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ORIGINAL PAPER

A comprehensive literature review of the demand forecasting methods of emergency resources from the perspective of artificial intelligence

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Abstract

In recent decades, several forecasting methods have been proposed so as to aid in selecting from all optimal alternatives in the demand of emergency resources. Academic research in the field of emergency management has increasingly focused on artificial intelligence. However, more attention has been paid to attempts at simulating the human brain, with little focus on addressing intelligent information processing techniques based on machine learning, big data and smart devices. In this paper, a comprehensive literature review is presented in order to classify and interpret current research on demand forecasting methodologies and applications. A total of 1235 academic papers from 1980 to 2018 in the SpringerLink and Elsevier ScienceDirect databases are categorized as follows: time series analysis, case-based reasoning (CBR), mathematical models, information technology, literature reviews, and discussion and analysis. Application areas from business source premier include papers on the topics of emergency management, decision-making, decision relief, logistics, fuzzy sets and other topics. Academic publications are classified by (1) year of publication, (2) journal of publication, (3) database source, (4) methodology and (5) research discipline. The results of this literature review show that, despite forecasting methods such as ARIMA, CBR and mathematical models appearing to play a pivotal role in promoting prediction performance, there is a need to explore more real-time forecasting approaches based on intelligent information processing techniques so as to achieve appropriate dynamic demand prediction that is adaptable to emergency and rescue situations. The intention for this paper is to be a useful reference point for those with research needs in forecasting methodologies and the applications of emergency resources.

Keywords Emergency event · Emergency resource · Demand prediction · Forecasting method · Literature review · Artificial intelligence

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1 Introduction

The prepositioning of emergency supplies was one of the first emergency decision-making problems addressed by the academic community so as to assist in the long-term preparation of responses to natural disasters (Goldschmidt and Kumar 2016). The demand of emergency materials refers to the minimum guaranteed requirements for an effective response to unconventional emergency events (Bingzhen et al. 2012, Table 1). Since demand prediction is closely related to the eventual number of rescued survivors, the accuracy and efficiency of the demand prediction of emergency resources are the key to the facilitation of effective emergency logistics. When an emergency strikes, a proper forecasting method for the possible demand of emergency resources is necessary in order to understand the magnitude of expected losses and to facilitate decision-making in relief operations (Wu et al. 2015). Despite the ambiguity and suddenness of demand targets, lack of human and capital resources, uncertainty of disaster relief environment and time limit pressures for rescue, at present no single demand forecasting model that solves the above issue has been developed. In order to effectively cope with urgent rescue situations and insufficient emergency decision-making time, it is necessary to develop effective forecasting approaches based on artificial intelligence in the context of the era of big data.

After 60 years of exploration, artificial intelligence can be summed up as having two general research approaches. One, the traditional research path, is the attempt to build an artificial intelligence system through a simulation of the human brain. This path stems from an in-depth exploration of the structure, thinking and behavior of the human brain and relies on multidisciplinary intersections in computer science, psychology, behavioral science and neuroscience. In the late 1960s, neural networks were widely used in the demand prediction of emergency materials as a new artificial intelligence method. However, simple models imposed restrictions on the development of neural networks and there have only been a few breakthroughs after decades of exploration. The other research approach of artificial intelligence is to take the superior arithmetic precision and data processing capabilities of machines as the advantage of machine learning based on big data and deep learning algorithms. At present, this approach has developed rapidly within Internet-based commercial logistics, mainly by technology companies represented by Google, Amazon, Alibaba and so on. In terms of emergency resource management, government departments possess the vast majority of relevant social data. Due to the conflicts and risks of data security, it is often

Table 1 Classification of emergency resources

Relief materials
Lifesaving: boat, lifebuoy or vest, life-detecting device, and small hoisting device
Life necessities: clothes, quilt, convenient food, relief tent, and water-purifying device
Equipment and facilities
Basic equipment: communication equipment, means of transport, lighting device, and productive device
Dedicated rescue equipment: detection equipment, emergency medical aid device, first-aid medicine, and emergency equipment
Technological resources
Satellite telemetering technology, communication technology, high-precision air-to-land observation technology, computer networking technology, andother spatial and attributive data
Manpower resources
Personnel who study various unforeseen events
Personnel who carry out emergency rescue in various unforeseen events: governments at different levels, meteorological organizations, public securityorganizations, and armed forces

difficult to obtain access to governmental emergency databases and public data. Thus far, in the demand prediction of emergency materials for large-scale emergency events, despite the urgent necessity of emergency resource management, no single demand forecasting model based on big data machine learning that solves this issue has been developed.

In somewhat limited ways, reviews from 1980 to 2018 have predicted the demand of emergency resources (Holguin-Veras and Jaller 2012; Sheu 2007; Wu 2012; Zhu et al. 2016; Guo and Zhou 2011; Liu et al. 2012; Tafahomi 2013; Zhang et al. 2012; Bin et al. 2014; Donkor et al. 2014; Bingzhen et al. 2012). Many of these reviews describe multiple approaches for predicting the demand of emergency supplies as preliminaries for the scheduling research of emergency materials. However, little emphasis has been placed on artificial intelligence, especially in terms of machine learning, as the key for demand prediction. What is more, there is a lack of a systematic review of the whole body of papers dating from roughly 1980 to the present that explores the differing approaches toward demand forecasting. The overall goal of this paper is to help fill this gap in the research and summarize the future direction in the prediction of emergency resources. The Elsevier ScienceDirect database has been the core database of one of the world's largest publishers since 1999, providing a great deal of users with online services for searching academic publications. SpringerLink is the world's largest online platform for academic resources in the field of science, technology and medicine. Business Source Premier is the most widely used database for business research, including full textual coverage of all business disciplines, including those of marketing, management, management information systems (MIS), accounting, finance and economics. This paper, therefore, attempts to provide such a review based on three global databases and to answer several questions concerning current state-of-the-art forecasting methods in various approaches toward the demand prediction of emergency supplies. According to the literature: (1) What forecasting methods have actually been most widely used to predict the demand of emergency resources during the last 28 years? (2) How does artificial intelligence perform the demand prediction of emergency supplies more precisely and scientifically? (3) Where are the gaps in the different approaches and what research efforts are needed to fill them? This paper is organized into five sections. Section 1 introduces the research background and the relevant literature. Section 2 provides a detailed description of primary forecasting methods and some of their advantages and drawbacks. Section 3 addresses the methodological framework of this paper through an analysis of the searched publications from three databases. Section 4 continues the overview and analysis of the literature with further discussion. Finally, limitations and directions for future research are given in Sect. 5.

2 Primary forecasting methods of emergency resources

Dynamic relief-demand management is the key to the success of emergency logistic operations under conditions of large-scale natural disaster. The difficulties in relief-demand management are rooted in the inherent uncertainty of relief-demand information (Sheu 2010). The classification of emergency resources is shown in "Appendix" Table 2.

2.1 Case-based reasoning

Case-based reasoning (CBR) is an important branch of artificial intelligence that aims to solve new problems by applying previously successful solutions to similar problems. As opposed to the traditional rule-based reasoning (RBR) method of analysis, case-based reasoning is a problem-solving technique that adapts previously successful solutions to similar problems. Over the years, this method has attracted increasing attention (Clancey 1985; Liu et al. 2012). CBR's retrieval mechanism identifies similar problems from the past in expectation of the solutions to these previous problems being useful for new problems due to them having similar properties. Due to the particularity of emergency rescue processes, in the field of demand prediction the total resource demand amount from previous similar disaster cases appears to be potentially important to the demand prediction of a target event. That is, without any complete and actual data, it seems both scientific and practical to use the previous experience of base cases for reference after a disaster has taken place. Taking earthquakes as an example, ground-shake parameters, including seismic magnitude and intensity, distance from the epicenter and focal depth, are often selected so as to obtain the most similar case as the target case (Zhu et al. 2016). CBR, then, is widely used to select the most similar case as the target case by retrieving previously solved problems and their corresponding solutions from a knowledge source of cases.

2.2 Time series analysis

Single-variable forecasting techniques are designed to detect patterns in a time series and, using this information, thereby extrapolate likely future values for the same series. There are a variety of simple techniques for forecasting a time series based on a weighted average of past values of the series, seasonal cycles and time trends (Donkor et al. 2014). When it is found that the time series of the total number of requests was non-stationary, the most effective approach to be used for modeling the time series for predicting the demand of emergency resources is the auto-regressive integrated moving average (ARIMA) method (Box et al. 1994; Sheu 2010). An ARIMA process is characterized by three parameters: p, d and q, where p denotes the number of auto-regressive terms; d is the number of times the series has to be differentiated before it becomes stationary; and q is the number of moving average terms (Gujarati 2003). An ARIMA process model is a combination of an auto-regressive (AR) process model and a moving average (MA) process model of the integration of the series. In addition, exponential smoothing models and independent and identically distributed (IID) models have also been widely used to deal with various problems of dynamic demand forecasting (Wei 1990; Box et al. 1994; Aviv 2003).

2.3 Mathematical models and intelligent algorithms

Due to the multi-objective, multi-period and multi-item features in solving emergency resource forecasting problems, multi-regression analysis, multi-objective programming models and fuzzy theory are all widely recognized as fundamental forecasting models for exploring the causal relationships between various explanatory variables and demand. In most cases, the aforementioned models are combined with machine learning algorithms—BP (back propagation) neural networks, support vector machines (SVM) and genetic algorithm to perform predictions. A major advantage of these approaches is that they provide a straightforward framework for quantifying changes in the consumption of emergency resources that can occur under various alternative assumptions regarding the future trajectories of the predictor variables (Billings and Jones 2008). As an addition, a further advantage of neural networks is their ability to incorporate nonlinear interactions between input and output variables without the need to specify the functional forms of these relationships in advance (Tu 1996; Zhang 2001). A concern, however, is that most of these mathematical models often do not account for all of the systematic variations in demand prediction, due to the fact that it is largely impossible to include all of the variables that influence the consumption of emergency materials.

2.4 Intelligent information processing techniques

Big data refer to large-scale and diverse data information that is difficult to collect, screen and process in a certain period of time. Further, its importance in recent years has focused on the fact that it can be utilized to assist in making effective decisions. In light of the great significance of big data-driven decision-making, big data-based methods may address the challenges faced by traditional methods. As a new approach of artificial intelligence, big data analytics and data mining technologies can be used to conduct in-depth analyses in order to explore the different characteristics of demand estimation and the routing scheduling of emergency materials, thus being able to make more practicable emergency decisions (Huang et al. 2018). Over the past few years, with the rapid development of cloud computing, the Internet of things (IoT) and virtual reality (VR), various smart devices such as computers and mobile phones have been used as data acquisition pathways.

In recent years, emergency materials demand prediction methods have tended to be geared toward incorporating artificial intelligence, with a significant amount of research focusing on the traditional approach of artificial intelligence that attempts to simulate the human brain. Despite the resultant considerable attention being paid to the rich variety of methods that are available in such areas as big data mining and the application of smart devices, in searching for demand forecasting approaches toward emergency resources, few studies to date have focused on such an approach (Hjorth and Kim 2011; Tzavella et al. 2018). Over recent years, a combination of smart devices based on big data analysis as well as other conventional forecasting methods has been proposed as a way to satisfy the dynamic demand prediction for emergency resources.

3 Overview and analysis of the literature

The theory and methodology concerning the research on emergency resource demand prediction have proved to be a controversial issue. Some existing research has commonly assumed that there could be a close association between the demand of emergency resources and the time-varying number of survivors trapped in affected areas (Sheu 2010; Wu 2012; Zhu et al. 2016; Fu and Chen, 2009; Guo and Zhou 2011). Nevertheless, other researchers have insisted that the demand prediction of emergency supplies is best calculated based on previous relief-demand information sources at different stages after a disaster strikes and not on the number of trapped victims (Holguin-Veras and Jaller 2011; Chiu and Zheng 2007; Holguin-Veras and Jaller 2012).

3.1 Comment on case-based reasoning

CBR has been widely used in recent years for dealing with demand forecasting problems. In the forecasting process for the demand of emergency materials, CBR is often combined with other approaches, such as mathematical models and time series-based analysis, in order to calculate and generate demand predictions. Liu et al. (2012) used a CBR method based on risk analysis to estimate the quantity, quality and type of emergency resources for public emergencies. Standing out from most studies dealing with demand prediction based on CBR, this paper introduced risk analysis into the case-based analytical process, improving the forecasting accuracy for the demand of emergency resources. Over the same period, in order to effectively estimate the mortality rates of emergency events, a number of models at the local or regional level have been established. Several papers have focused on exploring fatality predictions by drawing from historical databases (Fu and Chen 2009; Guo and Zhou 2011; Wu 2012). Chan et al. (2003) found that the immediate aftermath of the 1999 Taiwan earthquake included a higher proportion of female and elderly fatalities as well as an association between seismic death rates and earthquake damages in the disaster area. Zhu et al. (2016) predicted the final death toll in earthquakes using a case-based reasoning model through the proposal of a new concept: average population density from a realistic perspective. To validate the forecasting results, historical data from 18 large-scale earthquakes occurring in China were used to estimate the seismic mortality rates in each historical case. The strength of this paper is that it provides a scientific method with an overall forecast margin of error lower than 20%, thereby creating the possibility for conducting final fatality forecasts with a combined qualitative and quantitative approach.

3.2 Comment on time series analysis methods

In operations research and related applications, the theory of time series analysis can be applied both flexibly and effectively in the field of emergency demand prediction (Sheu 2010). As recent studies have indicated, several forecasting methods, such as auto-regressive integrated moving average (ARIMA) models, independent and identically distributed (IID) models and exponential smoothing models, have been widely adapted for the total demand and dynamic demand estimations of emergency resources. A principle advantage of this approach, especially with respect to multiple regression, is that it can detect patterns in the demand series that are not expressly linked to observable variables. However, the weakness of these approaches is that time series models require previous demand information, with it often being the case that previous information in most urgent emergencies is incomplete or difficult to obtain.

3.2.1 Arima

Holguin-Veras and Jaller (2012) conducted a quantitative study of the immediate resource requirements and their temporal patterns after 2005's Hurricane Katrina. As part of their research, ARIMA models were estimated for key commodity groups, thereby providing a framework for the prediction of resource needs after disasters. Their results clearly show that it is indeed possible to estimate robust ARIMA models to forecast resource requirements and through this open the door for the combined use of needs forecasting, inventory control and ordering models. Kenneth Gilbert (2005) examined ARIMA models for consumer demand and the respective lead times at each stage. Aviv (2003) considered a supply chain in which the underlying demand process can be described in a linear state space form. Wu (2012) proposed a forecasting method that combines time series analysis and a neutral network model in order to predict dynamic relief demands in areas affected by large-scale earthquakes. To validate the forecasting results from this model, data from the 2008 Wenchuan earthquake were used to estimate the demand in previous historical events. Wu concluded that the proposed model effectively dealt with dynamic demand forecasting.

3.2.2 Exponential smoothing models

Exponential smoothing methods are powerful tools that can denoise time series, predict future demand and decrease inventory costs. Tratar et al. (2016) developed a smoothing and forecasting method for demand time series which can efficiently handle additive and multiplicative seasonality. This method can be relied upon to accurately forecast the demand for individual products, thereby giving better short-term forecasts than the classical and damped trend Holt–Winters method. Zehna (1972) compared exponential smoothing methods with other potential demand forecasting alternatives, with simulation techniques being used to draw said comparisons. For a constant mean of normal demand, it was demonstrated that exponential smoothing does not produce results that are as accurate as those produced by ordinary maximum likelihood techniques. In the case of a linear mean changing over time, it was shown that the two methods are approximately comparable with respect to their analytical results.

3.3 Comment on mathematical models and intelligent algorithms

Within the existing searched literature, studies that have been conducted based on multiple linear regression, fuzzy theory and machine learning have increasingly attracted more attention. Mathematical models are often combined with artificial intelligence approaches, such as BP neural networks and time series-based analysis, to predict the demand of emergency materials. As documented by Jentgen et al. (2007), the potential advantage of such combinations is that neural networks may be better equipped than other alternative forecasting models in handling certain data limitations, such as gaps in the historical data. However, since the total amount for the estimated demand prediction is closely related to the eventual number of survivors, the ability to accurately forecast the number of survivors is the key to the demand prediction of emergency materials. A drawback of multiple regression techniques is that obtaining historical data for explanatory variables may prove to be difficult.

3.3.1 Multiple linear regression

Beginning with the premise that the number of survivors is given, Gaozhong et al. (2001) proposed a series of models that quantitatively determine the rescue needs of earthquake-affected areas which are suitable to China's national conditions. With regard to predicting the number of victims, Zhuo and Zhongliang (2005) put forward a simple model for forecasting the number of survivors of an earthquake. Wu et al. (2009) modified the previous exponential function by using data collected from the 2008 Wenchuan earthquake in China, the 1999 Chichi earthquake in Taiwan and the 1995 Kobe earthquake in Japan. The results show that the modified exponential model is capable of predicting the total future casualties of large-scale earthquakes. An emergency material demand forecast model for typhoon response was developed based on fine grid geographic data (Zhang et al. 2012). Bin et al. (2014) combined the earthquake risk evaluation method and the deterministic method in order to study and analyze emergency material preparation demand by taking as an example Datong, a city in Shanxi Province in northern China. Taskin and Lodree (2011) incorporated one of the National Hurricane Center's official prediction models into a Bayesian decision framework so as to address certain complex decisions made in response to forecast accuracy and deteriorating cost efficiency during the period when a storm is evolving. In this paper, the solution methodology is illustrated through numerical examples, with the benefits of the proposed approach compared to those of traditional approaches discussed along the way. Bing et al. (2018) put forward a demand forecasting model for emergency materials that considers the decision-maker's perceived value based on prospect theory (PT). Their proposed model is applied by adjusting the dynamic demand so as to calculate the optimal forecasting scheme, thus improving decision-making efficiency. From the perspective of linear programming, Park et al. (2018) developed a two-stage stochastic program for the managers of humanitarian organizations (HO) that procures and distributes perishable humanitarian goods with a limited budget to regions of need in conditions of demand uncertainty. The objective of their study was to minimize the total expected shortages during upcoming planning cycles. In consideration of the inadequate infrastructure and poorly planned logistics of Somalia, Wyk et al. (2013) also described a preemptive multi-objective programming model that addresses some of the issues in supply chain management with a trade-off between stockpile and shortage costs.

3.3.2 Fuzzy theory-based studies

Other studies have predicted the demand of emergency materials based on the number of survivors trapped in affected areas. For example, Sheu (2010) proposed several methodologies that include multi-source data fusion, fuzzy clustering and TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) with a view to studying time-varying relief demand based on accumulated numbers of fatalities. Considering that the main characteristics of emergency decision-making are that it occurs with insufficient risk identification, incompleteness and inaccuracy of available information and uncertainty of the decision-making environment, Bingzhen et al. (2012) proposed a fuzzy rough set model and approach that predicts the demand of emergency materials. Zhu et al. (2016) described a rough non-deterministic information analysis (RNIA) framework for tables with non-deterministic information and applied it to analyze incomplete or uncertain information regarding survivors of large-scale earthquakes. In addition, Sheu (2010) presented a hybrid fuzzy clustering–optimization approach with the aim of aiding emergency logistics co-distribution operations which respond to urgent relief demands during crucial rescue periods. Based on a proposed three-layer emergency logistics co-distribution conceptual framework, numerical studies regarding an actual large-scale earthquake disaster occurring in Taiwan were conducted. The corresponding results indicated the applicability of the proposed method and its potential advantages.

3.3.3 Comment on machine learning

The available literature on the field of machine learning is at present very limited. Methods such as BP neural networks, SVM, genetic algorithms and so forth aim to accurately predict the number of causalities. One of the few studies that forecasted emergency demand from the 2012 Yiliang Earthquake in China was conducted by Cao and Cui (2013), wherein they estimate the number of causalities. Gray relationship analysis has been combined with case-based reasoning to forecast the demand of emergency resources (Duan et al. 2014). In this paper, the gray relationships between rescue databases with a large amount of information and target cases were analyzed, with a model then being built where the similarities and gray relationships are integrated. A decision support system for forecasting emergency resource demand in oil and gas accidents was developed using Visual Basic, NET and an SQL Server database. In this study, an example was given in order to verify this decision support system, confirming that the forecasting model of this system is reliable. It shows that forecasting results from this decision support system meet situational requirements, thereby potentially providing the theoretical basis for emergency rescue activity after accidents (Xing et al. 2010).

3.4 Comment on intelligent information processing techniques

The coordination of humanitarian relief, such as during natural disasters or conflict situations, is often complicated by a scarcity of data that can inform planning. In the domain of emergency management, with the rapid development of emerging information technologies, a large amount of multi-source and heterogeneous safety-related data have been accumulated from almost every aspect of people's lives, where intrinsic details and patterns of hidden knowledge can be extracted and utilized. Performing demand prediction through the adaptation of information processing techniques, such as big data mining, geographic information systems and remote sensing (RS), appears to be more precise and scientific, especially when technology is the key to providing adequate infrastructure and services and an immediate response in emergency situations is vital for the rescue process (Lee et al. 2014). Safety data and information are the most valuable assets for an organization's safety decision-making (SDM), especially when it is combined with big data and smart devices (Huang et al. 2018). However, there is an inherent demand uncertainty in emergency situations, requiring a large scale of data sources to explore the characteristics of the target prediction case. A great deal of crucial information required for demand predictions is difficult to obtain in the hours immediately after an emergency event. Additionally, in order to save as many lives as possible, analysis of large-scale data requires information processing techniques and methods to be rapid and efficient, making the demand prediction problem based on information processing techniques unique and challenging.

Kima and Swanson (2018) studied the adequacy of big data in forecasting particular variables by outlining and discussing a number of interesting new forecasting methods that have been developed recently in the fields of statistics and econometrics. They observed strong new evidence of the effectiveness of dimension reduction associated with the specification and estimation of factors. Furthermore, they suggest that combining such dimension reductions with learning and shrinkage methods yields promising results when forecasting certain variables. Tafahomi (2013) described a research project that develops and tests a new approach in which the demand for shelters in a specific situation are methodically connected with available, innovative and sustainable shelter solutions, constituting a DSS (decision support system). Moreover, it is demonstrated that connecting accumulated big data to available solutions for providing a tailored aid, in this case shelter, can be realized with a DSS. Inspired by big data approaches, Jueyi (2018) put forward a demand forecasting method through an analysis of the reasons for the severe imbalance between the forecasting and actual allocation of tendering materials. In addition, Min and Jeong (2013) assessed whether there is a moderating effect on causal relationships visualized by big data. Hypotheses are designed to structure the decision-making process between awareness of an emergency situation and the response by defining the major attributes of big data: volume, variety, velocity and complexity. Their findings suggest that big data's attributes of accumulation, expandability, flexibility, real-timeness, analyticity and combination have a powerful influence on a disaster manager's situational awareness. Other studies have also considered approaches toward the analysis of the big data of time series. Tsay (2016) discussed a number of tools that can be utilized for an exploratory data analysis of resulting functional time series. The tools employed include K-means cluster analysis and tree-based classification. The paper proposes a threshold approximate factor model and a Hellinger distance auto-regressive model for the functional time series of continuous densities. When predicting high-dimensional time series, we use the results of cluster analysis in order to obtain parsimonious models. Remote sensing imagery, from satellites or drones, can give important insights into conditions on the ground, especially in areas which are difficult to access. Ishikawa et al. (2017) employed a loosely coupled SD-GIS assessment method to forecast changes in the supply–demand balance both spatially and temporally. Applications of this include situation awareness after natural disasters, structural damage assessment in conflicts, monitoring of human rights violations and population estimations in settlements. Machine learning approaches with remote sensing data were applied by Quinn et al. (2018) with the aim of accomplishing a mapping of refugee settlements.

4 Discussion

A literature review concerning the demand prediction of emergency resources was carried out with the aim of being aware of existing research and developing a framework for future research endeavors. A total of 1235 academic publications within three sizable global Databases—Business Source Premier (BSP), SpringerLink and Elsevier ScienceDirect—were searched.

1. A literature search of peer-reviewed publications conducted using a Boolean search ((“emergency resource” OR “emergency material” OR “relief demand”) AND (“prediction” OR “forecasting”)) was compiled from within the Business Source Premier, SpringerLink and ScienceDirect databases. The resulting literature, covering the fields of emergency management, decision-making, disaster relief, logistics, as well as other academic disciplines, produced a total of 1235 articles published over a period between 1980 and 2018. A list of journals with five or more articles published over this time frame is provided in “Appendix” Table 3.
2. In order to identify the application situation of different forecasting approaches in the three databases, Figs. 1 and 2 display the number of publications, categorized into time series analysis, case-based reasoning, mathematical models, information technology, literature reviews, and discussion and analysis, from journals in Elsevier ScienceDirect and SpringerLink, respectively. It can be seen that in the Elsevier ScienceDirect database, relevant pub-

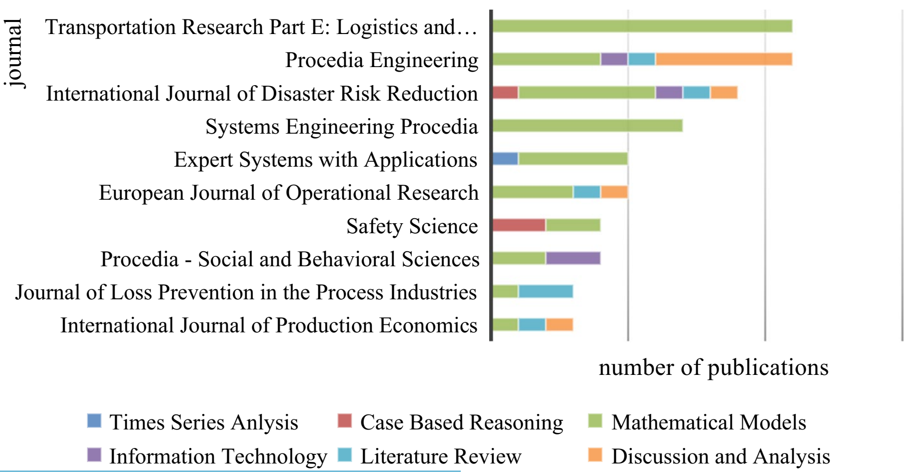

Fig. 1 Number of publications by journals from Elsevier ScienceDirect

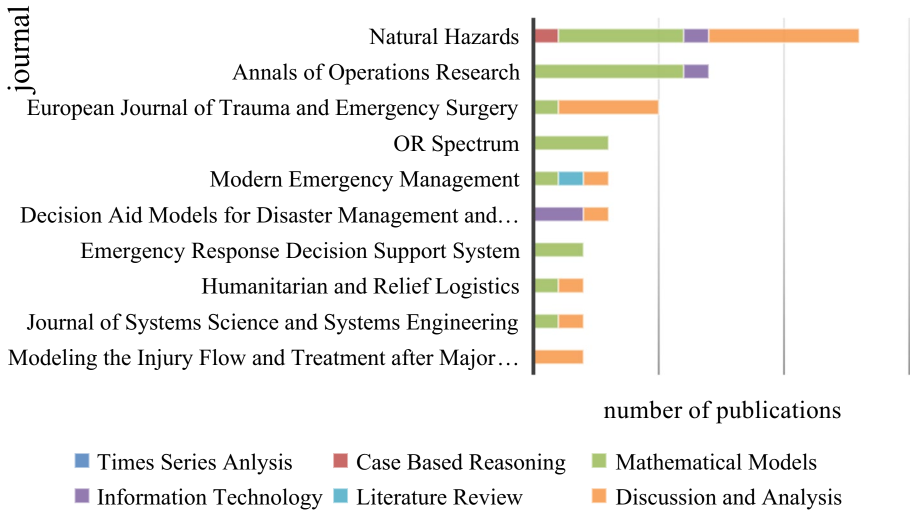

Fig. 2 Number of publications by journals from SpringerLink

lications in the field of mathematical models and discussion and analysis make up 64.52% and 12.90%, respectively. In SpringerLink, relevant publications in the field of mathematical models and discussion and analysis make up 47.62% and 38.10%, respectively.

Figure 3 shows the proportion of research disciplines through an analysis of publications from BSP. During the period from 1980 to 2018, publications from the BSP database in the fields of emergency management, decision-making and disaster relief account for over 10% of all publications: 33%, 12% and 11%, respectively. Over the past 28 years, there has been an observable and significant rapid growth in research on demand forecasting

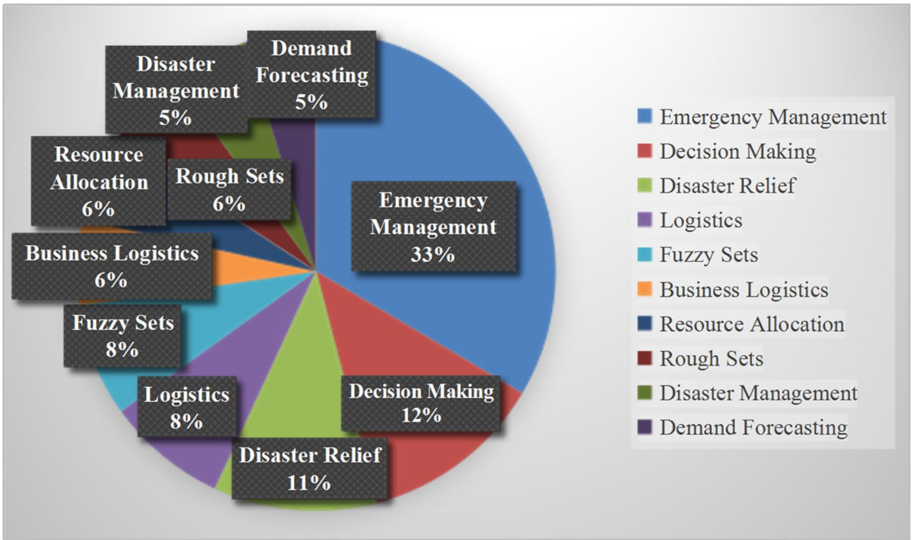

Fig. 3 Proportion of research field (discipline) by BSP

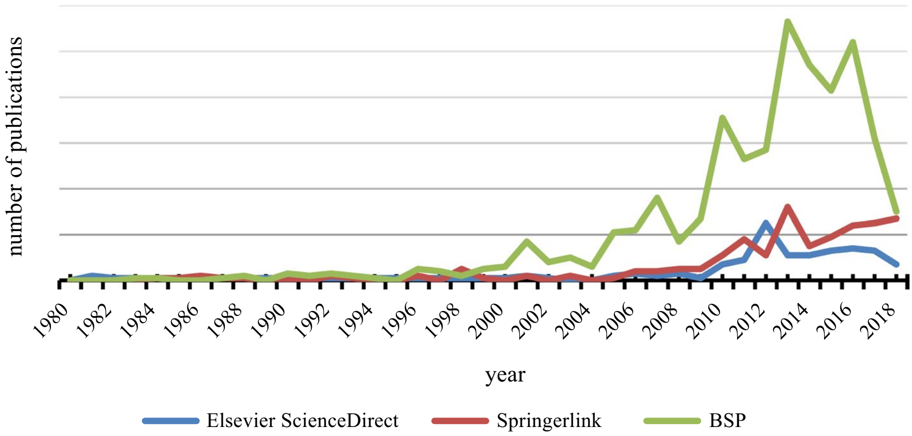

Fig. 4 Number of publications by year

approaches for emergency resources, as shown in Fig. 4 and "Appendix" Table 2. Further analysis shows that publications across the three databases peak in the years from 2012 to 2013, with 113 publications from BSP in 2013, 32 publications from SpringerLink in 2013 and 26 publications from Elsevier ScienceDirect in 2012. A keywords search publication list of the top 15 journals by the number of publications is shown in "Appendix" Table 3.

4.1 Limitations

The major limitation of this literature review is that it studied approaches toward the prediction of the dynamic and final demand of emergency resources instead of highlighting the characteristics and advantages of each forecasting method specifically according to the life cycle of disaster management, that is, its two phases of relief and development, in addition to the four activities of preparedness, response, rehabilitation and mitigation (Carter 1992). In the future, it would be of great interest if different demand forecasting methods were adopted by considering features of each phase and activity in the disaster management cycle. Especially when the initial response is considered, efforts within the first 72 h after the onset of a disaster are crucial in order to save as many lives as possible. At this stage, before any aid is delivered, the required emergency resources must first be located or procured and then transported to the impacted area before finally being distributed to the recipients (Goldschmidt and Kumar 2016), thereby requiring the applied forecasting method to operate quickly and efficiently without using previous information. The 90–100 days immediately following the initial response is the sustained response period. During this stage, since the demand required by the affected area tends to be relatively stable and previous information can be obtained, reacting to time constraints is not the overriding priority. On account of such differing needs and priorities, a more precise forecasting method should be considered for this later stage, one that performs estimations based on previous information. Thus, future research should investigate the effect of the disaster management cycle on predicting emergency resources. Another limitation of this paper is that since this study focused on emergency rescue operations in areas affected by natural disasters and not hospital emergency services, many important studies on emergency resource demand in hospital medical services had to be excluded due to differences in study background. In most construction studies, the supply chain management of emergency resources in hospitals was

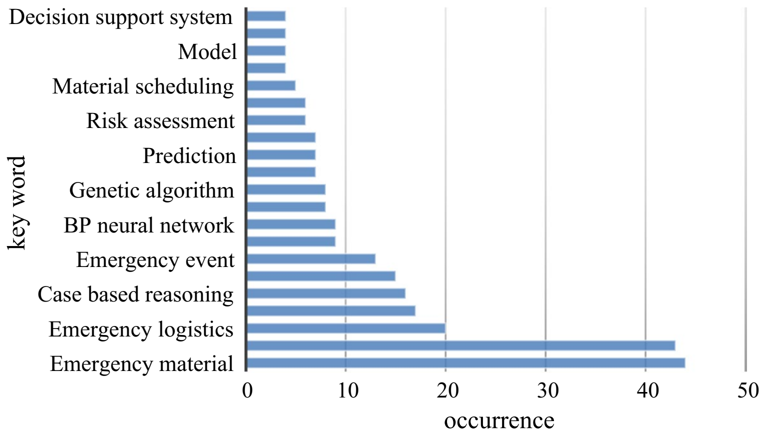

Fig. 5 Keywords and their occurrence in CNKI from 2003 to 2018

also reported as an understudied but key issue. Thus, future research can be expanded so as to include more studies in the current literature on emergency resources in hospitals.

4.2 Future research

In recent years, research into artificial intelligence in China has increased greatly, with some cutting-edge technology being produced. Often, this research may only be known within academic communities with China. Therefore, to provide supplementary work so as to support current research, forecasting methods in the domain of artificial intelligence in China were also studied. Figure 5 displays keywords and the frequency of their occurrence in publications searched in China National Knowledge Internet (CNKI), which is seen as the most authoritative database for academic publications in China. In these figures, from 2003 to 2018 case-based reasoning, BP neural networks and genetic algorithms have been the three most widely used research methods for predicting the demand of emergency materials. As can be seen, although research on emergency material management started late, AI has been applied widely in the prediction of emergency materials.

In the future, a way to build scientific knowledge in this domain is to adopt a consistent approach toward the demand assessment of emergency resources required by areas affected by natural disasters. This literature review suggests that more promising forecasting approaches based on information processing techniques should be explored by following the specific requirements of the disaster management life cycle in order to help predict the future demand of emergency resources more precisely and efficiently. The application of smart devices should be further developed along with a combined focus on big data, cloud computing and virtual reality in rescue context awareness.

5 Conclusion

As is apparent, relief-demand prediction underlines the challenges posed by intelligent information processing techniques in emergency management. This paper discussed several forecasting techniques with the aim of examining the existing literature from a new perspective of artificial intelligence, particularly in terms of big data machine learning in the prediction of emergency resources. This topic is clearly an area of active research with new results appearing in the literature with each new issue of peer-reviewed journals that focus on forecasting methods. This systematic literature review has identified methods that incorporate time series analysis, case-based reasoning, mathematical models and algorithms as well as conventional methods and identified intelligent information processing techniques as new approaches able to predict the final and dynamic demand of emergency resources. Following an overview of the different forecasting methods, the number of publications in journals from SpringerLink and Elsevier ScienceDirect, the proportion of the research field (discipline) in BSP and the number of publications by year were all discussed. By examining the literature from three research databases through this framework, the following can be deduced.

Among all of the surveyed literature, over the last 28 years (1980–2018), despite the number of relevant publications tending to increase and with more attention to it being given by researchers, there exists no comprehensive and straightforward forecasting method or authorized way of predicting the demand of emergency resources after a disaster event.

Considering the particularity of case-based reasoning and time series analysis affecting the process of demand prediction, CBR and ARIMA have been considered the most widely used methods thus far. However, as a result of the review, it was found that approximately half of the surveyed publications applied mathematical models and intelligence algorithms to conduct predictions, with most of them being based on the conventional approach of simulating the human brain in the domain of artificial intelligence. It is critical to note that methods such as mathematical modeling and CBR are mostly based on the estimated number of survivors and time series-based models are predicated on the time series of the previous demand.

Intelligent information processing techniques based on machine learning such as big data mining, remote sensing and GIS are promising methods, especially when applied with a combination of conventional forecasting approaches working to update dynamic demand information. However, its application is constrained due to the lack of data availability from governments concerning risk and safety issues during the urgent and limited time after unconventional emergency events have occurred. From this perspective, the access to open source data from governments should be properly unimpeded. Furthermore, a combination of smart devices based on big data machine learning should be applied as a way to satisfy dynamic prediction for emergency materials.

Finally, due to the incompleteness of information during emergencies, the inaccuracy of available information and the uncertainty of decision-making conditions there is also a need in future research to explore more demand forecasting approaches based on fuzzy information that can predict the demand of emergency resources. In addition, more computer simulations that incorporate the parameters of their given models would be useful so as to test their validity.

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Appendix

See Tables 2 and 3.

Table 2 Articles by database and year

Database	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Elsevier ScienceDirect	0	2	0	0	0	1	1	0	1	0	1	0	0	1
SpringerLink	0	0	0	0	1	1	2	1	1	0	0	0	2	1
BSP	0	0	0	1	1	0	0	1	2	0	3	2	3	2
Database	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Elsevier ScienceDirect	0	0	0	1	0	0	0	2	1	0	0	5	2	3
SpringerLink	0	0	2	0	5	1	0	2	0	2	0	1	4	4
BSP	1	0	5	4	2	5	6	17	8	10	6	21	22	36

Database	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Elsevier Science-Direct	3	1	8	9	26	11	11	14	14	13	11	141
Springer-Link	5	5	11	18	11	32	15	19	24	25	27	222
BSP	17	27	71	53	57	113	94	83	104	62	33	872

Table 3 Keywords search publication list by number of publications

1. Transportation Research Part E: Logistics and Transportation Review
2. International Journal of Disaster Risk Reduction
3. Safety Science
4. Natural Hazards
5. Journal of Intelligent & Fuzzy Systems
6. Annals of Operations Research
7. European Journal of Operational Research
8. Procedia Engineering
9. Applied Mathematical Modelling
10. Advanced Materials Research
11. Canadian Journal of Emergency Medicine
12. Expert Systems with Applications
13. Systems Engineering Procedia
14. European Journal of Trauma and Emergency Surgery
15. Modern Emergency Management

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