S. K. CHAULYA
G. M. PRASAD
S. ANSARI
R. KUMAR
and
D. KUMAR

Coal production and transportation monitoring system for opencast mines

Coal production and transportation monitoring system for opencast mines has been designed aiming at checking overloading of coal on trucks or dumpers and its efficient disposal from a mine site, and at the same time stopping of illegal transportation of coal through unauthorized routes. The system consists of five modules, namely (i) Weighbridge automation module for manless checking of overloading of coal on trucks or dumpers; (ii) Vehicle tracking and production module for keeping continuous watch on the vehicles on transportation routes, and monitoring of production as well as providing advice on optimum use of shovels and dumper and other auxiliary equipment to minimize their idling time; (iii) Close circuit television cameras for keeping their surrounding under constant vigilance, particularly to watch vehicles carrying coal; (iv) Periphery surveillance module for detecting intrusion of vehicles with the intention of illegal transportation of coal through unauthorized routes; and (v) Centralized monitoring station for overseeing all the activities of production monitoring and transport surveillance from a central location. This system would definitely be proved to be a boon to coal industry as it is quite effective in averting financial loss due to illegal coal transportation and at the same time improving the efficiency of smooth coal dispatch by optimum use of shovels and dumpers.

1. Introduction

Mining activities form an integral part in the economic development of any country endowed with mineral resources including coal. Unauthorized mining, vehicle overloading, poor transparencies during mineral transportation, lack of equipment optimization, improper production scheduling, idling of shovels and dumpers, etc. are some of the major causes of concern to the mine management. With a view to dealing with these problems CSIR-Central Institute of Mining and Fuel Research, Dhanbad, India has developed "Coal production and transportation monitoring system for opencast mines" using advanced vehicle tracking and surveillance technologies.

Messrs. S. K. Chaulya, G. M. Prasad, S. Ansari, R. Kumar and D. Kumar, CSIR–Central Institute of Mining and Fuel Research, Dhanbad 826 001, India. E-mail: chaulyask@yahoo.co.in

2. System description

Coal production and transportation monitoring system comprises different sub-systems as shown in Figs.1 and 2. These include:

(i) Weighbridge automation module for checking overloading of minerals on a truck or dumper.

(ii) Vehicle tracking and production monitoring module for (a) continuous watching the movement of trucks/ dumpers on their transportation routes and (b) monitoring production and advising on optimum utilization of shovels, dumpers and other auxiliary equipment minimize their idling time.

(iii) Closed circuit television camera for keeping day-and-night sharp surveillance on the surrounding, particularly the movements of the vehicles carrying coal.

(iv) Periphery surveillance module for detecting intrusion of vehicles for illegal transportation of coal through unauthorized routes.

(v) Centralized monitoring station for supervising all the activities related to production of coal as well as transport surveillance from a central location.

3. Functions of the sub-systems

3.1 Weighbridge automation module

Weighbridge automation module consists of radio frequency identification (RFID) tags, weighbridge (either in-motion or on-board type), radio frequency (RF) sensor, internet protocol (IP) camera, boom barrier, programmable logic controller (PLC), high definition infrared (IR) camera, network video recorder (NVR), etc.

RFID tag and global positioning system (GPS) device is issued for each empty truck entering the mining area. It uses wireless communication by using radio waves to transfer data between a RFID reader and RFID tag attached to an object for the purposes of identification and tracking of vehicles (Bandyopadhyay et al., 2009). Empty truck proceeds towards

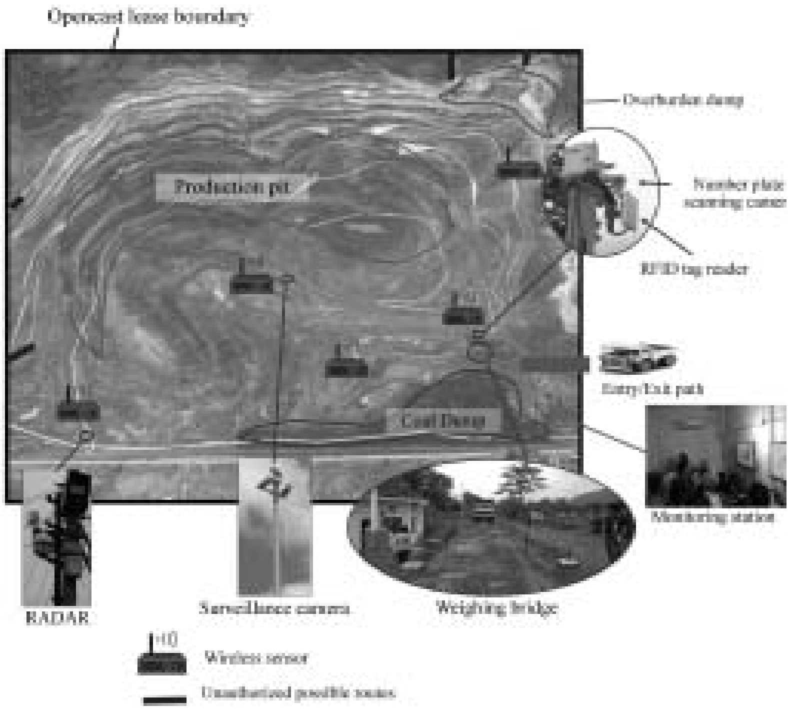

Fig.1 A view of coal production and transportation monitoring system

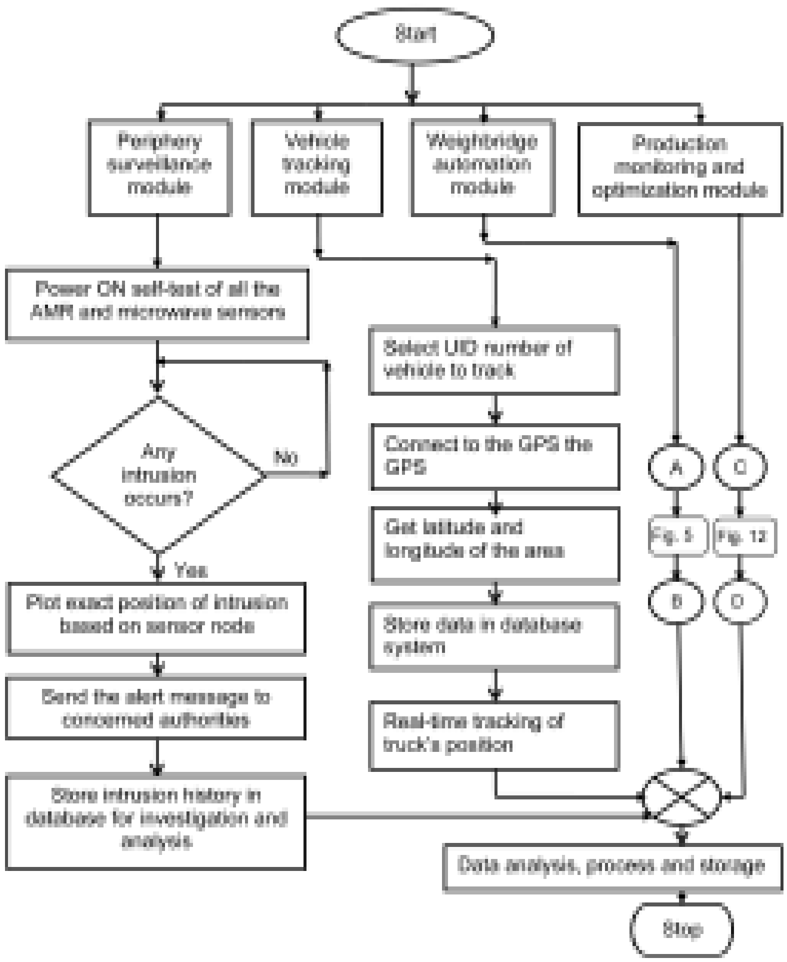

Fig.2 Flow chart of coal production monitoring and transport surveillance system

the weighbridge for weighing. When it reaches weighbridge platform, RF sensors ensure that the truck is completely on the platform. This totally eliminates chance of error in weight reading. If a portion of tyre is kept outside the weighing platform, the system refuses to display any reading. Then the weighbridge weighs the empty truck. An IP camera takes the photo of the empty vehicle, number plate of the truck and its driver for printing with challan (showing number plate and coal on the vehicle). All the information are electronically transferred to the computer. The truck then proceeds towards coal dump for loading. After loading, it goes for second weight. Radar/RF sensors ensure that the truck is completely on the platform, and no part of tyre is kept outside. Weighbridge provides tare weight, gross weight and net weight along with other details. If weight of coal is consistent with the client's requirement and authenticates the RFID tag number of the truck, the main computer takes printout of photo of the loaded vehicle and commands the road barrier to open. If the vehicle is found overloaded or RFID tag number is erroneous or both, an alarm generates and red light emitting diode (LED) glows. The main computer commands the barrier to remain closed. In case of overloading truck needs to remove the excess coal and if the RFID tag is found invalid then the authorization of truck should be verified manually by the weighbridge operator.

For better understanding the activities of the weighbridge module have been presented step-wise in the following steps:

Step-1 Truck at checkpoint

- Driver holds the RFID tag in front of RFID reader

Step-2 Boom barrier opens for weighing on weighbridge (if platform is empty).

Step-3 Truck is on the weighbridge for tare/ 1st weight

- RF sensor at edges of weighbridge platform checks the proper positioning of truck. If the truck is aligned properly only then it is ready for weighing
- IP camera takes photo of number plate, top portion of truck and driver
- Computer generates acknowledgment slip containing tare weight. Driver can see the weight on KIOSK display.

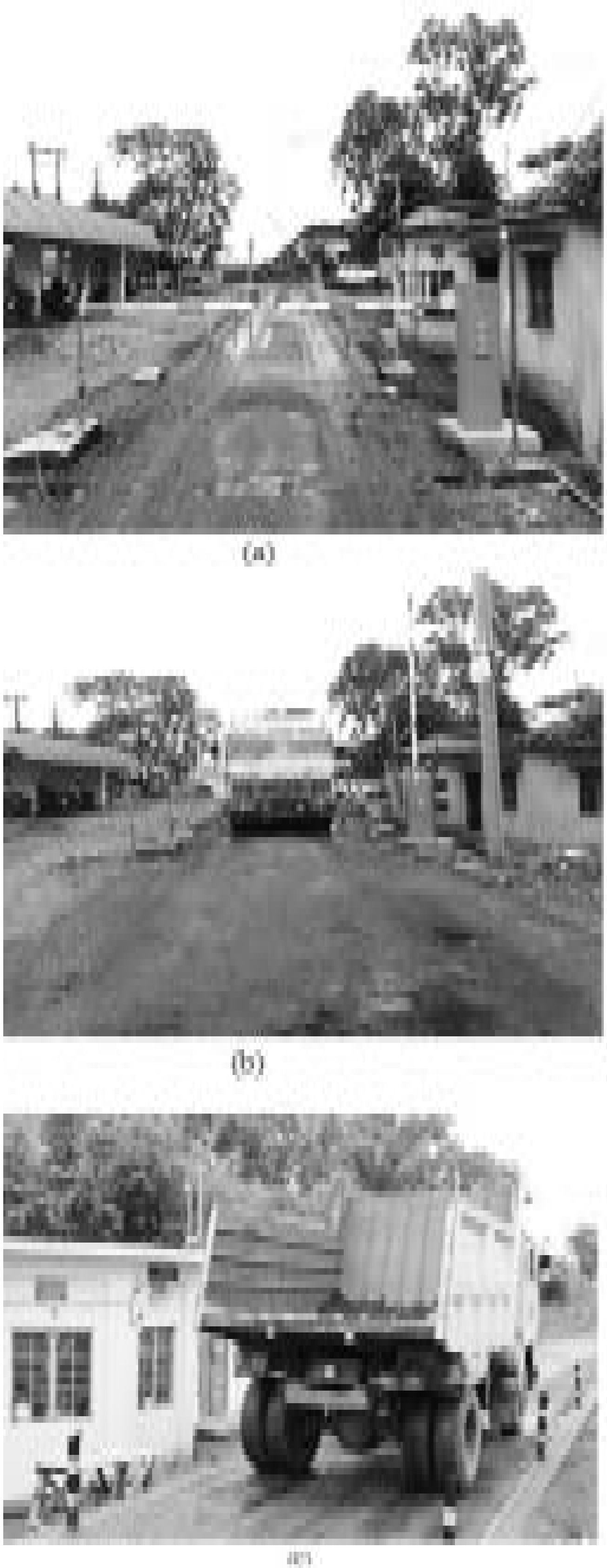

Fig.3 Weighbridge automation system installed in a mine: (a) Idle weighbridge, (b) Loaded weighbridge, (c) Closure view

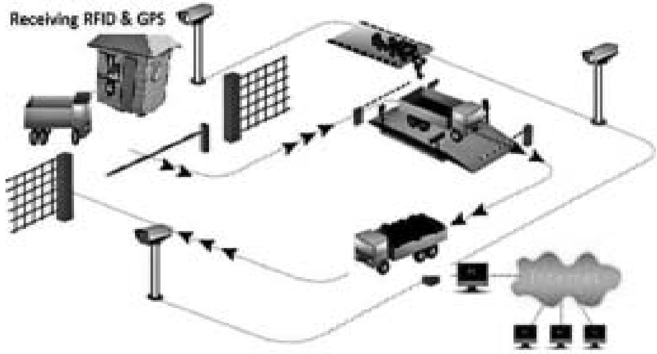

Fig.4 Digital weighbridge automation process

Step-4 Boom barrier opens and the truck proceeds to loading point.

Step-5 Truck is at the loading point

- If the RFID reader authenticates the truck then boom barrier opens and loading is done.

Step-6 Exit from loading point

- After loading the truck passes through another RFID reader. If it permits to leave the loading point, the system sends command to open boom barrier.
- The truck proceeds for 2nd weighing

Step-7 The truck is at the weighbridge for 2nd weight

- After authentication from RFID reader there are two possibilities:
  * If the weight is less than or equal to registered laden weight (RLW): the truck is allowed to go.
  * If the weight is more than RLW: then the weight is made equal to RLW by removing the excess coal.

Step-8 Truck proceeds to check point

- Truck driver deposits the RFID tag and GPS device.
- The driver is then given challan, invoice with all calculations, road permit etc.

Fig.5 shows flow chart of weighbridge automation module that explains the weighing procedure of authorized vehicle and report generation process for analyzing coal transport per vehicle/shift/day into the mine or exit from it and preventing overloading as well as unauthorized entry of vehicles.

3.2 Vehicle tracking and production monitoring system

3.2.1 Vehicle tracking module

This module presents an automatic vehicle localization technique using GPS and global system for mobile (GSM) communication modem. It detects location of vehicle and alerts the concerned person on his cell phone. Each RFID tagged vehicle is equipped with GPS transceiver which is interfaced with a GSM modem having the capability of sending GPRS data/SMS to a particular station without human intervention. Based on the information received from GPS, the software provides exact position of the vehicle in

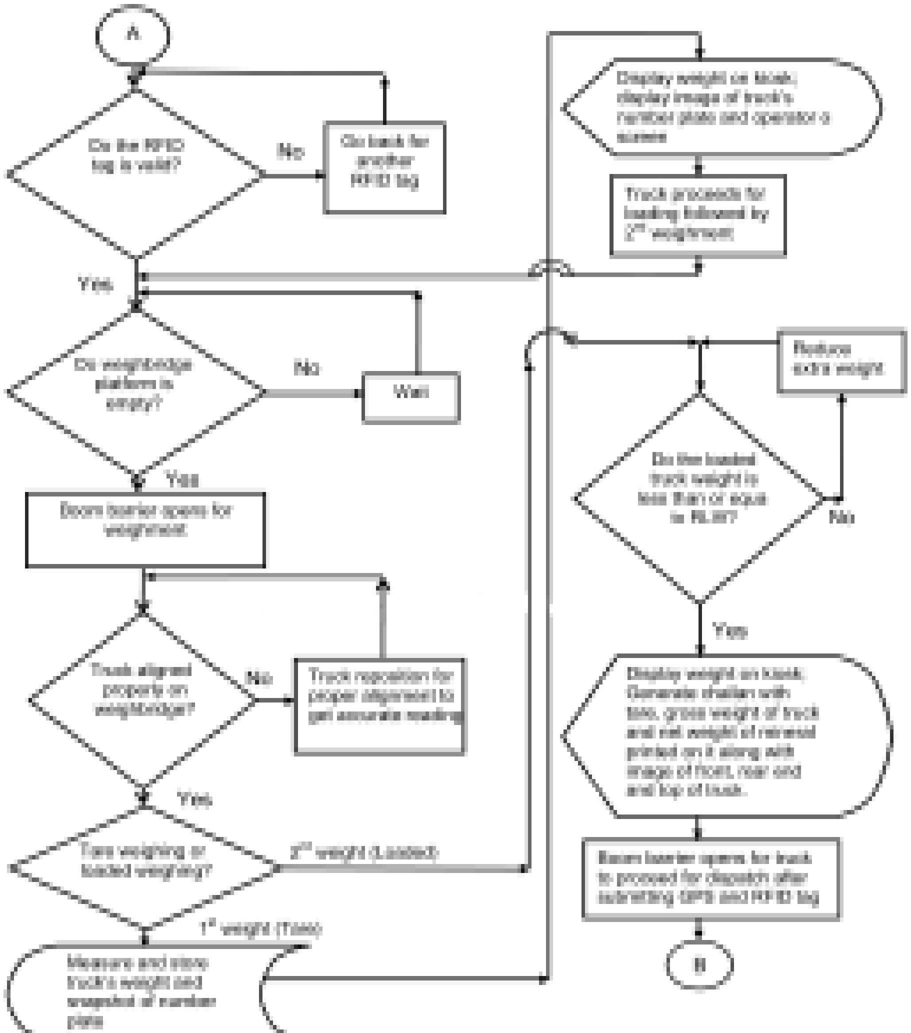

Fig.5 Flowchart of weighbridge automation system

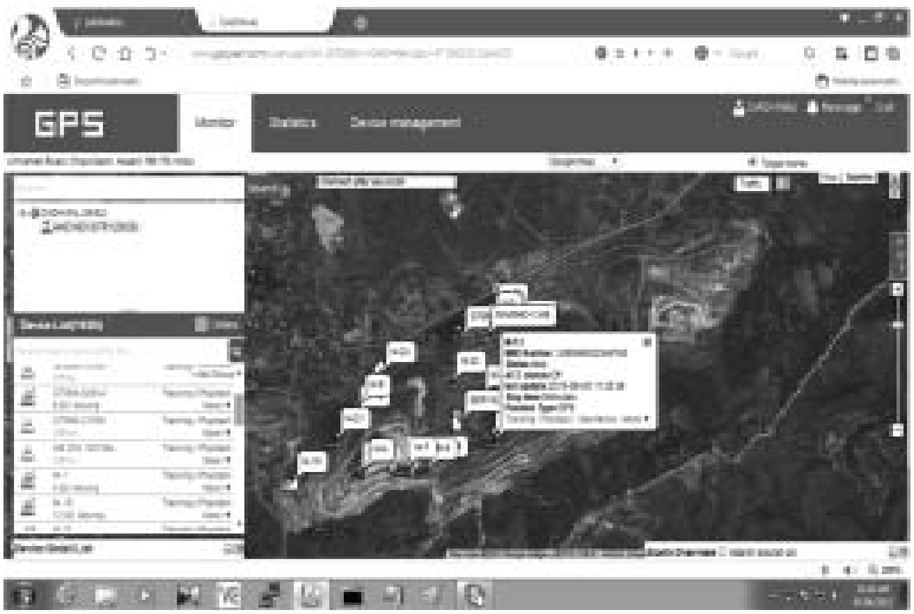

Fig.6 GPS-GSM based vehicle tracking system

terms of latitude and longitude along with its speed and time. The GSM network allows both way communications which is used to alert the drivers for deviating from recommended path or messaging any other information as shown in Fig. 6. GPS receiver records data in offline mode for the areas where GSM coverage is not available (i.e. signal blind zone) and transfers data as soon as it enters within the coverage area.

The hardware interfaces for GPS units have been designed to meet the requirements of National Marine Electronics Association (NMEA). Generally, message received by the GPS is in NMEA message format and NMEA protocol, in which most commonly used protocol is NMEA0183 protocol. GPS sentences begin with different specifications as given in Table 1 (www.etown.edu).

The software programming is done in ‘C’ language. Data (coordinates) received by GPS from the satellites are defined in the software. Decoding the NMEA protocol is the main purpose of developing this software. The mobile number of the user is included in the software programming in order to receive location values from the SIM card which is used in GSM modem. The NMEA protocol consists of a set of messages which are in American Standard Code for Information Interchange (ASCII) character set (Tsui, 2000). GPS receives data and presents it in the form of ASCII comma - delimited message strings. ‘$’ sign is used at the starting of each message. The software protocol consists of the global positioning system fixed data and geographic position in term of latitude/longitude.

The web application represents complete output of the system. In this system two applications have been incorporated that are linked to each other. First one is used to get the initial position of vehicle (starting

TABLE 1: FORMAT OF NMEA MESSAGES

Sentence ID	Description
$GPGGA	GPS fix date
$GPGSA	GPS dilution of precision and activate satellites
$GPGSV	GPS satellite in view
$GPRMC	Recommended minimum specific GPS/transit data
$GPVTG	Track made good and ground speed
$GPMSS	Beacon receiver status
$GPZDA	UTC date/time and local time zone offset
$GPGLL	Geographical position, latitude and longitude

point) and as the system receives different coordinates (longitude and latitude) switching to the next one is done to get the distance travelled between two positions.

3.2.2 Production monitoring module

The task of production monitoring module is to collect data of coal production on regular basis. These data are then analyzed to find out the trend of production. It helps the mine management to make proper planning for achieving their goal of touching the target production by removing the likely impediments in the process. In most of the cases improper utilization of equipment is proved to be a major bottleneck in achieving the target production.

Fig.7 Production monitoring automation system (www.faraz-gostar.com)

Fig.7 shows the production monitoring module layout showing GPS monitoring of dumpers and auxiliary equipment, radio base, dispatch module software, web servers, network servers and client.

3.2.2.1 Equipment optimization systems

It consists of software with a visual representation of equipment activity and performance. Either on a schematic diagram or over-laid on a mine map, the equipment position and status are updated instantaneously providing supervisors with the ability to make informed of decisions based on real-time operational updates (Verma and Bhatia, 2013; www.wencomine.com). Equipment optimization technique is based on timing and every step of mining process requires time for its completion. This technique allows mine process to utilize time and resource to the fullest. Dumper queuing at loading and dumping areas results in lower productivity as well as higher fuel consumption triggering an increase of 50-60% in total mining cost. This necessitates optimization of dumper assignments in real-time by minimizing both truck queuing and shovel hang time.

Fig.8 shows the software application in which various options are provided, namely drag and drop assignments, location and material identity, wait times, travel times, equipment constraints, equipment status, operator ID, fuel hours, engine hours, and the ability to assign activity-based cost codes. All the information are required to monitor and control each aspect of the operation. The dispatch application shows two shovels (0150 and 0080) are working in zone 5 and 7 respectively. The software calculates the estimated time of arrival (ETA) of trucks at loading point. The dispatch application also calculates the average (AVG) wait time for trucks entering stockpile or dumping zone. The module records virtually every relevant detail of each truck's haulage cycle including: the arrival time at shovel, queue time, loading time, location, shovel ID, haulage ID, material, grade, truck size and load tonnage.

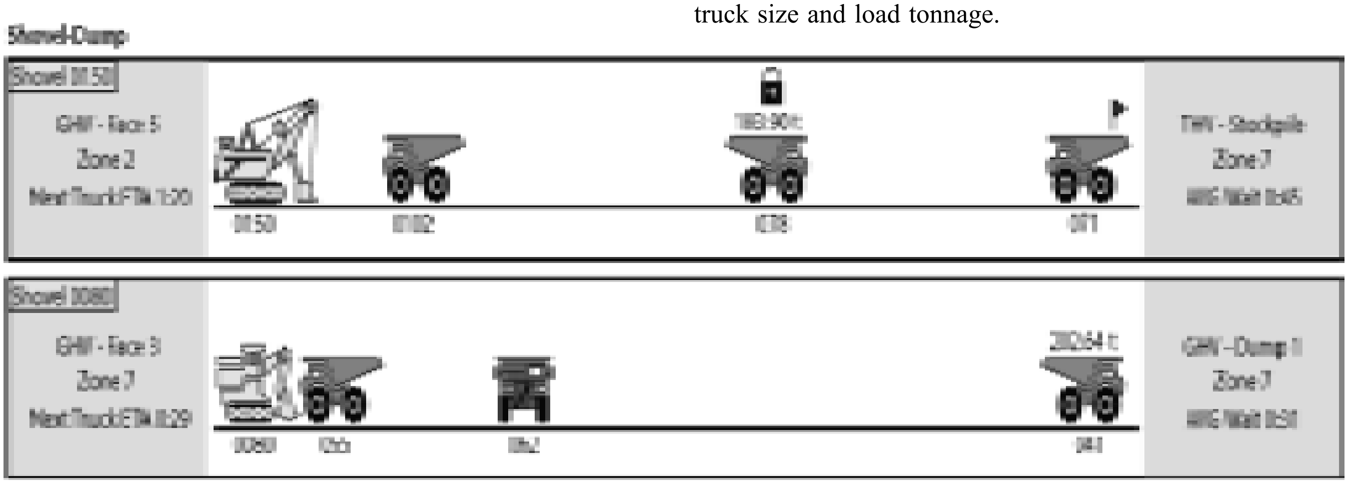

Fig.8 Real time dispatch application for productive information of all equipment in mine

Pit Hour Load

Shift: 01-AUG-2012 Night Shift

Crew: A

Shovel		Total	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00
E301		94	8	9	9	9	9	9	9	9	8	9	6
	Cumulative		8	17	26	35	44	53	62	71	79	88	94
E302		48	4	5	4	5	4	5	4	5	4	5	3
	Cumulative		4	9	13	18	22	27	31	36	40	45	48
E303		62	6	5	7	6	6	6	6	6	6	5	3
	Cumulative		6	11	18	24	30	36	42	48	54	59	62
Total		204	18	19	20	20	19	20	19	20	18	19	12
	Cumulative		18	37	57	77	96	116	135	155	173	192	204

Report generated on: August 1, 2012

Time: 11:37:04 AM

Generated by: SQLSERVER-RM\Administrator

Generated in (seconds): 6

Fig.9 Pit hour load efficiency of different shovels

Fig.9 shows the pit load efficiency of three shovels namely E301, E302 and E303 in night shift. It shows the shovel work categorized in hourly basis and cumulative process of each shovel reports generated by the administrator of concerned authority.

3.2.2.2 Real time payload monitoring

(a) On-board weighbridge

A driver can determine the approximate loaded weight by using an on-board weighing system. This system (www.transportenvironment.org) uses either load cell technology or pressure readings from air suspension to calculate weight on vehicle axles. It consists of several components that work together to form a complete operational system. These are sensors, vehicle unit and interconnecting cables as shown in Fig.10.

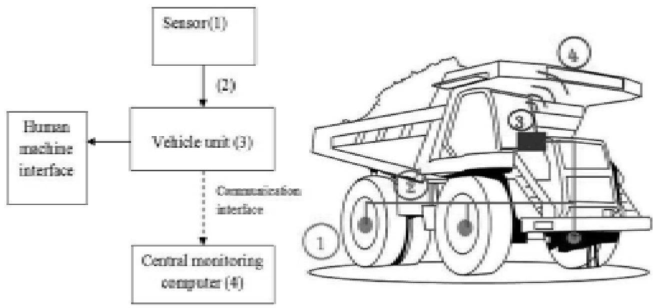

Fig.10 On-board mounted weighbridge

(b) In-motion weighbridge

In-motion weighbridge (www.fhwa.dot.gov) has been designed to measure vehicle's gross weight in its running condition at normal speed over the weigh measuring platform. The vehicle does not require stopping on the measuring platform to get the reading. The system consists of weight sensors, inductive loop detectors and a computer interface as shown in Fig.11.

Fig.11 In-motion weighbridge

The flow chart of production monitoring and equipment optimization module has been shown in Fig.12. The module monitors the activities of dumpers/shovels/auxiliary equipment and make sure that no equipment is in idle state. It also creates a unique ID and assigns a geo-fence virtual path for each truck. The optimization module also has the capability to assign real time work to trucks in working phase. It also generates reports consisting of a number of trips made by each truck per shift/day/month. The module also monitors the production of different grades of coal and generates grade-wise production reports for analyzing the productivity of entire system over a unit period.

3.3 Closed circuit television camera

Closed circuit television (CCTV) camera is used for surveillance of its surrounding including transport system in

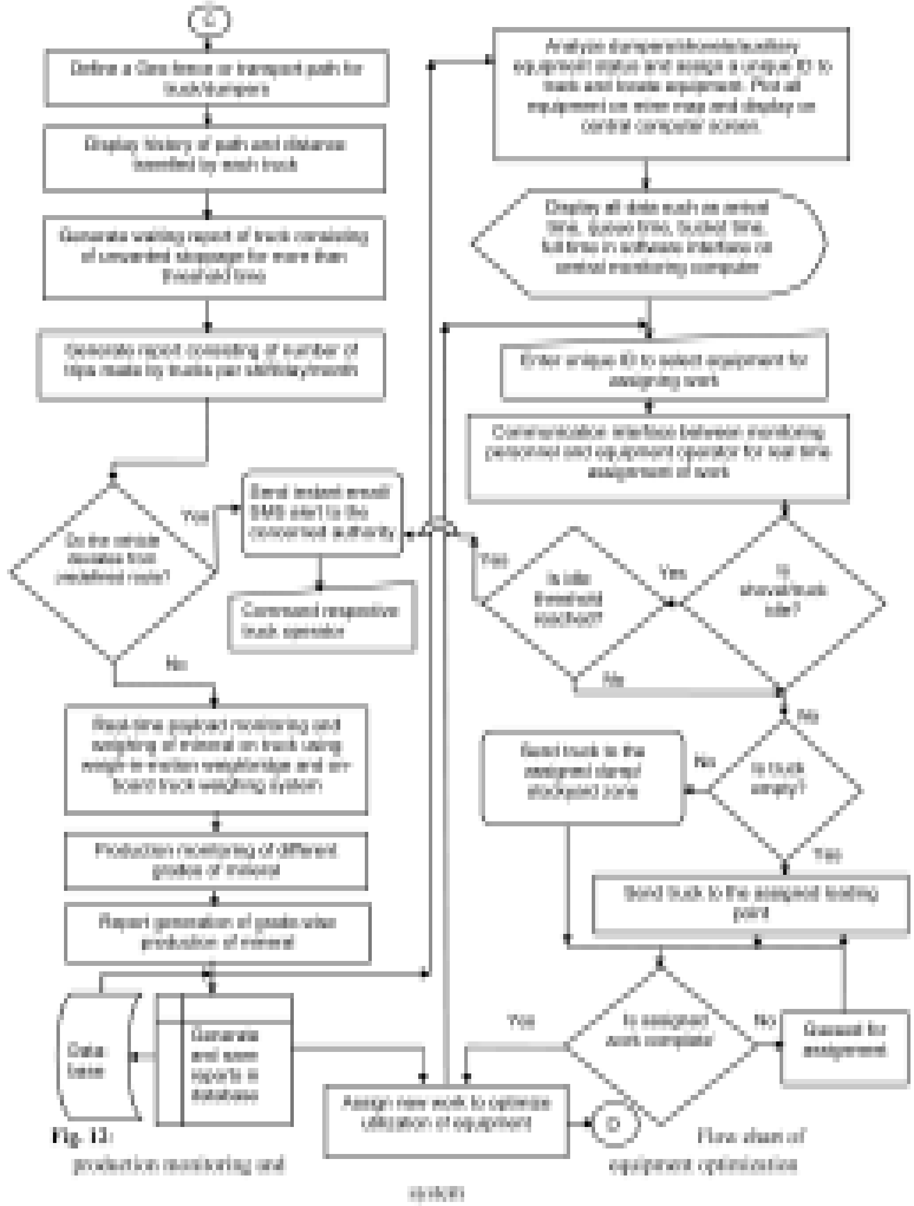

Fig.12 Flow chart of production monitoring and equipment optimization system

mines. It consists of different types of internet protocol (IP) and infrared (IR) cameras like pan, tilt and zoom (PTZ), dome, bullet, etc.

3.4. Periphery surveillance module

This module includes sensors for detecting entry of vehicles into the mine area through unauthorized routes. These sensors generate an electromagnetic field between transmitter and receiver creating an invisible volumetric detection zone. When an intrusion occurs, the electromagnetic field of sensor changes its state. These changes are registered and notified to the server administrator. The types of sensor used in this system are: (a) Anisotropic magnetoresistive (AMR) sensor and (b) Microwave sensor.

3.4.1 Anisotropic magnetoresistive sensor

Magnetoresistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. AMR sensors are directional sensors and provide only an amplitude response to magnetic fields in their sensitive axis. By combining AMR sensors into two or three axis configurations, a two or three dimensional measurement of the magnetic field passing through the sensors is possible with excellent linearity.

Each AMR sensor is installed in all possible unauthorized routes. As the vehicles come into the proximity of the sensor, it detects changes in the vertical and horizontal components of the earth's magnetic field produced by a ferrous metal vehicle as shown in Fig.13. It generates a voltage when a ferromagnetic object perturbs the earth's magnetic field. When the voltage exceeds a predetermined threshold value, the vehicle is detected (www.aerospace.honeywell.com). Each AMR sensor is connected with a sensor node. When the sensor detects an intrusion, the corresponding sensor sends data to control station administrator using wireless sensor network.

3.4.2 Microwave sensor

Microwave radar sensors transmit energy towards an area from overhead or side fire antenna. The transmitted radar energy is controlled by the size and distribution of energy across the aperture of the antenna. According to the Doppler principle, motion of a vehicle in the detection zone causes a shift in frequency of the reflected signal. This is used to detect moving vehicles and to determine their speed. Microwave sensors utilize electromagnetic fields and operate at frequencies starting from 300 MHz up to terahertz range. These are used for periphery surveillance (as shown in Fig.14) particularly to detect moving vehicles.

Fig.15 shows the microwave radar installed in the periphery of Tirap opencast mine of North Eastern Coalfields, Margherita, Assam. Microwave sensors are installed in all possible unauthorized routes. These sensors transmit high frequency microwave signals which are reflected by the

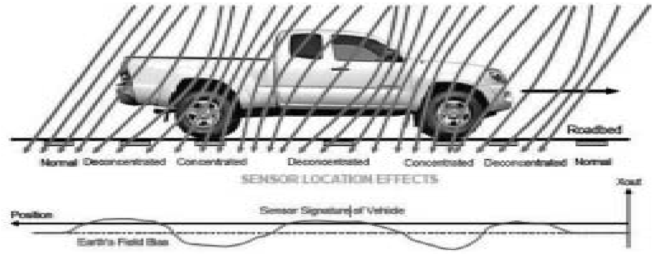

Fig.13 Earth’s magnetic field change in AMR sensor

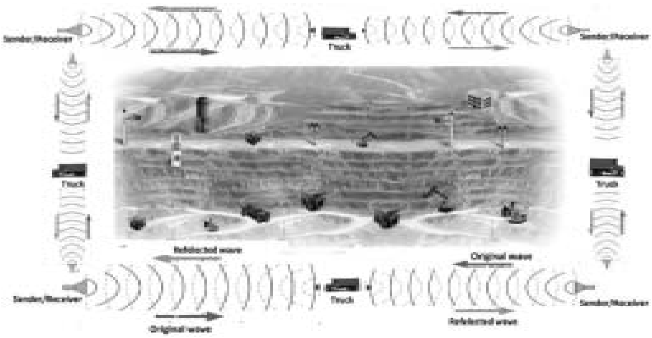

Fig.14 Microwave perimeter detection radar

unauthorized vehicle passing through its detection zone. When a vehicle passes through the antenna beam, a portion of the transmitted energy is reflected back towards the antenna. The energy then enters a receiver where detection is made and vehicle data, such as volume, speed, occupancy and length are calculated. A Doppler shift occurs between emitted and received signal which is used to determine the presence, direction and speed of the vehicle.

The sensor system is mounted in a fixed position overhead or side. Each microwave sensor is connected to other forming a wireless sensor network (WSN). Each such sensor network node has typically several parts: a radio transceiver with an internal antenna or connection to an external antenna, a microcontroller, an electronic circuit for interfacing with the sensors and an energy source. If any unauthorized vehicle is sensed to be entering into the boundary, wireless sensor nodes triggers an alarm and also sends intrusion notification to central monitoring computer. Position of the vehicle is traced by using position of transmitting sensor node. Moreover, long distance PTZ cameras (day/night) are also added into service along with the microwave sensor for making the periphery surveillance more perfect.

3.5 Centralized monitoring station

Centralized monitoring station consists of large digital display, computer, server, GPS antenna, walkie-talkie, alarm, centralized uninterrupted power supply, etc. It is also equipped with software modules to track and perform real-time assignments and operations. Sensor node is also connected to central monitoring station via wireless sensor network. This station performs various tasks such as creation of geo-fencing for each truck, tracking vehicle movement throughout

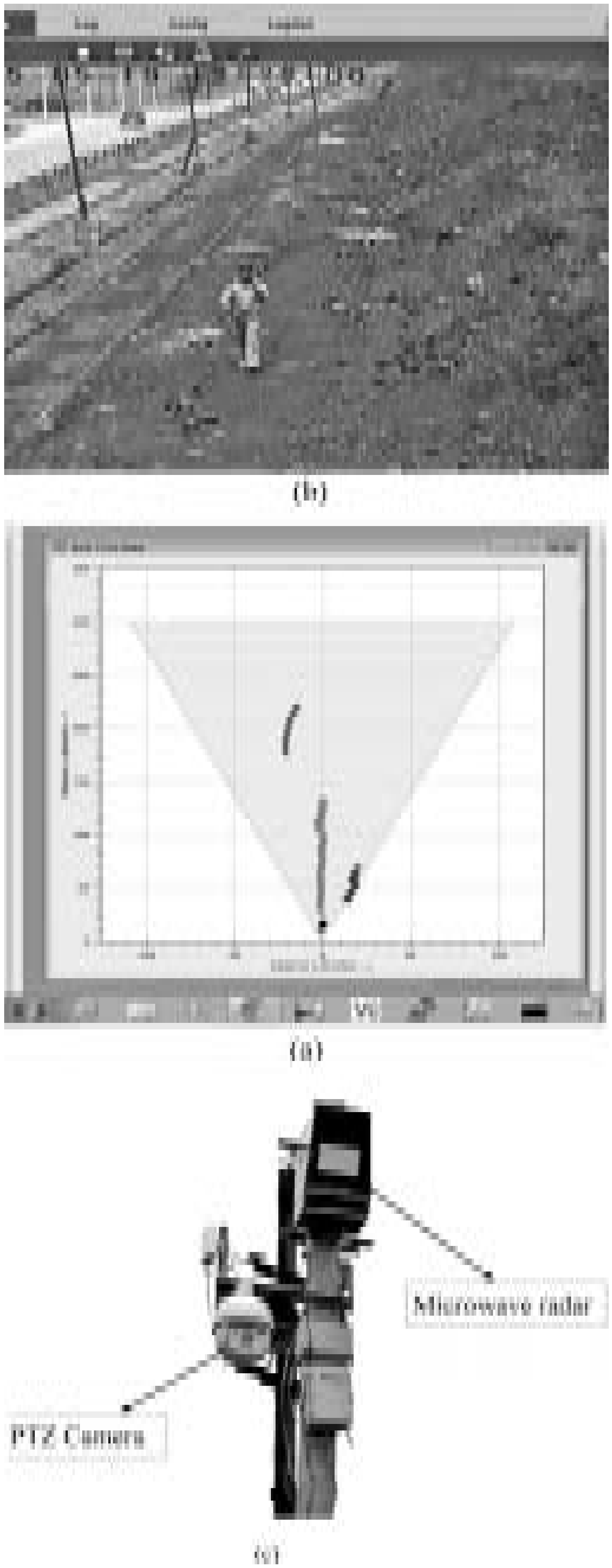

Fig.15 View of periphery surveillance in an opencast mine (a) Camera view (b) Tracker view and (c) View of the installed system

its transportation route, assigning truck in real time, etc. It is also responsible for monitoring operating threshold value for equipment and maintaining database. The monitoring administrator also has the facility to communicate with the truck/shovel operator. The central monitoring operator also generates an audible alarming signal in case of any accidents, mineral theft or illegal activities in mine's excavation area.

4. Conclusions

Coal production and transportation monitoring system is immensely useful for checking overloading of coal on trucks or dumpers and their efficient disposal from a mine site and at the same time averting unauthorized entry of vehicles with the intention of illegal transportation of coal. Hence, it brings substantial economic benefit to the coal producing industry by preventing loss of coal due to illegal transportation and improving the efficiency of its smooth dispatch by optimum use of shovels and dumpers.

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