A Review of Game Theory Application Research in Safety Management

QINGFENG MENG[1], SHAOHONG TAN [ID][1], ZHEN LI[1], BINGYAO CHEN[2], AND WEIXIANG SHI[3]

[1]School of Management, Jiangsu University, Zhenjiang 212013, China
[2]School of Economics and Management, Jiangxi University of Traditional Chinese Medicine, Nanchang 330004, China
[3]Australasian Joint Research Centre for Building Information Modeling, School of Built Environment, Curtin University, Bentley, WA 6102, Australia

Corresponding author: Zhen Li (janeli@ujs.edu.cn)

ABSTRACT There are many heterogeneous roles involved in safety management. The behaviour interaction and strategic interactions among them will have an important impact on safety processes in the execution phase. Game theory is a powerful method for clarifying the influence mechanism and is currently experiencing rapid growth in operations, planning and management, as well as in safety management. To comprehensively sort out the current situation of game theory in safety management and finally find out the development trend of applying game theory in safety management. This paper reviews 57 related articles (2010-2019) surrounding game theory and safety management. The main results show that the applications of game theory in the research of safety management is helpful to find out the cause and motive force of unsafe behaviours. We find that currently, most researches are mainly in traffic safety, and researchers may point to food safety, construction safety, coal mine safety, electrical safety and other fields in the future. In addition, game theory plays a very important role in guiding the decision-making of stakeholders in the process of safety management.

INDEX TERMS Game theory, safety field, safety issues, safety management.

I. INTRODUCTION

In the process of human production, safety is to control the possible and potential damage to human life, property and environment caused by operation throughout the project [8]. Safety issues exist in a wide range of areas, such as traffic safety, food safety, electrical safety, fire safety, information security, and closely relates to our lives. With the rapid development of economy, science and technology, engineering construction and other aspects, safety problems have been emerging in in many industries, which has been highly valued by practitioners and scholars in management. At the same time, it also continually puts forward higher, newer and stricter requirements for safety management personnel.

As a consequence of a safety accident is harmful, effective safety management is very important. There are many subjects involved in the process of safety management. The inter-

action between the subjects and their behaviour interactions has a very important impact on safety performance [10].To clarify the mechanism of the interaction between subjects on safety management, some scholars use game theory to study safety management [36]. Game theory can be described as a mathematical model of strategic interaction between independent subjects. Through simulation and analysis of the situation in the model, effective solutions can be determined, so as to provide participants with the best decision-making strategies [3]. The characteristics and advantages of applying game theory in safety management are listed as below: (1) The research object has universality: the conflict of interest and cooperation formed by different roles have become a common phenomenon in real life; (2) The research methods consist of modelling problems and finding optimal results: using mathematical models to describe the studied problems, making the analysis of game theory more accurate, and game theory can analyze and deal with complex behaviours that are difficult to solve by other mathematical tools; (3)

The associate editor coordinating the review of this manuscript and approving it for publication was Aniruddha Datta.

the research result is more effective: unlike the traditional assumption of complete competition and complete information and game theory only emphasizes rational decision-makers in the model, so it finds the research results closer to reality.

By reviewing the previous paper in safety management that scholars apply game theory, this paper finds that scholars have carried out a series of pioneering research in related fields, and have found out relatively important theoretical results, but there is still room for extending applications of game theory in the future research. First of all, there are few kinds of research on the game theory in safety management and the research fields are relatively scattered. Secondly, the subjects involved in the research are relatively simple, most of them are the strategic interactions between the safety regulators and the regulated parties. Besides, the existing research generally assumes that roles in the model are completely rational, and the unstructured factors in the system are often ignored in the construction of the model. Therefore, the advantage of game theory in safety management has not been fully found out, and the theoretical basis for decision-making in safety management is insufficient. Therefore, in order to clarify the research status of game theory in safety management, identify the existing problems in the research process, and guide further prospects for applying game theory in safety management trend. In this paper, through the preliminary search and retrieval, screening and organization of materials, coding and analysis of materials to integrate the relevant literature, and corresponding literature analysis, while pointing out the lack of research, and further prospects the future research trend of game theory in various fields of safety management, in order to provide research reference for researchers in related fields.

The chapter of this paper consists of four parts, the rest of which are as follows: Section 2 explains the selection process of the paper in detail, section 3 provides the literature review and research prospect of game theory in various safety management fields based on the final collected literature, and section 4 clarifies the findings of this paper.

II. LITERATURE OF PAPERS SCREENING

In this study, the selection process use methods used in other review articles [37]. The commonly used selection process in the literature review includes several steps, such as determining the database, retrieval rules, preliminary retrieval and literature screening. In the part of selecting, web of science and Google Scholar are used as database sources for selecting paper. All the selected literature are published in the academic journals in this field. Also, this study only reviews relevant journal articles using game theory.

The literature review is divided into three steps. It is necessary to explain in detail how the review process is conducted. The framework described in Figure 1 helps to illustrate the work of each stage in the paper review, specifically involving the methods and tools used in each stage and the text part of each stage. The specific procedures are shown in Figure 1:

A. PRELIMINARY SEARCH AND RETRIEVAL OF PAPERS

The purpose of this step is to select all relevant articles using game theory to study safety management through search theme (safety) and theme (game theory). There is no limit to time and literature types. A total of 407 articles are retrieved through web of science and Google Scholar. Papers come from journals in different fields, including safety science, complexity, sustainability, cities, advanced materials research, etc. In order determine the suitability and relevance of articles, we search keywords in specific fields such as "title", "Keywords" or "abstract" in articles published from 2010 to 2019, and manually select articles more relevant to this study. In this step, 215 articles are preliminarily identified. A complete list of references, including keywords, abstracts, and full-text materials available, was downloaded through endnotex7.

B. SCREENING AND ORGANIZING MATERIALS

Our original intention was to evaluate the title and abstract of each document. However, due to the limited information sometimes provided in the abstract, we decided to conduct content analysis, use the full text to evaluate each item, and finally select 140 articles. Also, we take out conference articles, review articles. The final number of articles is 98. Then we classify those articles into several major areas.

C. CODING AND ANALYSIS MATERIALS

In this step, 98 selected papers about applying game theory in safety management are being reviewed. It is worth noting that this study mainly focuses on the application of game theory in different fields of safety management, most reviewed literature only focus on one of those fields. It means that the research fields are relatively scattered, nearly 10 fields. We categorise them and found that the safety management articles applying game theory in safety management mainly focused on the five fields of traffic safety, food safety, construction safety, coal mine safety and electrical safety, and then sorted out the articles in five fields, finally 57 papers are determined.

III. LITERATURE ANALYSIS
A. OVERVIEW

This paper focuses on the analysis of 57 papers in the five fields of safety management. The five areas related to safety management are (1) traffic safety (2) food safety (3) construction safety (4) coal mine safety (5) electrical safety. Figure 2 provides a histogram of the number of papers in the five major safety fields in 2010-2019.It can be seen from the figure that every year some scholars study the safety management issues in transportation management based on the game theory. In food safety, the number of articles reached a peak in 2018, while the research in the fields of construction, coal mine and electrical safety has been relatively decreased in recent two years.
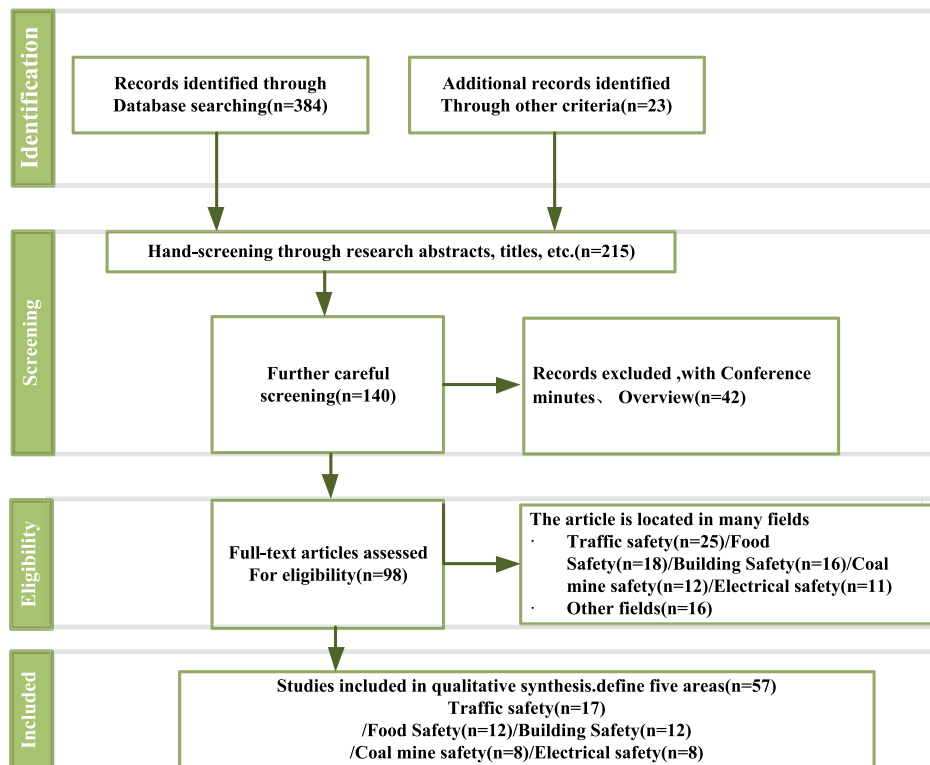
FIGURE 1. Flowchart of the systematic review process.

Number of publications in each field

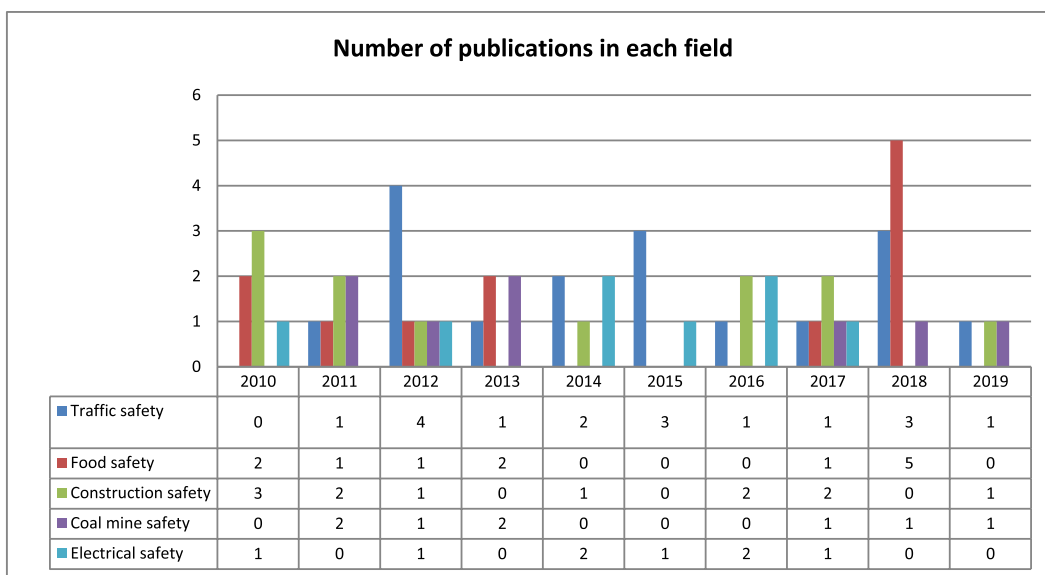|	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Traffic safety	0	1	4	1	2	3	1	1	3	1
Food safety	2	1	1	2	0	0	0	1	5	0
Construction safety	3	2	1	0	1	0	2	2	0	1
Coal mine safety	0	2	1	2	0	0	0	1	1	1
Electrical safety	1	0	1	0	2	1	2	1	0	0

FIGURE 2. Annual number of publications in various safety fields.

As shown in Table 1, 57 articles selected in the literature review come from 46 different journals, covering a wide range, including 2 or more articles in Applied Mechanics & materials, transportation research part c-emerging technologies and other journals.

B. RESEARCH STATUS IN FIVE FIELDS
1) TRAFFIC SAFETY
With the rapid development of transportation, the incidence of traffic accidents shows a certain upward trend. Traffic accidents not only cause casualties but also seriously affect

TABLE 1. Number of Journals.

Journal Name	Numbers
Applied Mechanics & Materials	3
Transportation Research Part C-Emerging Technologies	3
Solid State Phenomena	2
Polish Maritime Research	2
Journal of Intelligent & Robotic Systems	2
European Journal of Operational Research	2
Complexity	2
Applied Intelligence	2
Advanced Materials Research	2

the economic development and social stability. At present, it has attracted the attention of various governments. We have identified 17 papers using game theory to study related issues in traffic safety management, mainly focusing on vehicle safety and ship safety.

In recent years, the research on the cooperative driving behaviour of vehicles at signalless intersections has become a hot topic. Reference [56] proposed a cooperative game theory considering the safety, rapidity and comfort of driving for the case of possible collision risk of more than three vehicles approaching the signalless intersection from different directions; [2] proposed a dilemma game theory method to solve the driving conflict of unsignalized intersection. Each driver has two strategies of cooperation or defection. Through the research, it is found that the road capacity greatly depends on the driver's decision to pass the intersection.

The latest development of communication, sensing and information processing technology makes traditional driving connected to the Internet. Vehicles connected to the network can receive real-time information from surrounding vehicles. The received information can improve drivers' understanding of surrounding traffic conditions and so it assist drivers to make safe and efficient driving operations. Some scholars use the theory of repeated game to analyze the influence of the strategy of the driver group on safe driving. Reference [16] found that the use of self-adaptive cruise system improved the handling stability of the vehicle; [49] showed that the application of intelligent controller can improve the driving safety of vehicles; [30] said that the decision-making of each strategic interaction depends not only on the uncertain information of the current step but also on the future information calculated through the accessibility analysis to ensure the safe driving of

the vehicle. With the development of science and technology, intelligent driving comes into people's eyes, and safety problems are looming. Lane changing is a key task of intelligent driving. Lane changing decision-making is of great practical significance to ensure the smooth, efficient and safe operation of intelligent driving. Reference [45] explained the information flow in the connected vehicle communication scene by establishing the model of vehicle lane-changing behaviour, and showed that the proposed lane changing model has higher reliability than the theoretical model of the acceptable gap; [58] proposed a lane change model based on game theory. The model uses turn signals and lateral movements to simulate the driver's behaviour, and finally can produce effective lane change control, including strategic overtaking and safe distance selection; [51] established a lane selection model of multi-person dynamic strategic interactions with incomplete information by considering different driving tendency characteristics in the time-varying environment, providing the theoretical basis for the study of lane selection in intelligent driving under the condition of Internet of things.

At present, more and more enterprises go to the world and promote the development of water transportation industry. But at the same time, the development and growth of the water transport industry are also exposed. The frequent occurrence of safety hazards and accidents has affected and hindered the healthy development of the water transport industry. In recent years, based on the game theory, scholars have studied ship collision avoidance, safety track and other aspects in the navigation process to improve the level of ship safety management. Reference [42] introduced the game theory into the ship dynamic collision avoidance system, proposed the ship safety track evolution set, and established the ship dynamic

TABLE 2. Management decisions for traffic safety.

Traffic safety	Classification	Management decisions
Vehicle safety	About" Signalized intersection"	Focus on driving safety, speed and comfort, etc
	About" Internet"	Using adaptive cruise system, intelligent controller, etc
	About" Intelligent driving"	Consider driving preference characteristics, etc
Ship safety	About" Szlapczynski"	Infer the optimal safety trajectory, etc
	About" Lisowski"	Using Internet technology to obtain safe track, etc

collision avoidance model by designing the ship collision avoidance game expansion tree, which can achieve the goal of automatic collision avoidance between two ships; On this basis, [43]; [44] put forward the latest version of the safety track evolution set. For ships with given position and motion parameters, the optimal safety track is calculated, and the ship collision problem is solved by the cooperative evolution algorithm of game theory.

In recent years, Lisowski, a scholar, has made fruitful achievements in the study of ship safety management using game theory. Reference [20] introduced the general simulation mathematical model based on game theory for control process and ship course control in marine navigation Also, it proposed the non-cooperative and cooperative interaction and optimal control algorithm in the case of collision; [22] took the ship safety control process as an example, establishes a differential game model, synthesizes the ship safety track process into multi-level decision-making, and uses computer simulation to determine the ship safety track; [22] proposed a game theory method to determine the safety trajectory of ships. This method adopts the form of multi-stage matrix game, and simulates the safety trajectory of ships at sea under the actual situation through computer simulation; [23] used optimization theory and game theory to analyze the navigation safety of ships; [24] applied the game theory and optimization theory to the sea navigation in crowded waters, corrects the navigator decision-making in case of collision through the safety control system, and displays the ship's sea navigation record on the radar screen in real-time; [25] based on the application of difference strategic interactions and multi-stage static strategic interactions analysis automation in ship safety control process.

To sum up, in terms of vehicle safety, this section analyzes the potential risk of conflict and the possible road traffic jams caused by multiple vehicles driving to a signalless intersection, and proposes a game theory based vehicle cooperative driving model; in addition, with the application of the Internet, scholars have increased the research on the application

game of lane changing in intelligent driving. In the aspect of ship safety, more and more scholars apply the game theory to the ship dynamic collision avoidance system, put forward the evolution set of ship safety track, designed the automatic collision avoidance decision-making system to take reasonable collision avoidance measures for the collision avoidance between two ships, and the computer system and radar system are gradually applied to the ship safety control. Based on the literature review in t traffic safety, the effective management decisions in this section are shown in Table 2.

2) FOOD SAFETY

Food safety is directly related to the health and safety of consumers and is the most basic material condition for the survival and development of human society. It is a new expectation and requirement for people to eat safely and safely, and it is a difficult task to ensure food safety. The main stakeholders involved in food safety are government regulators, food producers, consumers, farmers, and media, etc.

Some scholars focus on the game between the unsafe behaviour of the main body and supervision. The strategic interactions between the interest main body is divided into two sides and three sides. In terms of bilateral games, [19] analyzed the possible strategies and development trends of food producers, operators and regulators, and established the evolutionary game theory model of food quality and safety supervision. The research shows that supervisors should improve the expected earnings of food quality and safety supervision to improve food quality and safety; [4] studied the current situation of food safety supervision, and established a game model between government supervision agencies and food production enterprises by using the mixed strategy Nash equilibrium method. Finally, the effectiveness and feasibility of the model were verified by an example; [39] showed that the previous research does not involve the strategic interaction between government supervisors and food manufacturers in the face of consumers. The author constructs a game model

between government and food manufacturers for endogenous consumption demand; [39] based on the evolutionary game theory, an evolutionary game model of food safety information disclosure between food enterprises and government regulators was constructed. The research shows that only relying on government supervision can the false problem of food safety information be effectively solved.

In terms of tripartite games, [17] used the cooperative game theory to establish the model of food safety governance and analyzed the process of government, market and third-party supervision participating in food safety governance to achieve the game balance. The research shows that the establishment of the cooperative mechanism of government, market and third-party supervision can improve the performance of food safety governance; [57] analyzed the role of government and media in food safety emergencies from the perspective of food safety incident communication, and used game theory, supply-demand curve and other analytical methods, pointed out that the government should appropriately supervise the media, and the media should ensure the authenticity of the report of food safety incidents, and finally put forward countermeasures to improve the relationship between government and media in food safety emergencies; [38] showed that farmers and manufacturers use food additives to improve food sales. The government will formulate punishment policies to regulate and curb the risk behaviours of farmers and manufacturers. By building a tripartite game model between the government, food manufacturers and farmers, a new policy perspective is provided for food safety supervision; Based on prospect theory and evolutionary game method, [29] constructed a three-party game model of food safety risk evolution, including food enterprises, food consumers and government regulatory agencies, and elaborated the impact mechanism of various factors such as consumers' subjective perception of food safety and certification effect of regulatory authorities on food safety risk evolution; [41] based on the evolutionary game theory, established the game revenue matrix among producers, operators and consumers. The results show that the quality information tracking technology, the interests of farmers and operators, the fair distribution of risks and the ability of consumers to maintain their legitimate rights and interests are the four key factors for the reliability and stability of food quality.

The food supply chain is becoming more and more complex and involves more and more links. While the global supply of food benefits consumers, it also makes the food safety problem more complex and difficult. Some scholars have conducted the corresponding game analysis based on the food supply chain safety. Reference [61] constructed the profit distribution model of the food supply chain by using game theory, and pointed out that reasonable profit distribution mechanism can promote food safety; [54] conducted a duopoly game analysis on the economics and feasibility of traceability of agricultural food supply chain, and established a game model of traceability of agricultural food supply chain; [5] designed a new quality management mechanism in food supply chain management, and the research shows that reward plan is more effective than punishment plan in food safety and quality.

Game theory provides a powerful analytical tool for studying food quality and safety issues. The occurrence of food quality and safety issues is mostly the process of continuous interactions between the government, food companies and consumers. According to the existing game analysis, the government must strictly regulate the food enterprises, and consumers should actively complain about the problem food enterprises in order to fundamentally stop the illegal activities of the enterprises. At the same time, food enterprises must strengthen self-discipline, especially the industry's "leaders", but also take the lead in demonstrating the role. Governments, enterprises, and consumers all do their things, and food quality and safety issues will be effectively controlled. Based on the literature review in food safety, the effective management decisions in this section are shown in Table 3.

3) CONSTRUCTION SAFETY
In recent years, the construction industry is in a period of rapid development, but at the same time, the safety situation is becoming more and more severe. The construction industry is an industry with high risk, and safety management has become one of the key control contents of the construction industry. The current literature mainly divides building safety into building construction safety and building evacuation safety in case of fire and other accidents.

On the one hand, the research focuses on the construction safety, and the construction project involves many stakeholders. How to balance the interests, reduce the conflicts between stakeholders, and effectively build an efficient construction team has become the key factor to reduce the construction safety accidents. Based on the strategic interactions between the government supervision department and the construction enterprise, some scholars analyze the safety of construction projects and get effective supervision suggestions. Based on the evolutionary game theory, [31] established a construction safety supervision game model with government supervision departments and construction enterprises as the main body. The research shows that the cost of supervision, accident rate and other factors affect the stability of construction safety supervision; [50] established an evolutionary game model for supervision in safety investment of construction enterprises and then proposed the long-term trend of supervision in construction safety investment. Finally, it provided theoretical and methodological guidance for safety investment of construction enterprises and government supervision and management.

Some scholars have studied the game between the supervision unit and the construction party to improve the safety management performance of the industry. Reference [62] established a third-party game model for rent-seeking behaviour of engineering safety supervision in view of the existing problems of engineering safety supervision,

TABLE 3. Management decisions for food safety.

Classification of food safety	Management decisions
About" Between unsafe behaviour and supervision"	Establish cooperation mechanism of tripartite supervision, quality information tracking technology, incentive policies, etc
About" Food supply chain"	Establish a profit distribution mechanism, quality management mechanism, etc
About" Media attention"	Improve the government's supervision over the media and the authenticity of media reports, etc

which effectively controlled the rent-seeking behaviour of engineering safety supervision; Based on the game theory, [46] discussed the collusion between the contractor and the supervisor in the construction claim, and finally provides suggestions for the government on how to reduce the collusion between the contractor and the supervisor; [13] used rent-seeking theory to analyze the cost-effectiveness of rent-seeking behaviour of construction safety supervision, established two-game models of rent-seeking behaviour of construction safety supervision, and put forward relevant supervision suggestions; [11] studied the sustainable and dynamic supervision of work safety license on the construction party, taking into account the standard mode of quality management, conditions of work safety license, the status of the enterprise itself and related industries, and the composition of assisting the regulatory authorities in implementation, etc. In addition, contractors and labour subcontractors are directly responsible for the organization and operation of the construction site, and play an important role in construction safety. Reference [62] analyzed the game between the contractor and the labor subcontractor from the perspective of construction safety. Based on the game theory and contract theory, this paper discussed the best action strategy between the contractor and the labour subcontractor. Reference [32] established the evolutionary game model for contractors and labor subcontractors. In the discussion, they focused on how to reduce the contractor's ''hidden behaviour'' selection and found out the countermeasures to improve the quality and safety of construction projects. Through the analysis of construction safety, the government supervision departments and construction enterprises are the main stakeholders in construction safety engineering. The existing research shows that strengthening the construction safety supervision will help the government to control the construction enterprises. It can reduce the accident rate, the safety cost, and create the safety atmosphere of the construction site.

On the other hand, the research focuses on building evacuation safety. At present, the technology of high-rise building, ecological building, underground building and large space building is not as dense and complex as before, and the safety problem in a building is increasingly prominent. In real life, building fire accidents occur frequently due to the neglect of building safety problems in the design, resulting in shocking casualties and property losses, which is hard to make up, so the problem of building safety evacuation should be paid attention to. [7] captured some key dynamic characteristics of evacuation crowd flow in multi-storey buildings, considered their micro and macro path selection, and obtained the optimal result of safe evacuation through multi-agent modelling and differential game method; [12] demonstrated the crowd movement of exit crowding under the condition of uncertainty in space through computer simulation and concluded that if the crowd is completely composed of risk-averse and risk-neutral people, even under high risk, it can effectively prevent the group disaster. Some scholars based on evacuation time, congestion and other factors to explore the impact of building evacuation safety.Reference [9] showed that in the existing literature analysis and research, people at risk could not be found accurately and quickly, and the establishment of game model can provide effective evacuation strategies; [34] considered factors such as crowding degree of people and internal structure of buildings and used game method to quickly and safely evacuate all people in buildings.

For construction safety, scholars build game models between government supervisors and construction enterprises, supervisors and construction parties, contractors and labor subcontractors, etc. It is concluded that the stable state of construction safety supervision is mainly related to the punishment strength of government supervision department, supervision cost, cost of safety measures taken by construction enterprises, conditions of safety production license, enterprises themselves and other factors; The main objects of building evacuation safety are individuals, small teams, and people. Scholars can explore the occurrence and evolution of potential unsafe behaviours by game theory, and get

TABLE 4. Management decisions for construction safety.

Classification of construction safety	The main body of game theory in construction safety	Management decisions
Safety of construction project	Government supervision departments and construction enterprises	Strengthen the cost of supervision procedure and the stability of construction safety investment supervision, etc
	Supervision unit and construction party	Crackdown on rent-seeking behaviour and establish safe production license and standard, etc
	Contractors and labour subcontractors	Reduce the "hidden behaviour" of contractors, etc
Building evacuation safety	Individual, small team, crowd	Consider crowding and internal structure of the building, etc

effective safety management suggestions. Based on the literature review in construction safety, the effective management decisions in this section are shown in Table 4.

4) COAL MINE SAFETY

With the development of economy, the frequent coal mine accidents have caused huge losses to the state property and the lives of citizens, which has been widely concerned by all sectors of society. The causes of frequent coal mine accidents involve many aspects, including natural factors, social, economic and cultural factors, as well as individual factors of coal enterprises. The main interest subjects of coal mine safety involve government regulators, coal enterprises, coal mine employees, etc.

Some scholars focus on the strategic interactions between unsafe behaviour and supervision of coal mining enterprises. Reference [14] used game theory to analyze the interesting relationship between safety production of coal mining enterprises and re supervision of government departments, and believed that innovation of supervision system is the key to improve the situation of coal mining production; [28] based on the three-party game model of government supervision, coal mining enterprises and coal mine employees, this paper analyzes the choice of enterprise safety strategy. The research shows that the penalty cost of government supervision has a great impact on the safety management efficiency of coal mining enterprises, as well as the behaviour of restraint measures and incentive measures will affect the safety management of coal mining enterprises; [27] used evolutionary game theory to describe the long-term dynamic process of the multiplayer game in coal mine safety supervision, analyzed the implementation effect of different punishment strategies on the game process, and provided a more effective solution for the research of multiplayer game.

Unsafe behaviour of coal miners is the main cause of accidents. Because of the asymmetry of game interests between managers and coal miners, it will lead to unsafe behaviour of coal miners, which leads to coal mine accidents. Reference [26] combined with the actual situation of coal mining enterprises, established the game model between the safety supervisors and the persons responsible for unsafe behaviours of coal mining enterprises by using the static game theory of complete information, and finally put forward relevant supervision suggestions for coal mining enterprises; [18] in order to observe the dynamic game evolution process of coal mine workers' behaviour stability, the results show that with the development of the game theory, when the safety inspection benefit of the safety manager is less than that of the non-inspection benefit, the safety manager may not carry out safety inspection, and the research results of this dynamic

TABLE 5. Management decisions for coal mine safety.

Classification of coal mine safety	Management decisions
About" Government regulation"	Take restraint measures, incentive measures and regulatory system innovation, etc
About" Unsafebehaviour of workers"	Improve the status of workers and supervise workers, etc
About" Relevant coal mine rules and regulations"	Formulate reward and punishment system and reasonable rules and regulations, etc

incentive regulation have been successfully applied to coal mine enterprises.

Some scholars improve coal mine safety management by establishing safety management valuation model, implementing coal mine safety regulations and optimizing occupational safety compliance control system of coal mine enterprises. [60] put forward a safe assessment system of mine water disaster based on these factors, and provided suggestions for management decision-making, so as to reduce the occurrence of risk. [48] combined the behaviour choice of coal miners and the control intensity of coal mine monitoring in a mathematical model from the perspective of behaviour interactions. The results show that the implementation of coal mine safety regulations is an important way to ensure coal mine safety production; [47] analyzed the causes of occupational safety violations in coal mining enterprises, established a fixed penalty control model and a model of punishing occupational safety violations by dismissal, and optimized the compliance control system of occupational safety in coal mining enterprises by game method.

Any coal mine safety accident contains instinct game psychology, lucky interest motivation and risk aversion consciousness. Based on the game theory, this paper analyzes the behaviour choice between the government departments and the coal enterprises under different conditions, which can effectively study the relationship between the government departments and the coal enterprises, so as to formulate a scientific and effective coal mine safety management method, and effectively improve the level of coal mine production safety management. Based on the literature review in coal mine safety, the effective management decisions in this section are shown in Table 5.

5) ELECTRICAL SAFETY

With the development of the smart grid, electrical safety is facing new challenges. It is related to the national property safety, the interests of people's lives and the health of electric workers. It is also the most fundamental benefit of electric enterprises. In recent years, Electrical safety production has stepped into a virtuous circle track, but there are still some

problems in safety production management, which need to be improved continuously.

Some scholars have studied the safety and stability of smart grid system. Reference [1] applied information and communication technology to smart grid, and proposed an end-to-end smart grid architecture for the first time, including main production, transmission, distribution, smart grid and network safety management personnel. Through the establishment of Bayesian game model, green electric source optimization is integrated into the electric grid, so as to improve the safety of the whole electric system; [35] proposed a general framework to evaluate the vulnerability of smart grid system to malicious attacks, constructed a zero-sum game between defenders and attackers, and applied von Neumann theorem to find the balance strategy between attackers and defenders, so as to improve the stability of electric system.

Some scholars think about how to improve the Electrical safety based on the type of electric generation. As a kind of clean and renewable energy, wind energy has been paid more and more attention from all countries in the world, and its accumulation is huge. Reference [50] considered the special operation environment and complex fault types of the wind turbine, established the decision-making optimization game model under the lowest maintenance cost, and provided scientific decision basis for the maintenance planning of wind turbine; [14] showed that accurate prediction of wind electric generation is of great significance to electric system scheduling and safe and stable operation. A new method of wind electric generation prediction based on cooperative game theory is proposed, which can effectively improve the prediction accuracy. Besides wind power, there is nuclear power, [52] combined the game theory with Monte Carlo method, and analyzed the characteristics of nuclear electric plant with fuel supply coefficient and safety assurance measure coefficient as basic elements, so as to improve the safety performance of nuclear electric generation; [53] studied the safety risk management of nuclear electric plant energy production, introduced the safety factor for analysis, and finally concluded that a nuclear safety assurance agreement should be established to improve the safety of nuclear electric generation system.

TABLE 6. Management decisions for electrical safety.

Classification of electrical safety	Management decisions
About" Smart grid"	Integrating green electric source optimization into the electric grid and balancing strategy, etc
About" Generation type"	Consider the operation environment, fault type and safety factor of the generator set, etc
About" Electrical safety"	Design of distributed real-time tariff mechanism and consumers with a rational price preference, etc

A reasonable price of electricity can make the demand for electricity stable. As the stakeholders of electric pricing, the seller and consumer of electric energy seek a balance based on game theory, which is of great significance to Electrical safety management. Reference [33] put forward a design method of distributed real-time electric price mechanism based on game theory, which assumes that electric sellers and consumers determine the supply and demand in a completely distributed way, and finally the electric market converges to Nash equilibrium through the iterative process; [6] introduced the framework of cooperative game theory, studied the cooperation and competition between consumers and electric sellers considering price preference in wholesale market, and finally improved electrical safety by balancing the relationship between consumers and electricity sellers.

At present, the research on the application of game theory in electrical safety mainly focuses on smart grid, electric generation type and electric market. The participants of the modern electric system in electric generation, distribution and electric consumption show diversified characteristics. How to determine one's own behaviour according to the behaviour of others to ensure the maximum benefit is the main problem solved by game theory, which provides a feasible method for all parties in the electric system to obtain a balanced benefit through decision-making, and for the electric regulatory authorities to determine reasonable norms to prevent monopoly behaviour. Based on the literature review in electrical safety, the effective management decisions in this section are shown in Table 6.

C. RESEARCH OUTLOOK
1) TRAFFIC SAFETY FIELD
Outlook 1: In the aspect of game theory research on vehicle safety, experts summed up the traffic safety problems of non-signal intersections. At present, there is still room for further expansion in the existing research. The game model of traffic at urban road intersections can be divided into the following: ① analysis of "traffic light" intersection with a countdown display, ② analysis of "traffic light" intersection without countdown display, ③ analysis of the phenomenon of "pedestrians crossing the road without looking at the signal lights", the competition between motor vehicles, non-motor vehicles and people on the road in urban road traffic, and in-depth exploration and analysis of the root causes of urban road traffic safety problems.

Outlook 2: In the aspect of game theory, the research on ship safety is not enough for the rescue after the accident. In the future, we need to think deeply about the fastest time, the shortest route and the best way of rescue.

2) FOOD SAFETY FIELD
Outlook 1: At present, based on the game theory, there are still further expandable aspects of the existing food safety research. Most of the literature only analyzes the behaviour of the government, food production enterprises and consumers by game theory, and rarely introduces the main body of food industry association, news media, intermediary organizations, third-party organizations for in-depth analysis and discussion. The future research direction can focus on the research of food safety from the four aspects of government, consumers, food production enterprises and third-party institutions based on the game theory, further improve the effect of food safety supervision, clarify the responsibilities and rights of all parties, take the interests related to food safety into consideration as a whole, and establish an orderly system of release, interpretation and update of food safety information.

Outlook 2: Use the fourth industry concept to build an "Internet plus" administrative regulatory platform, improve information disclosure and self-discipline, reduce regulatory costs and improve regulatory efficiency, and urge food regulators to appropriately increase the probability and punishment of poor quality food producers' active supervision according to the actual situation. And reasonably increase the response to consumer reports, so as to suppress the quality and safety risks of the food supply chain.

3) CONSTRUCTION SAFETY FIELD
Outlook 1: In the process of engineering safety supervision in the construction stage, it is difficult to carry out the supervision work based on the current situation of multi-party participation and complex dynamic changes in the game. At present, there are two deficiencies in relevant research: one is to pay attention to the work quality of the responsible subjects and ignore the conflicts of interest between them; the other is to

use the game theory method to analyze the internal problems of the project safety supervision organization, which mostly considers the mutual relationship between the two parties and rarely discusses the cross-influence of the three responsible subjects of construction, construction and supervision.

Outlook 2: At present, the focus of research is in construction safety, and the research on evacuation safety after risks is not detailed enough. In the future, we can think about evacuation time, evacuation path, evacuation mode, evacuation drill, etc. The construction safety management is a very complex problem which involves a wide range of areas. In the future, we can carry out a comprehensive study on various enterprises and personnel involved in the construction industry from both theoretical and empirical aspects, so as to achieve the ultimate goal of comprehensively improving the level of construction safety management.

4) COAL MINE SAFETY FIELD

Outlook 1: In the process of engineering safety supervision in the construction stage, it is difficult to carry out the supervision work based on the current situation of multi-party participation and complex dynamic changes in the game. At present, there are two deficiencies in relevant research: one is to pay attention to the work quality of the responsible subjects and ignore the conflicts of interest between them; the other is to use the game theory method to analyze the internal problems of the project safety supervision organization, which mostly considers the mutual relationship between the two parties and rarely discusses the cross-influence of the three responsible subjects of construction, construction and supervision.

Outlook 2: At present, the focus of research is in construction safety, and the research on evacuation safety after risks is not detailed enough. In the future, we can think about evacuation time, evacuation path, evacuation mode, evacuation drill, etc. The construction safety management is a very complex problem which involves a wide range of areas. In the future, we can carry out a comprehensive study on various enterprises and personnel involved in the construction industry from both theoretical and empirical aspects, to achieve the ultimate goal of comprehensively improving the level of construction safety management.

5) ELECTRICAL SAFETY FIELD

Outlook 1: From a macro point of view, at present, there are few types of research based on the game theory in electrical safety. In the future, we can consider to establish a cooperative game model between the government supervisor and the electric enterprise, and discuss the respective strategies that the government and the electric enterprise should adopt in electrical safety work and the conditions for achieving an equilibrium to the game. An equilibrium to the game between the government and the electric enterprises can be achieved through different strategy choices, which can be standardized through the terms of electric risk assessment, and the management system can be improved, and the strength of safety risk supervision can be strengthened. In the future, the electric

system planning, electric market, dispatching, control and other aspects can be elaborated.

Outlook 2: At present, the application research of game theory in the electric system mainly focuses on the electric market, and the research results are more and more mature, but the research of game theory in electric system control and defense is less. Preventive control is a kind of pre-control aiming at potential faults. Due to the uncertainty of actual faults, there may be conflicts between the preventive control measures of different faults, so the preventive control decision has the nature of game. In the future, the game theory-based analysis method will be paid more attention in the research of electric system defence strategy and electric grid fault treatment.

IV. CONCLUSION

Safety is the premise of human survival and development. Everyone is eager for safety, and harmonious development needs safety even more. safety management is particularly important. Unsafe hidden dangers have a devastating and lasting impact on our lives. Unsafe behaviours spread throughout all fields of society. Food enterprises will take into account the factors such as efficiency, sales volume, reputation and so on to interact and play games with food regulators. In the process of construction safety, the evolution of unsafe behaviours can be described based on the phenomenon of multi-party participation and complex dynamic game in the process of engineering quality supervision, Coal miners in coal mine safety can elaborate the potential impact of factors such as workers' emotions, external supervision environment, rules and regulations on the unsafe behaviours of coal miners through the interactions with the supervisor. Game theory plays an increasingly important role in the research of various safety fields. This paper summarizes the current situation of game theory based research in safety management, which can fundamentally explore the causes of unsafe behaviour and the evolution electric, and put forward management decisions.

We find that game theory has the most application research in traffic safety, which is a hot topic recently. Future research may point to food safety, construction safety, coal mine safety, electrical safety and other fields. This paper summarizes different models of game theory between specific subjects in the game, systematically analyzes and sums up the excellent point of view analysis and method application through collecting these scattered research results, points out the lack of research, and further predicts the research trend of future game theory in various fields of safety management, in order to provide the corresponding research reference for later researchers.

REFERENCES

[1] M. Attia, H. Sedjelmaci, S. M. Senouci, and E.-H. Aglzim, "Game model to optimally combine electric vehicles with green and non-green sources into an end-to-end smart grid architecture," *J. Netw. Comput. Appl.*, vol. 72, pp. 1–13, Sep. 2016, doi: 10.1016/j.jnca.2016.06.006.

[2] S. I. Bouderba and N. Moussa, "Evolutionary dilemma game for conflict resolution at unsignalized traffic intersection," *Int. J. Mod. Phys. C*, vol. 30, Feb. 2019, Art. no. 1950018, doi: 10.1142/s0129183119500189.

[3] J. Brickley, C. Smith, and J. Zimmerman, "An introduction to game theory and business strategy," *J. Appl. Corporate Finance*, vol. 13, no. 2, pp. 84–98, 2010.

[4] L. X. Cao and W. W. Chai, "A countermeasure model about food safety regulatory," *Adv. Mater. Res.*, vols. 781–784, pp. 1546–1549, Sep. 2013.

[5] Y.-H. Chen, S.-J. Huang, A. K. Mishra, and X. H. Wang, "Effects of input capacity constraints on food quality and regulation mechanism design for food safety management," *Ecological Model.*, vol. 385, pp. 89–95, Oct. 2018, doi: 10.1016/j.ecolmodel.2018.03.011.

[6] D. Csercsik, "Competition and cooperation in a bidding model of electrical energy trade," *Netw. Spatial Econ.*, vol. 16, no. 4, pp. 1043–1073, Dec. 2016, doi: 10.1007/s11067-015-9310-x.

[7] B. Djehiche, A. Tcheukam, and H. Tembine, "A mean-field game of evacuation in multilevel building," *IEEE Trans. Autom. Control*, vol. 62, no. 10, pp. 5154–5169, Oct. 2017, doi: 10.1109/tac.2017.2679487.

[8] R. Focardi and F. Martinelli, "A uniform approach for the definition of security properties," in *Proc. Int. Symp. Formal Methods*, 1999, pp. 794–813.

[9] N. E. Groner, "A decision model for recommending which building occupants should move where during fire emergencies," *Fire Saf. J.*, vol. 80, pp. 20–29, Feb. 2016, doi: 10.1016/j.firesaf.2015.11.002.

[10] M. Havas and D. Colling, "Wind turbines make waves: Why some residents near wind turbines become ill," *Bull. Sci., Technol. Soc.*, vol. 31, no. 5, pp. 414–426, Oct. 2011.

[11] Z. Huang, "Sustainable dynamic supervision of construction safety production license," in *Proc. Int. Conf. Intell. Transp., Big Data Smart City*, Dec. 2015, pp. 813–816.

[12] A. Mohd Ibrahim, I. Venkat, and D. W. Philippe, "The impact of potential crowd behaviours on emergency evacuation: An evolutionary game-theoretic approach," *J. Artif. Societies Social Simul.*, vol. 22, no. 1, p. 15, 2019, doi: 10.18564/jasss.3837.

[13] L. Jia and X. Z. Liu, "Control research of engineering safety supervision based on rent-seeking and game theory," *Adv. Mater. Res.*, vols. 243–249, pp. 1416–1420, May 2011.

[14] H.-Z. Jin, Y. Zhou, and N.-N. Zhai, "The game analysis of coal mining enterprises safe-production and government administration re-supervision," in *Proc. Int. Conf. Inf. Syst. Crisis Response Manage. (ISCRAM)*, Nov. 2011, pp. 319–323.

[15] L. Kangping and G. Yajing, "A combination method for wind power prediction based on cooperative game theory," *Electricity*, vol. 25, no. 2, pp. 36–40, Apr. 2014.

[16] C. Kim and R. Langari, "Game theory based autonomous vehicles operation," *Int. J. Vehicle Design*, vol. 65, no. 4, pp. 360–383, 2014, doi: 10.1504/ijvd.2014.063832.

[17] L. Qin, "A effective way to improve the performance of food safety governance based on cooperative game," *Agricult. Agricult. Sci. Procedia*, vol. 1, pp. 423–428, 2010.

[18] S. Li, Y. Wang, and Q. Liu, "A model of unsafe behavior in coal mines based on game theory," *Int. J. Mining Sci. Technol.*, vol. 23, no. 1, pp. 99–103, Jan. 2013.

[19] Z. Li and H. Li, "Analysis on food quality and safety supervision based on game theory," *Chin. Agricult. Sci. Bull.*, vol. 281, pp. 1541–1549, May 2012.

[20] J. Lisowski, "Game control methods in avoidance of ships collisions," *Polish Maritime Res.*, vol. 19, pp. 3–10, Oct. 2012, doi: 10.2478/v10012-012-0016-4.

[21] J. Lisowski, "The multistage positional game of marine objects with different degree of cooperation," *Solid State Phenomena*, vol. 180, pp. 56–63, Nov. 2012.

[22] J. Lisowski, "The characteristics of the matrix game sensitivity of the safe passing of ships at sea," *Solid State Phenomena*, vol. 210, pp. 258–264, Oct. 2013.

[23] J. Lisowski, "Optimization-supported decision-making in the marine game environment," *Solid State Phenomena*, vol. 210, pp. 215–222, Oct. 2013.

[24] J. Lisowski, "Determination and display of safe ship trajectories in collision situations at sea," *Solid State Phenomena*, vol. 236, pp. 128–133, Jul. 2015.

[25] J. Lisowski, "Game control of maritime objects," *J. Mar. Eng. Technol.*, vol. 16, no. 4, pp. 165–176, Feb. 2017, doi: 10.1080/20464177.2017.1384093.

[26] H. B. Liu and L. P. Chen, "Game analysis in investigating unsafe behavior of coal mine employees," *Saf. Coal Mines*, vol. 43, no. 2, pp. 189–192, Feb. 2012.

[27] Q. Liu, X. Li, and X. Meng, "Effectiveness research on the multi-player evolutionary game of coal-mine safety regulation in China based on system dynamics," *Saf. Sci.*, vol. 111, pp. 224–233, Jan. 2019, doi: 10.1016/j.ssci.2018.07.014.

[28] R. Lu, X. Wang, H. Yu, and D. Li, "Multiparty evolutionary game model in coal mine safety management and its application," *Complexity*, vol. 2018, pp. 1–10, Mar. 2018, doi: 10.1155/2018/9620142.

[29] J. Luo, B. Ma, Y. Zhao, and T. Chen, "Evolution model of health food safety risk based on prospect theory," *J. Healthcare Eng.*, vol. 2018, pp. 1–12, Oct. 2018, doi: 10.1155/2018/8769563.

[30] F. Meng, J. Su, C. Liu, and W. H. Chen, "Dynamic decision making in lane change: Game theory with receding horizon," in *Proc. UKACC 11th Int. Conf. Control (CONTROL)*, Aug./Sep. 2016, pp. 1–6.

[31] C. Min and C. Hui, "Game analysis of construction safety supervision," in *Proc. Int. Conf. E-Bus. E-Government (ICEE)*, May 2011, pp. 1–4.

[32] Q. Na and Q. C. Yong, "Behavioral analysis and countermeasure study of 'hidden action' of contractors in a view of evolutionary game theory," *Appl. Mech. Mater.*, vols. 209–211, no. 3, pp. 1305–1308, 2012.

[33] T. Namerikawa, N. Okubo, R. Sato, Y. Okawa, and M. Ono, "Real-time pricing mechanism for electricity market with built-in incentive for participation," *IEEE Trans. Smart Grid*, vol. 6, no. 6, pp. 2714–2724, Nov. 2015, doi: 10.1109/tsg.2015.2447154.

[34] N. Ding, T. Chen, and H. Zhang, "Simulation of high-rise building evacuation considering fatigue factor based on cellular automata: A case study in China," *Building Simul.*, vol. 10, no. 3, pp. 407–418, Jun. 2017.

[35] R. Piccinelli, G. Sansavini, R. Lucchetti, and E. Zio, "A general framework for the assessment of power system vulnerability to malicious attacks," *Risk Anal.*, vol. 37, no. 11, pp. 2182–2190, Nov. 2017, doi: 10.1111/risa.12781.

[36] W. Saad, T. Alpcan, T. Basar, and A. Hjorungnes, "Coalitional game theory for security risk management," in *Proc. 5th Int. Conf. Internet Monit. Protection*, May 2010, pp. 35–40.

[37] D. Seaberg, L. Devine, and J. Zhuang, "A review of game theory applications in natural disaster management research," *Natural Hazards*, vol. 89, pp. 1461–1483, Sep. 2017.

[38] C. Song and J. Zhuang, "Modeling a Government-Manufacturer-Farmer game for food supply chain risk management," *Food Control*, vol. 78, pp. 443–455, Aug. 2017, doi: 10.1016/j.foodcont.2017.02.047.

[39] C. Song and J. Zhuang, "Regulating food risk management—A government-manufacturer game facing endogenous consumer demand," *Int. Trans. Oper. Res.*, vol. 25, no. 6, pp. 1855–1878, Nov. 2018, doi: 10.1111/itor.12269.

[40] S. Yinghua, S. Ningzhou, and L. Dan, "Evolutionary game and intelligent simulation of food safety information disclosure oriented to traceability system," *J. Intell. Fuzzy Syst.*, vol. 35, no. 3, pp. 2657–2665, Oct. 2018, doi: 10.3233/jifs-169617.

[41] X. Su, H. Liu, and S. Hou, "The trilateral evolutionary game of agri-food quality in farmer-supermarket direct purchase: A simulation approach," *Complexity*, vol. 2018, pp. 1–11, Feb. 2018, doi: 10.1155/2018/5185497.

[42] R. Szlapczynski, "Evolutionary sets of safe ship trajectories: A new approach to collision avoidance," *J. Navigat.*, vol. 64, no. 1, pp. 169–181, Jan. 2011, doi: 10.1017/s0373463310000238.

[43] R. Szłapczyński and J. Szłapczyńska, "Customized crossover in evolutionary sets of safe ship trajectories," *Int. J. Appl. Math. Comput. Sci.*, vol. 22, no. 4, pp. 999–1009, Dec. 2012, doi: 10.2478/v10006-012-0074-x.

[44] R. Szlapczynski and J. Szlapczynska, "On evolutionary computing in multi-ship trajectory planning," *Int. J. Speech Technol.*, vol. 37, no. 2, pp. 155–174, Sep. 2012.

[45] A. Talebpour, H. S. Mahmassani, and S. H. Hamdar, "Modeling lane-changing behavior in a connected environment: A game theory approach," *Transp. Res. C, Emerg. Technol.*, vol. 59, pp. 216–232, Oct. 2015, doi: 10.1016/j.trc.2015.07.007.

[46] Z. Tong, "An analysis based on game theory about the complicity between contractor and supervisor in the construction claims," in *Proc. Int. Conf. Manage. Service Sci.*, Aug. 2010, pp. 1–3.

[47] A. A. Vasin, E. A. Kozyreva, and A. S. Tyuleneva, "Optimization of the occupational safety compliance control (OSCC) system at a coal mining enterprise," *J. Comput. Syst. Sci. Int.*, vol. 56, no. 5, pp. 810–817, 2017, doi: 10.1134/s1064230717050124.

[48] C. C. Wang, Y. J. Gu, W. W. Zhao, Y. P. Han, and Y. L. Dong, "Research on preventive maintenance cycle decision of wind turbine," *Adv. Mater. Res.*, vols. 860–863, pp. 383–388, Dec. 2013.

[49] M. Wang, S. P. Hoogendoorn, W. Daamen, B. van Arem, and R. Happee, "Game theoretic approach for predictive lane-changing and car-following control," *Transp. Res. C, Emerg. Technol.*, vol. 58, pp. 73–92, Sep. 2015, doi: 10.1016/j.trc.2015.07.009.

[50] W. Wang, Y. Qin, L. Mao, and Q. Yu, "Research on the construction safety investment regulation evolutionary game and application," in *Proc. 8th Int. Conf. Manage. Sci. Eng. Manage.*, 2014, pp. 145–153.

[51] X. Wang, F. Wang, D. Kong, Y. Liu, L. Liu, and C. Chen, "Driver's lane selection model based on phase-field coupling and multiplayer dynamic game with incomplete information," *J. Adv. Transp.*, vol. 2018, pp. 1–16, Aug. 2018, doi: 10.1155/2018/2145207.

[52] T.-H. Woo and U.-C. Lee, "Modeling of operational safeguard for power productions in the nuclear power plants (NPPs)," *Energy Explor. Exploitation*, vol. 28, no. 6, pp. 433–449, Dec. 2010, doi: 10.1260/0144-5987.28.6.433.

[53] T. H. Woo, "Nuclear safeguard assessment in nuclear power plants (NPPs) using loss function with modified random numbers," *Ann. Nucl. Energy*, vol. 43, pp. 1–7, May 2012, doi: 10.1016/j.anucene.2011.12.022.

[54] J. C. Wu, C. X. Wu, and Y. P. Liu, "The economics and feasibility of traceability in agri-food supply chain: Analysis with game theory between double Oligarchs," *Appl. Mech. Mater.*, vols. 397–400, pp. 2574–2580, Sep. 2013.

[55] L. I. Xiu-Yun, Y. Gao-Sheng, and U. Hohai, "Game between contractor and labor subcontractor from construction safety perspective," *J. Eng. Manage.*, vol. 28, no. 3, pp. 138–142, Jun. 2014.

[56] Z. Yang, H. Huang, G. Wang, X. Pei, and D.-Y. Yao, "Cooperative driving model for non-signalized intersections with cooperative games," *J. Central South Univ.*, vol. 25, no. 9, pp. 2164–2181, Sep. 2018, doi: 10.1007/s11771-018-3905-6.

[57] M. Ying, Y. Zhang, and K. Xie, "Game playing analysis of the government and the media for food safety emergencies response," in *Proc. IEEE 18th Int. Conf. Ind. Eng. Eng. Manage.*, Sep. 2011, pp. 1263–1266.

[58] H. Yu, H. E. Tseng, and R. Langari, "A human-like game theory-based controller for automatic lane changing," *Transp. Res. C, Emerg. Technol.*, vol. 88, pp. 140–158, Mar. 2018, doi: 10.1016/j.trc.2018.01.016.

[59] K. Yu, L. Zhou, Q. Cao, and Z. Li, "Evolutionary game research on symmetry of Workers' behavior in coal mine enterprises," *Symmetry*, vol. 11, no. 2, p. 156, Jan. 2019, doi: 10.3390/sym11020156.

[60] P. Bukowski, "Water hazard assessment in active shafts in upper silesian coal basin mines," *Mine Water Environ.*, vol. 30, no. 4, pp. 302–311, Aug. 2011.

[61] K. Zhang, H. F. Qi, and C. H. Shi, "Safety on food supply chain game basing on profit distribution," *Adv. Mater. Res.*, vols. 121–122, pp. 710–716, Jun. 2010.

[62] Z.-S. Lu, S.-L. Yang, and S. P. Yang, "Game analysis of engineering safety supervision based on rent-seeking theory," *J. Eng. Manage.*, vol. 24, no. 3, pp. 281–286, Jun. 2010.
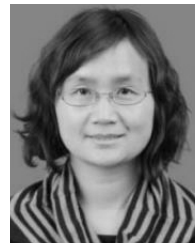
QINGFENG MENG was born in Tieling, Liaoning. He was a member of the Communist Party of China, the Doctor of Management Science and Engineering with Nanjing University, the Postdoctoral of Management Science and Engineering with Jiangsu University. He was also a Visiting Scholar with University, Australia. He is currently an Associate Professor and a Ph.D. Supervisor with Jiangsu University, an Outstanding Backbone Teacher with the Blue Project, Jiangsu, and the Young Academic Leader with the Young Backbone Teacher Training Project, Jiangsu University. He is also the Director of Complex Science Management Branch with the China Society of Technology and Economics, the Fund Review Expert with the Management Department, National Natural Fund Committee, the Executive Deputy Director with the Big Data and Sustainable Development Research Center, Jiangsu University, and the Part-Time Research Member with the Computing Experiment Center, Jiangsu University. His main research interests include complex engineering management, green supply chain management, behaviour operation management, complex system modeling, computational experiments, and so on.

SHAOHONG TAN was born in Nanjing, Jiangsu. He is currently pursuing the degree with the School of management, Jiangsu University. His main research interests include safety management, unsafe behaviour of construction, behaviour operation management, application of game theory, and so on.

ZHEN LI was born in Luohe, Henan. She was a member of the Communist Party of China, the Doctor of Management Science and Engineering with Nanjing University, and the Postdoctoral of Management Science and Engineering with Jiangsu University. She was a Visiting Scholar with University, Australia. She is currently an Associate Professor and a Ph.D. Supervisor with Jiangsu University, an Outstanding Backbone Teacher with the Blue and Green Project, Jiangsu, and the Young Academic Leader with the Young Backbone Teacher Training Project, Jiangsu University. She is also the Director of Complex Science Management Branch with the China Society of Technology and Economics, the Fund Evaluation Expert with the Management Department, National Natural Fund Committee, and the Part-Time Researcher with the Big Data and Sustainable Development Research Center and the Calculation Experiment Center, Jiangsu University. Her main research interests include complex engineering management, green supply chain management, and analysis and calculation experiment method of social complex systems.

BINGYAO CHEN was born in Nanchang, Jiangxi. She is currently a Lecturer with the School of Economics and Management, Jiangxi University of Traditional Chinese Medicine. Her main research interests include safety management, industry policies, application of game theory, and so on.

WEIXIANG SHI is currently pursuing the Ph.D. degree with the School of Build Environment, Curtin University, Perth, WA, Australia. His main research interests include construction management, information technology in construction, building information modeling, wireless sensor networks, and so on.

• • •