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Work safety evaluation in Mainland China using grey theory

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ABSTRACT

With rapid socio-economic development in Mainland China, work safety remains a serious and continuous concern for the country. To better understand work-related accidents, we propose to analyze the dynamic situation and future trends of work safety in Mainland China using grey theory. The forecasting models, i.e., GM (1,1) models are constructed by use of annual data sets of work-related deaths from five branches: mining and commercial casualties, highway traffic accidents, railway traffic accidents, fire disasters, and all fatal casualties. The effectiveness of these proposed models is demonstrated through accuracy test. The predicted results show that the death counts, not only in the four sub-sections but also overall, will decline continuously, suggesting that the work safety situation will improve.

1. Introduction

Most of the world's population spends one-third of their adult life at work; their work sustains the economic and material basis of society. With the growing complexity of society, organizations and systems, however, it has become apparent that human actions cannot be completely prescribed in procedures or training because working conditions have become more difficult to understand and to predict how they will interact [1]. Many people have been injured, died or contracted diseases at work; thus, work safety conditions have become an increasing concern for employees, employers, and governments. According to Leigh et al., approximately one hundred million occupational injuries (100,000 deaths) are estimated to occur worldwide each year [2]. Work-related injuries and diseases affect 15–20% of the population in the United States [3]. Of the 10.8 million Australian people who worked sometime in the previous 12 months, 6.4% experienced at least one injury or illness related to work [4].

Much of the population in Mainland China (approximately 150 million) has left the rural areas of the country to seek jobs in urban areas [5]. These migrant workers face many obstacles that inhibit their abilities to protect themselves from workplace hazards [6]. It is estimated that more than 16 million enterprises have occupational hazards in Mainland China, and more than 200 million workers are exposed to these hazards in the workplace [7]. According to the State Administration of Work Safety (SAWS), there were 347,728 work-related accidents in Mainland China during 2011, which led to 75,572 deaths and countless injuries [8]. With the country experiencing rapid socio-economic development, the frequency and seriousness of work-related accidents have increased in the 21st century. Thus, the concerns related to work safety in Mainland China remain severe.

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A reasonable assessment and prediction of current and future work safety issues is urgently needed to help identify and ultimately control the key problems that are causing this emergency situation. The present study aims to employ a new method – grey theory – to analyze the dynamic situation and future trends of work safety in Mainland China. It is known that one cannot use conventional methods and crisp data (i.e., complete, concise and accurate data), as opposed to fuzzy data (i.e., incomplete or ambiguous data that allows for approximate values and inferences) to model real-life situations because of the high level of uncertainty. Some concepts such as bounded data, ordinal data and fuzzy data have been developed in response to such situations [9]. Indeed, most of the decisions are not made on the basis of well-known calculations, and there exists a lot of ambiguity and uncertainty in decision-making. The application of grey numbers in such a situation will improve the ability of decision-making models to respond to the ambiguity that arises from having incomplete information. Additionally, relatively large data sets are required to analyze the current situation and make more accurate predictions through the traditional methods such as the Holt's Exponent, regression and ARIMA [10]. In contrast, the grey model (GM) – the core of the grey forecasting theory – can be applied when a data set is as small as four observations and does not need to make strict assumptions. This model could also be used to reach the desired level of analysis and prediction [11], which simplifies the data collection process and allows for the making of more timely predictions. In fact, the grey model is more suitable for smaller amounts of data [12]. From a government's viewpoint, grey theory could become a powerful and dynamic method to evaluate and forecast the work safety situation in a very short period of time, which would allow for more timely emergency preparation.

This paper is structured as follows: Sections 2 and 3 review the work safety situation and grey theory. In Section 4, the forecasting models are constructed via a GM (1, 1) to analyze the current situation and forecast the future trends of work safety; these models are also subjected to accuracy testing. A discussion of the results is then presented in Section 5. Finally, the conclusions are summarized in Section 6.

2. Work safety situation

Work-related injuries and diseases have become matters of increasing concern for employees, employers, and governments because of their significant impacts on the health and productivity of workers [13]. The International Labor Organization defines a work-related accident as an unexpected and unplanned occurrence, including acts of violence, which arises out of or in connection with work and results in one or more workers incurring a personal injury, disease or death. The *Regulation on the Reporting, Investigation and Handling of Work-related Accidents* (Retrieved from http://www.gov.cn/zwgk/2007-04/19/content_588577.htm) was promulgated by the Chinese government in 2007 to strengthen the supervision and administration over work safety and to prevent as well as reduce the number of work-related accidents. According to this regulation, work-related accidents can be generally divided into four grades on the basis of casualties or direct economic losses (i.e., unusual major accident, major accident, large accident and general accident). To demonstrate, an accident resulting in the deaths of more than 30 people, the injury of more than 100 people (including acute industrial poisoning), or direct economic losses totaling more than 100 million Yuan would be classified as an unusual major accident. The four accident grades are exhibited in Table 1.

Accidents may have potentially catastrophic consequences, not only for the people directly involved but also for the work industry and the larger society [14]. Work-related accidents could cause not only high economic costs but also severe social impacts [15]. The economic costs associated with work-related accidents can be defined as the direct, indirect and opportunity costs borne by employers, employees and the government (via the social security system) [16]. Comparatively, Keller [17] described the social costs as "losses or limitations in a person's ability to engage in major social roles and activities. These include working, parenting, or sharing leisure activities with or caring for friends and family." Two primary methods have been developed to estimate the economic costs of work-related accidents: the willingness to pay (WTP) method [18] and the human capital (HC) method [16]. Yet, very little research has tried to estimate the social costs; thus, the total costs of occupational injuries are often underestimated [19].

Efforts to enhance safety measures in the workplace are not only important for the health of workers, but they are also inevitable managerial activities required to improve the safety of the facility and to ensure the quality and continuity of production [20]. Most studies view work-related accidents as incidents resulting from a chain or sequence of events; thus, some proposed accident models have formed the basis for investigating and analyzing accidents, preventing future ones, and determining whether systems are suitable for use. Such event-based accident models explain accidents as multiple events sequenced in a chain over time [21]. However, the systems and context of such events continue to change; thus, new

Table 1
Four grades of work-related accidents.

Grades	Fatalities (person)	Serious injuries (person)	Direct economic losses (million Yuan)
Unusual major accident	$\geqslant 30$	$\geqslant 100$	$\geqslant 100$
Major accident	$\geqslant 10$ and <30	$\geqslant 50$ and <100	$\geqslant 50$ and <100
Large accident	$\geqslant 3$ and <10	$\geqslant 10$ and <50	$\geqslant 10$ and <50
General accident	<3	<10	<10

approaches are needed. According to Leveson [22], the changes include: (1) the fast pace of technological change; (2) the changing nature of accidents; (3) the new types of hazards; (4) the decreasing tolerance for single accidents; (5) the increasing complexity and coupling of accidents; (6) the more complex relationships between humans and technological automation; and (7) the changing regulatory and public views of safety. To accommodate such changes, Leveson developed the systems theoretic accident model and process (STAMP) technique, which focuses on the control processes and constraints between different levels in the safety organization. Similarly, Rasmussen [23] presented a series of models, including the AcciMap technique, which guide safety analysts to look into the workplace and organizational conditions that influence how operators adapt procedures and tools to meet multiple goals, control workload, and maintain a margin for change.

Significant improvements have been made over the last decade to better recognize work-related accidents and their relationships with other socio-economic factors. Early in 1980, Vilanilam claimed that due to a lack of education, most workers in the "developing" world are unaware of the hazards of their occupations, the general poor quality of sanitation, the poor nutrition, and the geographic region's susceptibility to epidemics, which aggravate their health hazards in the work environment [24]. This point is also proven by Agnihotram [25], who claimed that because of the structural changes (i.e., the traditionally labor-oriented markets are evolving with more automation and mechanization; and general awareness about occupational safety, occupational and environmental hazards have not spread throughout the society), the workers in low-resource settings are more likely to be affected by the dangers of high technology than their counterparts in developed countries. In a study conducted by Barth et al., a statistical analysis clearly shows that a growing economy is associated with declining injury rates (both fatal and non-fatal) in Austria [26]. Moniruzzaman and Andersson confirmed earlier cross-sectional findings through a longitudinal analysis of high-income member countries of the Organization for Economic Cooperation and Development (OECD) [27]. This study found that most injury categories seem to follow inverted U-shaped patterns, with trends that decline after peaking at various stages of temporal and economic development. Other scholars have also conducted similar studies of the inverted U-shaped relationship between work-related accidents and economic development [28–30].

In recent years, the relationships between work-related and social environmental factors such as work environment, culture, safety climate and practices have become subjects of analysis. Organizations have demonstrated a subtle shift in their recognition of the importance and role of their culture and management systems, as well as the processes that may contribute to accidents [31]. Employees continuously observe their work environment and the actions of their fellow workers and superiors, and they use such observations as a basis for cognitive models associated with safety [32]. Lindell defined the safety climate in terms of the workers' interpretations of features, events, and processes that are relevant to their safety in their work environment [33]. Mearns et al. collected safety climate surveys of 13 offshore oil and gas installations, as well as data on safety management practices to analyze the relationships of safety performance with safety climate scores, safety management practices and specific management practices [34]. The study by Bjerkan concluded that the work group has to be taken into account when studying the effects of work safety climate, the perception of the work environment on subjective health status, and accident frequency [14].

Many researchers in previous studies have conducted separate exploratory analyses of the factors that contribute to work-related accidents. Studies have examined the relationship between work-related accidents and socio-economic factors such as economic development, social environment, culture, safety climate, and the practices that we recognize as impacting the work safety situation. All of these definitions, attributing factors and relationships with work-related accidents could be summarized and expressed as different parts of "work safety", which is similar to the concept of "occupational safety and health". The connotation of "work safety situation" in this study refers to a series of measures and activities that are taken to avoid personal injury and property damage to ultimately ensure the personal safety of employees and smooth production and business activities. Work safety is the combination of both safety and work; to promote productivity, one must ensure the workplace is safe for employees. The "work safety situation" refers to the different safety situations in relevant industries, sectors or branches, in which work-related accidents can cause deaths, injuries or diseases.

The work safety situation is receiving increasing attention as a public health issue throughout the world; however, few relevant studies have been conducted in Mainland China, and most of those conducted have focused only on single sectors or branches, such as the traditional and high-risk construction [35], transport [36,37], and agriculture industries [38,39]. No existing studies have considered the overall situation of work safety in entire countries or regions, let alone conducted a reasonable assessment and prediction on the situation, especially in Mainland China. With the country's rapid socio-economic development, the frequency and seriousness of work-related accidents have increased in the 21st century. A reasonable assessment and future prediction on the work safety situation through powerful research methods could help governors obtain a clear understanding of current and future problems and ultimately find scientific means to control them.

3. Grey theory

The grey system theory, originally proposed by Deng [40], is used to address uncertain problems that are characterized by the existence of discrete data and incomplete information [41,42]. The scientific fields covered by grey system theory include systems analysis, data processing, modeling, prediction, decision-making and control; these fields are neither deterministic nor totally unknown, but rather they are partially known. Upon its introduction, grey theory received positive attention from domestic and foreign academic circles and from many workers. Between 1982 and June of 2006, approximately 15,000 grey system papers were retrieved from the Chinese academic periodical database in the China National Knowledge Infrastructure (CNKI) and 5986 papers from the EI Village database [43]. To date, the grey forecasting model has been widely applied in various fields, including economy and industry [44–46], energy and environment [47–49], medical and health [50,51], and risk assessment [52,53].

The grey forecasting model uses the operations of accumulated generation to reduce the variation in the original data series and to build differential equations by linearly transforming the data series [54]. GM (1,1), which is the simplest and most widely applied model of the grey forecasting theory, indicates one variable and one order grey forecasting model.

The general procedure for a grey forecasting model is derived as follows:

Step 1: Suppose the observed series, i.e., the original series of $x^{(0)}$, is expressed by the following equation:

$$x^{(0)} = \left(x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), \ldots, x^{(0)}(n)\right) = x^{(0)}(k), \quad (1)$$

where $k = 1, 2, 3, ..., n$ and $n \geqslant 2$.

Step 2: Ensure the class ratio $\sigma^{(0)}(k)$ of $x^{(0)}$ is within the interval $\left(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}\right)$,

$$\text{where } \sigma^{(0)}(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}, \quad k = 2, 3, \ldots, n. \quad (2)$$

$$\text{i.e., } \begin{array}{ll} n = 4, & \sigma^{(0)}(k) \in [0.670320046, 1.491824698] \\ n = 5, & \sigma^{(0)}(k) \in [0.716531310, 1.395612425] \\ n = 6, & \sigma^{(0)}(k) \in [0.751477292, 1.330712198] \\ \vdots & \qquad \vdots \end{array}$$

Step 3: A new sequence $x^{(1)}$ is generated by the Accumulated Generation Operation (AGO).

$$x^{(1)} = \left(x^{(1)}(1), x^{(1)}(2), x^{(1)}(3), \ldots, x^{(1)}(n)\right) = x^{(1)}(k),,$$

$$\text{where } k = 1, 2, 3, \ldots, n \quad \text{and} \quad x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i). \quad (3)$$

Step 4: Establish a first-order differential equation and is denoted as follows:

$$x^{(0)}(k) + az^{(1)}(k) = b, \quad k = 2, 3, \ldots, n, \quad (4)$$

$$\text{and } z^{(1)}(k) = \alpha x^{(1)}(k) + (1-\alpha)x^{(1)}(k-1), \quad (5)$$

where $z^{(1)}(k)$ is the whitened value and a, b are developing coefficient and grey input, respectively. Where $0 < a < 1$, and $\alpha = 0.5$ is typically used.

Step 5: According to Eq. (4) and by the Least Ordinary Square Method, coefficient $\hat{\theta}$ becomes

$$\hat{\theta} = \begin{pmatrix} a \\ b \end{pmatrix} = (B^T B)^{-1} B^T Y_N, \quad (6)$$

$$\text{where } B = \begin{pmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(n) & 1 \end{pmatrix}, \text{ and } Y_N = \begin{pmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(N) \end{pmatrix}.$$

Step 6: Eq. (4) can be denoted by another type (i.e., grey difference equation) through white process as follows:

$$\frac{dx^{(1)}(k)}{dk} + ax^{(1)}(k) = b. \quad (7)$$

We use the discrete sequence $x^{(1)}$ whitening equations to solve Eq. (6):

$$\hat{x}^{(1)}(k+1) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-ak} + \frac{b}{a}. \quad (8)$$

Because the grey forecasting model is formulated using the data of AGO rather than original data, the Inverse Accumulated Generation Operation (IAGO) can be used to reverse the forecasting value.

Namely, $\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1)$, $k = 2, 3, \ldots, n$.

$$\text{i.e., } \hat{x}^{(0)}(k) = \left[x^{(0)}(1) - \frac{b}{a}\right] e^{-a(k-1)}(1 - e^{a}), \quad k = 2, 3, \ldots, n. \quad (9)$$

Given $k = 1, 2, 3, \ldots, n$, the series of reduction is obtained as follows:

$$\hat{x}^{(0)} = \left(\hat{x}^{(0)}(1), \hat{x}^{(0)}(2), \hat{x}^{(0)}(3)\ldots, \hat{x}^{(0)}(n)\right).$$

To examine the accuracy of the new forecasting model, some testing methods are proposed, such as the residual error test and the class ratio error test. The formulas are as follows:

$$\varepsilon(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \times 100\%,\ \varepsilon(k) \text{ is the relative residual error;}$$

$$\varepsilon(avg) = \frac{1}{n-1}\sum_{k=2}^{n}|\varepsilon(k)|,\ \varepsilon(avg) \text{ is the average relative residual error;}$$

$$p^0 = (1 - \varepsilon(avg)) \times 100\%,\ p^0 \text{ is the accuracy;}$$

$$\rho(k) = \frac{\hat{\sigma}^{(0)}(k) - \hat{\sigma}^{(0)}(k-1)}{\hat{\sigma}^{(0)}(k)} \times 100\%,$$

where $\hat{\sigma}^{(0)}(k) = \frac{\hat{x}^{(0)}(k-1)}{\hat{x}^{(0)}(k)}$, $k = 2, 3, \ldots, n$, $\rho(k)$ is the model class ratio.

The forecasting model is considered useful if the relative residual error is within 10%, the accuracy exceeds 90% and the model class ratio is within 10% simultaneously.

4. An empirical application

4.1. Data collection

The SAWS is an agency directly under the State Council for overall supervision and regulation of work safety. The SAWS is also the working body of the Office of the State Council Work Safety Commission. The main duties of the SAWS are as follows: to organize nationwide work safety inspections and specialized safety supervision activities as authorized by the State Council; to organize the drafting of general laws and administrative regulations on work safety, to promulgate the general regulations on work safety of industry, mining and commerce; to develop work safety policies and standards and rules for work safety of industry, mining and commerce and organize their implementation; to release information on nationwide work safety; to exercise the overall management of statistics of nationwide workplace injuries and fatalities and the analysis of the situation of administrative enforcement of law on work safety; and to organize, command and coordinate workplace emergency rescue operations.

The SAWS collects information to analyze the country's safety situation and publishes the details of serious accidents from coast to coast on its homepage (http://www.chinasafety.gov.cn/newpage/). The SAWS will release the executive data of work safety that includes the actual death counts and the control targets in various regions and industry sectors within the past year, which can be obtained from the "safety analysis" column of the SAWS' homepage (http://www.chinasafety.gov.cn/newpage/aqfx/aqfx_ndtjfx.htm). On the basis of the statistics on work safety casualties of the first two years, and combined with the actual situation in various regions, the proposed control targets on work safety of this year have been set by SAWS. For example, there were 136,102 work safety deaths in whole country in 2003, which decreased by 3291 deaths (reduced 2.4%) compared to last year. So the control target on total number of work-related death in 2004 will be set reducing at least 2.4%.

According to the statistical data of the SAWS, the work-related fatal accidents occurred mainly in six industry categories: mining and commerce, highway traffic, railway traffic, fire disaster, agricultural machinery and others. The released information contains the actual counts of work-related deaths and their percentage of control targets in each category. According to the data, however, the number of work-related deaths occurred in the former four categories, i.e., mining and commerce, highway traffic, railway traffic, and fire disaster collectively contribute to over 98% of all deaths. In this study, we selected the annual nationwide work-related deaths in five branches for our analysis, i.e., deaths in all fatal casualties (AF), mining and commercial casualties (MC), highway traffic accidents (HT), railway traffic accidents (RT), and fire disasters (FD) between 2007 and 2011. The data are summarized in Table 2.

Table 2
The work-related deaths in five branches from 2007 to 2011 (unit: person).

	2007	2008	2009	2010	2011
AF	101,480	91,172	83,196	79,552	75,572
MC	13,886	12,860	11,532	10,616	9704
HT	81,649	73,484	67,759	65,225	62,387
RT	3156	2283	1825	1589	1522
FD	1419	1385	1076	1108	1106

4.2. Steps

Now, we apply GM (1,1), the Grey forecasting model and the data in Table 2 to calculate the annual work-related deaths between 2007 and 2011. Take the deaths in AF for example, the steps are as follows:

Step 1: Assume that $x_i^{(0)}$ stands for the ith primitive series. According to Eq. (1) and Table 2, the primitive series for the deaths in AF $x_i^{(0)}$ as below:

$$x_1^{(0)} = (101480, 91172, 83196, 79552, 75572)$$

Step 2: Calculate the class ratio $\sigma_1^{(0)}(k)$ of $x_1^{(0)}$ by Eq. (2),

$$\sigma_1^{(0)} = (1.1131, 1.0959, 1.0458, 1.0527), \quad k = 2, 3, 4, 5,$$

is within the interval [0.716531310, 1.395612425].

Step 3: According to Eq. (3), a new sequence $x_1^{(1)}$ can be obtained by AGO $x_1^{(0)}$, as follows:

$$x_1^{(1)} = (101480, 192652, 275848, 355400, 430972), \quad k = 1, 2, 3, 4, 5$$

Step 4: From Eq. (5) and $\alpha = 0.5$, $z_1^{(1)}(k)$ can be calculated and the result is:

$$z_1^{(1)} = (147066, 234250, 315624, 393186), k = 2, 3, 4, 5.$$

Step 5: Through step 4, matrix B_1 and constant vector Y_{1N} are accumulated as follows:

$$B_1 = \begin{pmatrix} -147066 & 1 \\ -234250 & 1 \\ -315624 & 1 \\ -393186 & 1 \end{pmatrix}, \quad Y_{1N} = \begin{pmatrix} 91172 \\ 83196 \\ 79552 \\ 75572 \end{pmatrix}$$

From Eq. (6), $\hat{\theta}$ can be obtained as

$$\hat{\theta} = \begin{pmatrix} \hat{a} \\ \hat{b} \end{pmatrix} = \begin{pmatrix} 0.0618 \\ 99213.8322 \end{pmatrix}.$$

Step 6: The forecasting model is acquired by substituting $\hat{a}$ and $\hat{b}$ into Eq. (9),

$$\hat{x}_1^{(0)}(k) = 95874.3744e^{-0.0618(k-1)}, \quad k = 2, 3, 4, 5. \tag{10}$$

Substituting $k = 1, 2, 3, 4, 5$ into Eq. (10), the series of reduction is obtained as follows:

$$\hat{x}_1^{(0)} = (95874, 90129, 84727, 79650, 74876)$$

4.3. Accuracy testing

Although the forecasting model can estimate the work-related deaths in AF, how can one determine the accuracy of such results? Testing methods should be proposed to examine the estimated results, such as the residual error test and the class ratio error test mentioned above.

Substituting $x_1^{(0)}(k)$ and $\hat{x}_1^{(0)}(k)$ into the following test formulas, the results can be obtained as follows:

$$\varepsilon(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \times 100\%, \text{ the relative residual error is}$$

$$\varepsilon(k) = (1.14\%, -1.84\%, -0.12\%, 0.92\%), \quad k = 2, 3, 4, 5.$$

$$\varepsilon(avg) = \frac{1}{n-1}\sum_{k=2}^{n}|\varepsilon(k)|, \text{ the average relative residual error is } \varepsilon(avg) = 1\%.$$

$$p^0 = (1 - \varepsilon(avg)) \times 100\%, \text{ the accuracy is } p^0 = 99\%.$$

$$\rho(k) = \frac{\hat{\sigma}^{(0)}(k) - \hat{\sigma}^{(0)}(k-1)}{\hat{\sigma}^{(0)}(k)} \times 100\%, \text{ where } \hat{\sigma}^{(0)}(k) = \frac{\hat{x}^{(0)}(k-1)}{\hat{x}^{(0)}(k)}, \quad k = 2, 3, \ldots, n,$$

the model class ratio is $\rho(k) = (0.0015\%, -0.0015\%, 0.0016\%)$, $k = 3, 4, 5$.

Table 3
The estimated results and accuracy testing from the forecasting models.

		2007	2008	2009	2010	2011	p^0 (%)
AF	Actual (person)	101,480	91,172	83,196	79,552	75,572	99.00
	Forecasted (person)	95,874	90,129	84,727	79,650	74,876	
	$\varepsilon(k)$ (%)		1.14	−1.84	−0.12	0.92	
	$\rho(k)$ (%)			0.0015	−0.0015	0.0016	
MC	Actual (person)	13,886	12,860	11,532	10,616	9704	99.46
	Forecasted (person)	14,034	12,782	11,643	10,604	9659	
	$\varepsilon(k)$ (%)		0.61	−0.96	0.11	0.46	
	$\rho(k)$ (%)			−0.0112	0.0141	−0.0133	
HT	Actual (person)	81,649	73,484	67,759	65,225	62,387	99.08
	Forecasted (person)	76,722	72,710	68,909	65,306	61,891	
	$\varepsilon(k)$ (%)		1.05	−1.7	−0.12	0.8	
	$\rho(k)$ (%)			−0.0017	0.0011	0.0006	
RT	Actual (person)	3156	2283	1825	1589	1522	95.49
	forecasted (person)	2556	2210	1912	1653	1430	
	$\varepsilon(k)$ (%)		3.2	−4.77	−4.03	6.04	
	$\rho(k)$ (%)			−0.0609	0.0715	−0.0641	
FD	Actual (person)	1419	1385	1076	1108	1106	93.65
	forecasted (person)	1395	1298	1207	1123	1044	
	$\varepsilon(k)$ (%)		6.28	−12.17	−1.35	5.61	
	$\rho(k)$ (%)			0.0617	−0.0553	0.0810	

From the test results, the forecasting model could be considered excellent due to the simultaneous relative residual error within 1.84%, the accuracy as high as 99% and the model class ratio within 0.0016%.

4.4. Results

The forecasting models and their estimated results can also be applied to the work-related deaths in other branches, i.e., MC, HT, RT and FD into consideration. The residual error test and class ratio error test have also been conducted. The estimated results and actual data are exhibited in Table 3.

4.5. Forecasts

Given $k = 6, 7, 8$, from Eq. (10), we can predict that the number of work-related deaths in AF will decrease from 70,389 in 2012 to 62,205 in 2014. Table 4 summarizes the forecasted results of the work-related deaths in five branches from 2012 to 2014. According to Table 4, between 2012 and 2014, the deaths in MC are forecasted to decrease from 8798 to 7298. Meanwhile, the deaths in HT are predicted to decrease from 58,656 to 52,683, in RT a decrease from 1237 to 925, and in FD a decrease from 971 to 840, as shown in Table 4.

5. Discussion

As mentioned above, relatively large data sets are required to analyze future trends through the traditional methods such as regression and times series models [10]. However, in grey theory, the minimum required number of data sets could be as low as four observations without suffering from a decline in predictive accuracy [11]. In this study, we drew from five annual data sets – from 2007 to 2011 – to propose a GM (1,1) model in each branch. The results showed that the accuracy in each branch exceeded 90%, all of the model class ratios were within 10% and most relative residual errors were within 10% (only one relative residual error exceeded 10%) simultaneously (see Table 3), which demonstrate that the proposed forecasting model was accurate and effective. The results also prove that the forecasted results could be used as references for scientific control. From the government's viewpoint, grey theory could become a powerful and dynamic method to evaluate and fore-

Table 4
The forecasted results in 5 branches from 2011 to 2014 (unit: person).

	2012	2013	2014
AF	70,389	66,171	62,205
MC	8798	8013	7298
HT	58,656	55,589	52,683
RT	1237	1069	925
FD	971	903	840

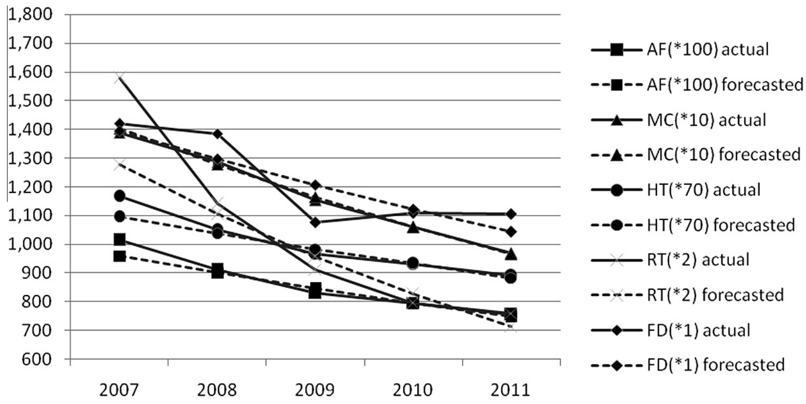

Fig. 1. The trend analysis for five branches (unit: person).

cast the work safety situation in a very short period of time, which could facilitate the country's emergency preparation efforts.

Fig. 1 shows the trend analysis for each branch of the actual and forecasted numbers of work-related deaths. To maintain all data in the same order of magnitude, some corresponding processing was conducted on the actual and forecasted data. The deaths in AF were divided by 100, the deaths in MC were divided by 10, the deaths in HT were divided by 70, the deaths in RT were divided by 2, and the deaths in FD were kept constant. This additional processing enabled the death counts in all branches to be exhibited within one interval [600,1800].

From the figure, we first found that both the forecasted results and the actual work-related death counts in each branch demonstrated a declining trend after the first year of collected data. In RT, for example, the number of deaths declined from 3156 in 2007 to 1522 in 2011, with an annual average decline of 10.35% during the last 5 years. As mentioned above, the forecasted results in the five branches between 2012 and 2014 also showed the same declining trend (see Table 4). We can thus conclude that the work-related deaths will continuously decline and the work safety situation will improve in the future. Secondly, the curving tendency of forecasted results coincides very well with the actual curves in the frequency of deaths in the five branches. It was also demonstrated that the proposed models are effective and the accuracy testing is valid (see Table 3).

In the second year, the SAWS will release its work safety executive data, which include the actual death counts and the control targets in various regions and industry categories over the past year. The control targets have also been collected in the present study. Table 5 exhibits the control targets, forecasted results and actual data of work-related deaths in five branches between 2007 and 2011. Some interesting findings can be drawn from the table. Firstly, it is important to note that the work safety situations in five branches have been under the expected control of the government during the past five years. All the actual counts of work-related deaths in five branches are lower than the control targets in the same year. Secondly, the actual numbers of work-related deaths in five branches are minimum, the forecasted results next, whereas the control targets are maximum. Moreover, the forecasted results are closer to the actual data than the control targets setted by SWAS. From the second finding, we can conclude that the control targets are not very accurate and the setting methods should be more scientific and effective. The accurate results in this study indicate that grey theory is a powerful and suitable

Table 5
The control targets, forecasted results and actual data of work-related deaths in five branches between 2007 and 2011 (unit: person).

		2007	2008	2009	2010	2011
AF	Control targets	111,394	100,079	89,942	82,012	78,721
	Forecasted results	95,874	90,129	84,727	79,650	74,876
	Actual data	101,480	91,172	83,196	79,552	75,572
MC	Control targets	14,097	13,608	12,603	11,318	10,345
	Forecasted results	14,034	12,782	11,643	10,604	9659
	Actual data	13,886	12,860	11,532	10,616	9704
HT	Control targets	88,365	80,575	72,625	66,897	64,650
	Forecasted results	76,722	72,710	68,909	65,306	61,891
	Actual data	81,649	73,484	67,759	65,225	62,387
RT	Control targets	5636	3110	2239	1789	1571
	Forecasted results	2556	2210	1912	1653	1430
	Actual data	3156	2283	1825	1589	1522
FD	Control targets	1518	1451	1399	1076	1108
	Forecasted results	1395	1298	1207	1123	1044
	Actual data	1419	1385	1076	1108	1106

method to evaluate and forecast work safety situations in a very short period of time, which will enable the formulation of more scientific and realistic control targets in the future.

Although the work safety situation is receiving increasing attention as a public health problem in Mainland China, most studies have focused only on the country's individual sectors or branches [35–39]. This study has attempted to comprehensively consider the current situation of work safety in Mainland China by developing forecasting models of work safety using grey theory. We examined five branches to evaluate the current situation of work safety, specifically the work-related deaths in MC, HT, RT, and FD industry categories. We have drawn not only from the historical data but also from the forecasted data of the work-related deaths in these related branches to obtain a more comprehensive understanding of the work safety situation in Mainland China.

6. Conclusions

In conclusion, this study was conducted to improve the understanding of work-related accidents and to analyze the dynamic and future situation of work safety in Mainland China by employing a new scientific method – grey theory. The estimated results of this paper indicate that the proposed model, GM (1,1), is effective and grey theory is a powerful and accurate method for quickly evaluating and forecasting the work safety situation if at least four observations are collected. Moreover, coming to understand the work safety situation in the near future and taking corresponding responses to cope with work-related accidents could significantly improve the environment of work and society.

The current study has a number of limitations. The grey model is powerful and especially suitable for smaller amounts of data; however, the feasibility and accuracy of forecasting with the GM (1,1) model depends on whether the class ratio $\sigma^{(0)}(k)$ of original series $x^{(0)}$ is within the interval $\left(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}\right)$ (as mentioned in Step 2 of grey theory). The estimated accuracy of AF, MC and HT are higher than that of RT and FD because the class ratios of sequences AF, MC and HT are well within the interval $\left(e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}\right)$, where RT and FD are not. However, we use the number of work-related fatal accidents in different branches only to reflect the work safety situation because we lack the data for work-related injuries and diseases. Other aspects such as the numbers of injuries, the direct economic losses and the provincial data should be taken into consideration when constructing forecasting models to enhance work safety in the future studies.

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