# Automatic Transportation Management System of Vehicles in Open Pit based on 3PGS and GPS

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Abstract

The management of mining trucks and other vehicles in the process of transportation is an important issue, in order to prevent from ore stealing and guarantee the obedience of scheduling commands in many open pits. In this paper, a new automatic management and control strategy - "three point guarding system(3PGS)" and GPS truck tracking strategy have been proposed. The objective of these strategies is to prevent stealing ore and monitor vehicles in real time. In 3PGS, three points should be arranged, which consist of weighing point in mining area, passing verification point of entrance and exit in open pit, and weighing point in unloading area. Using weighing sensor, radio frequency identification, automatic barrier control, Ethernet network technologies and systems engineering theory, the trucks and vehicles can be managed and controlled well through to pass three points orderly. Using GPS, the positions of trucks can be monitored in real time in the whole transportation process. Based on 3PGS and GPS, a new automatic transportation management system of vehicles in open pit has been designed and developed. The system has been applied in Sandaozhuang Molybdenum open pit. The application results show that it is an effective solution to prevent from ore-stealing, to manage inlet and outlet automatically and to monitor the trucks in real time in open pit mine.

Keywords: OPEN PIT, VEHICLES, STEALING ORE, AUTOMATIC MANAGEMENT, 3PGS, GPS.

**Introduction**

The transport vehicles in stopes of open pit are roughly divided into two kinds: mining trucks and auxiliary transportation vehicles. The mining trucks mainly transport ore and waste rock in open pit. The auxiliary vehicles usually give a ride to people and other materials between inside open pit and outside. The two kinds of vehicles play an important role in the transportation system of open pit. Most of trucks basically carry ore and unload ore inside open pit. But some trucks carry ore to ore-dressing plant outside or store ore outside. Some drivers always want to pursue more personal gain in the process of transportation. Thus, stealing ore often happens after the trucks are driven outside of the open pit. Also, some trucks don't obey scheduling commands in transit. For example, some trucks go wrong way and stop and unload in wrong places intentionally. Besides, some auxiliary vehicles also steal ore when they

exit the stope. According to statistics, since 2002 there are about 20 million yuan of average-lost each year due to stealing molybdenum ore in china. Therefore, prevention of ore-stealing should be addressed as an important issue in all open pit, in order to reduce the companies' loss.

At present, the means of management and control of vehicles in open pit domestically and internationally are tracking and positioning, automatic barrier gate and video monitoring. Tracking and positioning technology is most widely used in the management of mining trucks [1-2]. Examples are: Dispatch system developed by Modular Mining Systems in USA, Intelligent Vehicle Scheduling System developed by Dongfang Measurement and Control in china and Intelligent dispatching and monitoring system for trucks and shovels developed by Mining System Institutes in Xi'an University of Architecture and Technology. All these systems can track and obtain vehicles' positions in real time using GPS, WIFI or RFID[3]. The historical paths of vehicles can be shown in the map of open pit and can also be found in database at any time[4-5]. The systems can manage vehicles' transportation effectively and guarantee that vehicles are under dispatching commands. But one of the major disadvantages of these systems is that they only monitor vehicles' paths. If ore-stealing events happened in transit, they cannot be found and cannot be effectively managed. Video monitoring is typically used at some key points to monitor vehicles[5]. Monitoring equipments can gather the real-time scene and transfer it to the data center. The vehicles can be monitored in real time in this way. But the disadvantage is that there are often some blind spots, which cannot be monitored from limited number of cameras. Monitoring all routes requires more cameras than one can afford. The increased number of cameras also increases labor cost. The whole cost is pretty higher. Thus, it is not a reasonable way to this issue. The barrier gates are another way, which consist of two types, manual and automatic[6-8]. Manual barrier gates are usually installed in the entrance and exit of open pit. When a vehicle passes the entrance or exit, the worker here will check approved receipts according to his personal subjective judgment. Then the on-site worker will decide if the vehicle can pass through. In this case, fraud may happen. While the automatic barrier gates consist of barriers, barrier controller, induction coil, RFID reader, RFID tags and computer server so on. First, each vehicle is equipped with a RFID tag and the information of tag and vehicle is registered in the database. When the vehicle passes through entrance or exit, RFID reader obtains the exact number from tag and then by this number, the vehicle's information can be automatically queried and analyzed from the database. Then, according to this vehicle's permission type, the system will send commands to barrier controller. The vehicle can be determined to pass through. In this case, vehicles' access still depends on human assignment. Moreover, only vehicles in the gate can be monitored. So ore-stealing is still possible in transit. There are other methods to manage trucks' transportation process [9-10]. However, the goals of these systems aren't to solve the transportation problem in open pit.

To solve the above problem, this paper proposes a novel automatic transportation management system of vehicles in open pit that utilizes 3PGS(Three Points Guarding System) and GPS technologies. It can monitor automatically the whole transport process of vehicles. It is an effective solution to prevent stealing ore, control inlet and outlet automatically and monitor the trucks in real time in transit. With the application of this system, the loss of ore in open pit has been significantly reduced.

## 1. Three Points Orderly Guarding Model

### (1) Basic Theory

In this section, the basic theory of setting up 3PGS model will be proposed. The core idea of the whole strategy is that the amount of truck's ore loaded in starting point is always equal to the amount of truck's ore unloaded in unloading spot in all trips. Assuming that truck T, weight of ore W, the loading point S, the unloading point E, and $S\_W(i,j)$ is the weight of ore carried by truck i from loading point at j trip. $E\_W(i,j)$ is the weight of ore carried by truck i from unloading point at j trip. The result is stated in following theorems:

THEOREM 1: when one truck $T_i$ transports at *j* trip, the weight of ore in loading point should equal to the weight of ore in unloading point.

$$S\_W(i,j) = E\_W(i,j) \quad (1)$$

Note that if the above equation is satisfied, there is no ore-stealing behavior for truck $T_i$ at *j* trip.

THEOREM 2: when the truck $T_i$ transports at all *n* trips, the weight of ore in all loading points should equal to the weight of ore in all unloading points, where loading points and unloading points may be different.

$$\sum_{j=1}^{n} S\_W(i,j) = \sum_{j=1}^{n} E\_W(i,j) \quad (2)$$

Note that if the above equation is satisfied, there is no ore-stealing behavior for truck $T_i$ at all *n* trips.

THEOREM 3: when all trucks $T_1, T_2, ...T_m$ transport at all n trips, the total weight of ore in all loading points should equal to the weight of ore in all unloading points.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} S\_W(i,j) = \sum_{i=1}^{m}\sum_{j=1}^{n} E\_W(i,j) \quad (3)$$

Note that if the above equation is satisfied there is no ore-stealing behavior for all trucks at all n trips.

In actual process of transportation, due to measuring scale variances, ore weight loss and the computational variances, the exact weight of ore at loading point is not necessarily equal to the accurate weight of ore at unloading point. So within a given range of deviation, we can deduce that stealing ore doesn't happen in transit. For example, in practice, the equation (2) can be used as follows:

$$\left| \frac{\sum_{j=1}^{n} S\_W(i,j) - \sum_{j=1}^{n} E\_W(i,j)}{\sum_{j=1}^{n} S\_W(i,j)} \right| \le \delta \quad (4)$$

Where $0 < \delta < 1$, $\delta$ is an acceptable range of variation, which usually depends on measuring equipment, ore type and transport environment.δ

**(2) Three Points Management Model**

Based on the above theorems, three points orderly management model is proposed, three points are weighing point in pit, entrance and exit of the open pit and weighing point in unloading point. The main idea of the model is that: first, automatic weighing scales are deployed at important points of open pit, for example, crusher station. Before the truck carrying ore goes out from the crusher station, total weight of the truck and ore will be obtained automatically at the weighing point and weight data will be transmitted to the central server. When the truck approaches to the exit of open pit, truck's information from the central server including its last weight data and permission can be read by RFID tag. According to the information, the system will automatically judge whether the truck can be permitted to go out. Then, if the truck exits and arrives at the unloading point, normally a processing plant. The combined weight of the truck and the ore will be weighed again at the unloading point. The weight data will also be transmitted to the central server. All the data from those three points can be collected by Ethernet synchronously. In a transportation process of truck, all the data from three points will be gathered, analyzed and evaluated based on the theorems. The overall design of three points is shown in Fig.1.

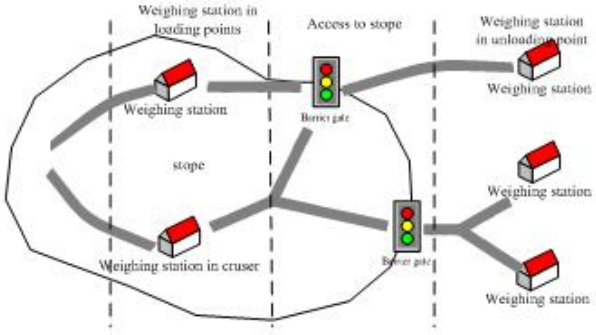


**Fig.1** The orderly layout based on three points

In an open pit, some vehicles are auxiliary, so that they can be managed only by automatic barrier gate at the entrance or exit. Most of the others are mining trucks, which should be managed and controlled by two points or three points. All vehicles in open pit are grouped into three categories. The first is the auxiliary vehicles that transport materials except ore and don't need to be weighed. If the vehicles are attended to enter or exit, their permission must be accepted. The second kind is trucks that transport only inside the open pit. When these trucks are trying to exit, they must be permitted by scheduling manager via electronic audits. Audit result will be recorded in the database. Then the truck can pass the barrier gate. The third is the trucks that carry crushed ore to extract processing plant. Those should be orderly managed by three points. Before the trucks exit from open pit, they should be weighed. In the whole process, the most important and complex process is to analyze whether the vehicle is permitted when it passes through the barrier gate. The activity diagram of the running mechanism in barrier gate point is shown in Fig.2

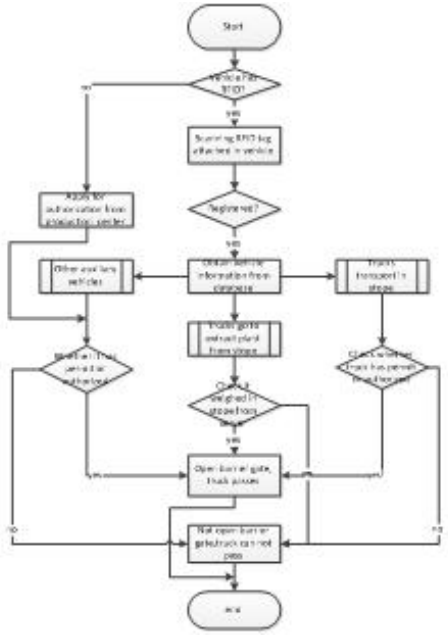

**Fig.2** Activity diagram of the running mechanism in verification point

**2. Tracking trucks strategy based on GPS**

Based on GPS, tracking trucks strategy can gather real time positions of trucks carrying ore in the transportation process. First, GPS mobile terminals are equipped in the trucks. The terminals can receive and send real time GPS satellite signals in any weather conditions. Then it can calculate relative position information of the truck spontaneously. The truck position data mainly includes longitude, latitude, altitude, speed and time. All data will be transmitted to the central server by wireless networks (GPRS or WiFi). The trucks' position data usually can be transmitted periodically in 10-15 seconds. In the central server, any truck's historical paths including speed can be found at any time, which also can be displayed in GIS. The electric fence can also be set up in GIS. The system will detect and alarm, if the truck goes beyond the fence. Using this, the trucks can be managed in stope[6-8]. The whole system data flow diagram is shown in Fig.3.

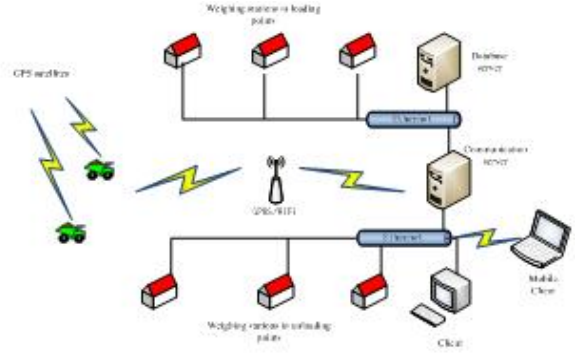

**Fig.3** The whole system data flow diagram

**3. Automatic transport management system of vehicles based on 3PGS and GPS**

**(1) System design and composition**

Based on 3PGS and GPS, the automatic transportation manage system mainly consists of hardware subsystem and software subsystem. The hardware subsystem are mainly scales, scale data terminals, RFID readers, RFID tags, LED display screens, barrier controllers, barriers, GPS mobile terminals, database server and communication server. Based on c#.net, serial port communication, MapX and database, four software clients are designed and developed. They are 3PGS vehicle communication and automatic control client, 3PGS remote authentication client, 3PGS and GPS data collection and analysis server and GPS vehicle tracking client, which can be shared with existing dispatch client.

The most important advantage of the whole system is that it is automatic in all process, especially in barrier gate. Through RFID remote identification technology, all vehicles can be identified automatically. Each mining truck carrying ore will be weighed twice in pit and outside automatically. The weight of ore will be checked at loading point and unloading point. Using auto barrier gates and using registry setting in advance to classify permission, automatic access control management of different vehicles can be realized. Using GPS tracking position technology, all mining trucks can be tracked in real time. So trucks' paths and quantity of ore can be monitored in the whole transport process. Combining the above technologies, the access to open pit and vehicle transport can be managed effectively. The composition of automatic transport manage system is shown in Fig.4.

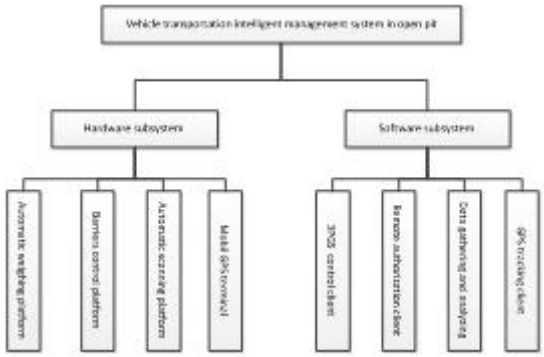

**Fig.4** The composition of automatic transport manage system

**(2) System development**

The automatic weighing and GPS tracking parts had been discussed in our research group's

previous literatures[2,6]. So they can be omitted in this paper. The automatic access control at entrance and exit is complex, so we discuss it in this section. The automatic access control involves the remote RFID readers equipped in the entrance and exit, barrier controller, barriers, access control software and SQLServer database. As shown in Fig.5, the barriers are installed in the entrance and exit of open pit. By default, two barriers are shut down and two lights in front of barriers are red. When a vehicle attends to enter the open pit, the RFID reader asks its tag for the number from first. Then according to the number, for example, 55737, all vehicle's information and permission can be queried in the central database. If the vehicle is permitted to enter, the access control system will send and 'open' signal to barrier controller. The barrier gate can be opened and the lights will change to green. Finally, when the vehicle passed, the barrier shut down immediately using ground sense coil. With similar process, the control of exit can be achieved. The overview of barrier gates in access point is shown in Fig.5.

One barrier controller is applied at an access point, which can control at least two barriers. Barrier controllers at different locations are connected via Ethernet, so that data consistency and synchronization can be guaranteed. Every barrier controller is also connected with upper computer by COM1, which can control the entrance barrier and exit barrier simultaneously by different addresses. RFID readers communicate with upper computer based on RFID communication protocol by COM2 and COM3. When the barrier controller communicates with upper computer, the computer sends command according to their protocol and then the barrier controller will make corresponding response. For instance, the command consists of an array of bytes, namely {barrier gate address, instruction}, such as {0x02,0xBF,0x01}. Where 0x02 is the barrier gate address, 0xBF and 0x01 is the command to turn red light on. The barrier can be only controlled by the above data from barrier controller via SerialPort.

**Fig.5** The view of barrier gates in access point

In some particular cases, all the RFID readers are remote and automatic in the entrance and exit. If the distance between two RFID readers is close, false scanning will probably be caused. For example, if vehicle's RFID tag is read by entrance reader when it goes out, the barrier gates in entrance and exit are both opened. This problem is solved by enlarge isolation distance or by software. In software development, a flag is set up to mark vehicle in or out. Before the vehicle goes out from exit, the flag should be check and the flag should be mark vehicle out. If not, false scanning happened. The request will be cancelled. This method is called "in and out discrimination mechanism". Due to improper distance between two RFID readers, after the vehicle passed the exit barrier, it's tag is still scanned by opposite entrance reader and then entrance barrier open. This also is not conform to the actual. So the "repeat read oversight mechanism" is designed to solve it. After the exit barrier opens, the time from last scanning will be calculated. If the total time is less than assigned value, for example, 3 minutes, the scanning information from this vehicle will be ignored. So, if all vehicles' information can be initialized correctly, the problem of scanning tag by mistake can be solved through above methods.

**System deployment and application**

The Sandaozhuang open pit is a super-huge molybdenum and tungsten open pit, one of the world's three largest molybdenum, China's second great tungsten, which belongs to mining company of Luoyang Luanchuan Molybdenum Industry Group.Inc. Its mining capacity has been up to 30000 tons/day since june 2006. Molybdenum is a rare metal and more expensive than simple metal. The behavior of stealing ore often happens in the transport process, especially in the night. Some trucks also violate dispatching

command. Due to three shifts a day, it is highly difficult to monitor and manage all vehicles in all day everywhere. So far, there are all kinds of vehicles about 208, where 40 tons haulage trucks is 40, 32 tons haulage trucks is 5, other heavy-duty trucks is 152, daily service bus is 8 and other pickup truck is 3. Some haulage trucks transport crushed ore from open pit to extract processing plants and other trucks always transport ore from blasting muck pile to crushing station. But all vehicles will go out from the barrier gate if they need repairing. Due to more vehicles in stope and complex situation, so access management and transportation is very important work in daily production management in the open pit.

In view of the above situation, with a series of advanced technologies such as 3PGS, GPS, GIS, wireless communication, electronic weighing, RFID technologies and system engineering theory,the new automatic transport management system of vehicles has been developed and successfully used in Sandaozhuang open pit since 2012.

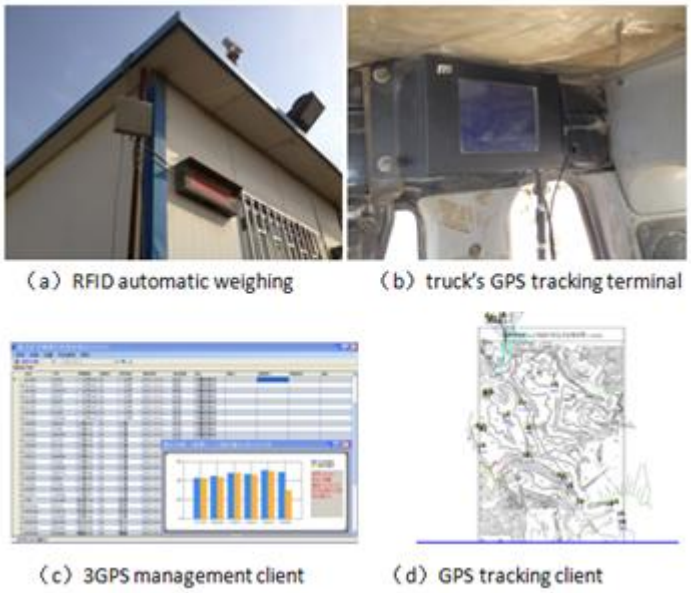


**Fig. 5** The typical application in automatic transport management system

At present, based on the enterprise Ethernet, automatic weighing points inside and outside have been successfully deployed. There are 10 automatic weighing points in the open pit, which normally are installed in important points, for example crushing station. And one automatic weighing scale is installed below the draw shaft from Taibaoshan crushing station, which is responsible for weighing ore transported to extract processing plant from draw shaft. There are 3 automatic weighing points in the unloading points outside the open pit. The two sets of inlet and outlet have been set up in 1309 and 1801 in the open pit, which can automatically read related vehicle's information by RFID and permit passing vehicle to enter or go out. There are 4 barrier machines, 4 RFID readers installed in inlet and outlet points. And there are 208 GPS mobile terminals and 208 RFID tags equipped in each vehicle, which can track each vehicle in real time. In the data center, there are 2 IBM3500 servers, one for communication, the other for database.

Since march 2012, the system has been improved continuously. The SQL server had been installed in all weighing stations, inlet and outlet points and central server. Adapting this method not only makes software faster and more effective due to local store, but also guarantees software to run if the network doesn't work well. Under the condition of local authorization, the software will automatically switch to run locally. Besides, the barrier control subsystem supports emergency open. Once several vehicles need to pass continuously, the barrier can always be opened until all the vehicles pass, which need authorized by different departments. Through the application of the system in Sandaozhuang open pit, stealing ore is prevented effectively and the whole transport process is monitored in real time. The system largely improves the level of vehicles management in the open pit.

**Conclusions**

(1) 3PGS management model makes weighing station in loading point, access to open pit and weighing station in unloading station work cooperatively. The involved technologies are reliable and mature. The application in Sandaozhuang open pit shows that the model is used effectively to prevent stealing ore in the transport process. It largely reduces the loss of ore in mining enterprises.

(2)with the wide application of GPS technology, GPS is combined with 3PGS in this system. On the one hand, the quantity of ore is monitored in transport by 3PGS, on the other hand, the transport path is monitored real time in whole process by GPS. The two are complimentary to realize the management of vehicles in open pit.

(3) Based on 3PGS and GPS automatic transport management system of vehicles in open pit is not only available in open pit, but also can be used to manage vehicle in other fields. for example, it can be available in logistic vehicles management.

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