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Concept Paper

Engineering Project: The Method 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 WSN technology can play a greater role in the narrow environment like underground mines according to the relevant literature, this concept paper just like a engineering project plan mainly tries to integrate the ZigBee WSN technology 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 for the engineering projects. As the mining engineers, we put forward the concept of this integrated system in this concept paper, but we need to continue to work hard for the future of the underground mines. This concept paper serves just as a guide to the *Tossing out a brick to get a jade gem*, has a few implications for the development of underground mine transportation.

Keywords: Driverless Transport Vehicle; ZigBee WSN technology; Communication-based train control (CBTC) system; Underground transportation; Mining Engineering; Concept.

1. Introduction and Background

1.1 Retrospective: The development of Driver-less Technology

With the continuous development of the science and technology, researchers 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, researchers 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.

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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 researchers 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 researcher[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, 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.

1.2 Retrospective: Driver-less Technology in the industrial transportation

Since the late 20th century, driver-less technology has been increasingly used in industrial transport.

However, as early as in 1998, E. Bordelon Hoff and B. R. Sarker[98][99] designed and applied automatic guidance vehicles (AGV) to industrial transportation based on driver-less technology, in 2001, applying driver-less technology to industrial transport, C. M. Barshick and M. M. Helms[100] described the process by which Alcoa USA implemented and used automatic guidance vehicles (AGV) to improve its production process. In 2011, D. Bellamy and L. Pravica[101] assessed the significance of introducing driver-less technology into the industrial transportation of an Australian open pit, and in 2014, R. Bartley[14] had also proposed the use of driver-less technology in the trucking industry.

After 2015, driver-less technology has begun to develop rapidly, especially in industrial transport. In 2016, F. Ohashi et al[102] solved the problem of using a group of small mobile robots based on the driver-less technology to transport large weights, and the robots they developed could use wheelbarrows for transport operations, which are ideal for use in industrial plants and other places. In fact, T. Sakuyama et al[103] proposed the robotic transportation based on driver-less technology in 2014, so that later researchers continued to optimize it. In addition to the robots, the advent of driver-less forklifts has also contributed to transport efficiency in factories and warehouses, in 2019, E. Brown[104] introduced the principles of driver-less forklifts used in industrial transport in recent years.

Besides, from 2015 to now, there is also an increasing number of ideas and practices on driver-less technology that are realized in industrial transportation. It is reported[105] that in 2017, driver-less trucks were being used to transport parts and components between factories, and in 2018, A. Hjalmarsson-Jordanius et al[106] developed and applied the driver-less technology for logistics transportation.

1.3 Retrospective: Driver-less Technology in the underground transportation

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 researchers 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. 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

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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 researcher[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 researchers 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 researchers on the research of mining engineering must make unremitting efforts.

2. Idea and Design

The purpose of this concept paper just like a engineering project plan is to conceptualize an integrated system for the monitoring and control of driver-less vehicles for the practical problems in underground mines:

In 2015, A. K. Dash et al[57] raised the opinion that there were two practical engineering problems in the engineering projects 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.*

Figure 1. The electric vehicle in the underground mine.

Therefore, the integrated system are required to be designed with the monitoring and control functions, also, for the developing countries like China, the cost of the integrated system is important as well.

2.1 The Comparison of ZigBee WSN technology and other technologies

5G technology is the first technology that we thought of for the monitoring and control of underground mining vehicles, and in fact, 5G technology has been used by researchers and companies in communications for underground mines. In 2019, M. Ghaddar et al[107] have used 5G technology to do some communication simulation tests in underground mines, and in 2020, Chinese researcher L. Ma[108] summarized the construction significance of intelligent mine construction and intelligent mine structure, and introduced in detail the application of 5G wireless communication system in intelligent mines, from then on, more and more Chinese researcher began to study the application of 5G technology in underground mines. It can be said that 5G technology is the most sophisticated communication technology currently, however, at this stage, the 5G technology is obviously not perfect, for example,

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its functional area coverage is small and the cost is high. For developing countries like China, 5G technology has not been widely applied on the ground communication, it is even less likely be widely used underground at this stage. So we do not consider using 5G technology in the monitoring and control of the underground mines because of the limitations mentioned above. The same, although Radar Sensor[111][112] has also been successfully used in the safety monitoring and location in the underground mines in recent years, its limitations are as the same as 5G technology, that is, High-cost and Non-universal.

Wi-Fi Communication System has also always been used in underground mines, H. Ikeda et al[109] tested and verified the application of Wi-Fi Communication System in underground mine environment in 2019, and recently, C. Min and Z. Jinhao[110] announced their progress in applying the Wi-Fi 6 technology to underground mines and achieved good results. As a flexible and convenient wireless communication technology, Wi-Fi technology is worth being widely used in mines, but the same time, the consumption and operating costs of Wi-Fi technology in underground operation are also unaffordable for the small and medium-sized mines, especially in the developing countries like China.

Generally speaking, ZigBee WSN technology is functionally similar to Wi-Fi technology and the energy consumption and operating costs of ZigBee WSN technology are lower. Meanwhile, in the research of M. A. Moridi et al[26][27], ZigBee WSN technology is often considered an economical, efficient and applicable option compared to other WSN in underground mines. And ZigBee WSN technology, they argued, could improve the workplace health and safety for workers, cost-effectiveness, management of technical issues, energy conservation, and real-time response to events. Therefore, ZigBee WSN technology is more suitable for the underground mines in the monitoring and control.

ZigBee technology was born around 2007, *Business Wire*[29] reported the birth of ZigBee technology.

The ZigBee WSN technology based on IEEE 802.15.4 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 WSN technology 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] theoretically analyzed the power consumption of ZigBee MAC using different modulations, and they proposed that low power consumption is the biggest feature of ZigBee WSN technology, and they believed that optimizing ZigBee WSN technology will bring benefits to all walks of life. In 2017, M. Uradzinski et al[25] found the positioning function of ZigBee WSN technology excellent, as a result, some researchers believed that ZigBee technology 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 WSN technology and other underground communication networks, and concluded that ZigBee WSN technology 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 WSN technology 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 WSN technology emerged, Y. Li-min et al[30] applied ZigBee technology to underground mine safety monitoring systems, they used the ZigBee WSN technology to collect temperatures, humidity and methane from underground coal mines, then ZigBee WSN technology 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 WSN technology. And in the year 2009, Z. Pei et al[32] put forward the superiority of ZigBee WSN technology in underground mines because of the narrow environment of the underground mines, narrow space could enhance the signal intensity of ZigBee WSN technology.

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

ZigBee WSN technology 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 WSN technology, 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 WSN technology to vehicle positioning in underground mines.

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

2.2 The Comparison of Communication-based Train Control(CBTC) system and other technologies

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.

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 WSN technology, 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.

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 researchers 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. Although the running environment of underground mine transportation is similar to that of subway, the running of subway is mainly for the service of passengers like Urban Rail Transit. Therefore, as the CBTC system can be used in the running of underground subway to some extent, with the precedent, it is believed that CBTC system is possible to be used in the underground mines.

Besides, J. Guo, J. Du and D. Xu[75] solved the problem of underground coal mine vehicle positioning based on IMU inertial navigation system, and they combined NAV2 inertial navigation unit and PNP photoelectric speed sensing to realize real-time interaction with upper monitor through wireless network. According to their report on the *2018 International Conference on Robots & Intelligent System (ICRIS)*, it seemed that IMU inertial navigation system performed well in locating vehicles in underground coal mines, especially in terms of positioning accuracy. And for other technologies used in the control and monitoring of the vehicle, K. Czaplewski et al[113] established the tracking equations for the monitoring and control of the railway transportation through Global Navigation Satellite System (GNSS) and Geodetic Networks (GN) in 2020, and J. Chen et al[114] established the tracking equations by 5G technology. For these technologies, although their emergence shows the progress of modern science and technology and promotes the development of vehicle monitoring system, it is obviously difficult to absolutely realize these technologies in practical engineering. Compared with these systems, the CBTC system is obviously a more developed technology at this stage, and the vehicle monitoring of the CBTC system in a fixed lane such as an underground mine environment is more convenient and low consumption than other systems with wireless transmission, but whatever control and monitoring systems will emerge in the future, as long as these systems can be applied to specific practical problems and engineering projects to achieve good results, the efforts of researchers around the world who are on the research of the innovative system will not be in vain.

2.3 Idea: System Integration

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 WSN, therefore, this concept paper mainly tries to integrate the ZigBee WSN 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.

As is known, ZigBee WSN 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 WSN are widely used in the environment monitoring of the underground mines. In 2020, X. Jia et al[50] put forward that ZigBee WSN 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 WSN. And in 2021, Y. Yang et al[52] improved the communication function of ZigBee WSN 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 WSN 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 and the underground environment, it is a good choice to combine ZigBee WSN with the 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 the monitoring and control function for driver-less electric transport vehicles, the integrated system is composed of three parts:

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

The ATO system collects the speed and distance information of each driver-less electric transport vehicle, ZigBee WSN collect the initial location information of each driver-less electric transport vehicle and the temperature, humidity, concentration of harmful gases in the underground environment, these information about underground environment can also serve as a reminder and reference for the whole project. When all the information is collected, it is transmitted to both the ATP and the ATS system by the ATO system and the ZigBee WSN. 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. And when he initial location information of each driver-less electric transport vehicle arrives at the ATS system, the ATS system will continue to track the location of the vehicle through known information and feed back to the screen.

As mentioned above, for the ZigBee WSN, we considered trying to locate the initial position of each static vehicle and monitor the temperature, humidity, concentration of harmful gases in the underground environment by the function of the ZigBee WSN. In our previous study, we tried to use sensors to identify and locate the initial position of the vehicle, but the effect was not good, so we planed to use ZigBee WSN to improve the positioning and testing of the initial position of the vehicles in the underground mines, and the location tracking of the running vehicles depends on the ATP system and ATS system in the CBTC system, we even established the tracking equations for the ATS system in our previous research, and here we briefly introduce the tracking equations we have established:

In(1)and(2), m represents the line mileage of the transport vehicle, S_b represents the blocked area, Y_β represents the mileage from m to the axle counting area end, L_u represents the length of the transport vehicle, L_{u-a} represents the transport vehicle position's uncertainty amount, and V_{max} represents the transport vehicle's maximum allowable operating speed.

$$T_{hesway\ of\ mine(m)} = \frac{S_b+L_u+L_{u-a}}{V_{max}} \quad (1)$$

$$S_b = Y_\beta - m \quad (2)$$

Equations. Tracking equations.

Therefore, the concept design of the integrated system is as explain below:

- The ATO system of the CBTC system collects the speed and distance information and sends to the ATP system.
- The ATP system of the CBTC system controls each vehicle in the underground mine according to the information provided by the ATO system.
- The ZigBee WSN collects the initial position of each static vehicle and monitor the temperature, humidity, concentration of harmful gases in the underground environment.
- The information of the speed, distance, temperature, humidity and concentration of harmful gases will be fed back to the screen of the ATS system, and the running process of the vehicles will be also fed back to the screen.

It is worth mentioning, in our concept design, the aim of collecting the initial position of each static vehicle is to ease the burden of the ATS system in vehicle monitoring and tracking, and the main control system of the integrated system is the ATP system.

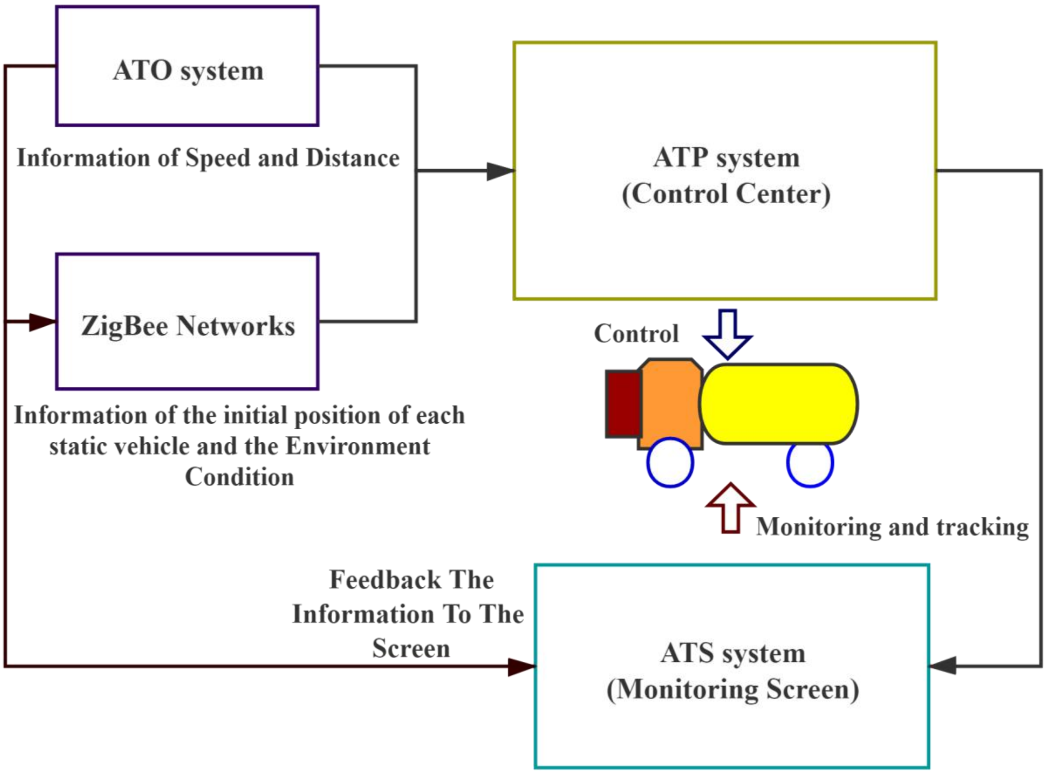

Figure 2. Concept Design of the integrated system.

3. Concept: The methods to solve the practical problems in the mining engineering projects

3.1 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 WSN 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 WSN, 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 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.* **2.** *If the rollover accidents appear, the control function of the ATP system will halt the nearby vehicles in the underground mine.* **3.** *If the emergency appears, the control function of the ATP system will halt all the vehicles in the underground mine.* **4.** *The information of the initial location and the environment condition collected by the ZigBee WSN plays an important role in the tracking&monitoring of the underground vehicles and the rescue of personnel in the rollover accidents or the emergence.* **5.** *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 WSN and the ATP system to solve the safety problems is shown in **Figure 3.**

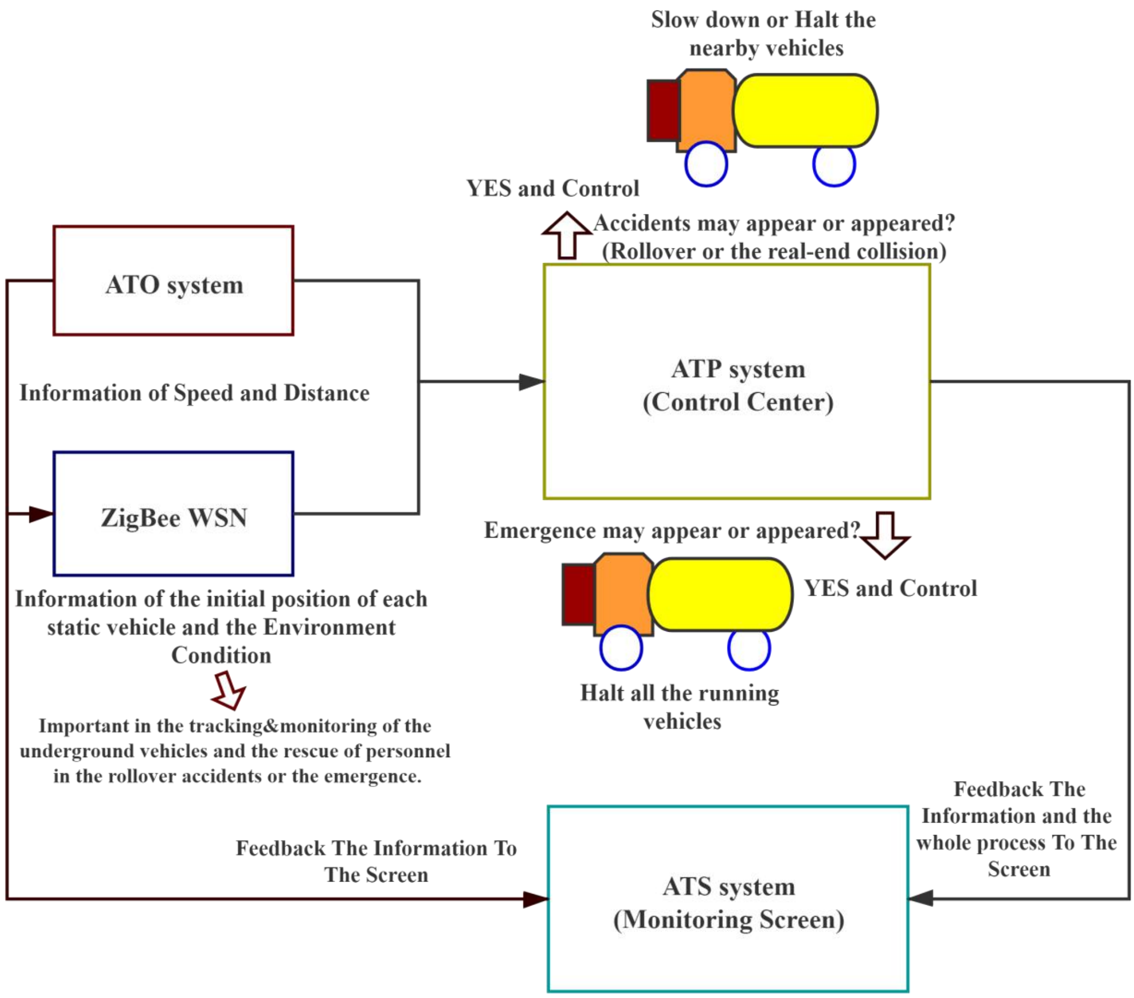

Figure 3. The process logic diagram of the solution to the Safety problems.

3.2 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 researchers 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, researchers[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 WSN, once there is a Stope that needs transport operations, the process begins running: **1.** *The ATS system and AI Computing analyze the congestion of each transportation route.* **2.** *When ATP system gets the feedback from the AI Computing, it will automatically choose the best route for the vehicles to the Stope to participate in the transport operations or the unloading places to participate in the unload operations.* **3.** *The information of the initial location and the environment condition collected by the ZigBee WSN plays an important role in the tracking&monitoring of the underground vehicles and the rescue of personnel in the rollover accidents or the emergence.* **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 researchers[59-67], the process logic diagram of the ATO system, ZigBee WSN and the ATP system to solve the safety problems is shown in **Figure 4.**

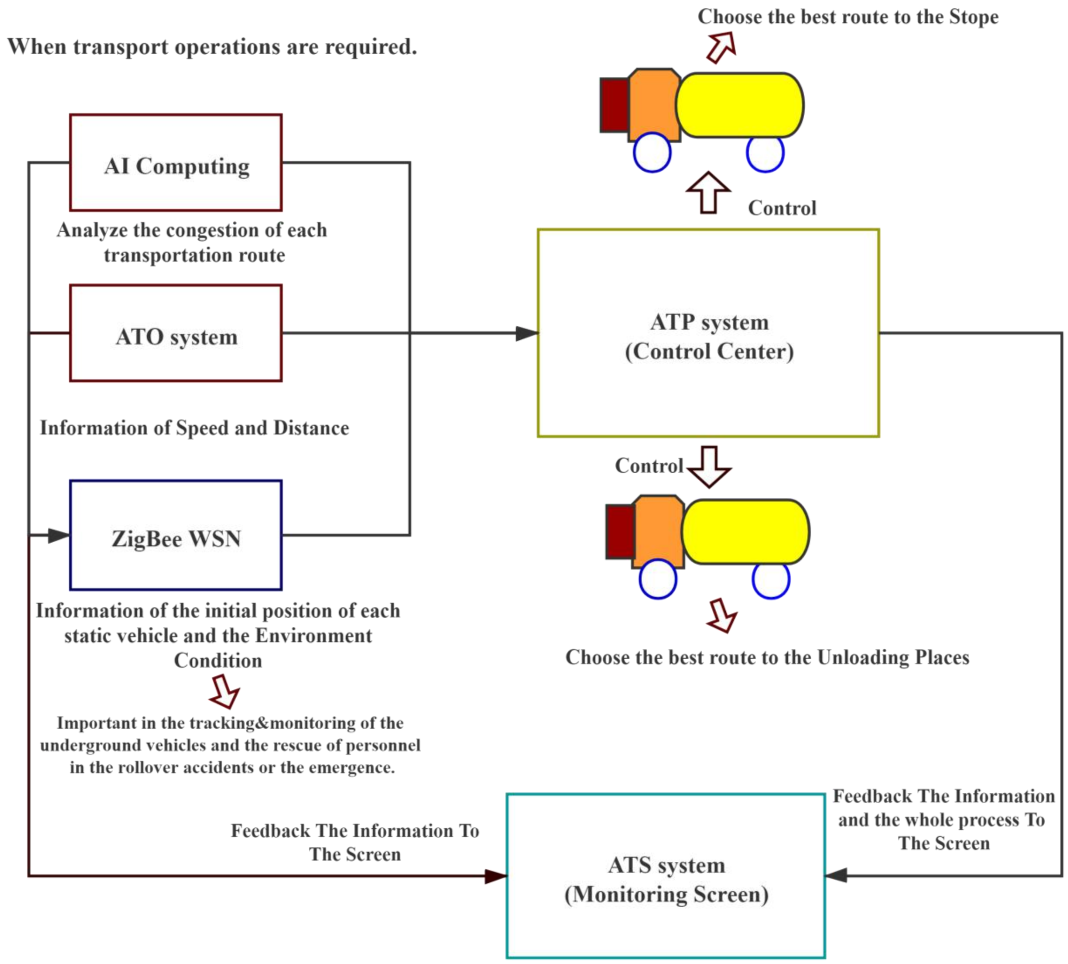

Figure 4. The process logic diagram of the solution to the Scheduling problems.

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4. The work for the next step

Although the concept paper does a great deal of work in the design of the integrated system which aims to solve the practical problems in the engineering projects, there are still a lot of weak points: **1.** Because we are the engineers doing the engineering projects, focusing on the application of advanced technology in engineering. In this design, we only proposed the concept of the integrated system, the topology of the system and the behavior of each node are ignored. **2.** The principle of how ZigBee WSN or AI computing can help solve practical problems is not thoroughly explained in the article. **3.** The design of the concept has not been validated in practice.

In fact, to solve the above weak points is the first problem we need to solve in our next research: **1.** We will continue the research with the experts who specialize monitoring and control systems to propose the topologies for the integrated system, and to confirm the behavior of each node, that is, what information each node should collect and where to transmit it. If we want to apply ZigBee WSN to underground mines, this problem is the first and the must to be solved. **2.** There is no doubt that the emergence of AI has benefited all walks of life, but the application of AI technology in underground mines is not very mature and perfect, especially in China. Therefore, in this respect, we need to conduct further research and exploration with relevant experts, it is a challenge for us.

Generally speaking, our aim is to solve problem **1** first, and then we urgently need to test the effect of the locate function of ZigBee WSN in the underground mine. Although a few literature[37][38][39][40] showed that the ZigBee WSN can be used for underground location, some of them are completely theoretical research, which does not show that ZigBee WSN can have a good application in the underground mines. Therefore, we need do the practical test for the locate function of ZigBee WSN in the underground mine. Our plan is to test the locate function of ZigBee WSN in the ring-shaped transport roadway in the southern section of Tianxing Iron Mine, which is a 10-million-ton level mine in China. The abridged general view of the ring-shaped transport roadway of the southern section of Tianxing Iron Mine is shown below.

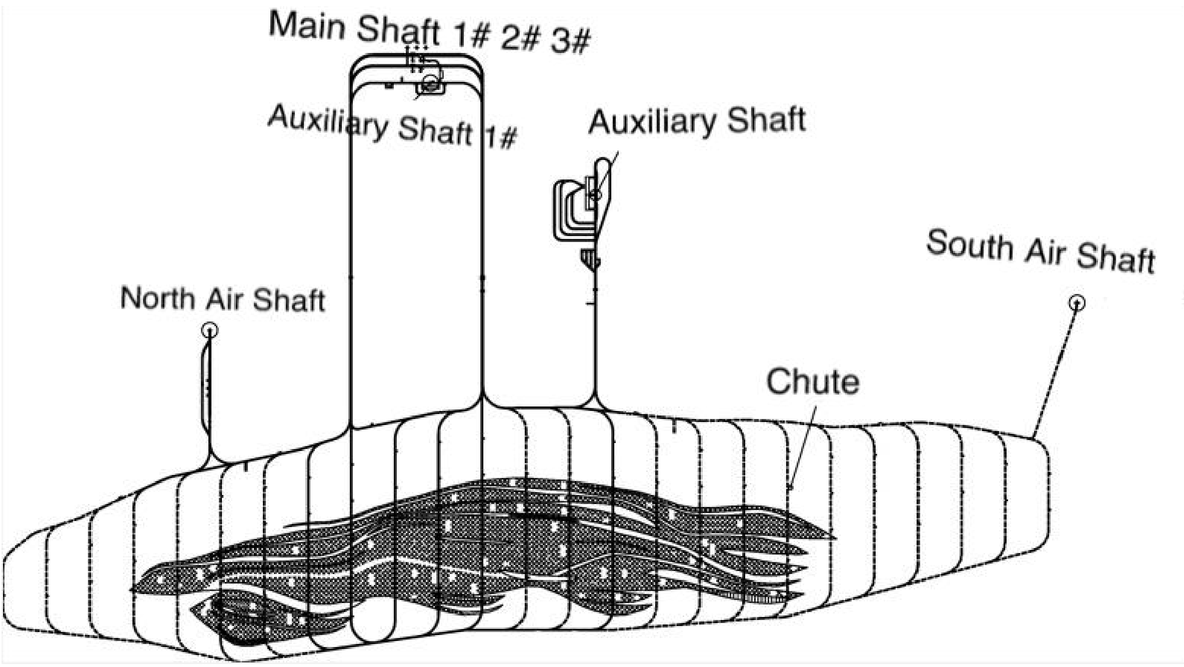

Figure 5. The abridged general view of the ring-shaped transport roadway.

If, with the efforts of experts and ours, we carry out a certain degree of the development in the ZigBee WSN and apply it to the location of the underground mines, then we will certainly carry out experimental verification on it at the first time. We believe that whether the results are good or bad, can bring some enlightenment to the relevant research.

5. 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 researchers[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 WSN applications in underground mines, which showed that ZigBee WSN could play a greater role in narrow environments like underground mines. ZigBee WSN, as the medium of information transmission, generally work with GIS(Geographic Information System) to monitor the underground environment condition[26][27]. GIS system is widely used in underground mines, especially monitoring and alarm, many researchers[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 researchers 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 researchers 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. 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 systems or tools will appear, as long as it can be applied to driver-less technology and can solve problems in real life or engineering, researchers 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 researchers as a challenge, it will become an opportunity. If this opportunity can be seized by people, then it will benefit mankind.

6. Summary

Overall, the type of this paper is a concept paper just like a engineering project plan, this paper discusses the possibility of applying CBTC system and ZigBee WSN 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 and Background part, the concept paper 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 concept paper introduces the background that driver-less technology is moving towards underground mines, thus, the concept paper further explores the advantages of ZigBee WSN and the CBTC system in underground mine for monitoring and controlling. Specifically, at the end of this part, the concept paper leads to its purpose, that is, to summarize the methods based on the CBTC system and ZigBee WSN to solve the practical problems of underground driver-less electric transport vehicle monitoring and control.

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In the Idea and Design part, this concept paper briefly summarizes the development process of ZigBee WSN 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 concept paper combines the functions of ZigBee WSN and CBTC systems into the integrated system.

In the part of Concept, this concept paper 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 researchers[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 work for the next step part, We summarize some shortcomings in the design of the integrated system, and put forward some future research programs to improve. For this part, we confirm the goal of our next step, that is, to perfect the ZigBee WSN and verifying it in practice.

In the Discussion and Outlook part, the concept paper puts forward the view that the emergence of driver-less technology is both an opportunity and a challenge, if researchers 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.

7. Literature recommendations for the readers

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

- On people's expectations about the driver-less technology, the concept paper recommends the relevant literature[84-86]:

Firstly, C. Legacy et al[84] believed that audio and video(AV) technology has the potential to change the urban landscape and existing transportation systems and networks, so in the literature, they revealed conceptual gaps, prospects and limitations, and their ideas in the framework of audio and video(AV) technology. While the video[85] in 2015 demonstrated the role of driver-less technology in energy consumption and environmental protection, and proposed a vision for future driver-less technology.

- On application of the driver-less Technology in Engineering, the concept paper recommends the relevant literature[87-89]:

In the year 2019, Robots[89] based on driver-less technology overcame the engineering challenges of safety and the news report "DRIVERLESS"[86] also played a important role to describe the development of driver-less technology, as well as the news report "Driverless car coming"[87] and "Driverless CARRIAGES"[88] to describe the applications of driver-less technology in the engineering.

- On the meaning of the driver-less technology to people's daily life, the concept paper recommends the relevant literature[90-94]:

In 2019, A. Salonen and N. Haavisto[90] summed up the feelings of passengers on the driver-less bus in Finland to describe the perception of taking a driver-less car. And as early as in 2017, some researchers[91] have carried out research on driver-less technology to improve the travel and life quality of people with disabilities, it is of great significance to the disabled.

In 2018, M. Blau, G. Akar and J. Nasar[93] started the research about the influence of the driver-less technology on the drivers in non-motorized lanes, especially the bike riders. It is an interesting work. And in 2020, D. Allan[92] reported the development of driver-less technology in the UK, and D. Bissell et al[94] explored the impact of driver-less technology on society.

- On the future of the driver-less technology from other perspectives, the concept paper recommends the relevant literature[95-97]:

E. R. Sanguinetti[95] and E. L. Talley[96] considered the future of driver-less technology from a perspective of the Law, and L. Forlano[97] considered the future of driver-less technology from a perspective of the business and urbanization.

- On the recent technologies applied in the driver-less vehicles, the concept paper recommends the relevant literature[115-116]:

B. Wu et al[115] used Bayesian Network modelling for safety management of electric vehicles transported in RoPax ships, and this research is of great significance to driver-less technology. Meanwhile, on the 12th International Joint Conference on Computational Intelligence, Emanuele Ferrandino et al[116] proposed a combination of public-transport electric vehicles and smart grids, that is, Nanogrids.

Finally, the authors claim that the concept paper 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 researchers will be interested and engage in the research of this field.

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The authors declare no conflict of interest.

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