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Condition monitoring for system performance

Şenol Erdoğan* and Çetin Tekin*

*TCDD, Ankara, Turkey

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ABSTRACT

Damage that arises from wheels and journal bearings has a significant effect on railway operational and maintenance cost. In this paper, a special condition monitoring system for wheel health has been investigated with respect to system performance. The assessment includes fundamentals of system engineering and interactions between assets, environment, human factors and users with evaluation of dependability and risk. General concepts of the wheel inspection systems are to measure geometric parameter of the wheel and to detect wear and give alarms in case of fault. The system must provide thickness, height and width of the flange, differences between the flanges, thickness of the rim, tread hollow, full wheel profile or equivalent conicity estimation and some additional measurements, such as wheel and axle box temperature detection. In future, railway maintenance approaches are changing from preventive or failure based maintenance to condition based maintenance. Condition monitoring system has been used many application areas and will continue to perform service in new implementation to achieve ever better performance, it is necessary to evaluate the algorithm used for detect potential multifunction and failing components.

1. Introduction

1.1. Background

The railway is the complex transport system because of the widespread assets and staff, tightly coupled equipment. Inherent complexity is not only one side of the operational issue but also new trend environmental attentions and political views in terms of passenger transfers and sustainable economic development consist of the cost and climate policy. Despite this high level complexity, the operating company should run the system in a dependable way 24 h/day, 7 days and 52 weeks.

As passenger comfort, punctuality of service and safety demands force railway industry to find new, lower cost and reliable techniques for sustainable train maintenance and operation. Condition monitoring is one of the latest technologies that put forward new proposals for real time inspection to allow early, cost effective and reliable detection of faults.

1.2. Justification

According to Bryan et al., (2010) main objectives of condition monitoring systems are to reduce derailments which comprise of track and equipment damages, injuries and mainline delay, terminal dwell time and in-service failures respectively. In as much as over 1340 equipment are resulted with damages which have a nearly $340 million caused by derailments that are stemmed from wheels, journal bearings and truck components by %78 from 1999 to 2008 in US Class-1 railroads (Bryan W.et al., 2010). This figure shows the condition based maintenance importance to understand average potential saving over $100 million.

1.3. Literature Review

Condition monitoring systems in railway has a value of rapidly rising. According to Robert et al. (2009) while the number of condition monitoring systems were 25 and as a cost of $5 million in 1998 it had been invested $75 million for 400 condition monitoring implementations in 2008 in USA. This number shows the demand of the condition monitoring systems for system performance.

A review of non-destructive testing of rails in terms of state and future development is argued by Papaellas et al. (2008). They found that non inspection techniques could not be applied by oneself expediently it must contain a combination of process because of the advantages and drawbacks. Delprete and Rosso (2009) stated an easy instrument and methodology for rail condition monitoring and

* Corresponding author. *E-mail address: senolerdogan@tcdd.gov.tr* (Ş. Erdoğan).

presented a simple transducer (MPQY) measuring lateral and vertical forces therefore it could be possible to estimate life cycle of the rail using of damage model. In addition, this transducer could be identified for ballast behaviour in the way of ballast maintenance and train safety.

Some concepts and techniques were investigated by Goodall and Roberts in 2006. The paper provided different kinds of possible solutions for condition monitoring systems for railway industry which needs to more integrity and condition based maintenance for crucial points of equipment in the way of safety. Hamdi et al. (2005) observed condition monitor systems and fault diagnosis of electrical motors which was a review study of various types of faults and signatures and their diagnosis.

Jardine (2002) suggested optimum condition monitoring system an reported the important economic benefits related with this new optimum condition monitoring system. Condition monitoring of point mechanism was concerned by Marquez et al., (2009) and they discussed a review of predictive fault detection and diagnosis in any specific case with combination of qualitative and quantitative techniques. Barke and Chiu (2005) reported a review of structural health monitoring of railway systems and defined detection methods and parameters with their measurable effects. Functional analysis and visual monitoring of cross levelling case study were put forwarded by Silmon and Roberts (2010) and Xue et al. (2008) respectively. Both of the studies introduced inspection method of railway crossing obstacle and functional analysis.

2. Critical Role of Wheel-Rail Interface

2.1. Human Factor and the Organisational Behaviour Analysis

In recent years, with development technology, equipment integration dependability has increased because of the monitoring system features. However, human skills and behaviours have not been changed despite the increasing rules and regulations.

A dependable railway includes reliable system operations with availability in a safe way which contains always human errors and risk assessments for interface points. It has been clearly identified which point or which boundary covers the system safety conditions and what are the severities of changing the level of the safety points. Human play an important role between the connection points of systems and affect organisational structure and behaviour.

If the organisational structure is evaluated in terms of system performance output and safety issue the most important feature can be seen as people oriented clearly. Figure 1 shows the simple people oriented railway structure.

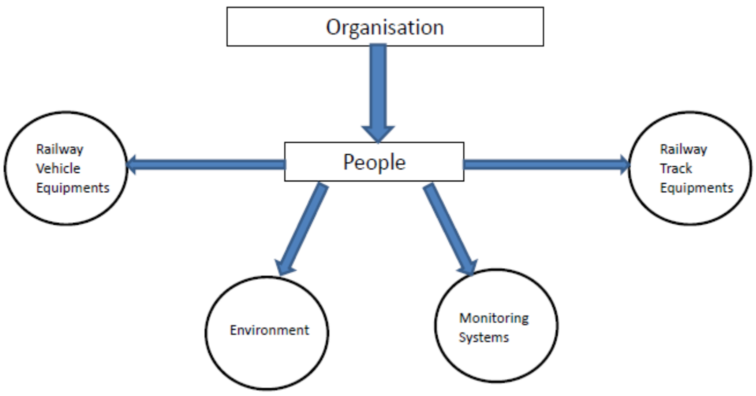

Figure 1. A simple railway organisational structure (By Author)

As is seen from the figure people always stand the centre of the system and control the parameters to take measurable and usable data for system efficiency. This structure can be controlled with user interface. Figure 2 describes the control points of the system with user interface which must be placed correctly or arranged the distance between people and equipment for system performance and safety. According to Wilson (2006) “The capacity, reliability, and safety of the railway may improve dramatically if better sensor-based inspection technology, greater functionality in road/rail vehicle and engineering trains, and improved design of track workers’ tools and equipment are deployed. To be effective, the design of all of these new technical systems must fit the real needs and capabilities of their users and must be human-centred”.

As it is seen from this point, it can be reached a high reliable and safe train operation with railway wheel inspection if the all new equipment are run properly in an effective way with human centred.

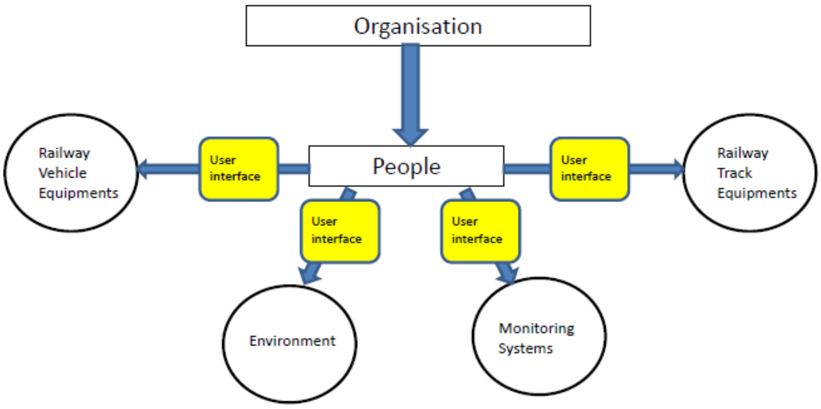

Figure 2. People oriented user interface structure (By Author)

3. Wheel Inspection System as a Case Study

The freight transportation with railways in a high traffic loads has several problems to check wagons and maintenance arrangements. The profile and damaging points of the wheel is important for long articulated trains in derailment times. Because of the fact that flange sizes and estimation of the wheel conicity or wheel and axle box temperature must be controlled periodically. Controlling these figures inside of the workshop or depot takes much time and is costly with human factors. Automatic wheel inspection systems maintain the system under control with comparing output data with high accuracy rate. Figure 3 shows measuring of wheel profile and diameter.

Figure 3. A view of wheel profile measurement(Web-1)

High speed passenger lines also should be high reliable, available with high rate safety. Preventive maintenance condition should be applied for passenger comfort and safety issues. Repair, inspection or unavailable time of the trains influence not only cost of the investment but also people's life. To increase mean time between failures arisen from wheel set and to have high reliable and safe operations wheel inspection system is needed for effective operation. For example, a failure in axle box as locking can be resulted catastrophically. Due to this reason wheel inspection with hot axle box and wheel detection system should be used to decrease maintenance time and increasing the inherent availability. Figure 4 illustrates the hot axle box and wheel detection system.

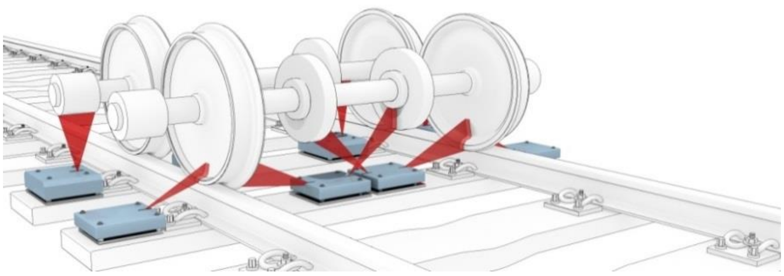

Figure 4. A view of hot axle box and wheel detection system(Web-1)

3.1. Negative Effects of the System

There are some issues that affect the performance of wheel inspection system. Accuracy is one of the important points to have healthy system working and to be applied right maintenance scheduling. Accurate input data and working properly and giving right solutions have significant effect on the lowest maintenance cost possible. In as much as wrong data output can influence whole system and periodic maintenance with increasing material consumption.

Analysis data is the second significant figure in terms of system efficiency because condition monitoring system should have fast processors and comparing the data with base one and give a decision correctly as much as possible. In this point, base data acquisition has another importance to divert people to prepare right maintenance applications.

Calibration is the third substantial point that condition monitoring system consists of many mechanic, electronic and computer bases equipment which should be calibrated periodically. It is important to obtain right output data which comes form system analysing and accuracy.

Weather condition is the fourth crucial point that the design of the system will be outside and should work properly in hard environmental conditions. The system should sustain data acquisition properly in hot, cold, humid or windy weather because the system should be assembled several types of areas such as deserts, north side of the world or high humidity places.

In consideration of all information detrimental effects which are accuracy, analysis data, and calibration and weather conditions create system complexity which is the most significant point of the condition monitoring system dependability. The monitoring system should have modular and easy maintainable structure which can be provided effective self-cleaning systems.
The next point it has been tried to analyse risk assessment for wheel inspection system.

4. Risk Analysis

Risk analysis of the system is extremely important for applicability or feasibility and should be evaluated from the point of acceptability. Hazards or effects can be divided into two main parts which are probability and severity. Probability can measure with "How likely is it?" question and severity or consequence can measure with "How bad is it?" question. To analyse risk and to develop management method first two questions should be "What can go wrong? and What do we do?" respectively.

4.1. Risk Evaluation for Wheel Inspection System

A high speed train in Britain derailed in 2000 near the Hatfield station and four passengers died and more than seventy passengers injured. According to investigation, there were several fatigue cracks on the rail. This derailment shows that determining the faults and predictive maintenance are very important for railways because it can be resulted with catastrophic events. To prevent unexpected failure the complex system should be controlled each moment and results should be compared with each other. Condition monitoring of wheel and rail becomes more of an issue in that point. According to Stichel (2008) "for railway wheel applications, RCF can be divided into three different categories:

- Surface-initiated fatigue, sometimes denoted as spalling.
- Subsurface-initiated fatigue, sometimes denoted as shelling.
- Fatigue initiated at deep defects, sometimes denoted as deep shelling or shattered rims".

To evaluate the risk of the wheel-rail contact behaviour, it has been known what kind of stresses can cause the fatigue, wear and derailment. According to Zerbst (2009) quoted from Esveld (2001) "the highest stresses occur at the running surface of the rail where the wheel–rail contact stresses typically can reach 1500 MPa for an axle load of 25 tonnes".

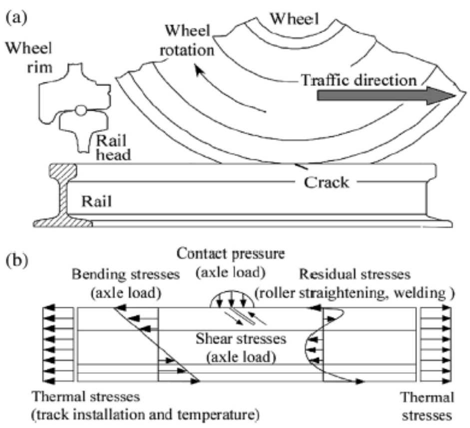

Figure 5. Wheel-rail contact stresses(Zerbst, 2006)

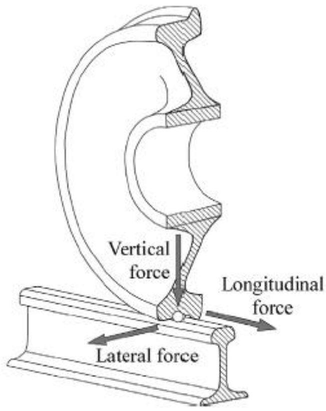

Figure 6. Forces introduced by railway wheel on a rail(Zerbst, 2006)

Figure 5 and Figure 6 show the composed stress profiles and forces on rails. These stresses which are produced by forces create derailment risk. Curves, welded point, rail wheel matching, weather conditions should also be taken into consideration in this risk evaluation.

Following parameters should be concerned for dependability and life cycle cost (Innotrack D 6.1.2 Models and Tools, 2007).

Insufficiency of data collected.
Inadequate involvements of Infrastructure managers and suppliers.
Unawareness respectively inconsistency of different RAMS and LCC terms.
No common understanding of LCC.
No common and consistent definitions concerning investment, operation, maintenance and renewal.

5. Requirements of a Comprehensive Wheel Inspection System

To capture system requirement clearly it has been needed different viewpoint about system however it must be some specifications such as measurable, achievable, single test statement and non-ambiguous. Good system decomposition of the system create good organisation and low cost at the final project time. The general system process can be shown as V diagram (Figure 7).

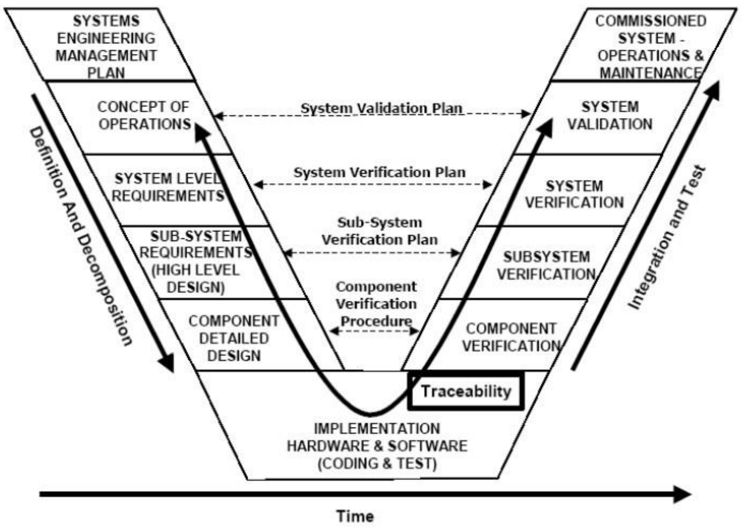

Figure 7. General V-process (Web-2)

According to this process after clarifying the concept mission right system requirements must be comprised using of all information coming from each view points from customers to user.

The start point of the system is designating the stakeholders of the system and then specifying the requirements for each stakeholder. Participants play an important role within the organisation and requirement tracking process.

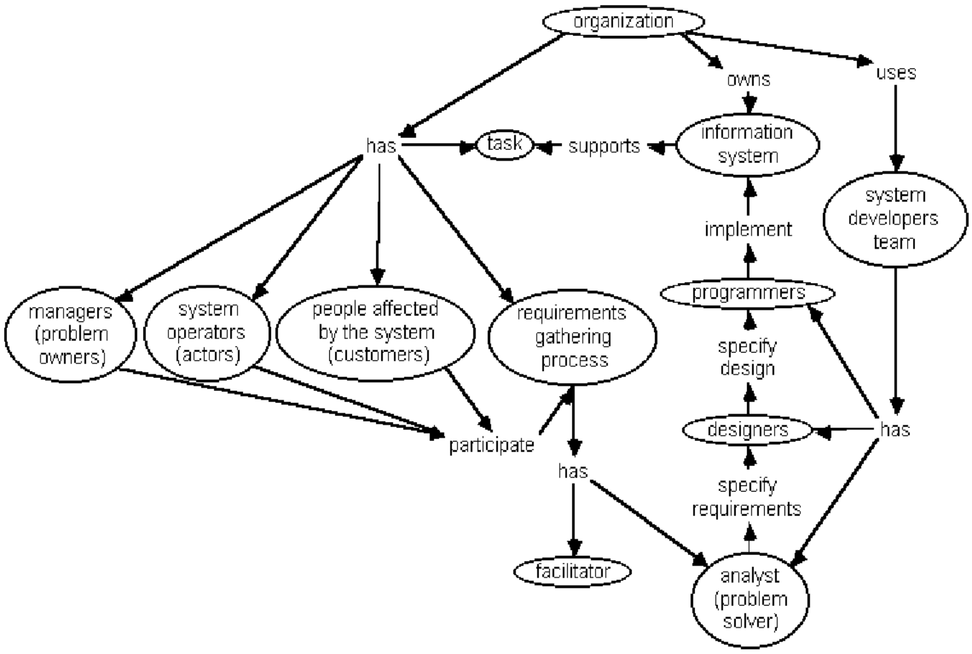

Figure 8. Concept map of participant's effect on system organisation (Web-3)

Stakeholders can be put in order as;
Funder
Freight train operating company
Passenger train operating company
Passengers
Infrastructure designers
Drivers
Equipment designers
Supplier

In this point, after elicitation of the requirement, requirement analysis follows as capturing measurable and achievable requirements and determining unclear, ambiguous or contradictory and incomplete points than last stage is recording the requirements.

6. Functional and Physical Models for Wheel Inspection System

Functional structure and physical characteristics of the system must reflect the requirements which have been captured by stakeholders. According to Blanchard (2006; p.78) "a *function* refers to a specific or discrete action (or series of action) that is necessary to achieve a given objective; that is, an operation that the system must perform, or a maintenance action that is necessary to restore a faulty system to operational use".

A functional analysis is changing the system requirements to specify system structure and divide the operation into the parts or sub-systems to achieve a process. In this part, it has been investigated and tried to draw functional and physical structure as block diagrams to identify the system characteristics and design. This system decomposition must represents the traceability from the starting point which is stakeholders and requirements and end point which is building the components and functional analysis and physical decomposition should take place respectively between these two parts.

Blanchard (2006; p.78) stated that "the objective is to specify the *whats* and not the *hows*; that is, *what* needs to be accomplished versus *how* it is to be done".

Figure 9 shows the functional analysis of the wheel inspection system. In this system there are two important sub-functions one of which is measuring wheel diameter flange height, thickness, width, back to back wheel gauge, hollow tread and estimation the conicity and the other one is measuring the temperature of wheel and axle box.

Final function of the system is to display the faults and designate the maintenance time using some software to inform that wheel needs to maintain in a certain time later or sending message to concerning people for emergency situation.

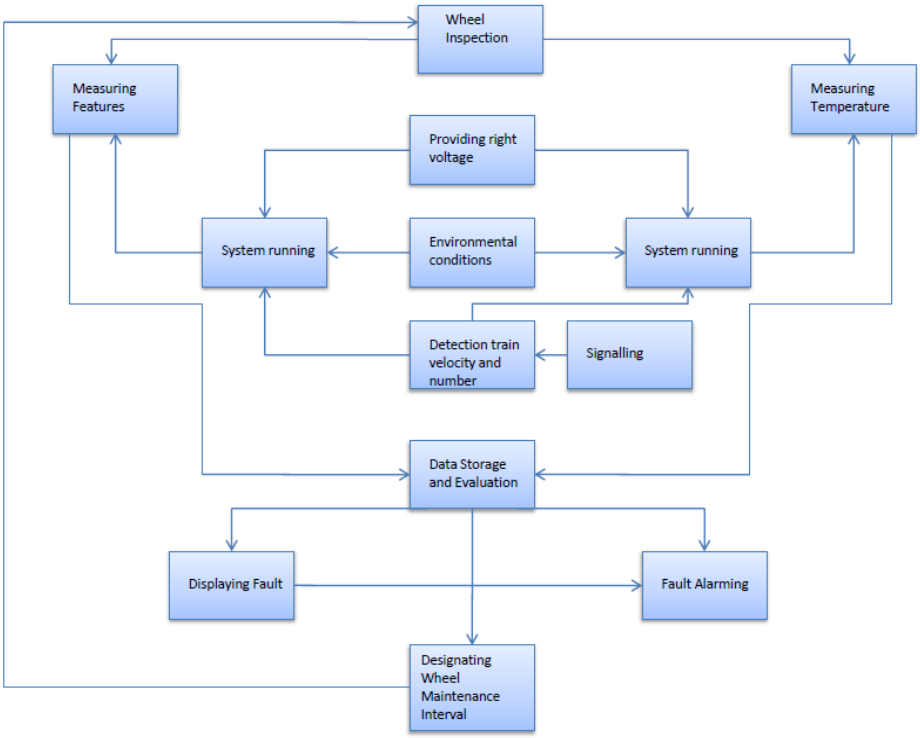

Figure 9. The functional analysis of the wheel inspection system

From this point, the system must be contained physical decomposition for each function and sub-function. The equipment should be relevant to substantiate the function in practice. Figure 10 describes which equipment needs to be performing which function and sub-functions reciprocally.

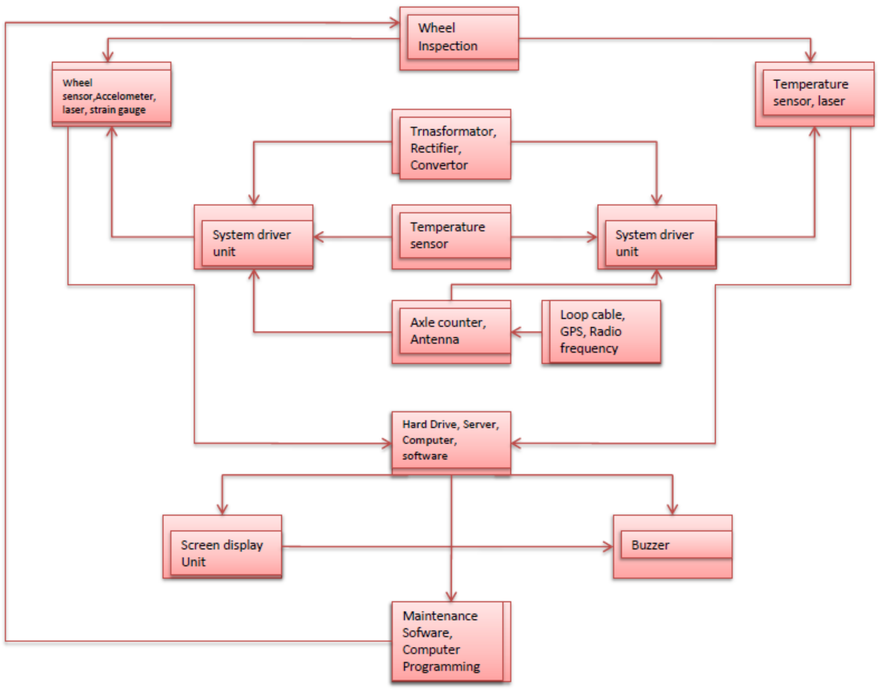

Figure 10. The physical decomposition of the wheel inspection system

In the following part there will be given some comments on system verification and validation process.

7. System Verification and Validation

This part contains some comments on how can we test the obtaining system and measure its specification or requirements whether to capture or not. After the obtaining functional decomposition, physical hierarchy and building the components, the right side of the V diagram must be implemented to the system. This side is called integration part of the system that functions and sub-functions must be tested and measured for verification and requirements must be analysed for validation process. In the verification and validation part of the process there should be researched some question’s answer for right analyse (UoB Lecture Notes, 2010).

Do our requirements capture our need?
Do our designs satisfy our requirements?
Do completed works comply with design?
Do completed works meet our needs?

If it has been compared the requirements part with functional and physical decomposition part it can be found these question’s answer.

To verify and validate the system there can be applied some techniques which are measurement, analysis, inspection, read across and escalation. These techniques give whether equipment can satisfy its requirement with measuring and analysing and all equipment compatible with each other with inspection and read across.

For example, this system comprise with several sensor and detector each of which should be tested and its data should be recorded for next calibration because the system is very sensitive and a little fault can inform the people wrong way. Lasers, computers and servers should be tested and measured for environmental conditions and analysed the values. There must be implied some test techniques for sensor, lasers, computer based systems, train signalling equipment. All part of the system must be passed from for environmental and visual testing and compared with conventional methods for correctness.

The most important verification and validation of the process is to run the system when the train arrives appropriate speed in appropriate weather conditions than system starts to run for measuring concerning points of the wheel sending data which includes the train and couch number to server for analysing the result. The process must provide a compatible equipment attitude for system accuracy.

The system should include argument tree design for risk assessment and to obtain right validation conditions. It must be examined and claimed that the results of the system reflect right information to right place in a right time because even if the process must not work properly the system will not be efficient. The aim of applying this system is to decrease the life cycle cost of the equipment using computer based machines to deduce right decisions for maintenance schedule. From this point of view, if the operator company cannot decrease the maintenance cost for wheelset overhaul due to verification and validation problems the process must be revised for safe and profit journey.

8. Conclusions

8.1. Findings

In this paper, it has been investigated a condition monitoring system which is a comprehensive wheel inspection system in consideration with system engineering fundamentals. After introduction and literature review human factor and organisational behaviour analysis has been discussed from general to specific and following part included dependability analysis of wheel inspection system with detrimental point of view. Before the elicitation of requirements which have compromised of operational, user and technical issues and utilizing traceability risk analysis and risk mitigation figures have been discussed.

After that system modelling which is functional and physical decomposition of the system has been illustrated in consideration of traceability. Validation and verification parts discussed about capturing of requirements with functional and physical decomposition of the system.

In the light of all information, condition based maintenance and monitoring systems have been proved for operation of more reliable, available and safe railway system design. Wheel inspection system is evaluated as a condition monitoring system there are many advantages for system operation in particular freight railway operation. If the system is operated efficiently which means all data acquisition is increased rapidly and human factors of the system are decreased to acceptable points and system requirements and decomposition, functional and physical, are captured each detailed points the system will redeem itself with saving maintenance and energy costs.

8.2. Recommends

In future, railway maintenance applications are changed from preventive or failure based maintenance to condition based maintenance. Condition monitoring system has been used many application points and will continue to perform new implementing field using with improvements in practicable algorithms.

Future of condition monitoring systems can be divided into two parts which are vehicle based and infrastructure based respectively.

With vehicle based system, condition monitoring equipment are assembled to the rolling stock and it can be investigated infrastructure and vehicle itself. This system can be applied for track monitoring for corrugation and wears, wheel-rail profile measurement, wheel rail adhesion monitoring, vehicle suspension system monitoring, catenary system monitoring which includes electric arc detection, thermal scanning, pole detection etc. and vehicle door monitoring. As mentioned before the other type of condition monitoring system is infrastructure based system which can be implemented point condition monitoring, track circuit monitoring, wheel profile measurement, wheel and axle crack inspection, brake inspection, vehicle weight detection and axle box temperature detection.

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