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Cost drivers of integrated maintenance in high-value systems

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Abstract

High value systems are determined by a wide structure, where operations are considered to be one structural component. Nowadays "down-time" as a major impact in the operation costs of any system. To avoid or minimize "down-time" it is essential to match the appropriate maintenance to each failure. Therefore, it is relevant to determine the cost drivers of integrated maintenance in any system, in order to minimize the overall cost. It is common to use Value Driven Maintenance (VDM) to capture the cost drivers in maintenance. VDM is a methodology which relies in four distinct areas: Asset Utilization; Resource Allocation; Control Cost and Health and Safety and Environment. Within each category it is possible to allocate different cost drivers, building a framework for each system studied. The aim of this paper is to categorize the cost drivers of rail infrastructure networks, associating them with the maintenance preformed for each case. Furthermore, analysis of which part of the track falls under each VDM category as well as the general failure causes and effects will be included in the framework presented. Finally relating the maintenance type for each effect will provide the necessary inputs towards a cost model structure. The benefit of achieving a successful model will be the optimization of the cost in integrated maintenance of the rail infrastructure.

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Keywords: Cost Drivers; Value Driven Maintenance; Rail Infrastructure Network

1. Introduction

A high-value system can be defined as all the value driven activities performed by the company, which involve the several structural levels of an organisation. To integrate maintenance along a high-value system it is necessary first to understand the normal structure of a dynamic organization. Usually it shows three different levels, Strategic, Tactical and Operational [1], all of them essential for a harmonic integration of any activity within a system. It is perceived that maintenance will be represented in all these levels.

Although the strategic level might do little work related with specific maintenance activities, the aims and objectives for the system quality and clear function of its structural components must come from the top level, determining the goals which the tactical level must achieve. Then tactical must understand which types of maintenance must be performed and ideally when they should be preformed. By replacing a component only when it is truly needed, its life cycle is increased as well as the costs regarding its maintenance are reduced. Finally the Operational level will represent all the tools and techniques, as well as the labour performed during the maintenance activates

The aim of this paper is to identifying the cost drivers of integrated maintenance in the Rail Infrastructure Network, (the high value system studied). In order to achieve a clear identification, literature on the subject was reviewed. Publications from the sector regarding maintenance investment and expenditure were analyzed and work on data was carried out. The main company studied is Network Rail which manages the train infrastructure system in UK, leasing access to the infrastructure to operators (Train services companies, Passenger or Freight). It is chosen not only because of its sponsorship of the "AUTONOM: integrated

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through-life support for high-value systems” project [2], but also the scale of the technical challenges facing the organisation. It is worth noting that around 70% of Network Rail staff works in maintenance and asset management [3].

It was decided to follow the Value Driven Maintenance (VDM) methodology [4]. Through it is possible to define four classes which drive value in maintenance, Asset Utilization; Resource Allocation; Control Cost and Health and Safety and Environment. Each class will be explained later in the paper, with the connection with performance drivers and killers helping in the determination of the Cost Drivers. By now it is relevant to clearly understand the differences between performance drivers and killers and the concept of cost divers themselves. Performance drivers are indicators of the system performance, are defined as inputs of that same system and they allow the understanding of how the system is functioning. Performance killers are the indicators of factors that affect the normal functioning of the system. They might be related with cost drivers because both show an impact on factors affecting the functioning of a system leading to unwished outputs. Although possessing a certain level of similarity, they are not the same since performance killers involve all structural aspects of an organization not being cost oriented.

Cost drivers are defined as a significant factor that shows a direct impact on the cost of the system analysed, they can be an activity, an indicator, a part, a product, a process among others. Regarding the cost drivers, not only their major categories will be identified, moreover they will be related with the most common roots of their value driven activities. Furthermore the agent responsible for the failures impacting the activities will be determine, as well as the specific parts of the system affected. To validate within each cost category where the impacts are noticed, is relevant to determine direct and indirect cost of the maintenance activities. Also it is interesting to study the relations among them, understanding how a specific failure agent can affect different cost drivers.

All the relations studied will launch the foundations towards a cost model, which will later on be built based on the findings and data analysis. The cost model is particularly interesting since Network Rail recently started Control Point 5 (CP5) and as a result some major investments in maintenance are being done; between 2014/2015 it is estimated an expenditure of 785 million GBP [3]. The cost model aims to improve optimization of the investment and expenses, in addition to understand how the change in the variables will impact the costs.

2. Related Research

In order to identify the main cost drivers regarding rail infrastructure it was necessary to find where the main failures occur. According to POETSCH et al [5] pantograph-catenary system is sensitive to trains which travel at high speeds. Moreover the power supply is seen as one of the key components in the rail infrastructure by Chen et al [6] Being the catenary part of the rail infrastructure it is considered to be one driver to take into account. Analysing the maintenance expenditure summary published by Network Rail it is noticeable that their biggest expenditures are track related; spending 391.1 million GBP exclusively on track maintenance activates [3].

Another relevant point of failure and a significant cost driver are switches and crossings. These areas require a lot of monitoring, as well as maintenance expenses related with signalling and communication systems. A novel cost engineering model was developed by Ling et al [7], showing the relevance of a cost model related with this particular area. A highly detailed study of this particular cost driver is carried-out, highlighting its great importance and revealing it as an important consideration for the framework. Also to take into consideration is the impact of the delays and the partial or total track closure which result in the re-allocation of resources. Nyström et al [8] studies how the delays affect the different stakeholders in the rail network. A particular interesting point is the consideration of secondary delays, meaning that one failure in a particular part of the infrastructure or train might not only affect a single track but a wider branch of the network.

From an information management point of view Nurmentaus et al [9] defines the major issues of organizing data under one solid structure. Commonly, conflicts among Enterprise Resource Planning and Asset Management Systems arise. Even if both of them are used, usually there is duplication and redundancy of the data leading to confusion and unnecessary costs. Moreover the failure of integration systems leads to time and resources wastage. A good data management system is essential for good communication systems. This way a track failure on the infrastructure might be able to trigger immediate responses. Moreover it is necessary to manage the data carefully in order to implement reliable condition-monitoring, Nicks el al [10].

Another factor to take into consideration and mentioned frequently in the Literature [8,11], is the weather. It might not be as obvious when the study is applied on the UK, though according to Shaw et al [12] it is a matter affecting costs. Different weather condition affect different parts of the infrastructure, each particular kind of climate might present a direct or indirect impact. For example during autumn the leaves accumulated in the track require removal to ensure the normal safety conditions for the rain to travel. Also when intense rain occurs and flood results from it, it is necessary to follow a set of standards to drain the water without compromising the land stability.

Furthermore it is important to understand under which maintenance type, each of the above stated drivers fall into. Patra et al [13] concludes that a system requires Preventive Maintenance (PM), Renewal Maintenance which is considered a special kind of PM and Corrective Maintenance (CM). He also specifies a series of formulas for some track related maintenance activities and an interesting one regarding the track down time cost. Although Condition-Based maintenance is not considered by Patra, it is considered in this paper.

The previous research work provides high level of detail for particular parts of the infrastructure, although it lacks an integrated view. There is no global view of the cost drivers throughout a rail infrastructure network. The lack of an integrated approach to maintenance can be identified as the main research gap in terms of the rail industry.

3. Cost Drivers

After conducting research of the rail infrastructure network, the cost drivers can be identified. But before determining them, it is necessary to understand in our system the performance indicators, the drivers and killers. As aforementioned these indicators determine how the system is performing. From these indicators it is possible to determine which kind of maintenance activity is needed when the system is being affected. As a result it is possible to allocate these maintenance activities under each cost driver category. According to Parida et al [14] the maintenance performance indicators in the rail industry are:

- Capacity utilization of infrastructure
- Capacity restriction of infrastructure
- Hours of train delays due to infrastructure
- Number of delayed freight trains due to infrastructure
- Number of disruptions due to infrastructure
- Degree of track standard
- Markdown in current standard
- Maintenance cost per track-kilometre
- Traffic volume
- Number of accidents involving railway vehicles
- Number of accidents at level crossings
- Energy consumption per area
- Use of environmental hazardous material
- Use of non-renewable materials
- Total number of functional disruptions
- Total number of urgent inspection remarks

Most of the above stated indicators are correlated, with maintenance activities that have a relevant impact in the cost of the general maintenance in the system.

Following the VDM methodology, it was possible to build a framework where, the most relevant train infrastructure cost drivers are included. Regarding Asset Utilization and focalizing in a more Operational level, the major categories of drivers are defined: the crossings and junctions, track miles and catenaries (the electrical system).

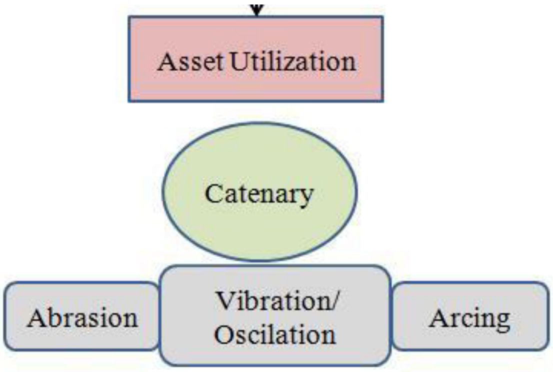

Figure 1: Asset Utilization

As it is possible to understand in *Figure 1* each category is associated with the most common factors which may lead to a failure. Shown in *Figure 2*, is the framework below "Catenary" with the agent responsible for these factors. For this part of the infrastructure it is usually speed of the train that is the agent responsible for the failure. Afterwards, it is possible to visualize the most common parts affected by the failures. Finally, in the lower boxes of figure 2 the cost drivers associated with the class. The costs drivers are divided into three different maintenance types: preventive, corrective and condition based. In the framework preventive corresponds to renewal and inspection costs, corrective to corrections and condition based to monitoring. The same structure is followed for the three other classes of the VDM methodology in the framework.

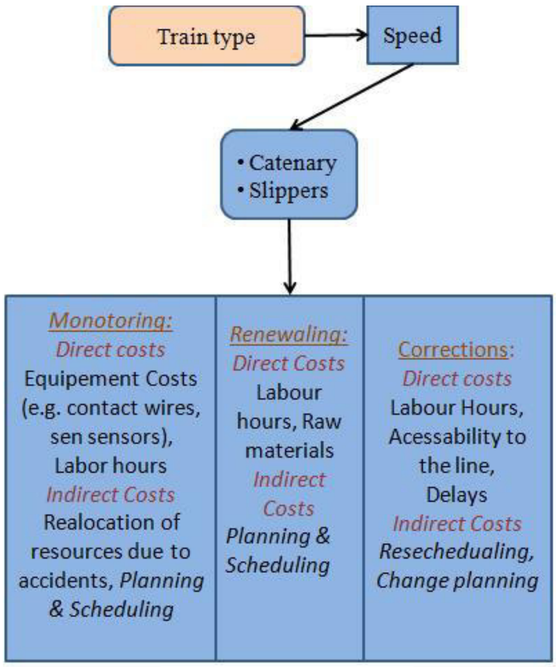

Figure 2: Asset Utilization

In terms of the Resource Allocation the highlighted classes are Data Management and Communication System. These will provide the Tactical level of the organization an opportunity to respond quickly to the problems on the infrastructure, by easily identification and location of the problem. Even though, these two classes assume a significant role in managing, scheduling and planning maintenance activities. It is also necessary to relate them with the partial or total track closure when a failure happens.

Falling under the tactical and strategic levels is Cost Control, this class alone could be responsible for all cost drivers within the system. But it seemed relevant to consider it in a high structural level of the organization. So the main driver is customer satisfaction being this one of the priorities of all companies top management. As it is located in a high structural level it also concerns the costs of maintenance associated with the three other VDM classes.
It is important to perceive that, customer satisfaction not only concern the external costumer (like operators or final service user), as well as the internal costumer, meaning all the workers involved in the diverse maintenance activates. The common factors which lead to the increase in costs are the accidents or delays and the fees regarding this king of problems. The Cost Control part of the framework can be observed in *Figure 3*.

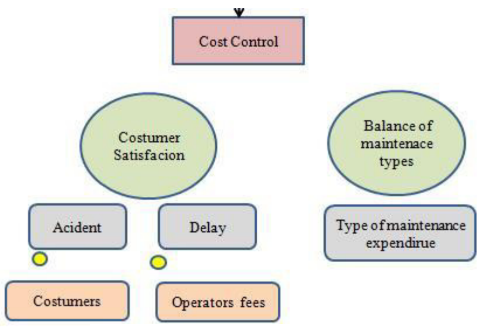

Figure 3: Cost Control

Last category is Health Safety and Environment (HSE) where infrastructure failures and fulfilling the standards are considered cost drivers with the most relevance. The infrastructure failures were generally attributed to the weather, since detailed parts of the infrastructure are consider in asset utilization. Following the standards is very important to ensure the health and safety of the organization and the infrastructure itself. Even though some standards and norms might require profound changes in the way activities are performed, or contract specific companies for determined process. This is not seen as a necessary evil, it is a process that will clearly improve the mechanisms and activities, although to implement can result in great cost. The last part of the framework is illustrated in *Figure 4*.

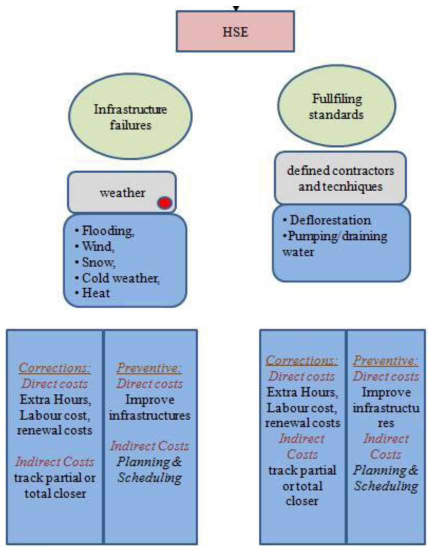

Figure 4: HSE

Once the cost drivers classes are defined and the specific cost associated with each class determined, it is possible to understand which direction a cost modelling tool for integrated maintenance must be developed. For each driver class it must relate to the structural levels of the organization, as well as the kinds of maintenance preformed. Moreover the indicators of cost and cost of each class must be then analyzed in detail to understand if the correct kind of maintenance is being performed or if the right entity is responsible for the tasks. It might be interesting for each class of the cost drivers to apply the maintenance process [15], *Figure 5* in a higher level of detail.

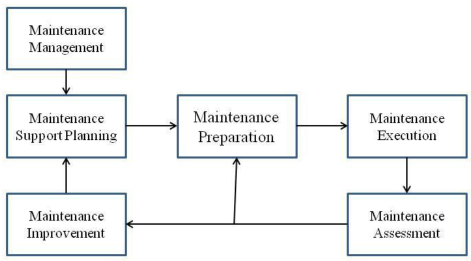

Figure 5: IEC 60300-3-14:2004

From *Figure 5* it is shown that maintenance is divided into different stages, but is clearly integrated. Although all stages represent different aspects of maintenance it is not possible to determine if one is more important than another. Only by their dynamic interaction is it possible to achieve excellence in maintenance. As a result of this application it would be possible to integrate the costs of the high-value system under their major drivers within a structural view of the organization in terms of the maintenance activities.

4. Conclusions

This paper presented the cost drivers of the rail infrastructure related with maintenance activities. It is important that most of the organizations understand their cost drivers, as well as determine their place in the top-down view. Although in the rail sector it is not simple to identify which cost drivers are more relevant in terms of the maintenance. This was a challenging due to the limited amounts of literature on the cost prediction of maintenance activities.

Future work is going to be carried out to improve the framework and develop a generic cost model tool, which will likely require developing of a parametric based method using multiple cost-drivers to predict maintenance costs and optimise maintenance schedules. Although the tool aims to be generic and possibly applied to different kinds of organisation for maintenance activities, it is also going to aim to be contextualized in the particular case studied.

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