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Concept Paper

The Function Design for the communication-based train control(CBTC) system: How to solve the problems in the underground mine rail transportation?

Haoxuan Yu[1,2] Shuai Li[1,*]

[1] School of Resources and Safety Engineering, Central South University, Changsha, Hunan Province, China.
[2] Institute of Electrical and Electronics Engineers (IEEE), USA.
* Correspondence: shuaige@csu.edu.cn

Abstract: With the continuous development of the mining industry, the world's major mines have gradually entered the intelligent stage. In the intelligent underground mine, the operation road of the underground transportation equipment is very complicated, and the monitoring and control of the underground traffic has become a problem to be solved in the intelligent underground mine. Therefore, on the basis of solving the practical problems of underground mines, the concept paper discusses the possibility of the rail transit monitoring system being applied to underground mines through the summary and induction of the related literature and propose the design for the CBTC system to solve the problems in the underground mine rail transportation. As the mining engineers, we put forward the concept of this design for the CBTC system in this concept paper, but we need to continue to work hard for the future development of the underground mines. And the concept paper serves as a guide to the *Tossing out a brick to get a jade gem*, has implications for the development and the future of the underground mine transportation.

Keywords: Underground mines; Rail transportation; Underground transportation; Monitoring and control system; Mining industry.

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1. Introduction: The development of the mining industry and the CBTC system

With the rapid development of mining science and technology in the world, many underground mines are gradually stepping into the intelligent stage.

Although the intelligentization is the ultimate goal of mine development, underground mine faces many challenges in the process of developing towards the intelligentization, such as underground transportation. In the past 20 years, many scholars have devoted themselves to the research of intelligent underground mine, including the research of intelligent underground mine transportation[1].

In the year 2020, L. Dong et al[1] committed to the research of underground intelligent mine autonomous driverless vehicles, they have made a great breakthrough on the function of Velocity-Free Localization of the underground vehicles. The same year, W. Chen and X. Wang[2] published the research progress of safety monitoring in coal mine, Y. Meng and J. Li[3] achieved the application of Internet of things technology in the underground mine. And earlier before, in 1999, I. M. MacLeod and A. Stothert[4] proposed intelligent control of the underground mine refrigeration system. And in 2008, Z. Ming-gui and C. Si-jing[5] put forward the intelligent system in underground mine production. While in 2013, L. Zhen[6] made great achievements in the research of underground ventilation monitoring system in coal mine.

For underground mines, with the continuous development of mining industry, rail transport has gradually been replaced by trackless transport. But there is no doubt that the monitoring and control of trackless transportation in intelligent underground mines is not as convenient as that of rail transportation. Therefore, in recent years, some mining enterprises have started to try to run rail transportation in intelligent underground mines, and achieved good results, especially in China, which is behind in the development of mining industry. Although rail transportation of the intelligent underground mine is not as flexible as trackless transportation is, rail transportation has low operating costs and has been widely used in recent years.

For the above-ground Urban Rail Transit, the CBTC(Communication-based Train Control) system is a common signal control system in the Urban Rail Transit System[7]. Admittedly, CBTC system is not perfect either, but with the maturity and development of Internet of things technology, the combination of CBTC system and Internet of things technology makes the CBTC system develop, which has become an academic consensus[8].

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The history of the CBTC system is very long, but the CBTC system first used in practice have been improved based on IEEE standards[40][43]. In 2003, W. C. Vantuono[41] noted that the CBTC system was gradually beginning to be piloted worldwide. 2005, New York began planning to implement the CBTC system according to the report of R. P. Alexander and E. A. Mortlock[42]. Around 2010, even some Chinese scholars[44][45] have achieved quite good results in the research of the CBTC system.

By the 2010s, the CBTC system had developed rapidly. B. Bu et al[46] and L. Zhu et al[47] put forward some suggestions for optimizing some functions of the CBTC system around 2014. In 2016, H. Wang, F. R. Yu and H. Jiang[48] improved the functionality of the WLAN in the CBTC system. Around the year 2017, J. Farooq et al[7] evaluated the wireless communication network performance of the CBTC system and suggested that the system could be further optimized, J. Farooq and J. Soler[8] did a survey on the CBTC system, the survey showed that many scholars believe that the combination of CBTC system and Internet of things technology could make CBTC system develop. Specially, in the research of X. Wang et al[9][11] around 2019, they focused on the safety protection and communications of CBTC system, they improved the CBTC system's wireless communication system by the Q-learning method based on LTE-T2T and obtained excellent application results. And recently, J. Liu et al[10] focused on combining the CBTC system with artificial intelligence computing**(AI Computing)**.

It is known that CBTC systems are always used in the above-ground Urban Rail Transit rather than underground transportation. In 2015, H. Wang, N. Zhao and L. Chen[30] thought that CBTC system is suitable for the above-ground urban traffic monitoring, and they also believed that the operation of CBTC system in urban traffic is a process of trial and error-reduce, because the monitoring of above-ground traffic can reduce the error of the monitoring conveniently by artificial reconnaissance and surveillance.

Unlike the above-ground Urban Rail Transit, the monitoring of the underground rail transportation is not susceptible to the artificial reconnaissance and surveillance because of the intricacies of the underground rail traffic. As well, above-ground traffic control system is mainly to ensure the safety of the traffic and the train departure planning but it is different in the underground mine rail transportation. In general, above-ground traffic control system is mainly for the service of passengers, and the underground mine rail transportation is mainly for the transport efficiency. Therefore, if the CBTC system is to be applied to underground mines, it is necessary to make some functional changes to the CBTC system.

At present, the CBTC system is a relatively advanced control system for the above-ground vehicles, which is applied to urban rail transit lines in various countries even developing countries. Years ago, W. Sun et al[12], X. Si, W. Kuang and Q. Li[13] all paid attention to the running-cost of the CBTC system and explored the possibility of its application in cities of developing countries like China.

For the current CBTC system, the train control center that coordinates and manages all trains running on the line is at the top level of the CBTC system, including the ATS **(Automatic Train Supervision)** system. L. Zhu et al[14] 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 the Data Communication System is to transfer data between modules, including wired and wireless communication network equipment. In the early year 2018, T. Wen et al[15] had already made a great breakthrough on the Access Point Deployment Optimization in the CBTC Data Communication System, and they emphasized the importance of the Data Communication System as the signaling medium of the CBTC system. Additionally, individual vendors have Data Communication System independence as subsystems.

The Car(on-broad system) includes the ATP**(Automatic Train Protection)** system, the ATO**(Automatic Train Operation)** system, man machine interface and so on. And the internal system of the station includes zone controller system, data storage system, CI**(Computer Interlocking)** system and so on. The unified operation of these systems are able to realize the interlocking and calculation of the station and the train. Transponder and axle counting system of the on-broad system are installed beside the track(in the track-side) to realize the real-time monitoring and position calibration of the incoming and outgoing trains.

Through the Letter in 2013, H. Wang et al[16] raised the importance of the overall coordination of the CBTC system, only through the combined operation of these systems, the functions of train safety protection, automatic driving, driver's communication and interaction can be realized.

Figure 1 shows the CBTC system's structure.

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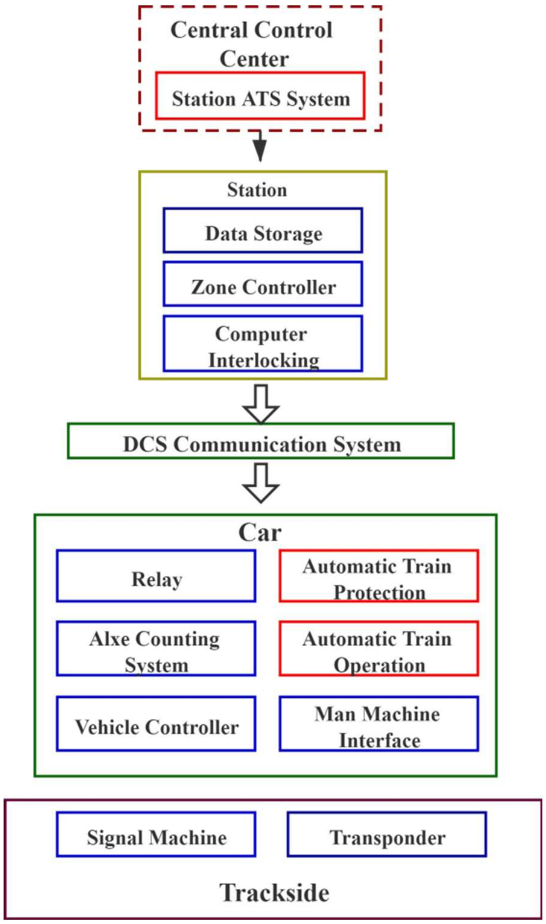

Figure 1. The structure of CBTC system.

The ATP system**(Automatic Train Protection)**, the ATO**(Automatic Train Operation)** system and the ATS**(Automatic Train Supervision)** systems are the Three most important subsystems to ensure the operation of the CBTC system. And in the Three Systems, the ATS system is the core of the CBTC system, it is a monitoring system based on a series of programs such as big data processing and computing, computer network sharing and real-time signal data conversion, it cooperates with the ATP system, the ATO system, the CI**(Computer Interlocking)** system and other systems to realize the real-time Monitoring, information collection, resource allocation and utilization of Urban Rail Transit System.

Figure 2 shows the structure of the ATS system, and **Figure 3** shows the specific functions of the ATS system.

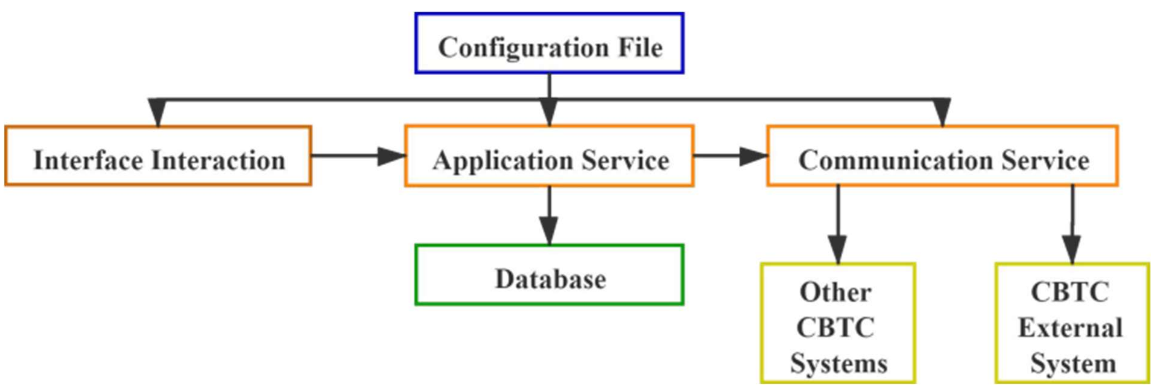

Figure 2. The structure of the ATS system.

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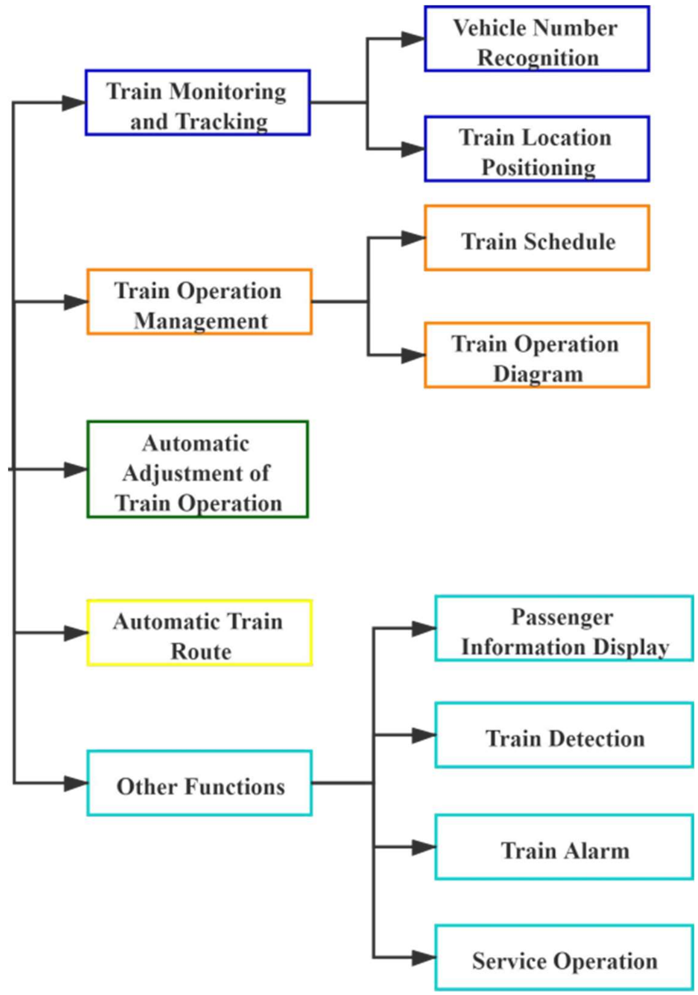

Figure 3. The functions of the ATS system.

Specially, the CBTC system not only has a excellent application effect on the ground, but also has an great application effect in the operation and monitoring of the subway[17]. As a kind of underground rail transport, subway is also not susceptible to the artificial reconnaissance and surveillance, so in 2016 through the improvements of the CBTC system, W. Carvajal-Carreño, A. P. Cucala and A. Fernández-Cardador[17] tried to applied the monitoring and tracking functions of the CBTC system to the subway transport and made good progress. In fact, as early as in 2006, N. BIN et al[34] put forward the concept of creating an underground city and suggested that the CBTC system should be the main traffic control and monitoring system under the ground. In 2013, H. Wang et al[35][38] published their research on the underground simulation of CBTC system on *2013 IEEE International Conference on Communications (ICC)*, and in 2014, D. Briginshaw[36] explored whether the CBTC system could be used in underground traffic in London. However, by 2015, underground traffic control and communications based on CBTC system seemed to have been achieved according to the research of A. Aziminejad, A. W. Lee and G. Epelbaum[37]. Through the news reports[39], by 2019, London had fully automated subway operations based on CBTC system.

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 intelligent underground mine after apposite improvements.

In a nutshell, this concept paper briefly introduces the progress in present stage of the research to apply CBTC system especially the Three Systems to the underground transportation in order to dedicate to solving the practical problems in the engineering of transportation in underground mines.

2. The Concept & Design: The function design of the CBTC system

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2.1 The background of the practical problems

In the majority underground mines of the world, the main transport equipment on the track is electric locomotive, which is call-replaced by **transport units** in the following text.

In 2015, A. K. Dash et al[31] raised the opinion that although rail transport is more convenient than trackless transport in the underground mines, there are still many problems to be solved, such as safety accidents and transport efficiency, the problems to be solved urgently in underground mines are mainly **Three**: **A. Safety Problem:** *The rear-end collision problem.* **B. Efficiency Problem:** *The transport efficiency problem.* **C. Monitoring and Control:** *The real-time monitoring problem.*

2.2 The function design of the CBTC system for the solutions to the practical problems

In order to dedicate to solving the practical problems of transportation in underground mines, the concept paper tries to summarize and propose the solutions to the above problems by applying and ameliorating the CBTC system especially the Three Systems(the ATO System, the ATP system and the ATS system) according to the related literature and the previous successful experiences.

The following is the function design of the CBTC system for the solutions to the practical problems:

A. Safety Problem: The rear-end collision problem

The ATP**(Automatic Train Protection)** system is the core system to control the speed of the transport units and the safe distance between the front and rear transport units. The ATP System controls and regulates the minimum interval and over-speed protection in the operation of the transport units to avoid the rear collision of the transport units. Its main components include range measurement equipment, vehicle speed monitoring equipment, vehicle-ground interaction equipment and emergency braking equipment. And it should be noted that in the rail transportation of intelligent underground mine, the maximum speed of the transport units should not exceed 40 *km/h* in order to avoid rollover caused by track bump. Therefore, in the application of the ATP system, when the speed of the transport units is detected to exceed 40 *km/h*, it will be slowed down by the control system.

On the 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), P. Gao et al[18] published the research on the safety function of the ATP system, they proposed a new analysis method for the ATP system, the Dynamic Fault Tree analysis method. The Dynamic Fault Tree is a system of methods for evaluating the reliability and safety of a complex system, it is also a kind of deductive method, which is based on the fault event and is analyzed step by step according to the top-down sequence through certain logical reasoning steps until the result is reached. The Dynamic Fault Tree analysis method is devoted to modeling the fault logic according to the dynamic fault behavior, and conforms to the functional design of signal system. It is worth mentioning that logical analysis based on the Dynamic Fault Tree analysis method method often analyzes the emergence of problems at the same time, instead of analyzing it layer by layer, it can greatly improve the efficiency of problem solving.

The order of problem solving based on the Dynamic Fault Tree analysis method 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(just like the ATP control system), analyze whether the fault events occur.* **4.** *If the fault events occur, solve them through the control system(just like the ATP control system).*

For the ATP system, the fault events in the underground transportation might caused by the over-speed, the safety-distance, Vehicle Rollover or the emergency. Therefore, the analysis of the fault events has been established: **1.** *The speed of each transport units are over 40km/h?* **2.** *Are all transport units within safe distance?* **3.** *Is there are any rollovers?* **4.** *Does the emergency appear?*

Through the monitoring and control functions of the ATP system and other auxiliary functions, *the rear-end collision problem* could be solved with the assistance of the Dynamic Fault Tree analysis method: **1.** *If the speed of the transport units is detected to exceed 40 km/h, it will be slowed down by the control function of the ATP system.* **2.** *If the distance between the transport units may cause an accident, the distance will be controlled by the control function of the ATP system through controlling the speed of the transport units.* **3.** *If a vehicle rollover accident is detected, the control function of the ATP system will halt the transport units nearby the accident.* **4.** *If the emergency appears, the control function of the ATP system will halt all transport units in the underground mine.*

With the improvements based on the Dynamic Fault Tree analysis method, the control function and working principle of the ATP system in the intelligent underground mine are shown in **Figure4**.

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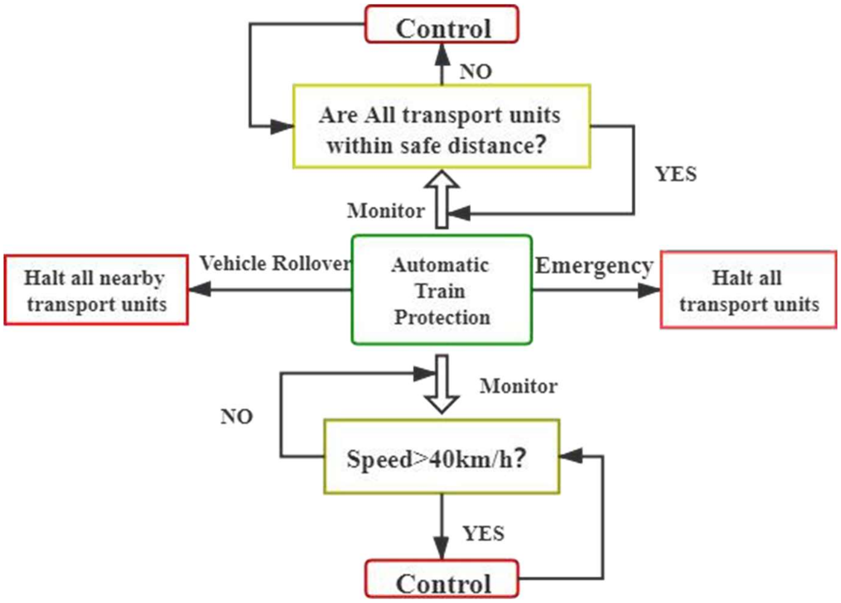

Figure 4. The control function and working principle of the ATP system in the intelligent underground mine.

B. Efficiency Problem: The transport efficiency problem

The distance and speed information of the transport units are collected by the ATO**(Automatic Train Operation)** system and transmitted to the ATP**(Automatic Train Protection)** system, and they both together control the speed of all transport units, to maximize the efficiency of the intelligent underground mines. In the year 2019, W. Wu and B. Bu[19] emphasized the crucial role of ATO System in security analysis, they put forward their viewpoint that although the ATP system is the core system of the security of the CBTC system, ATO system provide the significant information of speed and the distance of the transport units. The vital information not only works in the security monitoring of the ATP system, but also plays an important role in the supervision and tracking of the ATS system. To put it simply, all thanks to the useful information of speed and distance of the transport units provided by ATO system, ATP system and ATS**(Automatic Train Supervision)** system can achieve their respective control and monitoring functions.

As is known, the transport efficiency of the underground mine is determined by the speed of transport units to some extent. Therefore, both the ATO system and the ATP system indispensable to make the underground mine transportation achieve maximum transport efficiency. It's worth mentioning that calculating the speed of each transport unit when the maximum transport efficiency can be achieved is what ATP system or ATO system could not accomplish, so it's essential to draw support from the calculating function of AI Computing.

To solve the problem, first to establish a single analysis of the fault event on the basis of the Dynamic Fault Tree analysis method: **1.** *If the underground mine achieve maximum transport efficiency?* Through the monitoring and control functions of the ATP system, the information providing function of ATO system and other auxiliary functions, *transport efficiency problem* could be solved with the assistance of the Dynamic Fault Tree analysis method and AI Computing: **1.** *ATO system provide the significant information of speed to ATP system, and ATP system control the speed of each transport unit until the underground mine transportation achieve the maximum transport efficiency by the sustained calculating progress of AI Computing.*

With the improvements based on the Dynamic Fault Tree analysis method and AI Computing, the functions and working principle of ATO system and ATP system efficiency adjustment function in the intelligent underground mine are shown in **Figure 5**.

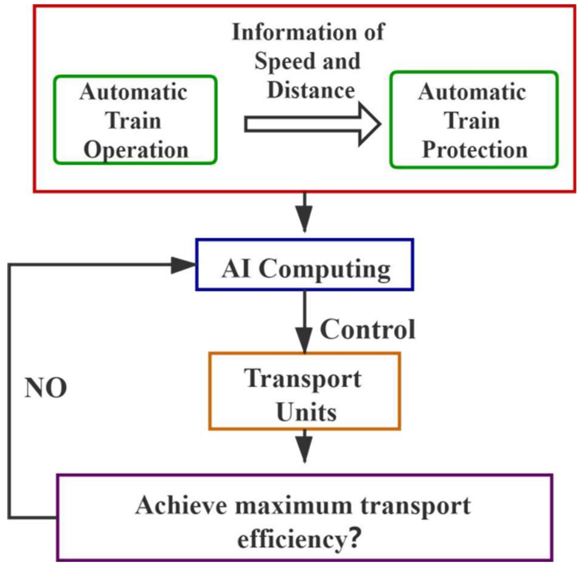

Figure 5. The function and working principle of the ATO system and ATP system efficiency adjustment function of the intelligent underground mine.

C. Monitoring and Control: The real-time monitoring problem

The real-time monitoring of the transport units is the biggest problem in intelligent underground mines. If the real-time monitoring of the transport units can be realized, it will be greatly beneficial to mining industry, for example, the monitoring of mine accidents and the search and rescue of Personnel. In the early year 2012, J. Xue and W. Liming[20] did the research on intelligent track positioning system so as to solve the problem of the mine accident rescue, they thought if the monitoring and tracking functions would be realized, the mining industry will enter a new stage of rapid development.

As the core of CBTC system, ATS system is divided into linear, centralized control, centralized monitoring and decentralized control, which is used to realize the real-time Monitoring, unified dispatching and management of transport units. In 2016, P. Gurník[21] raised his prospect of NGTC(**Next Generation Train Control)** project, he preferred to combining the CBTC(**Communication Based Train Control)** system with the ETCS(**European Train Control System)** system. And he thought most subsystems of the CBTC system should be replaced, but only the ATS system should be remained because of its advanced supervision function. In urban above-ground transportation, ATS system functions include train monitoring and tracking, train time and operation management, automatic train routing, automatic train adjustment, as shown in **Figure 3** above.

In 2010, X. Feng et al[33] made great achievements on the research of the Wireless Mobile Monitoring System for Tram Rail Transport in Underground Mine, but they considered there was still a large amount of problems to be solved of the real-time monitoring and control of underground mines. In the year 2015, M. M. Ali et al[32] tried to solve the problems of real-time monitoring and control of underground mines, they thought the problems in the real-time monitoring of underground mines were mainly **Four**: **1)** *The real-time monitoring of the transport units.* **2)** *The start-up time control of the transport units.* **3)** *The route adjustment of the transport units.* 4) *Transport units Tracking.*

1). The real-time monitoring of the transport units

It is necessary to monitor and control the transport units in real time because of the intricacies of the underground rail traffic, meanwhile, the identification of the transport units is also essential.

Firstly, each transport unit is required to be numbered, and a signal transmitting device which can be recognized by the number recognition sensors on the track is arranged on each transport unit. Identification information is transmitted to the ATS on-board Extension via optical cable and compared with the transport unit number in the number database. If the transport unit number recognized by ATS system does not match the information in the number database, three possibilities of the error are automatically identified: **1.** *Manually modify information.* **2.** *Wrong Number.* **3.** *Lost Number*. In the case of *Manually modify information*, the system retains the current transport unit number, otherwise the system re-assigns a new number to the current transport unit.

The Number Recognition and Repair Function is shown in **Figure 6**.

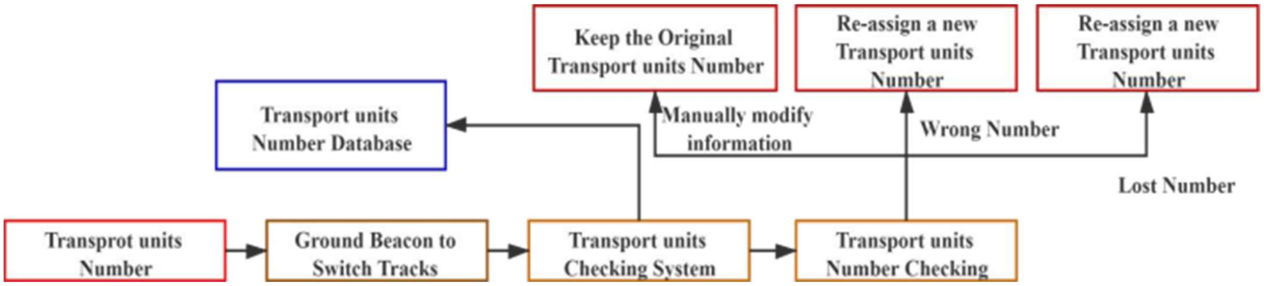

Figure 6. The Number Recognition and Repair Function.

In 2018, F. Mazzanti and A. Ferrari[22] combined Internet of things technology with ATS system using sensors on the track to monitor the train in real time. In addition, the number recognition sensors scattered throughout the track not only has the transport unit identification function, but also transmits the position information of each train to the ATS system in real time. The ATS system continuously monitors the position of each transport unit with the information provided by ATO system, and the position of each transport unit is continuously calibrated by the recognition sensors on the track, then the real-time tracking information of each transport unit is fed back to the screen of the ATS system control center. The real-time monitoring function of ATS system are as shown in **Figure 7**.

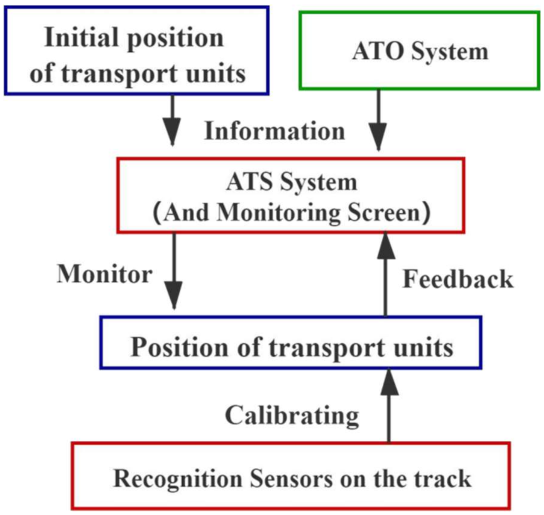

Figure 7. The real-time monitoring.

2). The start-up time control of the transport units

The start-up time control of the transport units is able to improve the transport efficiency of the underground mines, and the function of the start-up time control is accomplished through the monitoring and control of ATS system. As early as 2013, H. Anjomshoa et al[23] optimized the vehicle schedules in underground mines to control the start of the transport units. And in the year 2016, M. P. GEORGESCU[24] made the improvements to the CBTC system based on driver-less technology and Internet of things technology, and he proposed to use the ATS system of CBTC system to realize the start and stop of the driver-less train.

To solve practical problems in the underground mines, a process based on Internet of things technology and AI Computing has been established. When the Stope in the intelligent underground mine does not need transport operations, each transport unit needs to be on standby at the depot. Once there is a Stope that needs transport operations, the process begins running: **1.** *Calculate the amount of transport units that might be required in the operations.* **2.** *ATS system controls the transport units to the Stope to participate in transport operations with parameters such as ATP system and ATO system to assist in controlling the speed of the transport units.* **3.** *The whole process is fed back to the monitoring screen of the ATS system.*

The whole process of the start-up time control is as shown in **Figure 8**.

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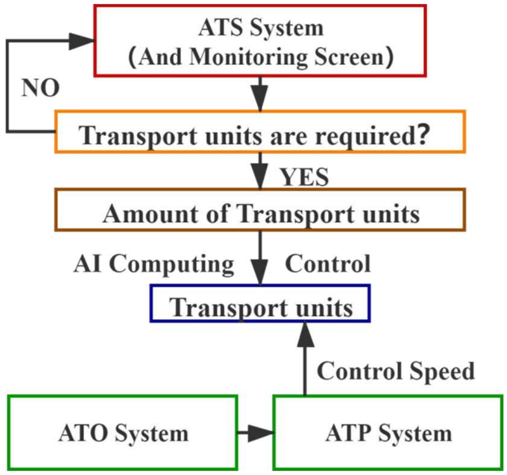

Figure 8. The start-up time control.

3). The route adjustment of the transport units

In intelligent underground mines, more than one concentrator is usually built, so there are always more than one unloading points for the transport units. If it is possible to choose the most suitable unloading route for each transport units according to the traffic conditions of underground routes, the transportation efficiency of underground mines will be greatly improved.

Back in 2005, M. Gamache, R. Grimard and P. Cohen[25] raised a shortest-path algorithm based on the AI Computing for solving the fleet management problem in underground mines, and in 2009, M. Li and Y. Liu[26] published their research on the underground coal mine monitoring with wireless sensor networks, the wireless sensor network was used to monitor and control the transportation route of each transport units in the underground mine.

In recent years, many people have studied the shortest-path algorithm, S. Jukna and G. Schnitger[49] optimized it through practice and simulation, Z. Zhiran et al[50] mentioned its superiority in large-scale road transport and A. Franceschetti et al[51] considered that the shortest-path algorithm is very effective in transportation scheduling.

By combining the ATS system and AI Computing function as an integral whole, a process based on shortest-path algorithm has been established: **1.** *The integral whole of ATS system and AI Computing analyzes the congestion of each transportation route.* **2.** *When ATS system gets feedback from AI Computing function, it will automatically choose the best route to the unloading place for each transport unit participating in the transportation operations.* **3.** *While the parameters such as ATP system and ATO system assist in controlling the speed of the transport units.* **4.** *The whole process is fed back to the monitoring screen of the ATS system.*

The whole process of the route adjustment is as shown in **Figure 9**.

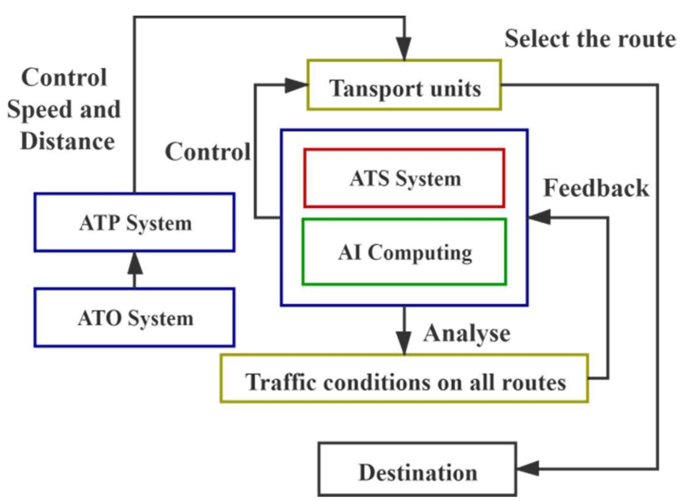

Figure 9. The route adjustment.

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4). Transport units tracking

On the 2013 13th International Conference on Control, Automation and Systems (ICCAS 2013), S. Oh et al[27] claimed that in non-CBTC systems, train position information is inaccurate and discontinuous, therefore, it is very necessary to establish the train tracking equation. For underground mine transportation, there are also such problems.

Based on the disturbance vibration and other factors, Z. Mao et al[52] established the train compensation tracking equation in 2018. In order to solve this problem, the concept paper draws on the method of Z. Mao et al[52] of tracking equations: The transport units location is tracked based on the ground beacon data, airborne information, Correlation Interval Algorithm and the *digraph*. Specially, transport units tracking equations are established using transport units measurement error, track wear and information transmission delay, as the following **equations** shown.

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

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

Equations. Tracking equations.

In(1)and(2), m represents the line mileage of the transport unit, 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 unit, L_{u-a} represents the transport unit position's uncertainty amount, and V_{max} represents the transport unit's maximum allowable operating speed.

Besides, in the application of tracking equations based on the *digraph*, the followings are essential: **1.** *The digraph is stored in the linked list.* **2.** *ATS system receives the transport units' main information including the units' running direction, the offset and the corresponding points in the directed graph.* **3.** *The directed graph edges and offsets at the beginning and end of the unit section are determined based on the relevant data in the packet, and then the coordinates of the start and end of the track are found in the directed graph.* **4.** *The specific position of the unit is determined according to the running direction of the unit and the edge direction of the directed graph.*

5). Other functions

The ATS System of the CBTC system can also realize the functions of alarm, record running process of the transport units, record running video, playback and so on.

3. Our Future Work

Although the concept paper does a great deal of work in the function design of the CBTC system which aims to solve the practical problems in the underground mine rail transportation, there are still a lot of weak points:

1. *For the methods such as the Dynamic Fault Tree analysis method and the tracking equations, there is no further explanation of its depth and how it works with the CBTC system.*

2. *Although the concept paper has made a lot of efforts in theoretical research, there is no practical engineering application or practice to verify the practicability of the design.*

As engineers, we are focusing on the application of the technologies in the engineering, therefore, we may be not very clear about the principles of the technologies which are used in the engineering projects, but in our future work, solving the practical application of the technologies will undoubtedly be the key of our research. And I promise here we will continue the research with the experts who specialize the related technologies and methods, and we will solve the above problem **1** and explain how these technologies and methods work with the CBTC system in our future articles. Besides, the tracking equation we have established is not very perfect and few factors are taken into account, so further optimization and application of the tracking equation will be carried out in our next step.

Also, in our next step after all the above problems have been resolved, we plan to test the design in the mining outlet roadway(The **roadway 1** in the **Figure 10.** below) of our engineering project, in **Figure 10**, the roadway 1 is the mining outlet roadway, roadway 2 is the ore drawing roadway, and the 3 is the Chute. To achieve this plan, we must overcome the difficulties in theory and solve the above problem **1** thoroughly before we can apply our conceptual design to the practice.

If, with the efforts of experts and us, we overcome the theoretical problems of the design and apply it to underground mines, regardless of the results of the study, we believe that these results can bring some enlightenment to the relevant research. And I promise here we will try our best.

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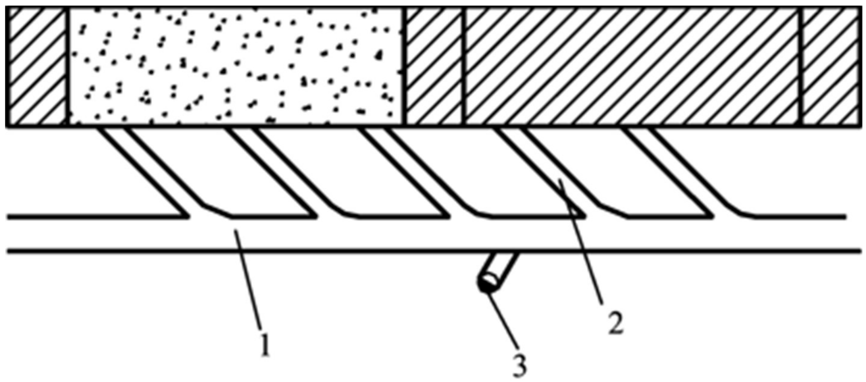

Figure 10. The Roadway Map(a part) of our engineering project.

4. Discussion and Outlook

The idea of Intelligent Trackless Underground Mine has been proposed for a long time, but because of its high cost and difficulty to monitor and control, Trackless Underground transportation is not widely used, especially in the developing countries like China. On the contrary, intelligent rail underground transportation is popular around the developing countries, not only because of its low cost, but also because it is easy to monitor and control, however, there are still a large amount of problems to be solved in the intelligent rail underground transportation.

With the precedent of the application of the CBTC system to the underground subway, this concept paper started the exploration in the possibility of application of the CBTC system to the underground transportation by reviewing the related literature. And this concept paper briefly reports the progress in the present stage of the research to apply CBTC system especially the Three Systems to the underground transportation in order to dedicate to solving the **practical problems** in the engineering of transportation in underground mines.

The New Dynamic Fault Tree analysis method proposed by P. Gao et al[18] on the 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC) gave the inspiration to this "concept paper" to try to summarize and propose to establish the analysis and the process of the fault event in order to solve the problem on the basis of the CBTC system.

For the practical problem of the safety rear-end collision problem in the underground mine transportation, a series of the analysis of the fault events have been established to estimate and control the hidden danger of the accident with the assistance of the ATP system. While in the practical problem of the transport efficiency problem, just a single analysis of the fault event have been established to make the underground mine transportation achieve the maximum efficiency with the together work of ATP system and ATO system. The results suggest that the more complex the practical problems are, the more analysis of the fault events need to be established in the New Dynamic Fault Tree analysis method, and the more complicated the diagram of the process will be.

For the practical problems of the underground mine transportation, safety and efficiency are relatively easier to solve with the assistance of ATP system, ATO system and the New Dynamic Fault Tree analysis method compared to the real-time monitoring problem. As is known, the real-time monitoring of the transport units is the biggest problem in intelligent underground mines, and the ATS system of the CBTC system is the core to solve the biggest problem out of question.

In the year 2018, Issad M, Kloul L, Rauzy A, Berkani K.[28] combined the ATS system of the CBTC system with the Internet of things technology, and conducted a simulation in the simulation environment, finally got good result. In fact, as early as 2017, the combination of the CBTC system and Internet of things technology would advance the CBTC system better to develop has become an academic consensus[8]. And nowadays, most of the CBTC systems used in various countries are "The Products" combined with Internet of things technology, but even such a complete CBTC system can not completely solve the problems in rail transportation of the underground mines. Thus, mainly four problems in the real-time monitoring of underground mines have been put forward by M. M. Ali et al[32] in 2015: **1)** *The real-time monitoring of the transport units.* **2)** *The start-up time control of the transport units.* **3)** *The route adjustment of the transport units.* 4) *Transport units Tracking.*

For the real-time monitoring of the transport units, the identification of the transport units is the prerequisite for solving the problem, due to the number recognition sensors on the track and ATS system, the identification and the monitoring of each transport unit can be realized, and the running of the whole process is fed back on the screen of the ATS system. For the start-up time control of the transport units, the similar analysis process to the Dynamic Fault

Tree analysis method has been established to control each transport units to the Stope to participate in transport operations by ATS system. And for the route adjustment of the transport units, a process based on shortest-path algorithm[25] has been established to adjust the running route of each transport unit to improve the transport efficiency and reduce the cost of the distance and the time. Finally for the Transport units Tracking, the tracking equations based on the *digraph* have been established to solve the problem that the position information of each transport unit is inaccurate and discontinuous in underground transportation.

The concept paper tries to summarize and propose the solutions to the **practical problems** in the engineering of transportation in underground mines with the assistance of the CBTC system, the functions of the CBTC system and its subsystems are also improved and applied to the solution of problems in the transportation of the underground mines.

But for the future, the CBTC system might be replaced by more advanced systems. As early as the year 2016, P. Gurník[21] raised his prospect of NGTC**(Next Generation Train Control)** project, he thought most of the functions of the CBTC system have gradually fallen behind. In this year 2021, as the representative of developing countries, China's research on NGTC**(Next Generation Train Control)** system is progressing rapidly, and there is even the possibility of pilot applications soon. And recently, Chinese scholars L. Yang and Z. Liu[30] reported their research on the modeling and verification of train departure scenario for next generation train control system.

With the appearance of more and more advanced systems, the dominant position of CBTC system in urban rail transit is likely to be gradually replaced. If the CBTC system were to be replaced in the urban rail transit control system one day, there is no doubt that CBTC system would disappear from the underground mine transportation.

For underground mine transportation, as early as in 2015, M. M. Ali et al[32] published their research on the development of underground mine monitoring and communication system integrated ZigBee**(based on IEEE802.15.4)** and GIS**(Geographic Information System)**, and they inferred ZigBee technology and GIS would be widely used in the control and communications of the underground mine transportation in the future. For the trackless transportation of underground mines, CBTC system may also become the leading role: If the path of the trackless transport equipment is planned within a certain range, the CBTC system can still have a good performance in the control and monitoring. Moridi[53] believes that if the low power and efficient information transmission of the ZigBee technology are applied to the underground control system, the mining industry will certainly make rapid progress, therefore, the combination of CBTC system and ZigBee technology may be a good performance in the control and monitoring in the underground mines. And for the tracking of the underground transportation, tracking technology has made great progress in recent years. Like K. Czaplewski et al[54], he established the tracking equations through Global Navigation Satellite System (GNSS) and Geodetic Networks in 2020. And J. Chen et al[55] established the tracking equations by 5G technology. As the progress of science and technology, the method of establishing tracking equations will be improved with the time, such as using 5G technology into the establishment of tracking equations.

Except for the GIS and the other systems mentioned above, there are a lot of advanced monitoring and control system emerging, such as WAMC**(Wide Area Monitoring and Control)** system. But whatever control and monitoring systems 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 scholars around the world who are on the research of the innovative system will not be in vain.

5. Summary

Overall, the type of this paper is concept paper, by summarizing the relevant literature, this paper discusses the possibility of applying CBTC system to the monitoring and control system of underground mines, proposes the function design of the CBTC system for the solutions to the practical problems, and reports the the progress in present stage of some existing research to apply CBTC system in the underground mines.

In the Introduction part, the paper combines the relevant literature, makes a series of analysis on the historical process and development of underground mine intelligence, and puts forward some urgent problems in underground mine, that is, the monitoring and control of underground mine transportation. Monitoring and control is always a troublesome matter for engineers in underground mines, which may not only take into account the cost and effect, but also have a certain relationship with the level of local mining development. Therefore, in the Introduction part, the paper puts forward the possibility that apply the CBTC system to the monitoring and control of underground transportation, and summarizes the development process and the functions of the CBTC system according to the relevant literature. Specially, the paper also summarizes and collates the related documents and literature of the application of CBTC system in underground transportation, in order to find the basis for the possibility that CBTC system can be applied in underground mine transportation. In the Concept & Design part, based on several previous methods or theories, such as the Dynamic Fault Tree analysis method[18] and the shortest-path algorithm[25][49][50][51], the paper finishes the function design for the CBTC system and summarizes the solutions to three practical problems in mines, that is, Safety Problem, Efficiency Problem, Monitoring and Control. In the Future Work part, the authors we have summarized some shortcomings in this design and proposed the plans for our future research. At the same time, in the Discussion and Outlook part, the paper discusses the thought of the whole article, explains some details in the article, and offers a vision for the future of the CBTC system and the underground mine monitoring and control systems.

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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Conflicts of Interest:

The authors declare no conflict of interest.

References

1. 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.
2. W. Chen and X. Wang, "Coal Mine Safety Intelligent Monitoring Based on Wireless Sensor Network," IEEE Sensors Journal, pp. 1-1, 2020.
3. Y. Meng and J. Li, "Research on Intelligent Configuration Method of Mine IoT Communication Resources Based on Data Flow Behavior," IEEE Access, vol. 8, pp. 172065-172075, 2020.
4. I. M. MacLeod and A. Stothert, "Distributed intelligent control for a mine refrigeration system," IEEE Control Systems, vol. 18, (2), pp. 31-38, 1998. . DOI: 10.1109/37.664653.
5. Z. Ming-gui and C. Si-jing, "An intelligent system for calculating the scale of rational, enlarged production of an underground non-ferrous metal mine," Journal of China University of Mining and Technology, vol. 18, (2), pp. 214-219, 2008.
6. L. Zhen, "Underground Coal Mine Ventilation Monitoring System Research," Applied Mechanics and Materials, vol. 353-356, pp. 3085-3088, 2013.
7. J. Farooq et al, "Performance Evaluation of a Multi- radio, Multi-hop Ad-hoc Radio Communication Network for Communications-Based Train Control (CBTC)," IEEE Transactions on Vehicular Technology, vol. 67, (1), pp. 56- 71, 2018.
8. J. Farooq and J. Soler, "Radio Communication for Communications-Based Train Control (CBTC): A Tutorial and Survey," IEEE Communications Surveys and Tutorials, vol. 19, (3), pp. 1377-1402, 2017.
9. X. Wang et al, "Joint Security and QoS Provisioning in Train-Centric CBTC Systems Under Sybil Attacks," IEEE Access, vol. 7, pp. 91169-91182, 2019.
10. J. Liu et al, "Towards Safety-Risk Prediction of CBTC Systems With Deep Learning and Formal Methods," IEEE Access, vol. 8, pp. 16618-16626, 2020.
11. X. Wang et al, "Train-Centric CBTC Meets Age of Information in Train-to-Train Communications," IEEE Transactions on Intelligent Transportation Systems, vol. 21, (10), pp. 4072-4085, 2020;2019;.
12. W. Sun et al, "A Cognitive Control Method for Cost- Efficient CBTC Systems With Smart Grids," IEEE Transactions on Intelligent Transportation Systems, vol. 18, (3), pp. 568-582, 2017.
13. X. Si, W. Kuang and Q. Li, "A Method of Generating Engineering Test Sequence for Urban Rail Transit CBTC System Based on Formalization," IOP Conference Series. Earth and Environmental Science, vol. 526, (1), pp. 12192, 2020.
14. L. Zhu et al, "Cross-Layer Defense Methods for Jamming-Resistant CBTC Systems," IEEE Transactions on Intelligent Transportation Systems, pp. 1-13, 2020.
15. T. Wen et al, "Access Point Deployment Optimization in CBTC Data Communication System," IEEE Transactions on Intelligent Transportation Systems, vol. 19, (6), pp. 1985-1995, 2018.

16. 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.
17. W. Carvajal-Carreño, A. P. Cucala and A. Fernández- Cardador, "Fuzzy train tracking algorithm for the energy efficient operation of CBTC equipped metro lines," Engineering Applications of Artificial Intelligence, vol. 53, pp. 19-31, 2016.
18. P. Gao et al, "A dynamic fault tree based CBTC onboard ATP system safety analysis method," in 2020, . DOI: 10.1109/ITSC45102.2020.9294605.
19. W. Wu and B. Bu, "Security Analysis for CBTC Systems under Attack – Defense Confrontation," Electronics (Basel), vol. 8, (9), pp. 991, 2019.
20. J. Xue and W. Liming, "Research on intelligent track positioning system to the mine accident rescue," in 2012 .
21. P. Gurník, "Next Generation Train Control (NGTC): More Effective Railways through the Convergence of Main-line and Urban Train Control Systems," Transportation Research Procedia, vol. 14, pp. 1855-1864, 2016.
22. F. Mazzanti and A. Ferrari, "Ten Diverse Formal Models for a CBTC Automatic Train Supervision System," Electronic Proceedings in Theoretical Computer Science, vol. 268, (Proc. MARS/VPT 2018), pp. 104-149, 2018.
23. H. Anjomshoa et al, "Optimising passing bay locations and vehicle schedules in underground mines," The Journal of the Operational Research Society, vol. 64, (2), pp. 241-249, 2013.
24. M. P. GEORGESCU, "Driverless CBTC : Specific requirements for CBTC systems to overcome operation challenges," in 2006, . DOI: 10.2495/CR060401.
25. 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.
26. M. Li and Y. Liu, "Underground coal mine monitoring with wireless sensor networks," ACM Transactions on Sensor Networks, vol. 5, (2), pp. 1-29, 2009.
27. S. Oh et al, "Design of ATP functions and communication interface specifications for korean radio-based train control system," in 2013, . DOI: 10.1109/ICCAS.2013.6704161.
28. Issad M, Kloul L, Rauzy A, Berkani K. Modeling the CBTC Railway System of Siemens with ScOLa. International Journal of Intelligent Transportation Systems Research. 2018;16(3):163-172.
29. L. Yang and Z. Liu, "Modeling and verification of train departure scenario for next generation train control system," MATEC Web of Conferences, vol. 336, pp. 2008, 2021.
30. H. Wang, N. Zhao and L. Chen, "An integrated capacity evaluation method for CBTC- system-equipped urban rail lines," Proceedings of the Institution of Mechanical Engineers. Part F, Journal of Rail and Rapid Transit, vol. 229, (3), pp. 291-302, 2015.
31. 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.
32. M. M. Ali et al, "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.
33. X. Feng et al, "Wireless mobile monitoring system for tram rail transport in underground coal mine based on WMN," in 2010, . DOI: 10.1109/CASoN.2010.107.
34. N. BIN et al, "CBTC (communication based train control) : System and development," in 2006, . DOI: 10.2495/CR060411.
35. 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.
36. D. Briginshaw, "Can CBTC cope with complex rail networks?" International Railway Journal, vol. 54, (2), pp. 2, 2014.
37. A. Aziminejad, A. W. Lee and G. Epelbaum, "Underground Communication: Radio Propagation Prediction for CBTC Data Communication Subsystem Design," IEEE Vehicular Technology Magazine, vol. 10, (3), pp. 71-79, 2015. . DOI: 10.1109/MVT.2015.2447520.
38. 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.
39. Anonymous "Circle Line junction CBTC," Railway Gazette International, vol. 175, (10), pp. 13, 2019.
40. Anonymous "IEEE Standard for User Interface Requirements in Communications-Based Train Control (CBTC) Systems," IEEE Std 1474.2-2003, pp. 0_1-19, 2003. . DOI: 10.1109/IEEESTD.2003.94409.
41. W. C. Vantuono, "CBTC--and beyond: looking at CBTC "not only as a train control system, but also in the context of an overall information, communication, monitoring, control, and management strategy"," Railway Age (Bristol), vol. 204, (6), pp. 65, 2003.
42. R. P. Alexander and E. A. Mortlock, "Controlling and executing communications based train control (CBTC) installation and testing with a CBTC-ready vehicle," in 2005, . DOI: 10.1115/RTD2005-70021.
43. Anonymous "IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements," IEEE Std 1474.1-2004 (Revision of IEEE Std 1474.1-1999), pp. 0_1-45, 2004. . DOI: 10.1109/IEEESTD.2004.95746.
44. R. CHEN and J. GUO, "Development of the new CBTC system simulation and performance analysis," in 2010, . DOI: 10.2495/CR100461.
45. Y. Xie and T. Tang, "Performance analysis of communication network for the CBTC system," in 2009, . DOI: 10.1109/IVS.2009.5164430.

46. B. Bu et al, "Predictive Function Control for Communication-Based Train Control (CBTC) Systems," International Journal of Advanced Robotic Systems, vol. 10, (1), pp. 79, 2013.
47. L. Zhu et al, "Communication-Based Train Control (CBTC) Systems With Cooperative Relaying: Design and Performance Analysis," IEEE Transactions on Vehicular Technology, vol. 63, (5), pp. 2162-2172, 2014.
48. H. Wang, F. R. Yu and H. Jiang, "Modeling of Radio Channels With Leaky Coaxial Cable for LTE-M Based CBTC Systems," IEEE Communications Letters, vol. 20, (5), pp. 1038-1041, 2016.
49. S. Jukna and G. Schnitger, "On the optimality of Bellman–Ford–Moore shortest path algorithm," Theoretical Computer Science, vol. 628, pp. 101-109, 2016.
50. Z. Zhiran et al, "The shortest path approximation algorithm for large scale road network," Ce Hui Xue Bao, vol. 48, (1), pp. 86-94, 2018.
51. A. Franceschetti et al, "A Shortest-Path Algorithm for the Departure Time and Speed Optimization Problem," Transportation Science, vol. 52, (4), pp. 756-768, 2018.
52. Z. Mao et al, "Adaptive Actuator Compensation of Position Tracking for High-Speed Trains With Disturbances," IEEE Transactions on Vehicular Technology, vol. 67, (7), pp. 5706-5717, 2018.
53. 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.
54. K. Czaplewski et al, "Application of Least Squares with Conditional Equations Method for Railway Track Inventory Using GNSS Observations," Sensors (Basel, Switzerland), vol. 20, (17), pp. 4948, 2020.
55. J. Chen et al, "A rail-to-rail ultra-wide bandwidth hybrid supply modulator for 5G applications with envelope tracking techniques," International Journal of Circuit Theory and Applications, vol. 47, (12), pp. 1907-1921, 2019.