding speed limits", which means driver error. In total, 122 precursors were got from these 83 accidents. In these 122 precursors, there are 74 equipment factors, 40 human factors, and 8 environmental factors. Calculations show their frequencies to be 61% equipment factors, 33% human factors and 6% environmental factors.

Table 5: Precursors to metro accidents

Type/Number	Description	Type/Number	Description
Human factors		P-13	Signal failure
P-1	Management negligence	P-14	Signal error
P-2	Violation scheduling	P-15	catenary failure
P-3	Unsafe behavior of passenger	P-16	Escalator failure
P-4	Illegally entering the tunnel	P-17	Cracked rail/other serious defect
P-5	Passengers carrying inflammable or dangerous goods	P-18	Caught in train door
P-6	Congestion on the platform	P-19	No screen door
P-7	Exceeding speed limits	P-20	Train failure
P-8	Poor maintenance	P-21	Screen door
P-9	Smoke in station/train	Environmental factors	
Equipment factors		P-22	Heavy rain and thunder

P-10	Equipment defect	P-23	External disturbance
P-11	Pipeline aging	P-24	Adverse geological condition
P12	Power failure		

It is well known that accidents often happen with two or more corresponding precursors rather than just one. The relationship between accident and precursor is complex. Table 6 gives the relevant precursors for every accident.

Table 6: Relevant precursors of collected accidents

Accident	**A-73**	**A-116**	**A-121**	**A-127**	**A-133**	**A-148**	**A-150**
Precursor	P-23	P-1, P-3, P-19	P-3, P-4	P-1, P-5, P-9	P-1, P-5, P-11	P-13	P-3, P-6, P-19
Accident	**A-156**	**A-160**	**A-163**	**A-168**	**A-172**	**A-174**	**A-175**
Precursor	P-1, P-2, P-7, P-10, P-12, P-14	P-12, P-15	P-12, P-15	PP-3, P-19	P-1, P-4	P-3, P-18	P-3, P-4
Accident	**A-176**	**A-191**	**A-194**	**A-195**	**A-197**	**A-201**	**A-208**
Precursor	P-10, P-12	P-12, P-15	P-6, P-8, P-16	P-3, P-18	P-3, P-18, P-19	P-3, P-6	P-3, P-19
Accident	**A-210**	**A-216**	**A-233**	**A-240**	**A-243**		
Precursor	P-3, P-19	P-8, P-16	P-8, P-16	P-12, P-20	P-3, P-6		

The analysis shows there are 24 precursors in all, which include most inducing factors. The frequency of occurrence of every precursor is illustrated in Fig. 9, which shows that several factors occur with a high frequency, e.g., P-20, P-3, P-13 and P-12. Additionally, many of the high-frequency precursors are closely related to technical failures, indicating the necessity for the regular inspection and maintenance of equipment.

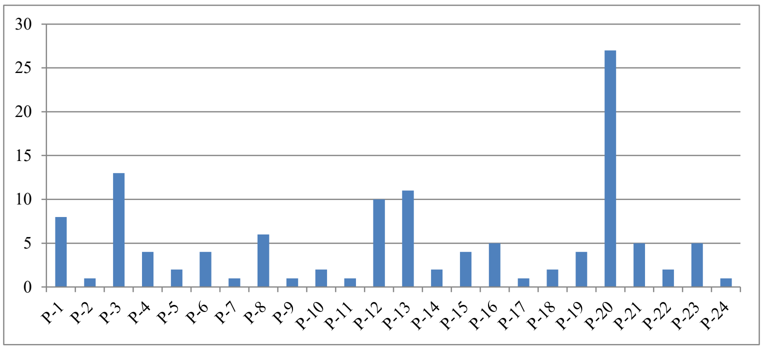

Fig. 9. Frequency of the 24 precursors

5. Recommendations: using precursor analysis to improve metro safety

Monitoring precursory information enables metro organizations to both identify dangerous events or conditions that could induce injuries or fatalities, and where investment is needed to reduce the possibility of accidents or alleviate their consequences (Hirsch, 2006). Although it is impossible to completely eliminate accidents, eliminating or effectively monitoring their precursors helps reduce their occurrence.

Different measures based on the different characteristics of the precursors involved can be selected to enhance safety management. Equipment failures cause most injuries or deaths due to the complex internal and external interference factors associated with metro operations. Therefore, the effective maintenance and continuous improvement in equipment reliability are the most important factors, which means engineers finding and resolving problems earlier, more rapidly and accurately. Our analysis of the Shanghai MOID points to the train and signal system being the key precursors. In addition, reinforcing vocational skill training and safety education would build up technique ability and safety consciousness and reduce human performance precursors through a better safety culture with a greater level of commitment and involvement in safety management.

Further possible improvements for the Shanghai metro are for manufacturers to improve the reliability of their equipment through improved design and manufacturing processes; the development of intelligent monitoring systems for the early warning of failure or faults; and the use of advanced technology to improve information collection. For example, a RFID sensor network could be installed to gather some types of precursory information and realize bidirectional control and data transmission.

6. Discussion and conclusion

This paper presents a metro operations incident database (MOID) comprising three types of incidents - serious accidents, non-serious accidents and near misses – and demonstrates its use in accident prevention. In practice, implementation of the MOID will involve four interrelated organizations: (1) government departments, (2) a research institution, (3) the metro operation company, and (4) equipment manufacturers as shown in Fig. 10.

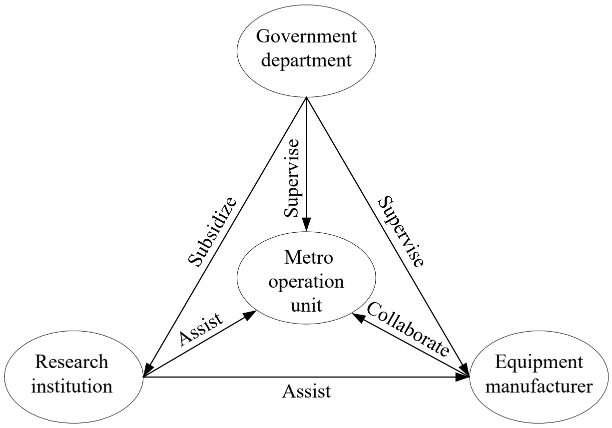

Fig. 10. Organization structure for MOID implementation

The main role of the government departments would be one of supervision and to stress the significance of the experience obtained from previous incidents. Of particular importance is the consideration of near misses, as their data provides a crucial foundation for safety analysis and evaluation. Implementing the MOID will also involve cooperating with and subsidizing a research institution to support their input. The role of the research institution would be to fully develop the MOID and assist in its implementation. This could be in the form of a management consultancy to help the metro operation company with MOID analysis and management and improving operation safety. The metro operation company itself would play a key role in implementation. This could involve a MOID management committee responsible for establishing the organizational structure and relevant regulations, responding to the management requirements of the government departments, cooperating with the research institution to operate the MOID effectively, and periodic evaluation of its operation. As the Shanghai incident statistics highlight, most incidents are caused by equipment failure, with about 70% of accidents being directly attributable to this cause. The equipment manufacturer, therefore, could use the MOID to analyze the failures that are occurring and help identify their root causes to improve technical design standards and manufacturing processes.

In this paper, designing and establishing MOID has been introduced in detail and the incidents of Shanghai metro have been collected and put into the MOID, which indicates that it is feasible to employ Access 2010 as the database tool. The incident characteristics have been analyzed and 24 accident precursors have been identified based on MOID, which demonstrates that MOID can be used to identify trends in the incidents that have occurred and anticipate preventing future accidents. In order to promote the application of MOID, an organizational structure has been proposed to guide and assist its implementation in metro organizations, which is supposed to enhance the safety level of metro operation.

The MOID presented here fulfils a research need in the safety management of metro operations and can be used as a significant foundation for future study. In brief, MOID research can be of significance in three aspects. First, it is very useful in supporting safety risk analysis - for example, as a qualitative tool for identifying precursors and as an effective quantitative tool in assessing safety levels. Second, an MOID will help in preserving and retrieving safety information of the metro system and can contribute to the formulation of new principles and regulations for enhancing safety levels. Third, the MOID could provide basic data for manufacturers to improve metro equipment performance and raise operational reliability.

In future research, continuous improvement of the MOID will enable the comprehensive analysis of incident precursors and the development of a real-time early warning system. Meanwhile, a detailed failure knowledge database (FKD) is needed, with case-based reasoning to analyze safety risks. In addition, the means by which the MOID can be used to improve the safety culture can be investigated to further contribute to the safety management of metro operations.

Acknowledgment

The research described in this paper was supported by the National Natural Science Foundation of China (Grant No. 51178116; 71303203) and the Humanities and Social Sciences Youth Foundation of China's Education Ministry (13YJCZH120), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD) and Postgraduates’ Science and Innovation Foundation of Jiangsu Province (Grant No. CXZZ13_0111). The authors also gratefully acknowledge those who provided data and suggestions.

References

Andersen, P. O., Maaloe, R., Andersen, H. B. (2010). Critical incidents related to cardiac arrests reported to the Danish Patient Safety Database. Resuscitation, 81(3), 312-316.

Cambraia, F.B., Tarcisio, A. S., Carlos, T. F. (2010). Identification, analysis and dissemination of information on near misses: a case study in the construction industry. Safety Science, 48(1), 91-99.

Cavalieri, S., Ghislandi, W. M. (2010). Understanding and using near-misses properties through a double-step conceptual structure. Journal of Intelligent Manufacturing, 21(2), 237-247.

Choi,Y., Park, S. Y., Ahn, K., Kim, D. H. (2008). Development and analysis of LOCA sequences for severe accident risk database. Nuclear Engineering and Design, 238(4), 1100-1105.

Codd, E. F. (1970). A relational model of data for large shared data banks, Communications of the ACM. 13(6) 377-387.

Dawson, R. J., Peppe, R., Wang, M. (2011). An agent-based model for risk-based flood incident management. Natural Hazards. 59(1), 167-189.

Edelman,T.U. (2009). GE security provides solutions to 25 metro lines in China, Security Industry Association, http://www.siaonline.org/content.aspx?id=5946 .

Fagin, R. (1981). A normal form for relational databases that is based on domains and keys, ACM Transactions on Database Systems. 6(3), 387-415.

Goh,Y. M., Chua, D. K. H. (2010). Case-based reasoning approach to construction safety hazard identification: adaptation and utilization. Journal of Construction Engineering and Management, 136(2), 170-178.

Groen, F., Stamatelatos, M., Dezfuli, H., Maggio, G. (2010). An accident precursor analysis process tailored for NASA space systems.

Hirsch, R. (2006). Reducing risk by probabilistic assessment, defense in depth and precursor monitoring, In: China International Railway and Metro Safety Conference. Imperial College, CoMET.

Jain, S., McLean, C. R. (2005). Integrated simulation and gaming architecture for incident management training. In Proceedings of the Winter Simulation Conference, IEEE.

Jones, S., Kirchsteiger, C., Bjerke, W. (1999). The importance of near miss reporting to further improve safety performance. Journal of Loss Prevention in the Process Industries, 12(1), 59–67.

Kent, W. (1983). A simple guide to five normal forms in relational database theory, Communications of the ACM. 26(2), 120-125.

Kirchsteiger, C., Vetere Arellano, A. L., Funnemark, E., (2007). Towards establishing an international hydrogen incidents and accidents database (HIAD). Journal of Loss Prevention in the Process Industries, 20(1), 98-107.

Kyriakidis, M., Hirsch, R., Majumdar, A. (2012). Metro railway safety: An analysis of accident precursors. Safety Science, 50(7), 1535-1548.

Labelle, J. E. (2000). What do accidents truly cost?, Professional Safety. 45(4), 38-42.

Leveson, N. (2004). A new accident model for engineering safer systems, Safety Science. 42(4), 90–99.

Liu,Y. Li, P., Wehner, K., Yu, J. (2013). A generalized integrated corridor diversion control model for freeway incident management. Computer-Aided Civil and Infrastructure Engineering, 28(8), 604-620.

Lu,Y., Hinze, J., Li, Q. M. (2011). Developing fuzzy signal detection theory for workers' hazard perception measures on subway operations, Safety Science. 49 (3), 491–497.

Lu,Y., Li, Q. M., Xiao, W. J. (2013). Case-based reasoning for automated safety risk analysis on subway operation: Case representation and retrieval, Safety Science. 57, 75-81.

McLennan, J., Holgate, A. M., Omodei, M. M., Wearing, A. J. (2006). Decision making effectiveness in wildfire incident management teams. Journal of Contingencies and Crisis Management, 14(1), 27-37.

Ministry of Construction P. R. China, (2007). Standard for the operation safety assessment of existing metro. China Construction Industry Press, Beijing.

Paté-Cornell, E. (2011). Accident precursors and warning systems management: a Bayesian approach to mathematical models, Wiley Encyclopedia of Operations Research and Management Science.

Phimister, J. R., Bier, V. M., Kunreuther, H. C. (2004). Accident precursor analysis and management: reducing technological risk through diligence. The National Academies Press, Washington, D. C.

Runciman, W. B., Williamson, J. A., Deakin, H. A., Benveniste, K. A., Bannon, K., Hibbert, P. D. (2006). An integrated framework for safety, quality and risk management: an information and incident management system based on a universal patient safety classification, Quality and Safety in Health Care. 15(suppl 1), 82-90.

Sepeda, A. L., (2006). Lessons learned from process incident databases and the process safety incident database (PSID) approach sponsored by the Center for Chemical Process Safety, Journal of Hazardous Materials. 130(1), 9-14.

Shin, H. S., Kwon, Y. C., Jung, Y.S., Bae, G. J., Kim, Y. G. (2009). Methodology for quantitative hazard assessment for tunnel collapses based on case histories in Korea. International Journal of Rock Mechanics and Mining Sciences, 46(6), 1072-1087.

Skogdalen, J. E., Vinnem, J. E. (2012). Combining precursor incidents investigations and QRA in oil and gas industry. Reliability Engineering and System Safety, 101, 48-58.

Tauseef, S. M., Abbasi, T., Abbasi, S. A. (2011). Development of a new chemical process-industry accident database to assist in past accident analysis, Journal of Loss Prevention in the Process Industries. 24(4), 426-431.

Travaglia, J. F., Westbrook, M. T., Braithwaite, J. (2009). Implementation of a patient safety incident management system as viewed by doctors, nurses and allied health professionals. Health, 13(3), 277-296.

Tsukahara, M., Koshiba, Y., Ohtani, H. (2011). Effectiveness of downward evacuation in a large-scale subway fire using fire dynamics simulator. Tunnelling and Underground Space Technology, 26(4), 573-581.

Van der Schaaf, T. W. (1992). Near-miss reporting in the chemical process industry. Doctoral dissertation, Eindhoven University of Technology, Eindhoven.

Van der Schaaf, T., Kanse, L. (2004). Biases in incident reporting databases: an empirical study in the chemical process industry. Safety Science, 42(1), 57–67.

Vinnem, J. E. (2012). Use of accident precursor event investigations in the understanding of major hazard risk potential in the Norwegian offshore industry, Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability. 1748006X12468670.

Wang, J., Fang, W. (2014). A structured method for the traffic dispatcher error behavior analysis in metro accident investigation. Safety science, 70, 339-347.

Yan, L., Tong, W., Hui, D., Zongzhi, W. (2012). Research and application on risk assessment DEA model of crowd crushing and trampling accidents in subway stations. Procedia Engineering, 43, 494-498.

Yang, H., Chew, D. A., Wu, W., Zhou, Z., Li, Q. (2012). Design and implementation of an identification system in construction site safety for proactive accident prevention. Accident Analysis & Prevention, 48, 193-203.

Zhang, D., Hu. H. (2014). An optimization on subway vehicle maintenance using a multi-population genetic algorithm, In International Conference on Sustainable Development of Critical Infrastructure.

Zhang, J., Xu, X., Hong, L., Wang, S., Fei, Q. (2011). Networked analysis of the Shanghai subway network in China. Physica A: Statistical Mechanics and its Applications, 390(23), 4562-4570.

Zhou, Q., Fang, D. P., Mohamed, S. (2011). Safety climate improvement: case study in a Chinese construction company. Journal of Construction Engineering and Management, 137(1), 86-95.

Zhou, Z, Li, Q., Wu, W. (2011). Developing a versatile subway construction incident database for safety management. Journal of Construction Engineering and Management, 138(10), 1169-1180.

Zhou, Z. P., Li, Q. M., Deng, X. P., Wu, W. W. (2009). Application of near-miss management system in safety management of metro construction. Journal of PLA University of Science and Technology (Natural Science Edition), 10(6), 597-603.

Zhou, Z., Li, Q., Wu, W. (2011). Developing a versatile subway construction incident database for safety management. Journal of Construction Engineering and Management, 138(10), 1169-1180.