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Review

Review: Methods to solve practical problems for the monitoring and control of Driver-less Electric Transport Vehicles in the underground mines

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Abstract: With the continuous development of Artificial Intelligence technology and Internet of Things engineering, more and more driver-less vehicles have been developed and put into the industrial production. The birth of driver-less vehicles undoubtedly brings new vitality to a large amount of industries, particularly in transportation. For the mining industry, transportation is undoubtedly an extremely important link in the whole production process. If the driver-less vehicles can be applied to the underground mines, it can not only improve the production and transportation capacity of the whole mine, but also can reduce the occurrence of many mine safety accidents. ZigBee Networks can play a greater role in the narrow environment like underground mines according to the relevant literature, this review mainly integrates the ZigBee Networks and the communication-based train control (CBTC) system to explore the possibility of the driver-less vehicles to be used in the underground mines, which aims to solve practical engineering problems. This review serves just as a guide to the *Tossing out a brick to get a jade gem*, has implications for the development of underground mine transportation.

Keywords: Driverless Transport Vehicle; ZigBee Networks; Communication-based train control (CBTC) system; Underground transportation; Trackless transportation; Mining industry

1. Introduction

With the continuous development of the science and technology, scholars all over the world have begun to devote themselves to the "revolution" of the Artificial Intelligence technology and Internet of Things engineering, and to contribute to the development of various industries. However, the driver-less technology of vehicles is also the product of this "revolution". With the comprehensive promotion of Artificial Intelligence technology, the driver-less technology presents a rapid development trend. There is no doubt that the driver-less technology has become the latest development direction of vehicle industry all over the world. Compared with traditional cars, self-driving cars can effectively improve the safety, traffic efficiency and comfort of vehicles.

For the vehicle industry giants, Germany, Japan, the United States have been on the research of the driver-less technology earlier before.

In a 2003 report of Cheon[1], Cheon noted that as early as 1939, the United States firstly exhibited the concept design of the driver-less technology at the New York World Expo. He thought although the design was simple, it was a sensation to some extent at the time. And the world's first driver-less vehicle was developed by the Carnegie Mellon University in 1984. This remarkable academic achievement made a really great sensation in the world, and even years later, scholars still reported on how the driver-less vehicle worked one after another. In 1987, after three years of the birth of the driver-less technology, Goto Y,Stentz A[2] published their core research on the CMU system which is derived from the Carnegie Mellon University.

As the research mentioned above, the early driver-less vehicles used CMU systems, a system based on Artificial Intelligence computing and Computer Control, which was studied by many scholars from the 20th century to the early 21st century.

In 1987, Y. Goto and A. Stentz[4][5] tried to apply the CMU system to the intelligent control of robots. In the year 1988, A. Parker, D. Thomas, D. Siewiorek, M. Barbacci and L. Hafer[5] studied the functions of automatic control of CMU system through practice, and suggested that CMU system can be further optimized. And in 1989, R. Stouffer[6] reported that the Carnegie Mellon University, the founder of the CMU system, had been doing the research on developing a new system based on the advantages and disadvantages that the CMU system had shown before, the same year, L. R. Carley et al[7] proposed some improvements to the simulation of the CMU system.

After entering the 21st century, it is obvious that more and more control systems appear, which provides favorable logistic support for the driver-less technology. Specially, a scholar[8] proposed the use of laser sensors to guide driver-less vehicles forward in 2005, and T. Zhang et al[9] built a new simulation platform for driver-less vehicles, which can evaluate the performance of driver-less vehicles more accurately.

As a pioneer in the introduction of the driver-less vehicle road testing, the Google officially launched the driver-less vehicle project in 2009[10]. Uber also launched the driver-less vehicle travel project in 2016[11], and in the same year, under the pressure of competition from peers, Google split the driver-less business and set up Waymo Company to accelerate the commercialization of driver-less vehicles[12]. Developing countries have also made significant breakthroughs in the area of driver-less vehicles in recent years, in August 2018, a driver-less minibus developed jointly by Baidu and Jinlong Bus of China achieved small-scale mass production[13].

At this stage, driver-less technology seems to be more used in people's daily travel, Google, Uber and so on are committed to the application of driver-less technology in people's daily driving. However, as early as in 2014, R. Bartley[14] had already proposed the use of driver-less technology in the transport industry.

With the continuous progress of industrial development, Artificial Intelligence technology and Internet of things technology are widely used in various industries. Therefore, driver-less technology has been gradually applied in industrial transportation, of course, mining industry is no exception. And with the rapid development of mining science and technology in the world, many underground mines have gradually entered the stage of intelligence. However, underground mines face many challenges in the process of intelligent development, such as underground transportation. In the past 20 years, many scholars have devoted themselves to the research of intelligent underground mines, including the research of intelligent underground mine transportation, especially driver-less transport vehicle.

In fact, driver-less technology began to be used in underground mines around 2015 through some news reports. In 2011, A. Benter, M. Antolovich and W. Moore[15] were the first to argue that the mining process is moving in the direction of driver-less on the *2011 6th International Workshop on Advanced Ground Penetrating Radar (IWAGPR)* Conference. And in the same year, J. Meech and J. Parreira[16] begun to explore the possibility of driver-less applications in mines and developed the simulation models. And in the year 2013, K. J. Korane[17] thought driver-less vehicles may signal the future of the mining industry, the intelligent mining. In 2015, S. Murden[18] from Australia reported on the effectiveness of driver-less trucks operating in Australian mines. And in 2016, a scholar[19] mentioned that the scheduling of vehicles in underground mines was a very important thing, but if the intelligent control of vehicles could be realized, a lot of cost and time was able to be saved. In the same year, W. Shiers and C. Barnett[20] from the US experimented with driver-less trucks, and the results were undoubtedly successful, and many scholars who studied mining also applied driver-less trucks in underground mines based on their successful experience.

In recent years, driver-less technology in underground mines has been further optimized and developed. X. Cheng[21] proposed to apply SINS/DGPS integrated navigation system to the navigation of driver-less vehicles in underground mines in the year 2019, and B. Doran and M. Lopez[22] believed that the application of driver-less technology to underground mines is definitely the way to ensure mine safety. And in 2020, L. Dong et al[23] suggested that underground mines be used as a pilot to promote driver-less vehicles, they thought the popularization and application of driver-less vehicles in underground mines can not only solve the problem of deep mining, reduce the frequent disasters under bad conditions, protect the life and property safety of miners, but also provide technical support for safe and efficient recovery of deep resources.

It can be inferred that to apply driver-less vehicles to the underground mines, the scholars on the research of mining engineering must make unremitting efforts. Therefore, this review mainly integrates the ZigBee Networks and the communication-based train control(CBTC) system to explore the essential functions of driver-less vehicles specially used in underground mines, which aims to solve practical engineering problems.

2. Background

2.1 ZigBee Networks

The concept of ZigBee Networks was introduced around 2007, *Business Wire*[29] reported the birth of ZigBee Networks.

The ZigBee Networks based on IEEE802.15.4 protocol is a new kind of wireless sensor technology, which has more advantages than other wireless sensor networks in underground monitoring and communication systems. Even if ZigBee Networks only provides low data rate, it also has benefits, that is, low power consumption, low cost, convenient network installation and maintenance.

Since 2012, S. Chen, J. Yao and Y. Wu[24] have done a lot of research on ZigBee Networks, and they have found that low power consumption is the biggest feature of ZigBee Networks, and they believed that optimizing ZigBee Networks will bring benefits to all walks of life. In 2017, M. Uradzinski et al[25] found the positioning function of ZigBee Networks excellent, as a result, some scholars believed that ZigBee Networks in the underground mine environment could play its specialty. Specially, M. A. Moridi et al[26][27] did two studies in 2014 and 2018, reporting comparisons between ZigBee Networks and other underground communication networks, and concluded that ZigBee Networks have more advantages. M. A. Moridi et al[26][27] indicated that the narrow space of underground environment significantly enhances the signal intensity, as a result ZigBee Networks can play a great advantage in the underground environment. As well, M. A. Moridi et al[28] studied the ZigBee applications of developing ZigBee nodes in underground monitoring and communication in the field of safety and health in practical cases to improve network performance.

In fact, as early as in 2008, the year after ZigBee Networks emerged, Y. Li-min et al[30] applied ZigBee Networks to underground mine safety monitoring systems, they used the ZigBee Networks to collect temperatures, humidity and methane from underground coal mines, then ZigBee Networks transfers data to ARM-based information processing terminals. In the same year 2008, H. Hongjiang and W. Shuangyou[31] achieved real-time monitoring and alarm of the underground environment and production parameters by the communication function of the ZigBee Networks. And in the year 2009, Z. Pei et al[32] put forward the superiority of ZigBee Networks in underground mines because of the narrow environment of the underground mines, narrow space could enhance the signal intensity of ZigBee Networks.

Since 2010, ZigBee Networks have been widely used in underground mines, especially in the safety monitoring and control of transportation equipment. A. Chehri et al[33] suggested that mining automation might be possible through ZigBee Networks, J. Bian[34] proposed that ZigBee Networks is to some extent an auxiliary tool for collecting information, and his view was recognized by most scholars. Interestingly, Q. Li, H. Zhao and P. Liu[35] designed a *high-performance* wireless robot network communication system for underground mines based on ZigBee Networks.

ZigBee Networks were first used in the location of underground mine personnel, and then gradually used in the monitoring of transport equipment. Around 2015, W. Jiang et al[37][38][39] have been on the research of the location of underground miners based on ZigBee Networks, B. Ge et al[40] mentioned that the use of traditional positioning methods would have a large error in the location of underground vehicles, therefore, he proposed a improved received signal strength indication (RSSI) positioning algorithm, and from then on, later generations began to try to apply ZigBee Networks to vehicle positioning in underground mines.

In general, ZigBee Networks is also often used as a medium for monitoring and controlling data transmission, which seems to have gradually become an academic consensus[41][42][43].

2.2 Communication-based Train Control(CBTC) system

Nowadays, the communication-based train control(CBTC) system is commonly used in the urban rail transit system all over the world, and the CBTC systems currently operating worldwide are the "Products" of advances in Internet of Things and Artificial Intelligence.

Although the current CBTC system is considered to be able to detect and monitor the operation of transport equipment in the Rail, in the environment like the underground mines, the running range of trackless transport equipment is defined by the driveway, so the CBTC system is also able to monitor driver-less vehicles in such environment of the underground mines. Through summarizing the successful application of CBTC system in Las Vegas monorail tram[80], some scholars put forward the application of CBTC system in underground driver-less vehicle monitoring. Although CBTC systems are generally used for railway traffic monitoring, they believed that the running environment of vehicles in the underground mines is restricted to the transport lanes which is not as wide as the ground traffic environment, just like monorail trams. In fact, as early as in 2006, N. BIN et al[44] proposed to create an underground city by the CBTC system. In 2013, H. Wang et al[45][46] published their research on the underground simulation of CBTC system, and in 2014, D. Briginshaw[47] explored whether the CBTC system could be used in underground vehicles in London.

In the CBTC system, the three subsystems that have outstanding performance in monitoring and control are the ATO system, the ATP system and the ATS system. The ATO system is the Automatic Train Operation system, like ZigBee Networks, the ATO system is also always used as a medium for monitoring and controlling data transmission. The distance and speed information of the transport vehicles are collected by the ATO system and transmitted to the ATP(Automatic Train Protection) system which is the control system of the CBTC system. And the ATS system is the Automatic Train Supervision system, the monitoring system of the CBTC system. L. Zhu et al[48] did the research on the Anti-interference ability of the CBTC system to optimize the Supervision Function of the ATS system in the year 2020, and through the early Letter in 2013, H. Wang et al[49] raised the importance of the overall coordination of the CBTC system, only through the combined operation of these systems, the functions of safety protection, automatic driving, driver's communication and interaction can be realized.

In general, CBTC system is always used as control and monitoring system in real engineering.

2.3 System Integration

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To achieve the remote control of driver-less electric transport vehicles in underground mines requires the combination of the monitoring and control function of the CBTC system and the information transmission function of ZigBee Networks.

As is known, ZigBee Networks can play a better role in the narrow environment such as underground mines, especially its short-distance communication and low power consumption characteristics can be fully applied.

Recently, ZigBee Networks are widely used in the monitoring of the underground mines. In 2020, X. Jia et al[50] put forward that ZigBee Networks gets information through various sensors in the underground mine and transmits the information to the station, K. Dorthi, N. Bayyapu and R. C. Karra[51] divided the mine into areas and independently monitored each area through the ZigBee Networks. And in 2021, Y. Yang et al[52] improved the communication function of ZigBee Networks based on the background of a mine. Although, M. Celaya-Echarri et al[53] also proposed several other monitoring methods for the underground environment, there is no doubt that, ZigBee Networks have greater superiority in information transmission of the underground environment.

As an effective train control system, the CBTC system is also remarkable in underground environment. For above-ground transportation, J. Blanco, A. García and J. d. L. Morenas et al[54][55] all agreed that the CBTC system required to be used in conjunction with wide-area sensing networks such as Wireless Sensor and Actuator Network (WSAN), but it is different in the underground mines because of the narrow environment of the underground mines. Therefore, to realize the monitoring and control of underground driver-less electric transport vehicles, it is a good choice to combine ZigBee Networks with CBTC system. In 2018, X. Zhang[56] proposed that CBTC system needs three parts of functional support for the control of transportation equipment, that is, information transmission function, monitoring function and control function. According to the idea of X. Zhang[56], the integrated system is established below.

To realize such a monitoring system for driver-less electric transport vehicles, it is necessary to integrate the information data of ZigBee nodes into the database of the control center. In short, the integrated system is composed of three parts:

1. *The information transmission function from the ATO system and ZigBee Networks.*
2. *The control function from the ATP system.*
3. *The monitoring function from the ATS system.*

The functions of the integrated system are shown in **Figure 1**.

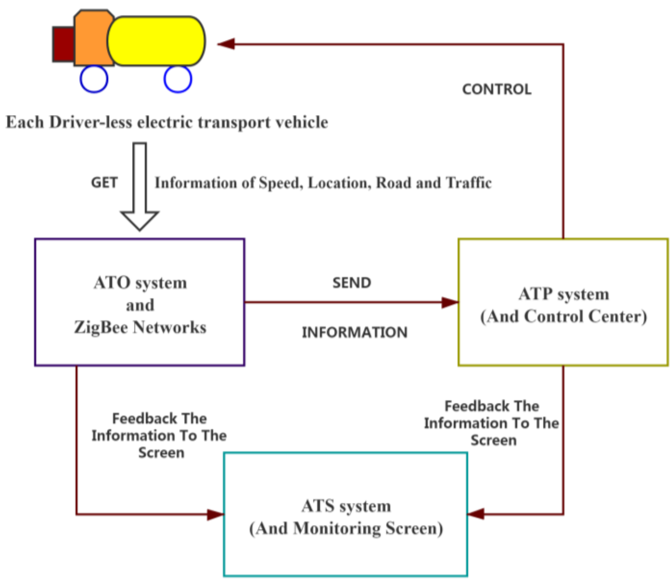

Figure 1. The functions of the integrated system.

The ATO system collects the speed and distance information of each driver-less electric transport vehicle, ZigBee Networks collect the location information of each driver-less electric transport vehicle, road condition information of underground mine and transportation traffic information. When all the information is collected, it is transmitted to both the ATP and the ATS system by the ATO system and the ZigBee Networks. When the information arrives at the ATS system, the information will be fed back to the monitoring screen of the ATS system. And when the information arrives at the ATP system, the ATP system will control each driver-less electric transport vehicle properly according to the information provided, meanwhile, the content of the control operation will be also fed back to the monitoring screen of the ATS system.

3. Methods for practical problems

In 2015, A. K. Dash et al[57] raised the opinion that there were three practical engineering problems that need to be solved urgently for underground mines driver-less electric transport vehicle：

1. **Vehicle Safety Problems:** Such as vehicle rollover and the rear-end collision.
2. **Vehicle Scheduling Problems:** Vehicle movement during transport operations.

In order to dedicate to solving the practical problems of underground mines driver-less electric transport vehicle in the underground mines, the review tries to summarize the solutions to the above problems by applying the integrated system mentioned above.

A. Vehicle Safety Problems

ATP system is the core system to control vehicle speed and vehicle safety distance before and after. ATP system controls and regulates minimum interval and over-speed protection in vehicle operation to avoid rear-end of vehicle. The main components of the ATP system include range measuring equipment, speed monitoring equipment, vehicle-ground interaction equipment and emergency braking equipment. To control the hidden danger of vehicle safety, it is also necessary to ZigBee Networks and the ATO system as the medium of information transmission. And the real-time running state of each vehicle is fed back to the monitoring screen of the ATS system.

On the premise of solving the problem, a method is needed to judge whether the problem appears or not. In previous studies, the control of underground mine transport vehicles is generally driven by manual driving, even driver-less vehicles will only be realized through some short-distance communication emergency control, on the 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), P. Gao et al[58] published the research on the safety function of the ATP system, proposed a new analysis method for the ATP system, the Dynamic Fault Tree analysis method. The Dynamic Fault Tree is a method system to evaluate the reliability and security of complex system, and it is also a deductive method based on fault event. It is analyzed step by step according to top-down order through certain logical reasoning steps until the result is obtained. The Dynamic Fault Tree analysis method is to model the fault logic according to the dynamic fault behavior, which accords with the function design of the signal system. It is worth mentioning that logical analysis based on the Dynamic Fault Tree analysis method usually analyzes the emergence of problems at the same time, rather than layer by layer analysis, which can greatly improve the efficiency of problem solving. The order of problem solving based on the Dynamic Fault Tree analysis method proposed by P. Gao et al[58] is: **1.** *Identify the possible fault events.* **2.** *According to the possible fault events, establish the analysis process of them.* **3.** *Through the control system, analyze whether the fault events occur.* **4.** *If the fault events occur, solve them through the control system.*

Through the analysis of the information transmitted by the ATO system and the ZigBee Networks, ATP the system begins to analyze whether the problem appears, and the analysis process of the fault events based on the Dynamic Fault Tree analysis method has been established: **1.** *According to the road information provided by the ZigBee Net-*

works, if there might be a rollover accident caused by the bumpy road of the underground mine, the speed of each vehicle on the road would be slowed down by the control function of the ATP system. **2.** *According to the speed and the distance information provided by the ATO system, if the distance between the vehicles may cause an accident, the distance would be controlled by the control function of the ATP system through controlling the speed of the vehicles.* **3.** *If the emergency appears, the control function of the ATP system will halt all the vehicles in the underground mine.* **4.** *The whole process will be fed back to the screen of the ATS system.*

With the improvements based on the Dynamic Fault Tree analysis method proposed by P. Gao et al[58], the process logic diagram of the ATO system, ZigBee Networks and the ATP system to solve the safety problems is shown in **Figure 2.**

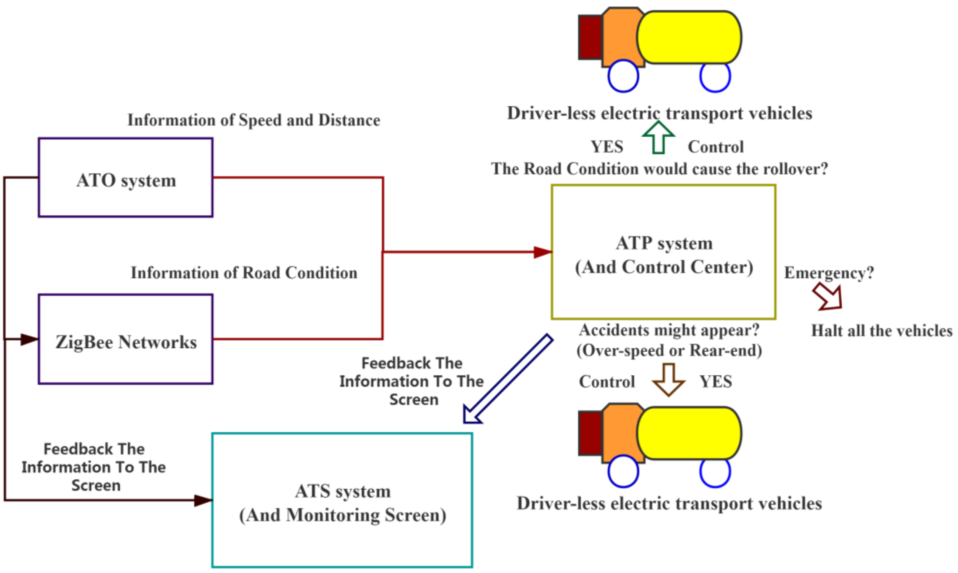

Figure 2. The process logic diagram of the solution to the Safety problems.

B. Vehicle Scheduling Problems

In the transportation operation, it is inevitable to encounter the problems of scheduling, such as the control of departure time and the choice of transportation route of transport vehicles, therefore, the importance of information transmission is particularly important at this moment. S.Terblanche and A. Bley[59] put forward their opinion optimizing the scheduling of underground vehicles is able to greatly improve the production and transportation efficiency of underground mines. As well, M. Åstrand et al[60] regarded the underground mine transportation system as a production workshop, and if the "Production Line" is well scheduled, it will significantly improve efficiency. In fact, as early as in 2005, M. Gamache, R. Grimard and P. Cohen[61] had proposed a shortest-path algorithm for the scheduling problems, and from then on, many scholars like D. O'Sullivan et al[62][63] began to do the research to optimize the shortest-path algorithm for the scheduling problems. In 2019, A. G. Yardimci and C. Karpuz[64] proposed adding Artificial Intelligence Computing capabilities into the shortest-path algorithm for the scheduling problems in the underground mines, which has become the direction of the efforts of later researchers.

Before the emergence of Artificial Intelligence, the scheduling of underground vehicles was done manually, but after the AI has appeared, scholars[65][66][67] proposed an analysis process based on the AI computing applying in the scheduling with the guidance of the CBTC system and ZigBee Networks, once there is a Stope that needs transport operations, the process begins running: **1.** *Calculate the amount of transport vehicles that might be required in the operations with the assistance of the AI computing and Analyzes the congestion of each transportation route through the road and traffic information provided by ZigBee Networks.* **2.** *Choose the best route to the Stope for each transport vehicle participating in*

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the transportation operations by the control of the ATP system. **3.** *And choose the best route to the unloading place for each transport vehicle.* **4.** *The whole process will be fed back to the screen of the ATS system.*

With the improvements based on the shortest-path algorithm and AI computing proposed by scholars[59-67], the process logic diagram of the ATO system, ZigBee Networks and the ATP system to solve the safety problems is shown in **Figure 3.**

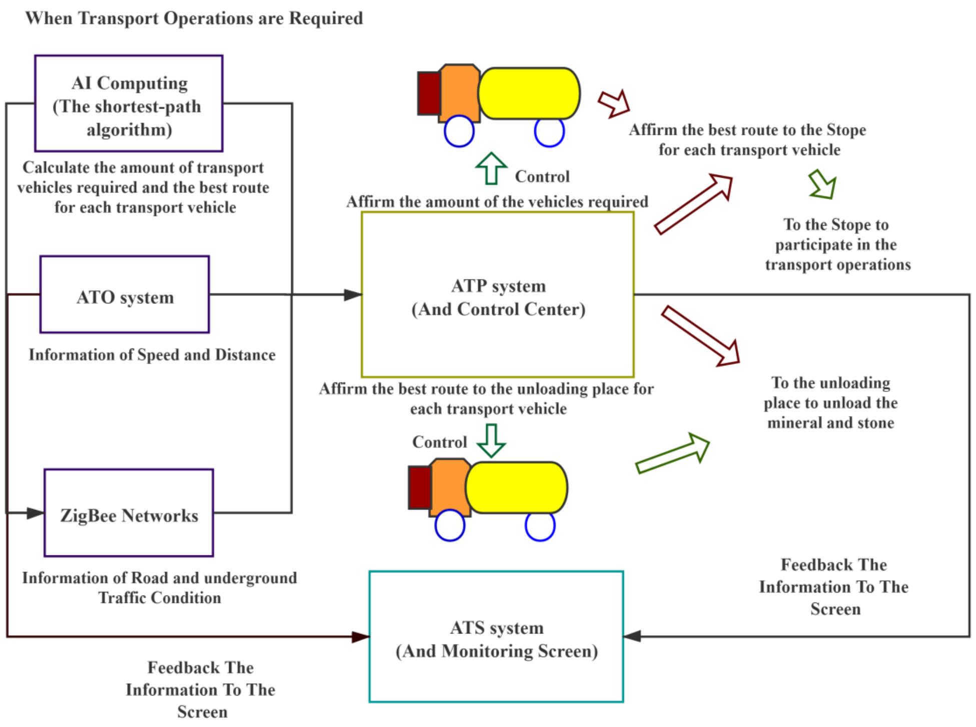

Figure 3. The process logic diagram of the solution to the Scheduling problems.

4. Discussion and Outlook

The emergence of driver-less electric vehicles undoubtedly brings opportunities and challenges to all walks of life. Some media[68][69] believe that the emergence of driver-less vehicles is clearly an opportunity to facilitate people's future lives and promote the development of the industries, but some scholars[70][71] believe that the emergence of driver-less technology is undoubtedly a challenge at this stage, and many problems are difficult to solve at this stage of science and technology, for example, the variability of traffic flows or the complexity of the transport environment.

Without doubt, the emergence of driver-less vehicles in underground mines is definitely a challenge to current mining technology. In 2016, driver-less technology was better used in subway through the report of J. P. Powell et al[72]. Around 2017, there were reports[73][74] that driver-less technology was going deep into underground mines, which can be seen as a starting point for the application of driver-less technology in underground mines. After 2017, driverless vehicles in underground mines are considered risky and cost-effective. J. Guo, J. Du and D. Xu[75] optimized the positioning accuracy of driverless vehicles in underground mines in early 2018, but there are still many defects in operating driverless vehicles underground. At the time, many people thought driverless vehicles had encountered bottlenecks in underground mines, but the turnaround also occurred in 2018, M. A. Moridi et al[26][27] published their second study of ZigBee Networks applications in underground mines, which showed that ZigBee Networks could play a greater role in narrow environments like underground mines. From then on, ZigBee Networks have been considered to be a new direction in the research of underground mine driver-less technology.

ZigBee Networks, as the medium of information transmission, generally work with GIS(Geographic Information System) to monitor and control the equipment in the underground mines such as vehicles. GIS system is widely used in underground mines, especially monitoring and alarm, many scholars[76][77] have used GIS system as monitoring system in underground mines. As well, GIS system is also used as the path planning control system for driver-less vehicles on the ground. K. Zhou et al[78] and L. Yu et al[79] both have used GIS system to route driver-less vehicles. Although the GIS system is widely used, it has some defects in the control of underground driver-less vehicles, therefore, more scholars prefer communication control systems to monitor driver-less vehicles.

Through summing up the successful application of CBTC system in Las Vegas monorail tram[80], some scholars put forward the application of CBTC system to the monitoring and control of underground driver-less vehicles. Although the CBTC system is generally used in rail transit monitoring and control, they believed that the running environment of driver-less vehicles in underground mines is restricted to the transport lanes which is not as wide as the ground traffic environment, just like the monorail tram.

The CBTC system is the traffic control system which is used in various countries at present, so the CBTC system does have a certain advanced in the control of vehicles, especially CBTC system can set algorithms in its control system, such as the shortest-path algorithm[59-67] mentioned in the above review. The CBTC system, as the monitoring and control system of underground mine transportation, there has been a lot of research on it in the past ten years, and there is no doubt that CBTC system will play a more and more important role in the transportation of underground mine in the future.

Besides the CBTC system, Volvo Motor Company[81] began to develop its own monitoring of underground driver-less transport trucks in 2016, and WaveSense[82] tried to use Ground-Penetrating Radar in the monitoring of the driver-less transport vehicles, and more and more kinds of sensors appear for the monitoring and control of the driver-less vehicles. The emergence of more and more monitoring systems undoubtedly lays the foundation for the development of driver-less vehicles. No matter what kind of system or tool will appear, as long as it can be applied to driver-less technology and can solve problems in real life or engineering, scholars who study driver-less technology will not waste their efforts all the time.

Therefore, whether in mining, industrial transportation or people's lives, if driver-less technology is conquered by scholars as a challenge, it will become an opportunity. If this opportunity can be seized by people, then it will benefit mankind.

5. Conclusions

Overall, the type of this paper is a review article, by summarizing the relevant literature, this paper discusses the possibility of applying CBTC system and ZigBee Networks to the monitoring and control system of underground mine, and reports the the progress in present stage of some existing research to apply CBTC system in the driver-less electric transport vehicles in the underground mines.

In the introduction part, the review sums up the development of the driver-less technology through some relevant literature and news reports and proposes the benefits of the driver-less technology to the modern society. More importantly, in this part, the review introduces the background that driver-less technology is moving towards underground mines, thus, the review further explores the advantages of ZigBee Networks and the CBTC system in underground mine for monitoring and controlling. Specifically, at the end of this section, the review leads to its purpose, that is, to summarize the methods based on the CBTC system and ZigBee Networks to solve the practical problems of underground driver-less electric transport vehicle monitoring and control. In the background part, this review briefly summarizes the development process of ZigBee

Networks and the CBTC system through some relevant literature, and summarizes the fundamental reason that both they can be applied to underground driver-less technology. And according to the idea of X. Zhang[56], the review combines the functions of ZigBee Networks and CBTC systems into the integrated system. In the part of Methods for practical problems, this review summarizes the methods of solving practical problems in engineering by referring to the existing literature, especially the proposal of P. Gao et al[58] and a few scholars[65-67]. In this part, the Dynamic Fault Tree analysis method[58] is the most important method used in the control system summarized in the relevant literature, it is an accident analysis method, often used in monitoring systems. In the discussion part, the review puts forward the view that the emergence of driver-less technology is both an opportunity and a challenge, if scholars can overcome the challenge, driver-less technology will benefit mankind. Besides, this part summarizes the development of the driver-less technology in underground mines, and puts forward the prospect of driver-less monitoring and control technology in the future.

Although the review has made great efforts in writing, it is not a comprehensive literature review, therefore, this review will make some recommendations for relevant references to the readers:

1. On people's assumptions about the driver-less technology, the review recommends the relevant literature[84-86].

2. On application of the driver-less Technology in Engineering, the review recommends the relevant literature[87-89].

3. On the meaning of the driver-less technology to people's daily life, the review recommends the relevant literature[90-94].

4. On the future of the driver-less technology, the review recommends the relevant literature[95-97].

Finally, the authors claim that the review serves just as a guide to the *Tossing out a brick to get a jade gem*, has a few implications for the development and the future of the underground mine transportation, and it is hoped that more and more scholars will be interested and engage in the research of this field.

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References

1. Cheon S. An overview of automated highway systems (AHS) and the social and institutional challenges they face[J].University of California Transportation Center Working Papers,Berkeley,CA,Spring 2003.
2. Goto Y,Stentz A.The CMU system for mobile robot navigation[C]//Proceedings 1987 IEEE International Conference on Robotics and Automation.Montreal Canada:IEEE Robotics and Automation Society,1987:99-105.
3. Y. Goto and A. Stentz, "Mobile Robot Navigation: The CMU System," IEEE Expert, vol. 2, (4), pp. 44-54, 1987.
4. Y. Goto and A. Stentz, "The CMU system for mobile robot navigation," in 1987, . DOI: 10.1109/ROBOT.1987.1088022.

5. A. Parker,D. Thomas,D. Siewiorek,M. Barbacci,L. Hafer. The CMU design automation system: an example of automated data path design[P]. Twenty-five years of electronic design automation,1988.
6. R. Stouffer, "Happy Motoring?: CMU Developing New Propulsion System," Pittsburgh Business Times-Journal, vol. 8, (25), pp. 1, 1989.
7. L. R. Carley et al, "ACACIA: The CMU analog design system," in 1989, . DOI: 10.1109/CICC.1989.56685.
8. Anonymous "SICK laser sensors guide driverless vehicles," Material Handling Management, vol. 60, (10), pp. 9, 2005.
9. T. Zhang et al, "A novel platform for simulation and evaluation of intelligent behavior of driverless vehicle," in 2008, . DOI: 10.1109/ICVES.2008.4640852.
10. Anonymous "Google unveils driverless vehicle prototypes," Mint (New Delhi, India), 2014.
11. Anonymous "The other driverless VEHICLE: Trials of autonomous cars by Uber and Waymo are grabbing the headlines, but this kind of technology also promises to transform industrial machinery," Engineering Designer, vol. 46, (1), pp. 20, 2020.
12. Anonymous "Waymo plans to offer completely driverless vehicles," Auto Business News (ABN), 2019.
13. Anonymous "Ford and Baidu announce joint autonomous vehicle testing," Just-Auto.Com, 2018.
14. R. Bartley, "Trucking industry, military test driverless vehicles," Fiercemobileit, 2014.
15. A. Benter, M. Antolovich and W. Moore, "Determining bulk density of mine rock piles using ground penetrating radar frequency downshift," in 2011, . DOI: 10.1109/IWAGPR.2011.5963892.
16. J. Meech and J. Parreira, "An interactive simulation model of human drivers to study autonomous haulage trucks," Procedia Computer Science, vol. 6, pp. 118-123, 2011.
17. K. J. Korane, "Drones come down to Earth: driverless trucks foretell the future of mining," Machine Design, vol. 85, (3), pp. 58, 2013.
18. S. Murden, "Autonomous vehicles lead Rio Tinto and BHP Billiton into cruise control," Australian Mining, 2015.
19. Anonymous "Plugging-in for Productivity," Engineering and Mining Journal (1926), vol. 217, (8), pp. 52, 2016.
20. W. Shiers and C. Barnett, "Automatic for the people: driverless trucks is a hot topic among manufacturers at the moment, and while some believe it won't be long before drivers are replaced, others are more conservative," Commercial Motor, pp. 38, 2016.
21. X. Cheng, "Application of SINS/DGPS integrated navigation technology in unmanned mining vehicles," IOP Conference Series. Materials Science and Engineering, vol. 569, (4), pp. 42001, 2019.
22. B. Doran and M. Lopez, "AUTONOMOUS VEHICLES AND MSHA," Pit & Quarry, vol. 111, (10), pp. 72, 2019.
23. L. Dong et al, "Velocity-Free Localization of Autonomous Driverless Vehicles in Underground Intelligent Mines," IEEE Transactions on Vehicular Technology, vol. 69, (9), pp. 9292-9303, 2020.
24. S. Chen, J. Yao and Y. Wu, "Analysis of the Power Consumption for Wireless Sensor Network Node Based on Zigbee," Procedia Engineering, vol. 29, pp. 1994-1998, 2012.
25. M. Uradzinski et al, "Advanced Indoor Positioning Using Zigbee Wireless Technology," Wireless Personal Communications, vol. 97, (4), pp. 6509-6518, 2017.
26. M. A. Moridi et al, "An investigation of underground monitoring and communication system based on radio waves attenuation using ZigBee," Tunnelling and Underground Space Technology, vol. 43, pp. 362-369, 2014.
27. M. A. Moridi et al, "Development of wireless sensor networks for underground communication and monitoring systems (the cases of underground mine environments)," Tunnelling and Underground Space Technology, vol. 73, pp. 127-138, 2018.
28. Moridi Mohammad Ali Kawamura Youhei Sharifzadeh Mostafa Chanda Emmanuel Knox Wagner Markus Jang Hyongdoo Okawa Hirokazu, "Development of underground mine monitoring and communication system integrated ZigBee and GIS," International Journal of Mining Science and Technology, vol. 25, (5), pp. 811-818, 2015.
29. Anonymous "Helicomm and Venture Design Services Announced Text Messaging Mobile Communicator," Business Wire, 2007.
30. Y. Li-min et al, "Design of monitoring system for coal mine safety based on wireless sensor network," in 2008, . DOI: 10.1109/MESA.2008.4735664.
31. H. Hongjiang and W. Shuangyou, "The application of ARM and ZigBee technology wireless networks in monitoring mine safety system," in 2008, . DOI: 10.1109/CCCM.2008.266.
32. Z. Pei et al, "Anchor-free localization method for mobile targets in coal mine wireless sensor networks," Sensors (Basel, Switzerland), vol. 9, (4), pp. 2836-2850, 2009.
33. A. Chehri et al, "Experimental testing of IEEE801.15.4/ZigBee sensor networks in confined area," in 2010, . DOI: 10.1109/CNSR.2010.62.
34. J. Bian, "Application of the wireless sensor network based on ZigBee technology in monitoring system for coal mine safety," in 2010, . DOI: 10.1109/CMCE.2010.5610009.
35. Q. Li, H. Zhao and P. Liu, "Research on robot network communication system in underground coal mine based on ZigBee," in 2010, . DOI: 10.1109/ISIP.2010.131.
36. Z. Cao, H. Lu and Q. He, "Research of underground staff positioning system based on wireless sensor network," in 2011, . DOI: 10.1109/CSSS.2011.5972081.
37. W. Jiang and F. Yang, "Positioning Algorithm of Underground Personnel Based on ZigBee Technology," Applied Mechanics and Materials, vol. 532, pp. 121-125, 2014.
38. Q. Q. Zhang, Y. F. Sun and D. H. Wang, "Design of Wireless Voice Communication System in Underground Coal Mine Based on ZigBee," Applied Mechanics and Materials, vol. 548-549, pp. 1402-1406, 2014.

39. Q. Liu, X. Han and Y. Q. Chu, "Research on MCL for Mobile Underground Miner Location System Based on ZigBee," Applied Mechanics and Materials, vol. 713-715, pp. 2325-2328, 2015.
40. B. Ge et al, "Improved RSSI Positioning Algorithm for Coal Mine Underground Locomotive," Journal of Electrical and Computer Engineering, vol. 2015, pp. 1-8, 2015.
41. A. Abane et al, "NDN-over-ZigBee: A ZigBee support for Named Data Networking," Future Generation Computer Systems, vol. 93, pp. 792-798, 2019.
42. Z. Chi et al, "Simultaneous Bi-Directional Communications and Data Forwarding Using a Single ZigBee Data Stream," IEEE/ACM Transactions on Networking, pp. 1-13, 2021.
43. F. Shariff, N. A. Rahim and W. P. Hew, "Zigbee-based data acquisition system for online monitoring of grid-connected photovoltaic system," Expert Systems with Applications, vol. 42, (3), pp. 1730-1742, 2015.
44. N. BIN et al, "CBTC (communication based train control) : System and development," in 2006, . DOI: 10.2495/CR060411.
45. H. Wang et al, "Finite-state markov modeling of tunnel channels in communication-based train control (CBTC) systems," in 2013, . DOI: 10.1109/ICC.2013.6655381.
46. H. Wang et al, "Finite-State Markov Modeling for Wireless Channels in Tunnel Communication-Based Train Control Systems," IEEE Transactions on Intelligent Transportation Systems, vol. 15, (3), pp. 1083-1090, 2014.
47. D. Briginshaw, "Can CBTC cope with complex rail networks?" International Railway Journal, vol. 54, (2), pp. 2, 2014.
48. L. Zhu et al, "Cross-Layer Defense Methods for Jamming-Resistant CBTC Systems," IEEE Transactions on Intelligent Transportation Systems, pp. 1-13, 2020.
49. H. Wang et al, "Finite-State Markov Modeling of Leaky Waveguide Channels in Communication-Based Train Control (CBTC) Systems," IEEE Communications Letters, vol. 17, (7), pp. 1408-1411, 2013.
50. X. Jia et al, "Zigbee-based wireless gas monitoring sensor alarm system in coal mine," IOP Conference Series. Earth and Environmental Science, vol. 446, (2), pp. 22012, 2020.
51. K. Dorthi, N. Bayyapu and R. C. Karra, "Zigbee based Wireless Data Acquisition System for monitoring of partition stability above old underground coal workings," Arabian Journal of Geosciences, vol. 13, (8), 2020.
52. Y. Yang et al, "Research on Optimization Measures of Zigbee Network Connection in an Imitated Mine Fading Channel," Electronics (Basel), vol. 10, (171), pp. 171, 2021.
53. M. Celaya-Echarri et al, "Radio Wave Propagation and WSN Deployment in Complex Utility Tunnel Environments," Sensors (Basel, Switzerland), vol. 20, (23), pp. 6710, 2020.
54. J. Blanco, A. García and J. d. L. Morenas, "Design and Implementation of a Wireless Sensor and Actuator Network to Support the Intelligent Control of Efficient Energy Usage," Sensors (Basel, Switzerland), vol. 18, (6), pp. 1892, 2018.
55. P. Fraga-Lamas et al, "Towards the Internet of Smart Trains: A Review on Industrial IoT-Connected Railways," Sensors (Basel, Switzerland), vol. 17, (6), pp. 1457, 2017.
56. X. Zhang, "Advanced Parabolic Equation-Based Propagation Modeling for Train Communication Systems." , ProQuest Dissertations Publishing, 2018.
57. A. K. Dash et al, "Study and Analysis of Accidents Due to Wheeled Trackless Transportation Machinery in Indian Coal Mines – Identification of Gap in Current Investigation System," Procedia Earth and Planetary Science, vol. 11, pp. 539-547, 2015.
58. P. Gao et al, "A dynamic fault tree based CBTC onboard ATP system safety analysis method," in 2020, . DOI: 10.1109/ITSC45102.2020.9294605.
59. S. Terblanche and A. Bley, "An improved formulation of the underground mine scheduling optimisation problem when considering selective mining," Orion (Johannesburg, South Africa), vol. 31, (1), pp. 1, 2015.
60. M. Åstrand et al, "Underground mine scheduling modelled as a flow shop: a review of relevant work and future challenges," Journal of the Southern African Institute of Mining and Metallurgy, vol. 118, (12), pp. 1265, 2018.
61. M. Gamache, R. Grimard and P. Cohen, "A shortest-path algorithm for solving the fleet management problem in underground mines," European Journal of Operational Research, vol. 166, (2), pp. 497-506, 2005.
62. D. O'Sullivan and A. Newman, "Optimization-based heuristics for underground mine scheduling," European Journal of Operational Research, vol. 241, (1), pp. 248-259, 2015.
63. F. Manríquez, J. Pérez and N. Morales, "A simulation–optimization framework for short-term underground mine production scheduling," Optimization and Engineering, vol. 21, (3), pp. 939-971, 2020.
64. A. G. Yardimci and C. Karpuz, "Shortest path optimization of haul road design in underground mines using an evolutionary algorithm," Applied Soft Computing, vol. 83, pp. 105668, 2019.
65. P. Nesbitt et al, "Underground mine scheduling under uncertainty," European Journal of Operational Research, 2021.
66. K. Fathollahzadeh et al, "Review of Solution Methodologies for Open Pit Mine Production Scheduling Problem," International Journal of Mining, Reclamation and Environment, pp. 1-36, 2021.
67. F. Sotoudeh et al, "Integrated underground mining and pre-concentration systems; a critical review of technical concepts and developments," International Journal of Mining, Reclamation and Environment, vol. 35, (3), pp. 153-182, 2021.
68. Anonymous "DRIVING ON THE CUTTING EDGE OF AUTONOMOUS VEHICLE TECH," States News Service, 2021.
69. Anonymous "Agree on rulebook for testing, developing autonomous vehicles," Automotive News, vol. 95, (6967), pp. 10, 2021.
70. Q. Chen et al, "Sensing system of environmental perception technologies for driverless vehicle: A review of state of the art and challenges," Sensors and Actuators. A. Physical., vol. 319, pp. 112566, 2021.

71. X. Liu, Y. Yan and H. Gan, "Research on pedestrian detection algorithm in driverless urban traffic environment," MATEC Web of Conferences, vol. 336, pp. 6002, 2021.
72. J. P. Powell et al, "Potential Benefits and Obstacles of Implementing Driverless Train Operation on the Tyne and Wear Metro: A Simulation Exercise," Urban Rail Transit, vol. 2, (3), pp. 114-127, 2016.
73. J. Daly, "Mining minus the miners; Forget cars--the driverless-vehicle revolution is happening deep underground.(Brief article)," Globe and Mail, pp. P14, 2017.
74. B. FITZGERALD, "Driverless trucks head deep underground," The Australian (Canberra, A.C.T.), pp. 19, 2015.
75. J. Guo, J. Du and D. Xu, "Navigation and positioning system applied in underground driverless vehicle based on IMU," in 2018, . DOI: 10.1109/ICRIS.2018.00012.
76. M. Bascompta et al, "A GIS-based approach: Influence of the ventilation layout to the environmental conditions in an underground mine," Journal of Environmental Management, vol. 182, pp. 525-530, 2016.
77. H. Liu et al, "A Tightly Coupled GIS and Spatiotemporal Modeling for Methane Emission Simulation in the Underground Coal Mine System," Applied Sciences, vol. 9, (9), pp. 1931, 2019.
78. K. Zhou et al, "Local Path Planning of Driverless Car Navigation Based on Jump Point Search Method Under Urban Environment," Future Internet, vol. 9, (3), pp. 51, 2017.
79. L. Yu et al, "A Path Planning and Navigation Control System Design for Driverless Electric Bus," IEEE Access, vol. 6, pp. 53960-53975, 2018.
80. C. Bantin and J. Siu, "Radio CBTC For The Las Vegas Monorail," WIT Transactions on the Built Environment, vol. 77, 2005.
81. Anonymous "Autonomous Volvo truck testing in regular operations underground," Just-Auto.Com, 2016.
82. S. S. Stevenson, "WaveSense Uses Ground-Penetrating Radar to Help Driverless Cars See," Xconomy [BLOG], 2018.
83. Anonymous "Robotics researchers track autonomous underground mining vehicles," NewsRx Health & Science, pp. 244, 2017.
84. C. Legacy et al, "Planning the driverless city," Transport Reviews, vol. 39, (1), pp. 84-102, 2019.
85. A. Levy, "Go green, go driverless," Nature (London), 2015.
86. Anonymous "DRIVERLESS," States News Service, 2019.
87. Anonymous "Driverless car coming," Engineering Review, vol. 39, (18), pp. 18, 2014.
88. Anonymous "Driverless CARRIAGES," Engineering Designer, vol. 46, (6), pp. 20, 2020.
89. P. McGee, "Driverless car groups look past the engineering challenge," FT.Com, 2019.
90. A. Salonen and N. Haavisto, "Towards Autonomous Transportation. Passengers' Experiences, Perceptions and Feelings in a Driverless Shuttle Bus in Finland," Sustainability (Basel, Switzerland), vol. 11, (3), pp. 588, 2019.
91. Anonymous "Could driverless cars improve life for people with disabilities? -BYLN- Ashley Halsey III The Washington Post," Daily Herald (Arlington Heights, Ill. : Arlington Heights Ed.), pp. 0, 2017.
92. D. Allan, "Driverless cars," Herald (Glasgow, Scotland), 2020.
93. M. Blau, G. Akar and J. Nasar, "Driverless vehicles' potential influence on bicyclist facility preferences," International Journal of Sustainable Transportation, vol. 12, (9), pp. 665-674, 2018.
94. D. Bissell et al, "Autonomous automobilities: The social impacts of driverless vehicles," Current Sociology, vol. 68, (1), pp. 116-134, 2020.
95. E. R. Sanguinetti, "Planning for the Driverless Future: As roads dominated by driverless cars become an increasing reality, plaintiff auto attorneys should prepare now for likely changes to their practices and their clients' needs," Trial, vol. 54, (9), pp. 50, 2018.
96. E. L. Talley, "Is the Future of Law a Driverless Car?: Assessing How the Data-Analytics Revolution will Transform Legal Practice," Journal of Institutional and Theoretical Economics, vol. 174, (1), pp. 183-205, 2018.
97. L. Forlano, "Stabilizing/Destabilizing the Driverless City: Speculative Futures and Autonomous Vehicles," International Journal of Communication (Online), pp. 2811, 2019.