Discussion on top frame and key technologies of intelligent heavy-duty train

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April 13, 2019

Discussion on top frame and key technologies of intelligent heavy haul train

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ABSTRACT: This paper presents the development of artificial intelligence in the countries of the world and the intelligent monitoring of heavy haul trains in China and abroad. The intelligent monitoring top frame of heavy haul trains is designed from the perspectives of internet of things and big data, and the whole monitoring system is divided into four sections, as on-board monitoring system (heavy haul car), ground monitoring system, car and ground data transmission system (car to ground) and ground data processing center, of which the formation, working principle and key technologies have been explained respectively. It is necessary to monitoring the conditions of heavy trains, such as hunting performance, braking system, bottom door mechanism and couplers, from the view of operation safety and maintenance cost. The last part of the paper presents that BHP company using ore car maintenance model to optimize the maintenance period and apply condition-based maintenance based on big data, which have practical significance for maintenance cost reduction of condition-based maintenance.

1 GENERAL

Since the 21st century, the modern communication and information technology, network technology and control technology is sweeping through all walks of life and is regarded as the fourth industrial revolution by all countries in the world. In 2011, Germany proposed the "Industry 4.0" strategy, and in 2015, Japan proposed the "Robot Strategy", which aims to promote information sharing and realize mass production changing to mass customization. In 2014, General Electric Company, Telephone and Telegraph Company, Intel Corporation and Cisco have jointly established the "Industrial Internet Consortium". In 2015, the State Council of China proposed and issued the "Made in China 2025" development plan of which the purpose is to realize low cost, high efficiency and more safety operation through the support of internet, cloud calculation and big data analysis and management.

For intelligent heavy haul train development, the major heavy haul countries in the world now focus on the existing ground monitoring technologies, integrated with the application of on-board monitoring technologies, to provide diversified and massive data for ground data processing centers to ensure the establishment of model base of critical systems and major components. The combination of model analysis and monitoring data shall help to determine the remaining service life of the components and to achieve the purposes of high safety and efficiency operation with low maintenance cost.

1.1 *Current status of intelligent heavy haul cars abroad*

In the United States, monitoring is mainly based on the ground, and due to high maintenance costs, it is shifting toward the direction of on-board monitoring. Research on on-board monitoring technology is most prominent by GE and AMSTED, who have jointly developed on-board monitoring platforms and modular active intelligent monitoring products, which have been used on about 22,000 wagons owned by UP and the BNSF for trial in the United States, covering the freight cars like container flat cars, refrigerated cars, tank cars, automobile carriers, hazardous chemicals cars, etc. The on-board monitoring content is mainly of cargo tracing, bearing temperature and vibration (acceleration), and also monitoring the internal temperature and humidity of the refrigerated cars and the internal pressure of the tank cars. Up to now, the monitoring system has been placed into service for more than three years by UP, and the entire monitoring system is still under smooth operation.

Australia is a resource-based and heavy haul transportation country, mainly doing ore and coal transportation. In 2012, Rio Tinto began the research of unmanned technology and on-board monitoring technology for heavy haul trains and applied on-board intelligent monitoring technology together with QRRS on the 40-ton axle load stainless steel ore cars developed by QRRS. At the end of 2018, Rio Tinto officially launched the "automatic driving + condition monitoring" automatic drive intelligent train. The on-board monitoring content includes the track condition, train longitudinal force and other parameters, which shall match the bearing temperature and acoustic signals, the temperature and defects of the wheel, the thickness of the brake shoe and the state of the pins collected by the ground monitoring system to serve the safe operation of the trains.

In 2013, the Shift2Rail project presented the idea of sustainable and attractive European freight transportation technology. In May 2018, DB began to use tracking, monitoring and remote information equipment on freight cars. So far, DB has used intelligent monitoring systems on more than 1,000 railway freight cars. The on-board system on the freight car mainly includes the on-board GPS system and various types of sensors. The monitoring content is the loading status of the freight cars (load carried, unbalance loading, etc.), the internal temperature of the refrigerated cars, etc., which can more accurately predict the arrival time of the goods and improve the efficiency of time arrangement.

1.2 *Current status of intelligent heavy haul cars in China*

In China, the intelligent monitoring is mainly based on ground monitoring. The former Ministry of Railways had applied a number of information systems such as Railway Freight Car Technology Management Information System (HMIS) and 5T Railway Vehicle Operation Safety Monitoring System to realize the dynamic monitoring, networked operation, remote monitoring, and information sharing of the ground system for passenger and freight cars to improve the safety and security protections of railway vehicles. In 2017, the Railway Corporation (former Ministry of Railways) proposed the project of developing braking performance monitoring technology against the weak point of braking performance monitoring on the freight car running on Daqin railway line (project number: 2017J004-H). In early December 2018, on-board brake system monitoring system were installed on 66 C80B open top wagons on Daqin railway line for a trial test of 6 month to mainly focus on train pipe pressure, pressure of auxiliary air reservoir and brake cylinder pressure.

2 TOP FRAME DESIGN OF INTELLIGENT HEAVY HAUL FREIGHT TRAIN

The intelligent heavy haul freight train is accomplished through a system platform, namely: Intelligent Monitoring and Health Management Platform (IMHM), which is mainly composed of on-board monitoring systems, vehicle data transmission systems, ground data processing systems and existing ground monitoring system and shall realize the status monitoring, health assessment, fault diagnosis, fault warning, fault prediction and operation and maintenance plan of the train, so as to achieve the goal of health management of railway freight cars. From the view of data flow, the platform can be divided into two categories: “freight car as the monitoring unit” and “freight train as the monitoring unit”, and the principles of ground monitoring system first, minimum energy consumption of on-board monitoring system first, modular unit design of on-board monitoring system first, advance and reliable on-board monitoring system shall be followed.

2.1 *Top frame 1 (freight car as monitoring unit)*

Intelligent Monitoring and Health Management Platform (IMHM) is mainly composed of on-board monitoring systems, vehicle data transmission systems, ground data processing systems and existing ground monitoring system, as shown in the following Figure 1:

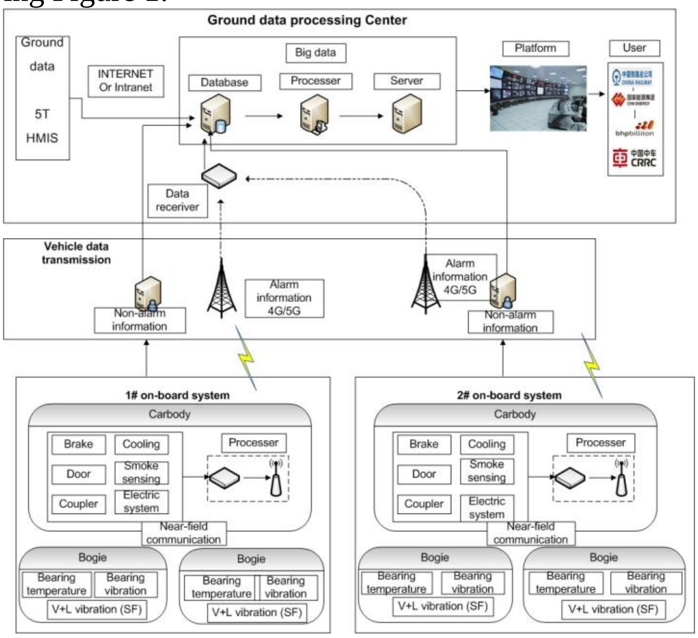

Figure 1. HMHM platform and working procedure

2.1.1 *On-board monitoring system*

The on-board monitoring system is part of the IMHM platform and mounted on each car of the freight train, and mainly consists of vehicle wireless sensor unit (WSN), vehicle gateway (WGW), and GPS or Beidou positioning system module.

Vehicle Wireless Sensor Unit (WSN): mainly consists of sensors, pre-processing modules, storage units, wireless communication modules,and batteries,etc. and responsible for collecting data, storing a small amount of data and pre-processing data (single parameter model data), and regularly exchanged data with the vehicle gateway (WGW) via wireless technology in the form of automatic reporting or passive searching according to the requirements of "Monitoring Data Transmission Protocol";

Vehicle Gateway (WGW): mainly consists of wireless communication module, pre-processing module (multiple parameter model data), storage unit, microwave data transmission module, and battery, etc. and is responsible for automatically receiving data, pre-processing data (multiple parameter model data) and storage data according to the requirements of "Monitoring Data Transmission Protocol". Early warning, alarm, and fault data are sent to the ground data processing center in 4G form, and the original data is sent to the ground data processing center in the form of microwaves.

GPS or Beidou positioning system module: mainly composed of GPS or Beidou positioning system and battery and be responsible for vehicle positioning, running mileage calculation and running speed detection.

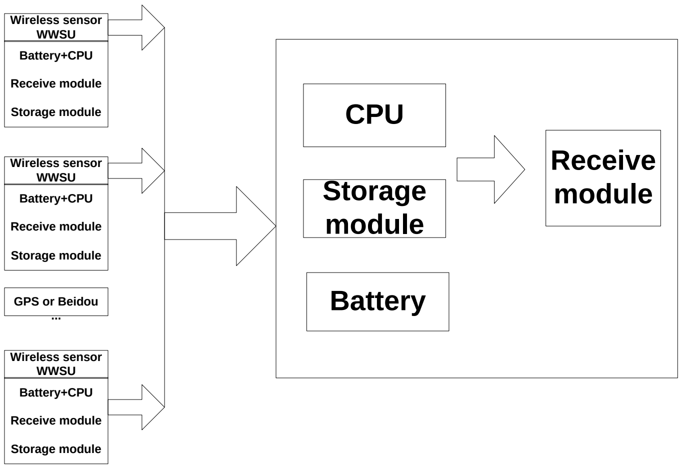

Figure 2. Hardware frame of on-board monitoring system

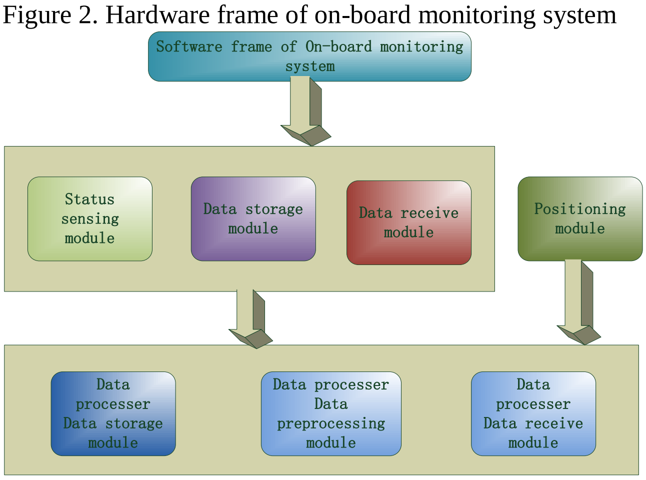

Figure 3. Software frame of on-board monitoring system

2.1.2 *5T Ground data monitoring system*

The 5T ground data (vehicle data captured by the ground monitoring system) monitoring system is part of the IMHM platform. The data is imported into the ground data processing system via the Internet/Intranet network and saved to the database server.

2.1.3 *Vehicle data transmission system*

The vehicle data transmission system is a key part of the IMHM platform for connecting on-board monitoring systems and ground data processing systems. The monitoring data of the vehicle on-board monitoring system is divided into two channels: one is to transmit warning and alarm data to the ground data processing system through 2G/3G/4G network or satellite network for real-time data management (receiving data through the receiving module); the other one is to transmit the original data to the ground data processing system through microwaves (as the data volume is large) and saved to the database server when the train arrived the station.

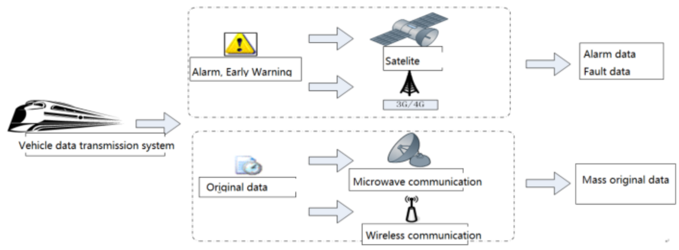

Figure 4. Top frame of on-board data transmission system

2.1.4 *Ground data processing system*

The ground data processing system is the core of the entire vehicle IMHM platform and shall receive real-time data and original data transmitted by the on-board monitoring system and the ground data monitored by the 5T system and act comprehensive analysis, then a mathematical model shall be established to perform health assessment, fault diagnosis, fault warning, fault analysis, fault prediction and operation and maintenance decision on the key systems and main components of the vehicle.

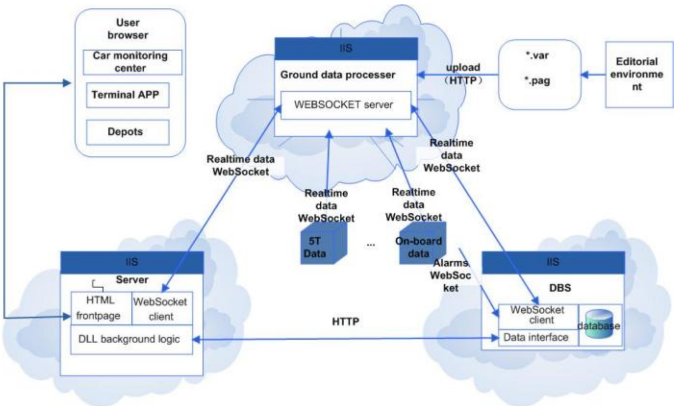

Figure 5. Hardware frame of ground data processing system

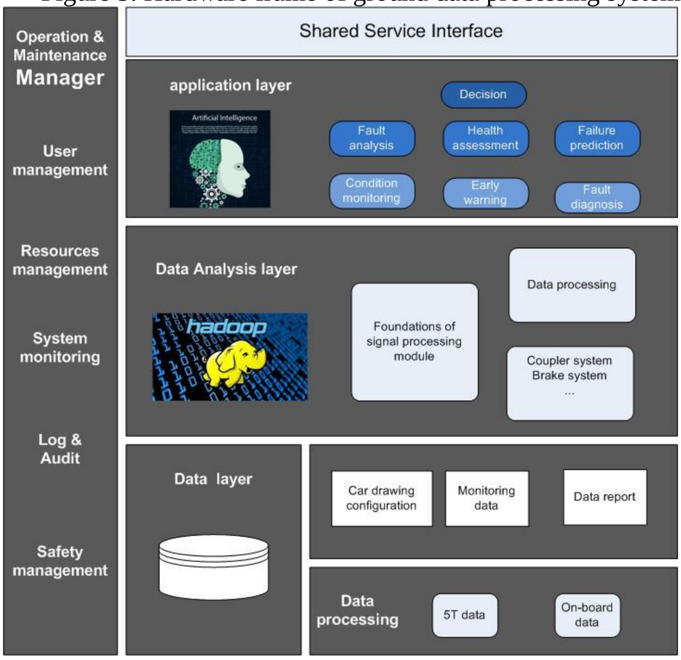

Figure 6. Software of ground data processing system

2.2 *Top frame 2 (freight train as monitoring unit)*

Intelligent Monitoring and Health Management Platform (IMHM) is mainly composed of on-board monitoring systems, vehicle data transmission systems, ground data processing systems and existing ground monitoring system, of which the vehicle data transmission system and ground data processing system is the same as the top frame 1, as shown in the following Figure 7:

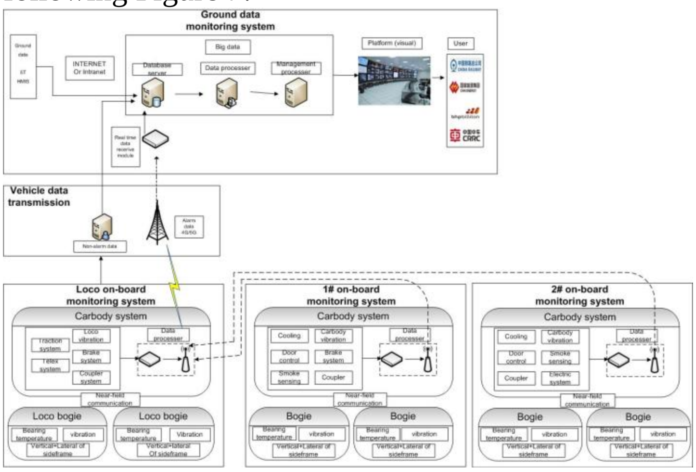

Figure 7. HMHM platform and working procedure

2.2.1 *On-train monitoring system*

On-train monitoring system is part of IMHM and mainly consists of on-train monitoring system and on-board monitoring system being installed on the hauling locomotive and the hauled freight cars. The main formation of on-train monitoring system is train gateway (TGW), and the on-board monitoring system mainly consists of sensing element (WSN) and car gateway (WGW).

Vehicle Gateway (WGW): mainly consists of wireless communication module, storage unit(RAM), and battery, etc. and is responsible for automatically receiving data from WSN and transmit to train gateway (TGW) via wireless technology according to the requirements of “Monitoring Data Transmission Protocol”.

Train Gateway (TGW): mainly consists of wireless communication module, pre-processing module, storage unit, microwave data transmission module, GPS/Beidou positioning system, and battery, etc. and is responsible for automatically receiving data from the WGW, pre-processing data (multiple parameter model data) and storage data according to the requirements of “Monitoring Data Transmission Protocol”. Early warning, alarm, and fault data are sent to the ground data processing center in 4G form, and the original data is sent to the ground data processing center in the form of microwaves.

2.2.2 *5T Ground data monitoring system. Same as Clause 2.1.2.*

2.2.3 *Vehicle data transmission system. Same as clause 2.1.2.*

2.2.4 *Ground data processing system. Same as clause 2.1.3.*

2.3 *Key technology*

According to the above said top frame design, the key technologies shall include:

(1) three levels of IOT freight car platform technology: sensing (on-board monitoring system), internet (vehicle data transmission system), and intelligent application (ground data processing);

(2) distributed computing technology: cloud calculation (ground data processing center)+ edge computing (on-board data processor, and sensing unit);

(3) modularized, low power and active on-board monitoring technology;

(4) reliable network transmission technology for on-board monitoring system and vehicle data transmission system;

(5) fault and life prediction technology based on big data, i.e. to establish model base for key systems or main components through big data analysis to predict their possible fault and life.

3 APPLICATION OF MONITORING AND HEALTH MANAGEMENT PLATFORM

Our company now is developing a monitoring and management platform for a company in China based on the above said top frame to solve the challenges of freight car in service and improve the operation efficiency, details as follows:

3.1 *Main problems of freight cars in service*

In 2017, our investigations on the carbon steel gondola cars and aluminum alloy gondola cars been in service for 8 years held by a Chinese company showed that:
(1) Carbody: the main problems are the steel plate corrosion and bottom door deformation. The corrosion rate of the steel plate is about 0.22-091mm/year; and the replacement ratio of bottom door because of corrosion and deformation is about 34.1%～46.4%.
(2) Bogie: the main problems are bearing failure and to fast brake shoe consumption.The failure ratio of bearing cage is 17.2%, and the replacement frequency of brake shoe is about every 4 to 5 months.
(3) Braking system: Brake valve and empty/load valve tend to fail. Brake valve failure shared 42% of total brake cut-off cases, and empty/load valve shared 9.5% of the total brake cut-off cases.
(4) Draw gear system: the crack rate of coupler body and knuckle is high. The cracking ratio of coupler body is 3.2-17%, mainly happened on the 13 series coupler body; the cracking ratio of knuckles is 5.1-9.68%, mainly happened on the knuckles used on 70t freight cars.

3.2 *Determination of major monitoring items*

The investigation results showed that the carbody corrosion, bottom door deformation and brake shoe failure can be identified by the TFDS system, the bogie bearing failure can be identified by the THDS system, but the brake system failure and coupler/knuckle cracking can not be identified by ground 5T system, therefore, the following investigations are recommended:

(1) Brake system failure monitoring. The failed wagon can be identified via the monitoring of brake cylinder pressure, brake pipe pressure and the brake cylinder travel, and the main valve or the empty/load valve failure can also be determined, which shall help ease the labor intensity of the routine maintenance operators.

(2) Coupler and knuckle monitoring. Since the upper and lower pulling lugs and the palm of the coupler and the knuckle cannot be equipped with sensors, it is necessary to monitor the stress data of the same sensitive parts as the above mentioned three parts to obtain the stress change of the sensitive parts and the fracture rule of the knuckle by big data analysis, then a mathematical model of the knuckle fracture can be made and verified to achieve the goal of monitoring the coupler and the knuckle.

(3) From the safety point of view, it is necessary to carry out monitoring, analysis and research on the hunting performance and bottom door mechanism. of freight cars.
The following monitoring items have been selected:

SN.	Monitoring point	Monitoring time	Monitoring triggered by	Indications	communication
1	Bottom door	Loading/ Unloading	Top cover	Mechanism position	LoRa
2	Bottom door	Loading/ Unloading	Top cover	Mechanism position	LoRa
3	Bottom door	Loading/ Unloading	Top cover	Mechanism position	LoRa
4	Brake cylinder pressure	Whole journey	Braking application	Pressure value	LoRa
5	Brake pipe pressure	Whole journey	Braking application	Pressure value	LoRa
6	Piston	Braking	Braking application	Piston travel	LoRa
7	Piston	Braking	Braking application	Piston travel	LoRa
8	Carbody vibration	Running	Running	Carbody lateral acceleration	LoRa
9	Coupler stress	Running	Continuous	Stress	LoRa

As the above said project is undergoing, the relevant monitoring data and analysis results can only be available when the project is finished.

4 BIG DATA ANALYSIS SUPPORT FOR CONDITION-BASED MAINTENANCE

At the end of twentieth century, BHP Australia had finished the development of ore car maintenance management model based on the data collected from the 17 kinds of ore cars since 1989. The ore car maintenance management model relates directly to the failure ratio of components, ore car components current conditions, repair information of the components, cost and financial factors, and the nominated maintenance period of the components, and the said model can also provide the data information, such as maintenance period (cycles), component failure ratio(%), quantity of annual repaired components, annual maintenance cost($), annual risk cost($), and annual total maintenance cost($), to help determine the best maintenance plan and the economy results brought by the optimized measures to realize precautionary measures in maintenance.

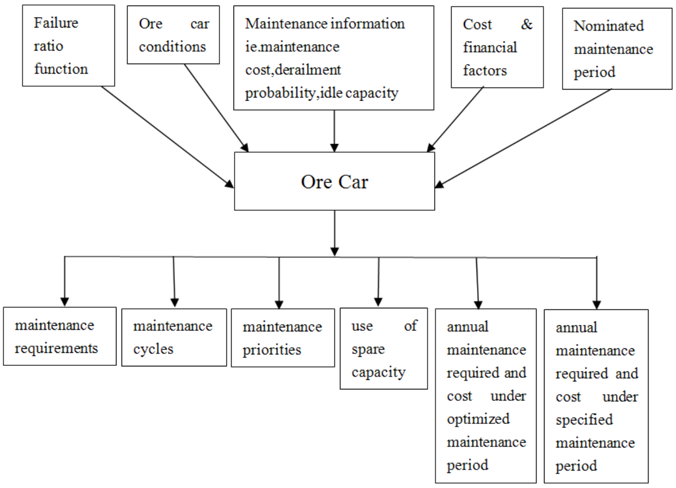

Figure 8. Ore car maintenance model of BHP Australia

With the development of sensing technology, IT, network technology and big data, we can continuously establish and complete the data model of key components via the statistics of component conditions, big data analysis, replacement period of main component, and the relevant running mileage and track conditions, to form the model base to help predict the remaining life and possible failure time of the components and provide theoretical support for condition-based maintenance.

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