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A case study of Product-Service integration for Train Braking Systems

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Abstract

A product service system requires coordinated approach from multiple stakeholder groups. Industry, government, and civil society must work together to create and promote the deployment and smooth operation of these systems for a more sustainable economy. The train braking system problem areas such as failure detection, big data collection and sensor-based degradation monitoring have created opportunities for researchers to create jobs in the service sector. The paper aims to design product-service integration train braking system as a big data component with combination of dataset, volume, speed, and data diversity. The big data potentials and analysis using "V" model for train brakes integration and ishikawa diagram for the electro-pneumatic brake system that is applicable to the railcar brakes manufacturing industries fuse railcar's sensory components innovation to market. This is where advanced analysis to examine the available data and organize it using advanced visualization techniques.

Keywords: Product Service System, Internet of Things, Servitisation, FMEA, Sensors, Integration;

1. Introduction

Sensors analysis as a tool that can be used to analyse the degradation of train braking system. However, many railway transportation problems are caused by brake system failure [1]. Increase in safety and efficiency can be obtained through maintenance tasks optimization. The research focuses on a Tier 1 rail company consortium with the mandate to replace South Africa's outdated rolling stock by delivering the trains of the future. Multiple train crashes have been recorded on the Gauteng province region in South Africa railway are related to signalling and brake failure after investigation. The energy consumption in a single braking attempt is very high with high carbon emission and cost. The advances in concepts and technologies, maintenance and control system integration advances, production and information technology are areas in which concepts are drawn with complementary areas of new technologies providing scalable solutions to problems that could not be solved historically [2].

The electro-pneumatic brake systems are generally used for railway vehicles. These systems are heavy-duty units subjected to higher contact pressures, temperatures, frictions and moisture. Such operating conditions result in serious wear of the brake system components and leads to frequent changes of the brake blocks or discs. Developing an intelligent transport systems for predicting train driver behaviour is critical to ensuring safe travel and braking, while the mechanical energy of the train bogie are transformed into thermal energy [3] or converted to the electrical energy by regenerative braking to reduce the total energy cost [4] with dissipated energy to environment.

In integrated systems, the overall architecture is very important, because the traditional boundaries have been blurred or completely removed. In recent years, the cost of microelectronic components has fallen and continues to fall with digital electronics penetrating the sensors, actuators, transmitters, and controllers of industrial control equipment. Such electronic equipment, previously considered to be discrete entities, are connected through digital networks to permit communication between devices in the automation system. The work of [5] on Product-Service Systems (PSS) across Life Cycle Novel Tools for PSS expounds on the tools to support effective engineering of services around such products are still rare. The paper aims to design product-service integration framework design for train braking system as a big data component with combination of dataset, volume, speed, and data diversity. The paper is organize as follows: Section 2 state of the art in theory; Section 3 describes the Product Service System case study. Section 4 presents theory and practice; and Section 5 concludes the paper with some perspectives and future work.

2. State of the art in theory and practice

The integration of monitoring equipment and maintenance systems can be used to detect rail car failures and to reduce manual inspection requirements of the national safety regulatory agency. These elements include products (hardware, software, and firmware), processes, people, information, technology, equipment, services, and other support elements [6]. Combining process information with expert system vibration analysis and wear analysis improves the accuracy of fault detection of rotating machinery and remote monitoring of trains while in operation. The use of integration technology in braking is critical to ensuring efficient systems [7]:

This integration is useful for monitoring, quality, programming, and remote monitoring of electronic devices and controls for data acquisition in high voltage networks. Distribution grids are distinguished from transmission grids by voltage level and topology [8]. Lower voltages are used in distribution networks because lower voltages require less spacing. The train has an air supply system built into the bogie of the train. This includes a compressor with air trapped between the two rotating screws. The shape of the screw is designed to reduce the available space and increase the pressure. One unit is sufficient to cover the normal air consumption of a train (suspension, brakes, wipers, pantographs, toilets, horns). Pressure adjustment between 8.5 bar and 10 bar. The brake system consists of two different parts: the brake control system and the brake actuation system. The brake control system, including the brake control panel, interprets and responds to signals from the TCMS, making the target brake pressure available in the brake actuation system [9]. The creation of service of brakes embedded sensor elements, through data processing and transmission communicating. While IoT for brakes health assessment, compare, prediction, user relationship and zigbee wireless communication, with informed decisions to the manufacturing processes are presented in figure 3, is the product life cycle through a co creation, integration and operation.

Surprisingly, unforeseen incidents, poor design issues, failure of train systems, improper use or misuse of the system, the effect of such safety issues negatively influences system values and discards quality. As connectivity to the Internet grows with a smart industry outlook, the side effects of these surprises may become large scale and complex [10]. However, the risks must be reduced to a manageable level. This encourages the goal-oriented approach which imposes more freedom and more responsibility on the rail industry. The product and service integration methodology consists of components that are linked by the infrastructure, which is the coupling element between the product and service elements. Infrastructure as a service (IaaS), which forms the server storage network consisting of data centres, hardware, virtual server space, bandwidth, and cloud hosting. The braking system is a critical element of the bogie in the train with the objective to ensure a safe conversion of kinematic to potential energy. Manufacturing industry faces a trend of servitization [11]: numerous manufacturing companies' business offerings have become a combination or an integration of physical products and services. Potential, often still unexploited, innovative value propositions enabled through Smart PSS are listed in [12]: for instance, smart production and smart inspection during the manufacturing stage; smart tracing and quality assurance during logistics; smart self- and context-aware, adaptive performance during use; smart sorting and disassembly for a better end-of-life performance.

3. Method

3.1 V model

The V model for the railway industry [13] reveals that the focus of its right section falls on integration. Figure 1 presents a V model which can be used for the brakes integration. Integration, acceptance and validation are the main areas on the right of the diagram. Engineers and IT specialists assume that the realisation and integration will be realised according to their plans in the design phase, but experience shows that is not the case and unexpected problems may appear at the integration phase. The installation of new technology into new trains may result in integration issues. The experience shows that integration is not a clear-cut process resulting in cost reduction, delay or concerns in the project.

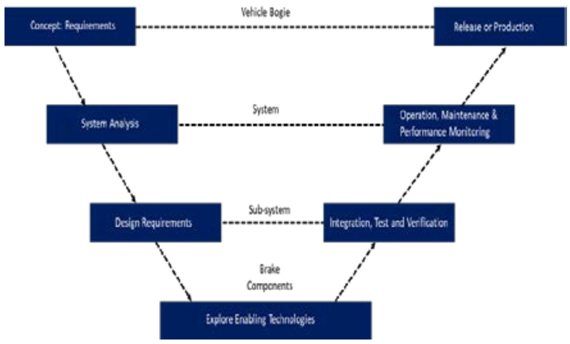

Fig. 1. The "V" model for train brakes integration

Companies are opting for service orientation of their organisation because they provide continuous revenue streams, have higher profit margins, and require fewer assets than manufacturing companies. A service-oriented organisation with multiple revenue streams obtained by servicing represents ten to thirty times the value of new product sales. To revitalize railway systems into smarter machines, science needs to be further advanced by addressing some of the basic issues that Lee (2014) classifies into five different categories [14]. The braking capability needs to apply the required force to stop the train over a minimum distance.

3.2 Ishikawa diagram

We used the ishikawa diagram in figure 3 to determine the causes of the failure of the train braking system. The diagram works as a tool to analyse and diagnose the failures that occur from the train control system. Kimita et al. [15] used FMEA as a concept to design a highly reliable PSS. They [16] propose a modified FMEA to improve circulation from the viewpoint of the system. This is achieved by adding another column to FMEA called "causality". In this version of FMEA, the designer also considers whether one failure mode affects another and calculates the "net cause or effect" for each failure mode. This value is calculated using the method of the Decision Testing and Evaluation Institute (DEMATEL).

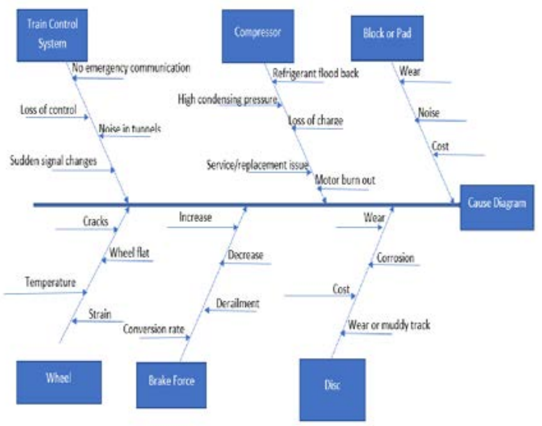

Fig. 2. Ishikawa diagram for the electro-pneumatic brake system

The components for the train brake systems are depicted in figure 2: Ishikawa diagram for the electro-pneumatic brake system and presented as follows:

• Train Control System – The drivers of trains require a high level of mental concentration to ensure that passengers arrive at their destination safely. The irregular working hours that drivers endure require them to get enough rest before the shift begins. When the train passes through tunnels, the noise has a damaging effect on the hearing ability of the drivers. The lack of emergency communication and sudden signal changes in the driver's cabin can lead to an accident with other trains route.

• Compressor – The compressor supplies air to the doors and the braking system of the train. The high temperatures in the system can break down the motor winding insulation of the compressor. Each car has its own compressor that regulates the air flow of which high condensing pressures can lead to damage. The motor running the compressor can burn out, thus shutting down the air supply in the rail car.

• Block / Pads – The braking blocks and pads can wear out quickly which means that constant replacement is necessary which is costly exercise for the company. When the brake pads are worn, they tend to make a noise signifying the end of their life.

• Wheels – The wheels of the train can be derailed causing the train to run off the rails. Although this is temporary, it can pose danger to the health and safety of the passengers. Derailment can be caused by objects that lie in the path of the train, broken rails, and mechanical failure of the wheels. A flat wheel is a fault in shape of a railroad wheel.

• Brake force – The force applied by the train driver needs to be sufficient to cause the train to decelerate until the train comes to a halt. A force will facilitate the conversion from kinematic energy to potential or heat energy.

• Discs –In comparison with the brake pads, the discs take longer to wear out. There are various measures to ensure that rust does not affect the surface. The environment in which braking happens affects the process. Replacement of the discs can be costly.

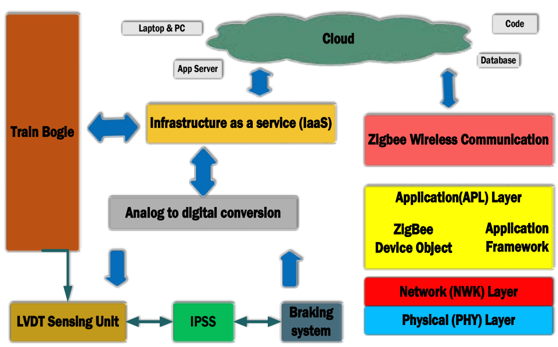

Fig. 3. Product life cycle through a co-creation, integration, and operation

There is currently no way to confirm that the brakes press or release, as in cars. The only way to do so is to perform a visual inspection during the routine brake inspection before the train leaves the terminal [17]. This method can identify multiple problems, but many problems are overlooked or develop once the train is running; a stuck brake is considered a major problem in the rail industry. This application requires an inexpensive, self-powered wireless sensor element [18]. To meet the requirements of this work, we hope to develop a product consisting of three subsystems, namely a sensor to measure force, a wireless platform to communicate statistical data so that some actions can be taken, and a device to collect the energy data so that the maintenance system is not affected.

4. Product-Service Integrated Monitoring System

Revatilization of the rail sector from today's status into more efficient transport requires further advancement in the science by tackling several fundamental issues, divided into five distinct categories [19]:

4.1 Manager and train driver interaction

The train driver operates the train as the manager, and the supervisor is responsible for designing the logistics schedule for the operator and the train. The determination of the health of train components is a very important factor for operators to communicate truck failures to managers. The product service system takes advantage of this gap, even if the hidden problems on the railway will be designed around information generation algorithms to detect and solve the problem of machine degradation and component wear on the factory floor.

4.2 Train fleet

It is very important that identical train brakes are exposed to completely different working conditions for different tasks. The health management method uses these identical train brakes for fleets when storing valuable knowledge drawn from various instances. Additional analysis of the prognostic health management algorithm is an adaptive and effective way to manage, classify and handle data. Since the train brake with a similar operating mechanism may be exposed to different working conditions, one can draw conclusions from the data. The data can be analysed to better understand the health condition of the brakes.

4.3 Brakes and process

Brake quality can provide information for system control, which can be used to improve scheduling of the manufacturing process. The feedback loop used to monitor quality is not available and needs further study. The feedback loop is a predictive health management analysis engine that can capture these failure characteristics from multiple wagons to enhance its failure detection and estimation capabilities.

4.4 Big data and cloud

The importance of using the flexibility and capabilities provided by cloud computing is inevitable but adjusting prediction and health management algorithms to effectively implement current data management techniques requires further research and improvement. There are many data sources available to provide cost-effective information about different aspects of truck brakes. In the brake upgrade phase, it is an important research topic to use data to understand the current situation and detect faults and failures.

4.5 Sensor and controller network

The sensor failure and degradation can also send an incorrect reading to analyse the algorithm, which will result in false results. Most predictive health management strategies can access asset data only for objectives. Asset data can be affected by the readability of sensory data and the system as well as provide adequate information and prediction results for modern brakes. However, there is much information that should be considered in the current implementation of the forecast management method. It is the same as evaluation of a fleet of brakes, the same historical data of the life cycle of the brake and system configuration, and there are almost no examples of ignoring most of the data.

The product developed in this study may be a system consisting of three main subsystems: sensing, wireless network, and energy harvester. The purpose of having a detector is to measure brake forces. It can be installed and applied where the magnitude of the forces have to be measured, in this case, the brake beam of the bogie. Furthermore, besides using it for brake forces, other application areas include temperature, velocity and displacement. The system can be used in insulating the bogie and observing the onset of mechanical failure [20].

To meet cost targets, smart sensors can be built from consumer electronics products off the shelf. These estimates include isolating the system by encapsulating all the electronic components to withstand the conditions of the under-vehicle environment. A car usually requires four sensors, one of which acts as a router, and 24 sensors are required for the entire train.

4.5.1 Installation

A brake beam is crosswise extension member of the brake rigging that distributes the force from the master cylinder to the brake blocks on either side of the wheelset. With the new technology, the brake beam of each car can be equipped with a sensing element equipped with a strain gauge. The degree and direction of deformation provides a direct indication of the braking force applied to the wheel.

Fig. 4. Brake beam

If the brakes are stress-free, the stress value should be close to zero, and if they are applied so that the shoe presses on the wheel, the stress greater than zero, constructed according to the amount of braking force applied. This is not just one mensuration of the hydraulic brake cylinder force or displacement; this method will offer information for every wagon, wheelset, and maybe even every wheel, depending on the number of sensors a personal user needs to apply. It is feasible to measure the brake beam force and calculate the brake stress by using the existing technology and structure. However, these systems are expensive and access to the equipment is not easy. Installation could cost thousands of rands. Thee power generation is such that the batteries need replacement monthly. The available measurement methods make the brake beam monitor too expensive and a different method must be found. Our goal was thus to provide a framework that would lead to the development of low-cost devices to reduce the maintenance costs. This is most feasible by using consumer information rather than studies and engineering technology.

Fig. 5. Sensor mounted on a brake beam

The sensor is fixed to the beam using physical bolts to reduce installation costs. A portable stud welder to connect the sensor is used (Figure 5). This work can be performed by semi-skilled workers and does not require qualified technicians to immediately apply strain gauges to the brake beam. Single car sensors are configured directly in the local area network (LAN). The sensor nodes are configured in a star shape for optimal communication with other sensors and routers on the same rail car. This is configured throughout the initial installation process. Each sensor contains a unique identifier. One of the benefits of the remote monitoring and braking system networked sensors is that by providing an independent measurement of the braking force applied to the entire train, the improved stopping distance calculation will be modified. Rather than relying on average train stopping distances or applied mathematical estimation, the stopping performance of each train can be calculated during the initial braking test. Algorithms related to estimating the stopping distance can be mechanically updated each time that braking is applied.

4.5.2 Transmission elements

If the brake is applied with a comfortable force, the wheel may not turn a little, creating a flat spot on the wheel because it will slide over the head of the rail. The slipcovers are the source of many problems. Overheating can cause a layer of brittle solid solution to form, which can lead to premature wheel failure. Flat spots will undoubtedly bring about an important dynamic quality in the structure of the track, considering the size of the flat terrain. Therefore, if protruding brakes are detected before the brakes can cause injury, each vehicle would have a huge advantage and keeps track of safety and performance.

4.5.3 Data collection

Zigbee wireless transceivers use a powerful mesh network protocol to provide communication between smart sensors. It is an analogue electronic module and processor, which controls the sensor information extraction activity and provides signal adjustment for the tension and acceleration sensor. The Internet of things allows one to keep online records, samples and analytics while documenting the collected information for eventual transfer for analysis.

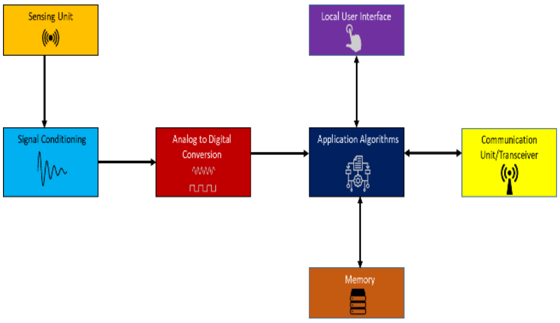

Fig. 6. Building blocks for smart sensor

5. Results and Conclusions

Figure 4 show a proposed PSS framework design for the maintenance of the braking system. A theme of the rail transport industry is the use of sensors, computers and virtual communications to collect, process and disseminate statistical data to improve the safety, security and operational efficiency of railways. It combines the three elements of the computer, sensor technology, and virtual communication in one low-cost consolidation unit. By analysing big data researchers, train technicians, operators, and passengers can learn more about train operations and schedules. Data is exchanged through embedded sensor applications to understand product degradation and aid timeous service interventions.

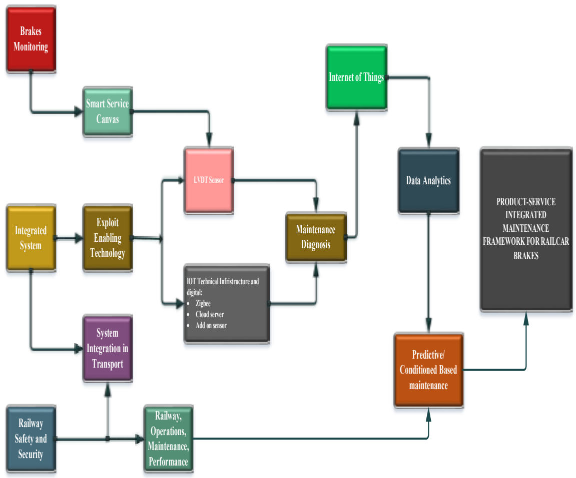

Fig 7. Product-Service integration framework design for train braking system maintenance system

This contribution describes the further development of a modified PSS tool to support the development of PSS integration in rail components based on insights from the application in a case company. The developed V model can for railcar brakes can further help researchers to decompose system requirements and integrate at a bogie level down to a component. The proposed PSS-FMEA methodology was found to be effective and supporting in the process of PSS development. We have introduced a framework that combines rail vehicle brake detection units and service design technology with the ultimate goal of creating an innovative approach to the organization. The framework facilitates strong connections between process owners, users, and the technical context of services. Service design is now the focus of the electronic component manufacturing industry and is widely used in railway vehicles and other industries. However, the use of industrial sensors greatly increases data collection on trucks.

6. License

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