OPTIMISATION OF RAILWAY ASSET LIFE CYCLE PERFORMANCE THROUGH A CONTINUOUS ASSET *IMPROVEMENT* PROCESS AS PART OF THE MAINTENANCE MANAGEMENT PROGRAMME

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ABSTRACT

The challenge to sustain railways is driven by the ability to optimise the utilization of the asset base. It demands the establishment of a continuous asset improvement process and program that requires maintenance personnel to continuously improve their understanding of the infrastructure's performance and the relevance of the configuration to this performance. A successful asset management process incorporates these elements and results in the optimisation of the infrastructure life cycle by extending useful life while minimising the operational interference thereby increasing capacity.

INTRODUCTION

Background

Over the past 10 years, the Chair in Railway Engineering at the University of Pretoria, Transnet Freight Rail and Amtrak collaborated in various infrastructure maintenance projects. During the course of these projects, the need to develop philosophies of Railway Infrastructure Maintenance Management became apparent.

These methods and processes were developed and expanded over the years and will be presented in this chapter. It is known that the full potential of the existing railway capacity is not completely utilised. Therefore, the industry has to consider other approaches to create additional capacity and ensure better utilisation of available capacity. The integration and efficient utilisation of information is a major contributor to ensure maintenance effectiveness (Ebersöhn and Ruppert 1998).

The effect of condition-based maintenance is illustrated, demonstrating how this maintenance strategy will increase maintenance effectiveness (doing the right things at the right places) resulting in a decrease in maintenance cost. With this in mind it is apparent that with an increase in maintenance effectiveness, less time will be spent to maintain assets. This increases the availability of assets adding to the business objectives.

Objectives of this paper

The optimisation of production maintenance machines has always been a challenge to railways. The integration and utilisation of automated condition assessment data within an information management system can assist in the optimisation of maintenance effectiveness. This paper's objectives include the following:

- Review asset management principles.
- Develop a maintenance decision-making model and process.
- Utilise technology to integrate data and develop optimized maintenance plans for mechanised tamping activities.
- Evaluate the algorithm used to optimise the maintenance requirements based on condition-based parameters.

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ASSET CENTRIC APPROACH

The viewpoint of the authors is that of an Asset Centric approach, whereby operations and maintenance are integrated elements of a system and need to be managed as such. Illustrated in Figure 1 below is a high-level presentation of an Asset Centric business model that fits into the railway environment.

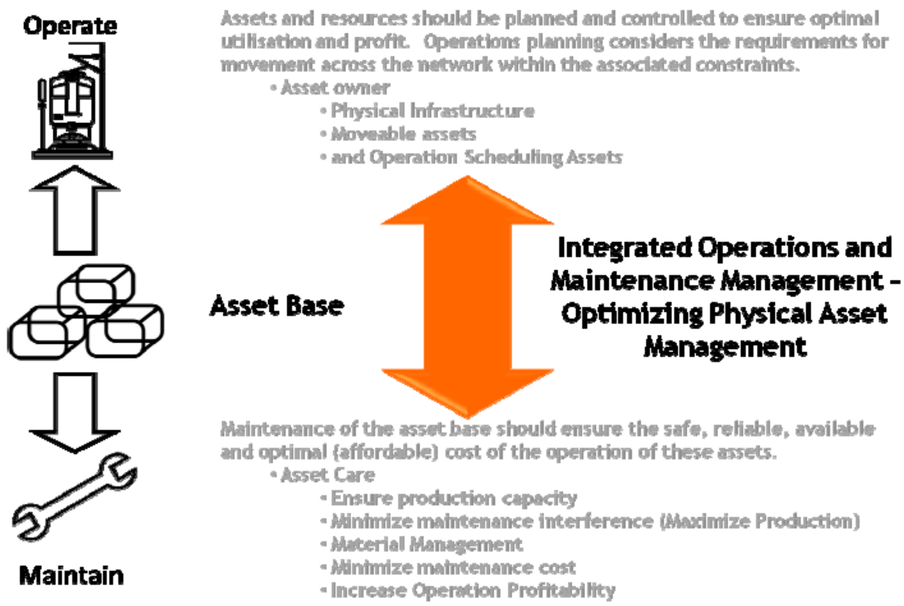

Figure 1: Asset Centric Approach

From this approach it is evident that the authors believe that the traditional approach of "silo" functional activity-centred organisations is not effective and businesses should make a paradigm shift in their way of thinking. This viewpoint is supported by many leading experts in the field of asset management and will be discussed in sections to follow.

Asset and Maintenance Management

Asset management can be defined as the holistic approach within an entire business to improve its overall performance. On the other hand maintenance management is defined as one of many components within the asset management approach.

What is asset management?

According to Mitchell et al. (2007), Physical Asset Management has a single objective and that is to increase the value and return delivered by the physical assets. It is then discussed that Physical Asset Optimisation is a program that is a business initiative focusing on and determined by opportunities to create value in different areas. These opportunities can include areas such as the reduction of costs and improvement of availability/capacity.

Mitchell et al. (2007) states that the starting point of asset optimisation is to realise that the business is at an initial state, though it has a specific goal to achieve. It is from this initial/current state the business should build on to achieve greater effectiveness. Woodhouse (2001) defines asset management as a group of tools, processes, methods and disciplines that is utilised to optimise the physical asset's whole-life. Peterson (2007) also describes asset management as a process for asset care decision making.

The common denominator between these authors is an approach that requires a close partnership, a synergy, between production/operations (the asset owner) and maintenance/engineering (the asset caretaker). Some areas identified to improve the required service objectives for asset management optimisation (Mitchell et al. 2007) are listed below:

- Improve production availability;
- Reduce operating cost;
- Increase asset effectiveness;
- Increase reliability and quality;
- Flexible and reliable processes;
- Improve efficiency.

Mitchell et al. (2007) further emphasize that value opportunities are generated by asset management optimisation. A list of some of the value opportunities are discussed below.

- Production, utilisation and effectiveness improvement:
    - This improvement is translated in meeting delivery commitments at less cost or delivering more at the same cost.
- Increased stability and reliability will minimise uncertainty.
- Reduce spending
    - When reducing costs, it should be sustainable, therefore looked at from an asset lifetime perspective, and not from the traditional budget constraints perspective.
    - Reducing cost can be achieved by:
    - Reducing failures - ensure the cause of the failures is understood and that the correct action is taken to reduce these failures;
- Increase effectiveness - being results orientated;
    - This is to perform the correct tasks (doing the right things) efficiently to the right assets (at the right place).
    - Recognise consequences due to failures and operation variation;
    - Improve maintenance efficiency and reliability;
    - Skill levels need to increase as equipment and systems complexity increase.
- Improve capital effectiveness:
    - Capital reduction has the same influence as the reductions in operational costs i.e. reduce the number spare parts/inventory.

These elements support the authors' view that asset management should be a continuous process that aims to optimise the asset with a single tangible result in mind, which is to maximise the value and return delivered by the physical assets.

What is maintenance management?

Maintenance can be defined as the care, correction and servicing of assets and their components, whether physical or functional, for the purpose of ensuring satisfactory operations of the assets and components before failure or major defects occur that will influence the operational ability thereof. In short, maintenance can be called **asset care.** It ensures the availability and capacity of assets to deliver either a product or a service, depending on the business objective. The benefits of asset care within the asset optimisation process include but are not limited to (Mitchell et al. 2007):

- Reduce incidents;
- Increase utilisation;
- Improve quality;
- Maximise effectiveness;
- Reduce and minimise failures;
- Reduce operating and maintenance cost;
- Reduce spares/inventory.

Peterson (2007) defined a process of implementation to achieve asset optimisation with 5 phases depicted in Figure 2 below, consisting of:

- Planned maintenance;
- Preventative maintenance;
- Organizational excellence;

- Engineered reliability and
- Operational excellence.

The details of the activities, tool, processes, procedures, strategies and disciplines will not be discussed in detail as it falls outside the scope of this paper.

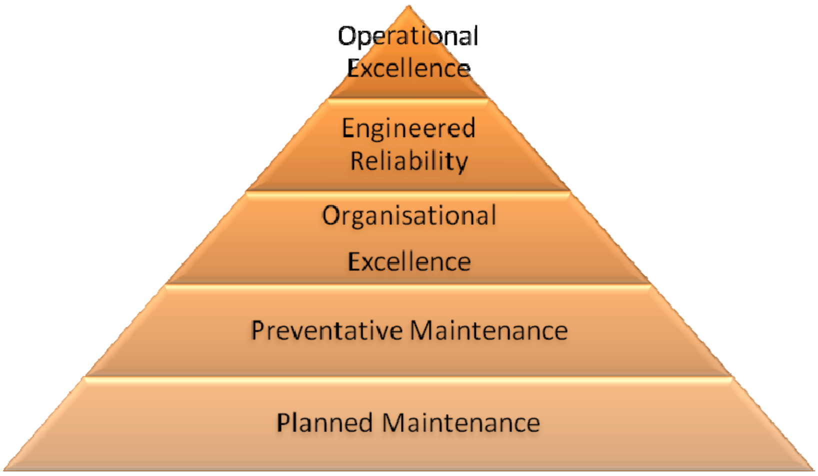

Figure 2: Phases of organisational maturity - Asset Healthcare Triangle (adopted from Peterson 2007)

It is important that maintenance/engineering should form a synergetic partnership with operations as this will add to the bottom-line. It is therefore required that maintenance is a core management responsibility within the asset centric business.

Mitchell et al. (2007) explains in Figure 3 how service interruption can influence asset effectiveness, showing the need for a partnership between maintenance and operations. The shaded areas above the breakeven line is requirements to achieve the objective of making a profit, while the shaded areas below the breakeven line represents areas where there are interruptions within the operational objectives that realise a loss within the business.

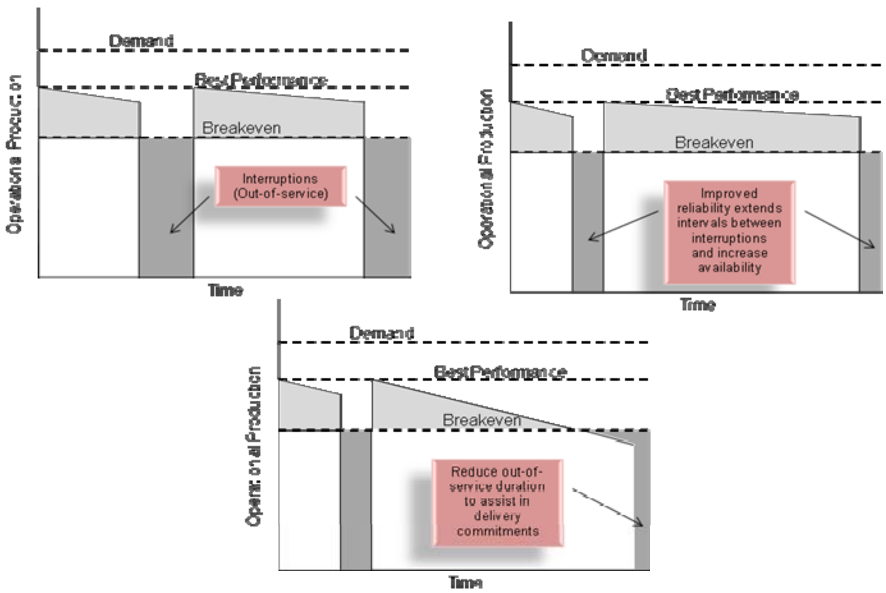

Figure 3: Intervention affecting Asset Effectiveness (adopted from Mitchell et al. 2007)

In the next section the objective will be to show how maintenance management in the railway industry can add value to the asset management optimisation process.

Maintenance process

According to Mitchell et al. (2007), leaders within the asset centric business approach consider maintenance as an integral part of the operations and business process generating and adding value to the business. The importance of a well defined and documented maintenance process to assist in the delivery of the business objectives must be fully recognised. Dunn (1997) categorises the maintenance management decision-making process into six typically phases. These typical phases are as follows:

- Work identification;
- Work planning;
- Work scheduling;
- Work execution;
- Recording work history;
- Analysis.

At the end of the sixth phase, there is a feedback loop where the decision making process will start at phase 1 to identify the new maintenance requirements. The authors have further established that this cyclic process should aim to improve the overall performance of the assets after each cycle. We refer to this process as continuous improvement. This process relates to the familiar management philosophy Theory of Constraints (Goldratt 2004), proposing that at any given point in time - at least one constraint limits the system's performance. As the process re-occurs over time the constraint may change, but it also might be that the same constraint that re-appears over time. Our challenge is to improve the methods used to support continuous improvement.

Ebersöhn and Ruppert (1998) and Woodhouse (2001) also share these phases in their maintenance cycle. At first it seems a bit different; but in fact, it is the same process indicating the fundamentals of the maintenance process. The principles of maintenance management solidify when analysing the maintenance process model of Mitchell et al. (2007). The basic maintenance process is presented in figure below.

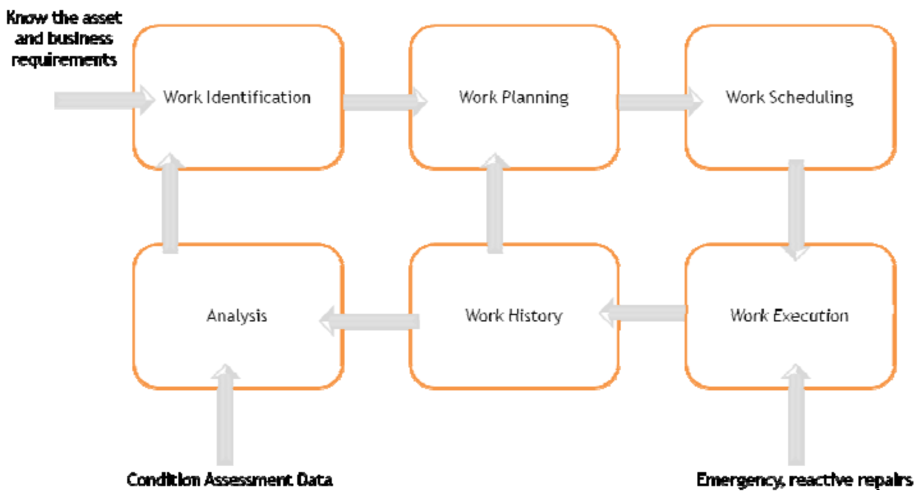

Figure 4: The Basic Maintenance Process (adopted from Dunn. 2007)

ANALYSIS METHODOLOGY

A model was developed to assist in the optimisation of an effective maintenance management programme. It is presented in Figure 5 and consists of the following steps:

- Setup a maintenance management database that consists of:
    - Asset Register;
    - Condition based assessment data:
    - Automated Condition Assessment and
    - Visual Condition Assessment.

- Develop or acquire a maintenance management system that fully integrates into the maintenance management process;
- Utilise the data and system to assist in the analysis phase;
- The analysis process consists of:
    - Understand Operational input requirements:
    - Know the operational needs;
    - Understand the asset base and its configuration;
    - Understand the assets functions and purpose;
    - Understand asset deterioration and
    - Know the maintenance strategies for the different assets.
- Condition Analysis:
    - Define the maintenance input parameters where required and
    - From the above, utilise parameters to analyse the current condition status.
- Identify maintenance need:
    - Utilising results identify maintenance needs and
    - If required make changes to parameters according to engineering knowledge.
- Setup a preliminary maintenance plan (Plan and schedule):
    - Quantify work load;
    - Determine resource requirements and
    - Develop a preliminary budget.
- Setup maintenance plan (Final plan and schedule):
    - Integrating other maintenance functions preliminary maintenance plans with each other;
    - Optimise the maintenance plan accordingly and
    - Setup budget.
- Execute maintenance;
- Measure Performance and Continuous Improvement.

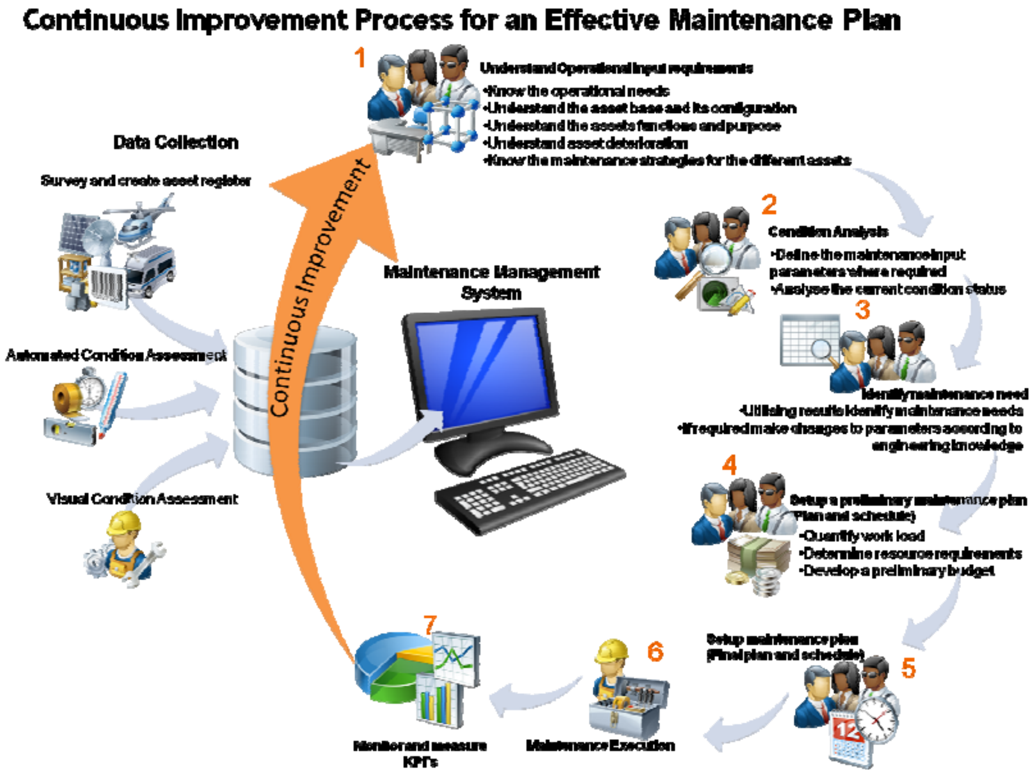

Figure 5: Maintenance Management Model for Effective Maintenance Planning

Options to support maintenance decision making: A model for effective maintenance needs

Option 1: Condition Based Maintenance Intervention

A condition based maintenance strategy is followed instead of a routine (intervention based) strategy to assist in the optimisation of maintenance requirements. Before analysis can be conducted, the operational requirement has been taken into account that assisted in the determination of condition based intervention limits to assist in identifying the maintenance areas that should be considered for maintenance input.

For tamping optimization, track geometry condition measurement data was utilised to determine the condition of a track, indicating areas with irregularities requiring maintenance input. According to Gräbe and Maree (1997) the maintenance parameters that will improve the condition of track geometry relating to tamping are the standard deviation for vertical profile and horizontal alignment.

The parameters utilized in the algorithm during this study were Roughness and is described as the sum of squares with variable summation lengths. This condition index was developed by Ebersöhn (1995) and is expressed in equation (1) below:

$$R^2 = \left(\frac{\sum_{i=1}^{n} d_i^2}{n} \right) \quad (1)$$

- Where:
- n = number of measurements in the summation length and
- d_i = is the mid-chord measurement for profile and alignment and deviation for twist and gauge.

In effect the Roughness index is a variation measurement of each condition parameter under consideration.

As an example, the mid-chord measurements for a length of track are plotted in Figure 6 that includes a good and a poor section. The corresponding plotted running roughness was calculated using the mid-chord measurements values and a 50 m calculation length. The beginning and end of the good and poor sections can clearly be identified.

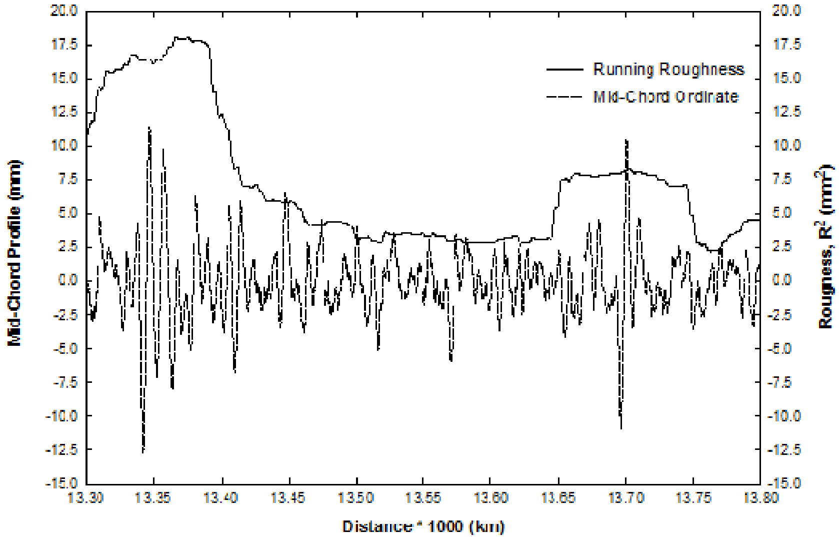

Figure 6: Mid-Chord measurement and associated Roughness index plot (adopted from Ebersöhn 1995)

Maintenance Algorithm

A maintenance algorithm was developed with the purpose to assist in the optimisation of the track tamping activity. The model assist in identifying maintenance requirements based upon parameters that can be defined by the user to provide agility to the maintenance identification requirements. The parameters within the algorithm consist of:

- A selection of up to five track geometry condition assessment parameters to calculate a condition index. Each parameter can be multiplied with a weighted average, and the result of these values are added to one another
- A variable **maintenance intervention limit** utilized to identify all areas that require maintenance.
- A variable cluster length, this length is utilized to cluster maintenance areas into one group if the areas not requiring maintenance between identified maintenance areas is less than this length.
- An option to include radius configuration data, to ensure that the result is applied to the extent of the curve.

Results - Maintenance Needs

The following process and parameters were utilised in the research project:

- Identify maintenance needs utilising a $R_{profile\ tamp}$ and $R_{alignment\ tamp}$ consisting of the profile left and right, and alignment left and right parameters respectively.
- A maintenance intervention limit was calculated at $17mm^2$ and utilised in the algorithm.
- Utilise a cluster length concept to ensure that in the case where maintenance needs are interrupted for distances smaller than the defined cluster length, the activity will be optimized/grouped to continue with the activity uninterrupted.
- After this result, utilise radius information to ensure that if a portion of a curve needs tamping, the result should be extended to include the total curve.
- Compare $R_{profile\ tamp}$ and $R_{alignment\ tamp}$ and determine final tamping requirements to ensure all needs are adhere too for both indices.

All of the above are illustrated in Figure 7 below.

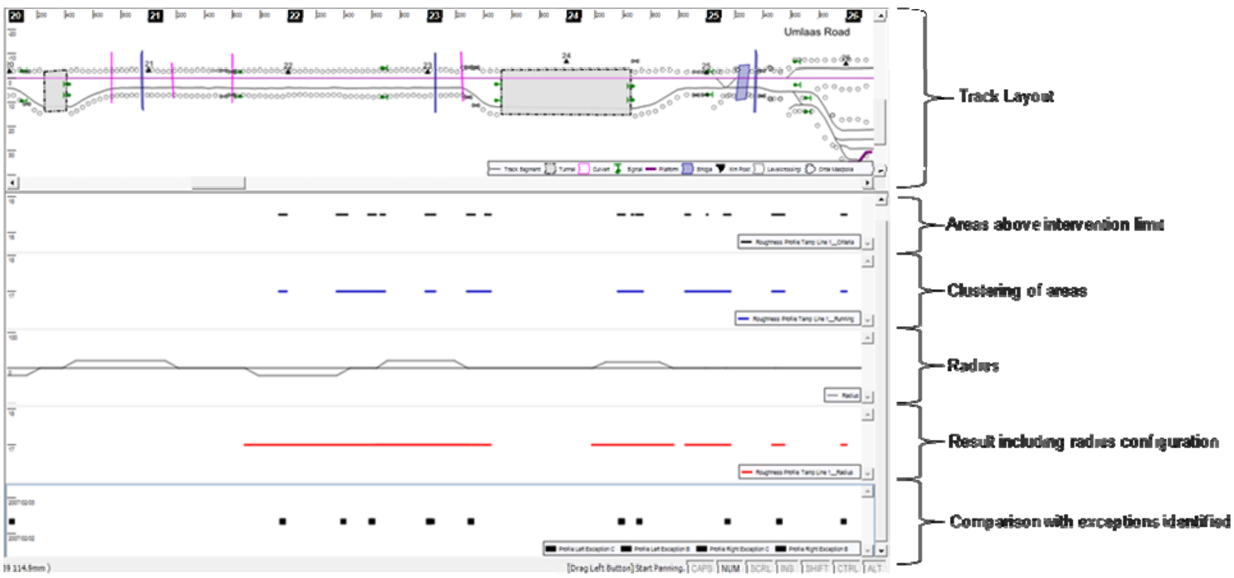

Figure 7: Optimise maintenance needs related to Transnet Freight Rail Exception Data

From Figure 7 it is clear that the calculated maintenance intervention limits and the maintenance need process - optimise a continuous tamping action while it corresponds with the Transnet Freight Rail exception data. This justify that the model will provide a result that ensures that the majority of exceptions will be attended to during the tamping execution, indicating the model can be used for effective maintenance management identification.

Compare $R_{profile\ tamp}$ and $R_{alignment\ tamp}$

By comparing the $R_{profile\ tamp}$ and $R_{alignment\ tamp}$ a final maintenance requirement for tamping can be planned. In Figure 8 the $R_{profile\ tamp}$ and $R_{alignment\ tamp}$ are presented separately as well as in a superimposed view to indicate the final tamping requirements for the section.

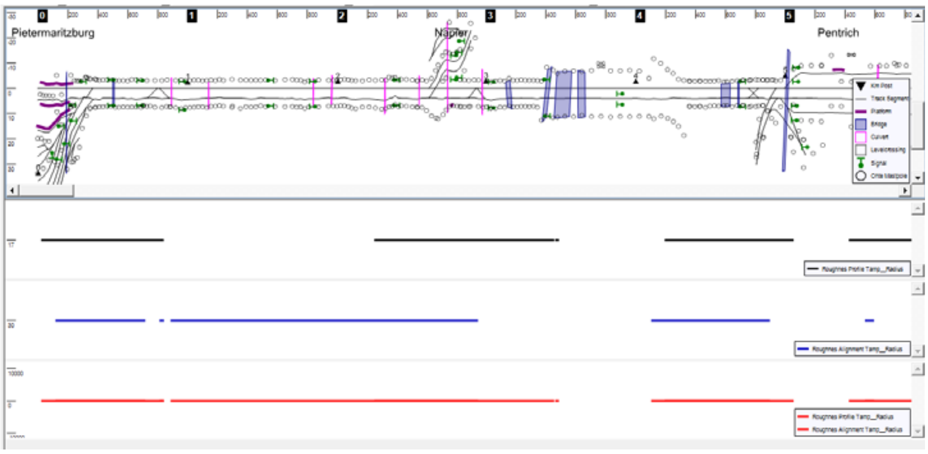

Figure 8: $R_{profile\ tamp}$ and $R_{alignment\ tamp}$ superimposed to indicate the tamping requirement changes.

Option 2: Deterioration and Improvement Index Maintenance Intervention

A additional method proposed by the author adding value to the current maintenance intervention limit, to assist in the continuous improvement of track geometry condition, is as follows: Compare the year-on-year roughness data by subtracting the consecutive yearly condition assessment data from each other to determine the areas that deteriorated over the past year, we will name it Deterioration and Improvement Index (Dii). The result is presented in the following equation (4) below.

$$\Delta R^2 = R_{n-1}^2 - R_n^2 \qquad (4)$$

Where:

ΔR^2 : Delta roughness (Dii), all values smaller than zero indicates an improvement;

R_{n-1}^2 : Roughness condition data for the period n-1 and

R_n^2 : Roughness condition data for the period n.

In areas where *Delta Roughness* is greater than zero the condition state deteriorated from the previous assessment and therefore presents areas requiring maintenance input.

If these areas were effectively maintained the condition at these areas will improve, resulting in an overall improvement of the track quality for the section. If this process is continuously implemented the total track quality will improve over time, until it reaches its optimum condition (the point from where the condition cannot be improved) from where it will be necessary to sustain the optimum condition.

For demonstrating purposes on the Pietermaritzburg – Durban section it is assumed that maintenance should be applied to areas where *Delta Roughness* is greater than 3 mm^2. Using equation (4) for the period 2004 to 2006 resulted in the maintenance of the following area depicted in Figure 9 below.

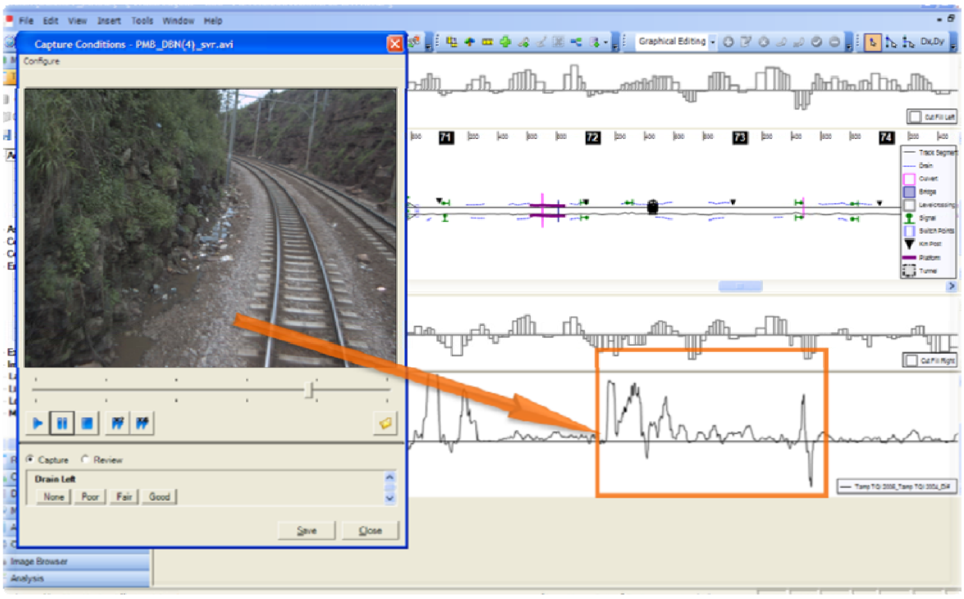

Figure 9: Delta Roughness is greater than zero for the period 2004 to 2006

If effective maintenance where applied to this section indicated in Figure 9 the same section should not require maintenance input for the period 2006 to 2008. Figure 10 below presents the same analysis as discussed above but for the period 2006 to 2008.

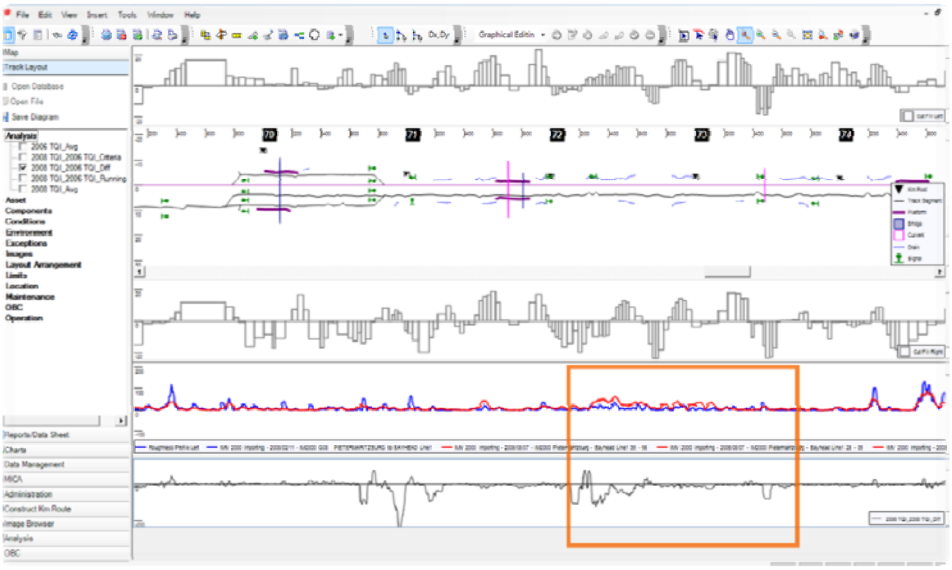

Figure 10: Delta Roughness is greater than zero for the period 2006 to 2008

From Figure 10 above it is apparent that the area identified in the period of 2004 to 2006 was maintained effectively, resulting in an improvement for the period 2006 to 2008. If we can improve new areas, where the *Delta Roughness* is greater than 3 mm^2, the total track quality will improve. The improvement will result in the frequency plot moving towards the established target.

<u>Comparison of Option 1 and Option 2:</u>

Finally we also compare the difference in the analysis results of maintenance intervention limits and the newly defined Deterioration and Improvement Index, indicating that both methods have a place in the maintenance planning environment. In Figure 11 below we indicate that at km 88 the Deterioration and Improvement Index indicates that a maintenance requirement has been identified, while at the same location the maintenance intervention limit has no requirement. This indicates that the Deterioration and Improvement Index analysis methodology can indicate areas that are deteriorating at a high rate that will within a short period of time reach the maintenance intervention limit and only then be identified as a required maintenance area. In this specific case the Deterioration and Improvement Index methodology assist in the identifying areas before it reaches the maintenance intervention limits adding value to the preventative maintenance strategy.

If looked at the analysis approximately 100 meters further, over the past year maintenance was performed ensuring an improvement of more than the Deterioration and Improvement Index intervention limit, resulting in the analysis methodology not identifying the required area. Although this is correct with regards to the rules implemented, the area's condition is still above the maintenance intervention limit.

This resulted in the maintenance intervention limit methodology identifying the maintenance area correctly as the value is above the required limit allowable for normal train operational requirements. From this it is apparent that both methodologies have a role within the maintenance planning environment ensuring effective maintenance management.

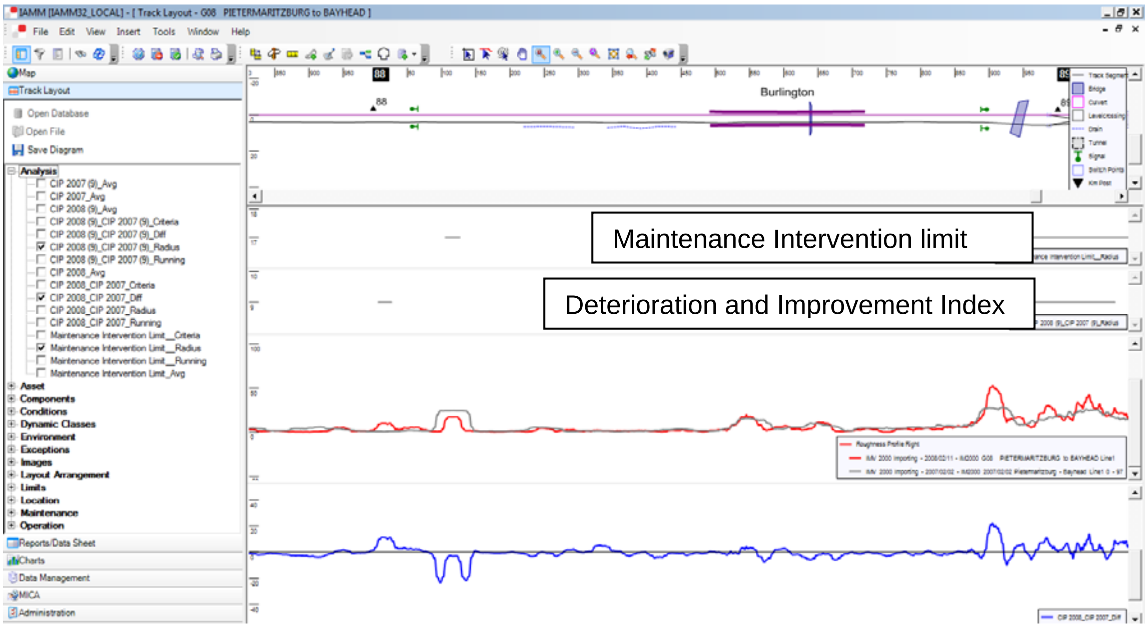

Figure 11: Maintenance Intervention limit compared to Deterioration and Improvement Index

Continuous Improvement Methodology

The approach to use a deterioration and improvement index in relation to the condition based maintenance intervention methodology to identify maintenance requirements can be further extended by a continuous improvement methodology as the next step in the asset optimisation process. This will assist the business in achieving its objectives. Only the theory of continuous improvement will be discussed in this section in order to provide a holistic approach to the way forward.

Continuous Improvement is a process whereby the condition assessment and maintenance work forms inputs on to a repetitive analysis cycles to identify and priorities areas of under-performance. As the process is repeated new priorities will arise and over time the overall performance of the assets will improve. The outcome of continuous improvement leads to optimisation of its asset performance. If the right maintenance requirements are addressed through root-cause analysis, the failures will be eliminated resulting in new constraints appearing.

This approach can result in reduction of intervention limits that improve reliability and availability of the track. For illustration purposes we use the profile geometry parameter frequency plot for both the Pietermaritzburg to Durban - and the Coal line section.

In **Error! Reference source not found.** the Pietermaritzburg to Durban section and Coal line profile parameter's standard deviation frequency plots are superimposed on each other indicating the hypothetical goal set on the Natal Mainline within the next five years.

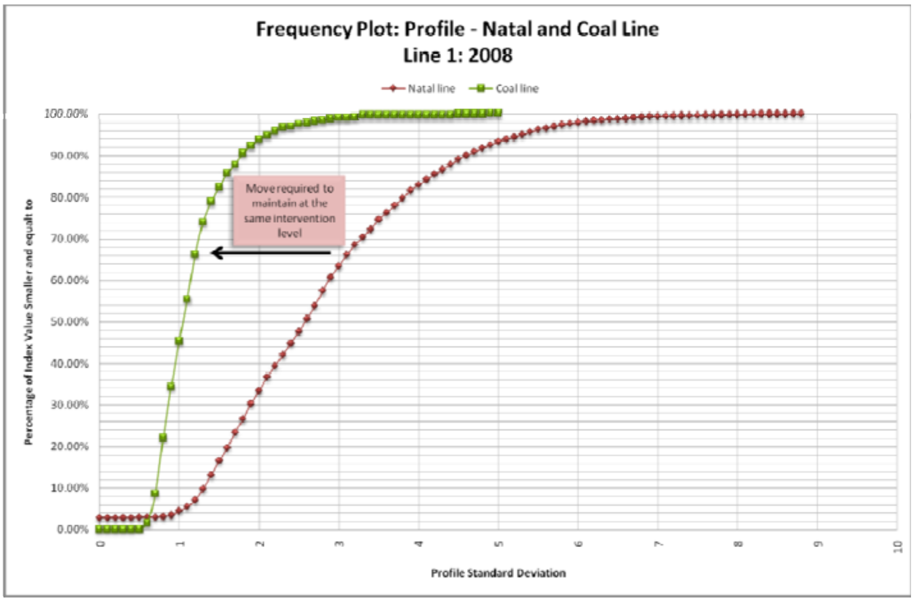

Figure 12: Superimposed profile standard deviation frequency plot for the Natal and Coal lines.

The Continuous Improvement approach to systematically improve the current track condition state, year-on-year; will ensure an improvement is reached to get to required target.

CONCLUSIONS

From the study the following conclusions can be made.

- The developed maintenance decision-making model/process assists in identifying effective maintenance requirements.
- The utilisation and integration of technology assist in the optimization of maintenance effectiveness related to mechanised tamping maintenance activities.
- The algorithm developed will optimise and cluster the maintenance requirements based on condition-based maintenance.
- Both Deterioration and Improvement Index as well as Maintenance intervention limit methodologies have its place in the planning process.
- The combined analysis methodologies resulted in a maintenance effectiveness improvement resulting in maintenance cost savings, while increasing the operational availability of the right-of-way.
- The Continuous improvement methodology can assist in the long term total improvement of asset performance.

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