Maintenance improvement of 210 km Coal Export yard though Integrated Track Condition Monitoring Solutions and Track Inspection

M.K. Lekala
Maintenance Manager, BTech, Pr. TechniEng, Rail Network, Transnet Freight Rail

T. Khathi
Engineer, Rail Network, Transnet Freight Rail

ABSTRACT: The purpose of this paper is to present maintenance strategies and or philosophies employed by Transnet Freight Rail to reduce infrastructure down time and failures. In particular, the paper presents how Integrated Track Condition Monitoring Systems were used in conjunction with track inspections to improve maintenance effectiveness. Furthermore, from a maintenance point of view in the heavy haul environment, various maintenance activities such as ultrasonic rail defects detection, rail & track geometric measurements and a grinding philosophy were also discussed which form a part of the maintenance philosophy of the yard. The results indicate that this type of coal export yard requires a minimum of 48 hours on a monthly basis and 240 hours of annual maintenance time. The results are also indicative of an overall increase in network availability and decreased down time.

1 INTRODUCTION

The South African railway industry made an introduction into heavy haul in the 1970s with the construction and inception of the iron-ore and the coal line (Transnet Freight Rail, 2010). Starting at Mpumalanga’s coal-rich mines, the 580 km rail line descends from Ogies through rural KwaZulu-Natal and terminates at Richards Bay. The coal line transports coal, primarily for Eskom usage, general freight and export coal.

Due to the increasing demand for coal, operators and railway entities have been forced to increase the overall capacity of the infrastructure as well as optimize train operations to decrease turnaround times. In order for the infrastructure to be able to withstand the additional volumes transported, certain sections were upgraded from 20 ton/axle class lines to 26 ton/axle lines. In addition, new loop lines were built and existing loop lines were extended.

Plans to streamline the existing processes were implemented in order to increase the efficiency of daily operations using lean six-sigma principles, in turn optimizing business performance to ensure the targeted tonnages are attained each financial year.

1.1 *Maintenance Philosophies in TFR*

Increasing tonnages, the speed of trains, weather patterns and lack or insufficient maintenance of the track results in deviations of the mechanical and physical properties of the track infrastructure (Rhayma, et al., 2013). If not corrected, these deviations could be detrimental to the infrastructure. According to Rhayma, et al., (2013), maintenance activities should be conducted to assess and prevent these deviations. Track maintenance is done to ensure that the track fulfills its intended function throughout its lifespan (Garrido, 2017). Maintenance assesses and eradicates the consequence of failure to the infrastructure and the business. Routine preventative maintenance (RPM), is done to assess the current condition of the track and prevent potential failures (Garrido, 2017). In the Ermelo yard the RPM is governed by the Manual for Infrastructure Condition Assessment (MICA). Stress measurement of rails, track geometry measurements, rail wear measurements and foot patrols are considered to be RPM (Kumar, et al., 2016). Foot Patrols entails the track inspector to physically inspect the track. The efficiency of this type of maintenance depends on the experience and skill of the personnel to use the rail gauge equipment and to visually inspect the track to identify deviations (Kumar, et al., 2016). Foot patrolling is also used as a method of verifying faults that are picked up by a condition monitoring system. However, if the track inspector is incompetent, the quality of the information received to conduct corrective preventative maintenance will be inaccurate (Kumar, et al., 2016). Rail wear is monitored by a rail gauge during foot patrols as well as autonomously by the Track Infrastructure Measuring Vehicle (Kumar, et al., 2016). Deviation in track geometry is also measured by the Track Infrastructure Measuring Vehicle (Rhayma, et al., 2013).

When the potential failure is found, such as excessive stresses, deviation in track geometry, rail wear and rail defects, corrective preventative maintenance (CPM) is done to prevent failure from occurring. If an infrastructure failure, like a rail fracture or a broken sleeper occurs, it could lead to a derailment (Kumar, et al., 2016). Such incidents will result in financial loss to the business due to the repairs of the damage as well as due to the unavailability of the network for operations.

1.2 *Ermelo Yard Maintenance*

The Ermelo Yard located in Ermelo (Figure 1), is an intricate shunting yard, consisting of four yards joined by a multitude of remotely and manually operated turnouts. The four yards are the A, B, C and D yards and each has an operational function. The B-Yard is where 100 wagon trains exit the yard and move to the various mines to load coal. Upon returning from the mines, the loaded trains enter the D-Yard where they are then coupled to form 200 wagon trains. These trains are then sent to the A Yard where they are staged until they depart to the Richards Bay Coal Terminals. Upon their return from Richards Bay, the empty 200 wagon trains then enter the C-Yard where they are uncoupled into 100 wagon trains and sent to the B-Yard, thus completing the cycle.

Figure 1: Ermelo Yard (Google Earth, 2019)

The Ermelo Yard departs up to 16 loaded 200 wagon export trains per day. The shunting movements of these trains which take place on a daily basis accelerates the deterioration of the infrastructure in the yard. This therefore warrants a regular maintenance regime in order to keep the yard infrastructure in a reliable and safe condition. Traditional philosophies for track maintenance which are stipulated in maintenance manuals do not make provision for upkeep of the infrastructure with limited maintenance slots. Thus due to the ever-increasing business demand to haul more volumes, maintenance slots are cut down.

The majority of infrastructure failures that occur in the yard are due to rail fractures and turnout component fractures. These failures are more prevalent in the A and D Yards due to the repetitive train movements that occur during shunting activities. The D Yard infrastructure is currently in the worst state due to the nature of the shunting movements that occur. Therefore A and D yard are a maintenance priority aiming to resolve the majority of the issues in the Ermelo Yard. A basic 12 hour maintenance window is allocated per month and this coupled with limited budget allocations prompted the maintenance engineers to develop a more specialized maintenance strategy to address the challenges in the yard by introducing the use of Integrated Track Condition Monitoring Systems (ITCMS) in unison with the tradition maintenance regime thus improving the way maintenance is done, aiming to reduce failures and repair time.

2 LITERATURE REVIEW

Zhang et al. expressed that many previous publications either put focus on maintenance planning or train scheduling in isolation but rarely considered the two simultaneously. Therefore, problems are defined in isolation and usually solutions would not work effectively when applied in practice.

Most literature on maintenance improvement suggests the use of complex algorithms and models such as the heuristic algorithm based on Lagrangian relaxation to solve the problem (Chuntian Zhang, 2018). Xuesong Zhou (2005) proposed a generalized resource-constrained project scheduling model. A branch-and-bound algorithm was proposed to obtain feasible timetables with guaranteed optimality thus increasing the opportunity to execute maintenance.

these algorithms tend to be quite complex, therefore a more practical approach is needed to improve the maintenance regime for a complex and heavily trafficked heavy haul export yard. This stems from a similar idea proposed by Pieter Vansteenwegen (2015) to avoid maintenance conflicts by using a *Maintenance Conflicts Avoidance Algorithm* (MCAA). Similarly, it is intended to integrate the use of traditional condition assessments with automated track condition monitoring systems with the intention of reducing the downtime due to infrastructure failure without increasing the maintenance window.

This paper is focused more on the condition based maintenance of the track in that it is becoming difficult to execute preventative maintenance in light of financial and operational constraints. Currently, in the event of an infrastructure failure, major maintenance is required which can restore the track and in some cases it’s restored to a better standard than it was in before the repairs because of the lack of maintenance before the failure (Dongyan Chen, 2005).

The combination of condition based maintenance strategies and ITCMS instrumentations like the Wheel in Motion – Weigh in Motion (WIM-WIM) system and the Continuously Welded Rail Measuring System (CWRMS), a more robust maintenance strategy can be created. The function of the WIM-WIM system is to measure the weight of the train whilst in transit, which at the same time detects if there is a surplus or shortage in terms of wagon loading that causes an imbalance of axle loading (Ansaldo STS, 2015). The WIM-WIM also detects the impact load on the rails caused by the wheel as a train passes the system whilst also detecting defects on the wheels (Ansaldo STS, 2015). The rolling surface of each wheel in contact with the rail is measured, therefore allowing for the type of defect such as a flat wheel on a specific wheel to be identified (Ansaldo STS, 2015).

This information is then relayed to the operator, by means of the optic fiber sensors, who then alert the relevant maintenance personnel before further damage is caused to the track system by the defective wheel (Ansaldo STS, 2015). If this information is not detected and relayed, defective wheels cause non-conformal contact with the rail which induces higher dynamic forces onto the rail (TLC Engineering Solutions, 2009). The high stresses in the rail caused by these defects will lead to Rolling Contact Fatigue (RCF) if the yield stress of the rail is exceeded (Singh, 2011). RCF will cause minute cracks to develop on the rail crown which will propagate over time (Singh, 2011). Under cyclic dynamic loading caused by the passage of trains, RCF will lead to the ultimate tensile strength of the rail being exceeded and subsequently cause points of failure such as a rail fracture to develop (Singh, 2011).

TLC Engineering Solutions (2009) further adds that the WIM-WIM is able to detect a skew bogie. When the bogie of the train makes contact with the rail at an angle, the bogie is considered to be skew (BBB9007 , n.d.). According to BBB9007, skew bogies increase the wear rate of wheel and the rail by inducing high lateral forces at the wheel-rail contact point. The increased wear rate will result in the deterioration of the rail and consequently the development of cracks on the rail (POPOVIĆ, et al., 2014). Thus leading to potential rail fracture and increasing the risk of a derailment (POPOVIĆ, et al., 2014).

Therefore, information from the WIM-WIM of defective wheels are critical to infrastructure maintenance as the defective wheel should be repaired before it becomes detrimental to the track. Hence the use of the WIM-WIM decreases the deterioration of the track and rolling stock. In addition, if analyzed in conjunction with track condition data, it can guide maintenance engineers to create predictive maintenance plans.

According to Lim, et al., (2013), one of the main advantages of a continuously welded track is to sustain the track components to their potential life span whilst decreasing the cost of maintenance. However, having a long fixed length of track causes induced thermal stresses to develop within the rail (Lim, et al., 2013). When the thermal stresses within the rail are above the allowable range of stress, this causes the rail to move in a lateral direction which consequently results in the deterioration of track geometry (Lim, et al., 2013). Furthermore, Gräbe, et al., (2007) states that these induced stresses are not only caused by thermal conditions but are also due to the imposed loads caused by the passage of trains.

High tensile stresses within the rail causes the rail to fracture (Lim, et al., 2013). According to Gräbe, et al., (2007), excessive rail stress is the cause of between 50% - 60% of train delays that occur on the Coal line in South Africa. Therefore, the stresses in the rail need to be measured so that corrective action such as destressing can take place before failure can occur. Thus an effective continuously welded rail management system (CWRMS) needs to be in place.

Usually the stresses within the rail are measured by the lifting frame (Transnet, 2012). However, stress measurement using the lifting frame can only be conducted when the temperature of the rail is between 5◦C-20◦C, therefore stress measurements in Ermelo are generally conducted in winter (Transnet, 2012). This conventional method of stress measurement also requires a team to be on site and physically measure the stresses (Transnet, 2012).

Therefore, an innovative and time efficient method that reduces the reaction time and prevents the occurrence of failure needs to be adopted. Thus, a system called the Wayside Intelligent Longstress Management (WILMA) system, which was then replaced with the Continuously Welded Rail Monitoring System (CWRMS) is used to monitor the real time stresses within the rail to prevent the negative impact of rail fractures and buckling (Gräbe, et al., 2007). This system utilizes temperature and strain gauges to measure the stresses within the rail at set intervals on a daily basis (Gräbe, et al., 2007). The data is received from GPRS modems and stored by the monitoring server within the system so that stress measurements of the rail can be obtained remotely at any time (Gräbe, et al., 2007). The CWRMS utilizes Equation 1 to calculate the stress temperature within the rail.

$$N=EA\alpha\Delta T \tag{1}$$

Where:
E = Young's modulus for the rail [N/mm2]
A = total cross-sectional area of the rail [mm2]
α = coefficient of expansion [/°C]
ΔT = *Tneutral* - *Tactual* [°C]

According to Transnet (2012), the stress free temperature (SFT) for Ermelo is 20◦C - 40◦C. When the SFT is below 20◦C, this indicates that the rail is in compression whilst when the SFT is above 40◦C this indicates that the rail is in tension (Manual, 2012). The server transmits warning signs to the respective maintenance teams if the stresses within the rail are outside the stress free temperature range.

3 METHODOLOGY

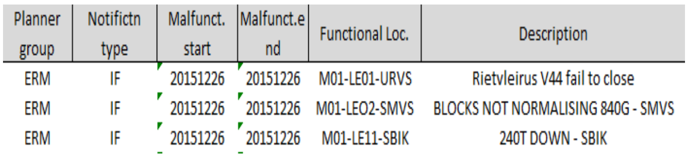
The following section serves to illustrate how the data from Integrated Track Continuous Monitoring Systems (ITCMS) was used in conjunction with information and reports obtained from infrastructure inspections to create a dynamic maintenance strategy specifically for the Ermelo Yard. The strategy was created such that it caused minimal service interruption but yielded the best outcomes in terms of infrastructure sustainability. Analysis of the effectiveness of the maintenance strategy was conducted over the three year period since it was first implemented in Ermelo, hence the years considered for analysis were 2016, 2017 and 2018. This type of analysis began in 2016 but only using the CWRMS data and in 2018 the addition of WIM-WIM was made.

3.1 *Maintenance inspection*

Various methods of maintenance inspection were conducted and each were used either to supplement a different inspection type or it was used in conjunction with track and vehicle monitoring systems.

3.1.1 *Chronic failures*

The team needed to be able to track and quantify the type and severity of all infrastructure failures which occurred in the yard as well as the repair time per incident. This information was drawn from the Systems, Applications and Products in data processing (SAP) system for every month of the three year period considered for analysis as indicated in Figure 2 below.



Planner group	Notifictn type	Malfunct. start	Malfunct.end	Functional Loc.	Description
ERM	IF	20151226	20151226	M01-LE01-URVS	Rietvleirus V44 fail to close
ERM	IF	20151226	20151226	M01-LEO2-SMVS	BLOCKS NOT NORMALISING 840G - SMVS
ERM	IF	20151226	20151226	M01-LE11-SBIK	240T DOWN - SBIK

Figure 2: SAP data indicating infrastructure failure

3.1.2 *Daily Foot Patrol Inspections*

Daily foot inspections are to be conducted in the yard by a dedicated patrol team whereby the current capacity consists of 5 track personnel (Transnet, 2018). Due to the size of the yard, it takes the patrol team 15 working days to complete a full foot patrol inspection of the entire yard. These inspections are critical in identifying existing and unknown failures as well as impending failures. The team records the failures they detect and also identify locations that show signs of impending failure.

3.1.3 *Ballast fouling*

Ballast fouling tests are executed in the yard as per the procedure outlined in the S406 specification as indicated in Table 1 below (Transnet, 1998).

Ballast Characteristic	
Ballast Replacement Condition	0.7 – 1.2 = Good 1.2 – 1.4 = Screening > 1.4 = Total Rejection
Fouling %	Heavy Haul < 60% Mainline < 75%

Table 1. Ballast fouling specifications (Transnet, 1998)

3.1.4 *Rail and Turnout wear monitoring*

These measurements are critical in determining the condition and approximating the remaining service life of the rails. This becomes especially critical in a heavily trafficked yard. The measurements are done using our Infrastructure Measuring Vehicle. To determine the combined wear of the rail we use the formula:

$$Combined\ Wear = \sqrt{(Side\ Wear)^2} + (Crown\ Wear)^2$$

Having determined the combined wear for multiple years, one can calculate the combined wear rate for each of the 4 yards and plot graphs which was used to determine the wear rate of any given radius in any of the yards. This can be observed in Figures 3 to 6 below.

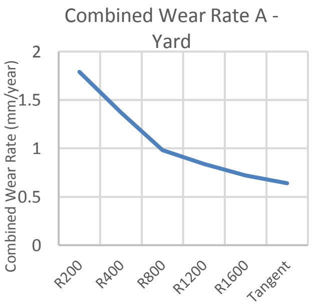


Figure 3. Combined Wear Rate for A-Yard

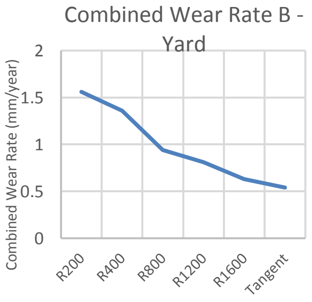


Figure 4. Combined Wear Rate for B-Yard

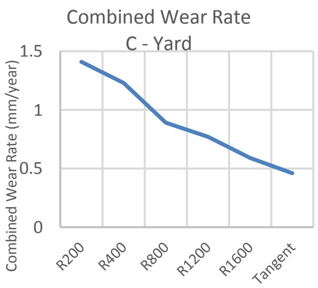


Figure 5: Combined Wear Rate for C-Yard

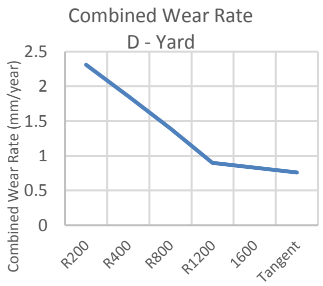


Figure 6: Combined Wear Rate for D-Yard

3.1.5 *Sleeper and Fastening condition*

The condition of the sleepers and fastenings are critical as the impending failure is not visible by the naked eye. Failure only becomes apparent if there is notable geometry loss or via physical inspection. Each component in the fastening system needs to be individually inspected for damage and wear. The sleepers must be inspected for major cracks to ensure they are still structurally sound. Figure 7 below depicts the components of the sleeper and fastening system.

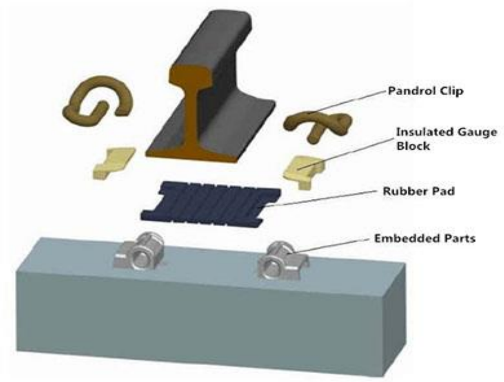


Figure 7: Sleeper and Fastening System

3.1.6 *Ultrasonic rail testing, grinding and track geometry measurements*

The machine runs in certain portions of the yard, providing vital information on the state of the track. Post processed data is critical for the determination of high wear areas.

The ultrasonic testing of the rails is a compulsory part of the track maintenance philosophy as it is from these tests that it can determined if new rails have any existing factory defects as well as to monitor the frequency of failures on the rails.

Arguably the most important element of traditional maintenance is a consistent grinding regime. Due to the scarcity of maintenance budget, methods of optimizing the resources that are available are necessary to ensure that the most critical areas are prioritized.

3.2 *ITCMS*

Integrated Track Condition Monitoring Systems are used in the track environment to acquire and avail alarm information, as well as train and track condition. The system initiates actions in the event of an equipment malfunction or emergency detection on the train.

3.2.1 *WIM-WIM*

The Wheel impact monitor and Weigh in motion system is a high speed system that measures the following:

- Locomotive detection within any part of the train
- Wheel impact identification from parameters given
- Speed determination for each vehicle
- Static and maximum dynamic mass of each passing wheel
- Skew bogie identification from parameters given
- Automatic triggering
- Coverage of bi-directional traffic

The most important alarms in terms of maintenance of the track are the skew bogie and wheel impact alarms. A skew bogie induces high lateral forces in the rail thus leading to accelerated wheel and rail wear, sharp flanges and high spin creep forces.

Wheel impact alarms are generally caused by flat wheels. The high instantaneous forces cause cracked sleepers, ballast crushing and high rail stresses.

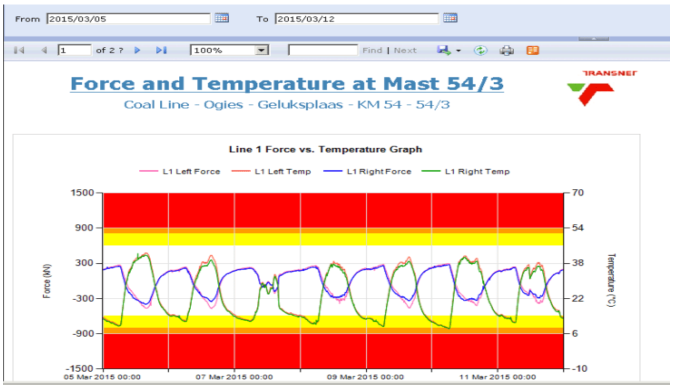
An analysis of this data shown in Table 2 below gives an indication of the number of trains that enter the yard with either skew bogies or flat wheels.

Component	**Time**	**Train #**	**Severity**	**Type**
EMR.WDD1.WDD.WIM.01	2019/02/27 2:31	AH00004803270219	Continue to depot	Lateral Force [A]
EMR.WDD1.WDD.WIM.01	2019/02/27 2:31	AH00004803270219	Continue to depot	Gauge Spreading Force [A]
EMR.WDD1.WDD.WIM.02	2019/02/27 1:49	20190227-014922D	Continue to depot	Flat Wheel
EMR.WDD1.WDD.WIM.01	2019/02/27 7:00	AH00009445270219	Continue to depot	Skew Loading
EMR.CAM1.CAM.WIM.01	2019/02/27 9:30	AH00014221270219	Continue to depot	Serious Flat Wheel
EMR.WDD1.WDD.WIM.01	2019/02/27 2:31	AH00004803270219	Continue to depot	Lateral Force [A]
EMR.WDD1.WDD.WIM.01	2019/02/27 2:31	AH00004803270219	Continue to depot	Skewness [B]

Table 2. Data analysis from the WIM-WIM system

3.2.2 *CWRMS*

The most recurring mode of failure in the yard was found to be the tensile fractures of the rail. Hence in the maintenance strategy it was important to employ a method to mitigate the risk of these tensile fractures occurring. An example of the system interface is shown in Figure 8 below.



From 2015/03/05 To 2015/03/12

1 of 2 ? 100%

Force and Temperature at Mast 54/3

Coal Line - Ogies - Geluksplaas - KM 54 - 54/3

Figure 8. CWRMS interface

3.3 *Integration of ITCMS and Maintenance Inspection*

The integration of traditional track maintenance philosophies with ITCMS brought to light a new type of maintenance strategy for the export yard. This is known as ‘Smart Maintenance’. A schematic representation of the systematic process followed to formulate the integrated plan is shown in Figure 9 below.

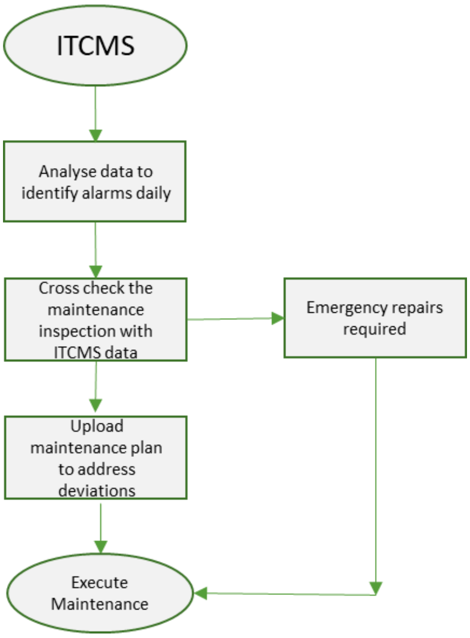


Figure 9. ITCMS systematic process

3.3.1 *Integration of the CWRMS with Track Inspection*

3.3.1.1 Patrol teams

Traditionally, patrol teams would be deployed to inspect the entire Ermelo yard once a month. In the new maintenance strategy, the teams approach the yard systematically starting in areas known to be high tensile stress areas (Stress-free temperature>40). This method greatly increased the effectiveness in picking up failures.

3.3.1.2 Rail and turnout wear monitoring

The measured locations with combined rail wear > 11 mm are interrogated in conjunction with the high stress locations identified by the CWRMS. These locations are monitored daily by track personnel until they can be put on the plan to de-stress them.

3.3.2 *Integration of the WIM-WIM with Track Inspection*

3.3.2.1 Ballast fouling

Adequate scrutiny of the WIM-WIM data indicated evidence of several trains that would enter the yard with flat wheels and result in the crushing of the ballast, subsequently leading to ballast fouling. Attentive tracking of the WIM-WIM reports will give a weekly indication to how many trains with flat wheels could’ve traversed certain sections in the yard. Therefore, preventative maintenance can be planned before residual settlement occurs that will affect track geometry.

3.3.2.2 Rail and turnout wear monitoring

The rail and turnout wear monitoring incorporates the CWRMS, WIM-WIM and the maintenance inspections. The WIM-WIM data is cross-referenced with the high stress locations identified using the CWRMS. If a worn section of rail is also experiencing high tensile stresses combined with a significant enough wheel impact, it will cause the rail to fracture. Hence, if the WIM-WIM data is tracked daily many failures can be avoided.

3.3.2.3 Sleeper and Fastening Condition

The WIM-WIM data is integral in determining the locomotive and wagon defects that tend to induce lateral forces on the rail. The alarming defects are investigated immediately to ensure that the damaged bogie does not damage the fastening system.

In addition, the flat wheel alarms are heeded to ensure that the wheel does not damage any sleepers.

3.3.2.4 Ultrasonic Rail Testing, Grinding and Track Geometry Measurements

The defects located by the ultrasonic tests are marked accordingly and monitored until they are removed to ensure that any train which registered a flat wheel alarm does not traverse that section and cause a rail fracture and possibly a derailment.

3.3.3 *Bathtub Failure Analysis*

For the Ermelo Yard, the time it takes for any rail to reach its design-life limit (shown in Figure 10 below) is greatly accelerated due to the heavy traffic and sharp curves. Hence the rails in the yard can be said to have a premature wear out rate as compared to the wear out rate of rails on a heavy haul line with a wear rate of 0.8 (Manual, 2012).

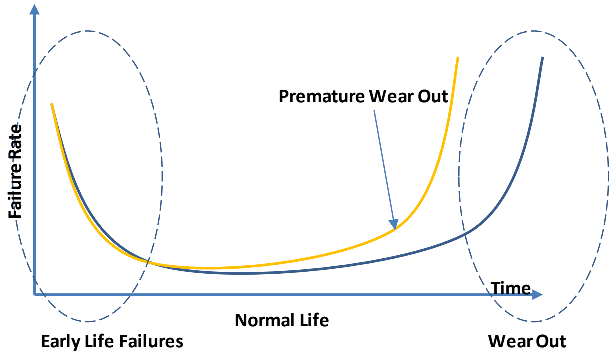


Figure 10. Life Cycle of rails in the Ermelo yard

4 RESULTS AND ANALYSIS

Presented in Figure 11 below, are the results from the application of the integrated maintenance strategy over 3 years.

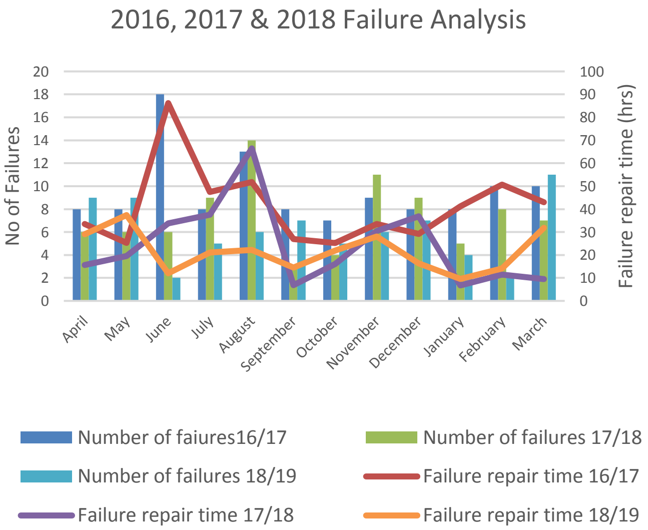


Figure 11. Results from integrated maintenance strategy

4.1 *Number of Infrastructure Failures*

The total number of failures that occurred in the yard in 2016 was 155, in 2017 there were 88 and in 2018 there were 73. This is a 47% drop in the failures in a period of 3 years. The distribution of these failures is illustrated in Figure 12 below.

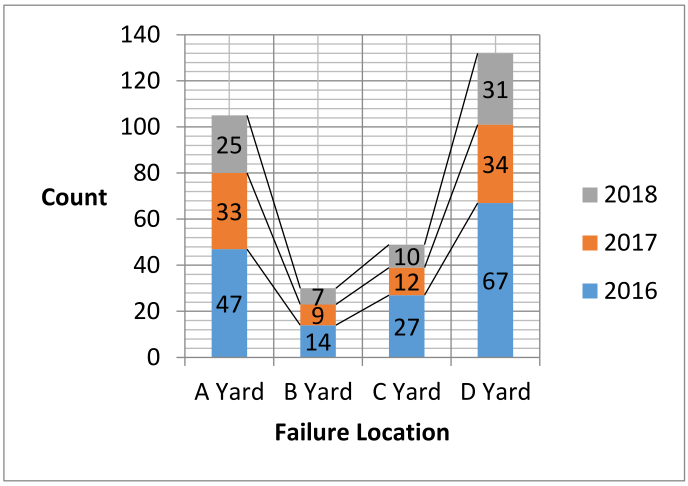


Figure 12. Distribution of failures in the Ermelo Yard

It is apparent that the majority of the faults are occurring in the A and D yards as would be expected. Hence the integrated maintenance plan focuses more on these yards.

The addition of the WIM-WIM data analysis to the maintenance strategy was the most beneficial as a drastic reduction in the number of infrastructure failures subsequent to its addition was found.

4.2 *Infrastructure Measurements and Grinding*

The results of the measurements and preventative grinding or rail profiling campaigns are represented in Table 3 below:

Maintenance Activity	**Results**		
	2016/17	**2017/18**	**2018/19**
1. Ultrasonic Measurements	6	9	11
2. Grinding (Rail Profiling)	1. Removed corrugations 2. Restored profile		
3. Geometry Measurements	19	22	25

Table 3. Results for rail profiling campaigns

Table 3 above illustrates that the number of ultrasonic defects located in the yard are increasing. This implies that the condition of the rails and turnouts is deteriorating. The geometry measurement is indicative of a decline in the track geometry. This implies that the condition of the infrastructure is slowly deteriorating due to lack of maintenance slots.

4.3 *Infrastructure Failure Analysis*

Figure 12 below illustrates the types of failures and that occurred in the yard during the three years in which the integrated maintenance plan was implemented as well as the impending failures that were prevented.

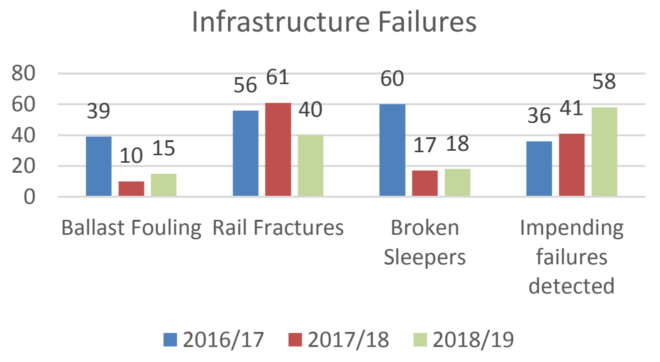


Figure 12. Infrastructure failure results

The ballast fouling failures showed an overall reduction from 2016 to 2017, reducing by 74% and then it increased slightly by 33% from 2017 to 2018. The broken sleepers that were detected from 2017 to 2018 showed a great reduction of 72% and then a 6% increase from 2017 to 2018. Rail and turnout fractures showed an increase from 2016 to 2017 of 8% and then decreased by 34% from 2017 to 2018. It is apparent that the impending failures that are detected each year are increasing annually. This suggests that the integrated maintenance strategy is showing improvement in preventing a greater number of infrastructure failures from occurring annually.

4.4 *Failure Repair Time*

Data drawn from the SAP system indicates that the total annual failure repair time in 2016 was 494 hours, which translates to a monthly average of 41 hours monthly. In 2017 the annual repair time was 291 hours which translates to an average monthly repair time of 24 hours. In 2018, the annual repair time for all failures was 258 hours translating to an average of 21 hours. This information is substantial in that the current maintenance window times are currently 12 hours monthly.

5 CONCLUSION

This paper highlighted the effect that the integration of traditional maintenance inspections with Integrated Track Condition Monitoring Solutions had on maintenance improvement. A comparative analysis spanning over 3 years (2016, 2017 and 2018) showed continuous improvement in the frequency of infrastructure failures and the impact thereof. Over the winter months (June, July and August), there is a noticeable reduction in the number of failures most of which would be tensile fractures of the rail during that period. Another critical aspect of what the results have shown is that the severity or impact of the infrastructure failures is diminishing. The average monthly failure repair time reduced from 42 hours in 2016 to 24 hours in 2017, shows a 59% reduction. It further reduced from 24 hours in 2017 to 21 hours in 2018. This implies that the current maintenance window of 12 hours monthly is insufficient and even with integrated maintenance strategies, another 12 hour window is required per month. It can be concluded from the results that the integration of traditional track inspection and ITCMS yields higher network availability, preserves the asset life time and also reduces maintenance costs. Hence the implementation of this type of maintenance strategy should be considered for use in all railway environments.

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