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OPTIMISATION OF MECHANISED MAINTENANCE MANAGEMENT

eBOOK INSIDE

Abstract

Railway track infrastructure is a complex system consisting of various subsystems which require incremental maintenance from all engineering disciplines; all of whom are competing for the limited time and number of available maintenance windows.

The constant demand for higher traffic volumes, increased train speeds and heavier axle loadings all result in an exponential increase in maintenance requirements but the time available for maintenance is as a result even further reduced. This requires a more scientific lifecycle approach to infrastructure maintenance management. It also requires increased performance from mechanised construction, maintenance and renewal machines to keep the infrastructure reliable, available, maintainable, affordable and safe within the short available maintenance windows.

The objectives of this book are to address the optimisation of infrastructure maintenance management and to provide a model with selection criteria for maintenance machinery and their features for the prevailing circumstances.

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CHAPTER 1
INTRODUCTION

An efficient transport system is a critical component of any country's economic development and growth. It links different markets thereby allowing specialisation of supply and transports people efficiently and inexpensively between home and their workplace. Low transport costs can improve the competitiveness of a country and its individual producers on world markets for the export of products, especially high volume comedies such as coal, iron ore, etc.

Rail transport as a mode of transport with steel wheels running on steel rails encounters low frictional (rolling) resistance making it more energy efficient than road transport. In the USA, for example, where the tractive effort is provided mostly by diesel locomotives, rail freight is on average 63% more fuel efficient than road transport (World Bank, 2017).

Adding to the advantages of rail transport, it is safer than any other land transport system and is friendlier towards the environment, especially where electric traction is used. In large cities where pollution by motor vehicles is a problem, electrical trains and trams are a solution to reduce emissions.

The right of way infrastructure and the steel wheel on steel rail efficiency allows longer trains, heavier axle loads and higher train speeds which all means that more freight or passengers can be transported in shorter times (for long distances) at lower transport rates. The economy of scale is normally transferred to the client/commuter. As distances increase the overall efficiency of railway transport continues to increase over that of road transport or any other mode of transport.

Modern society and industry at large have ever increasing demands from the railway. They demand even shorter transit times which produced trains running at speeds exceeding 300 km/h. They demand higher throughput (tonnages transported) which produced trains with axle loadings of 40 metric tons, freight trains longer than 4 km using distributed power along the length of the train and shorter headways (distance between trains) by changing train signalling systems to in-cab systems as opposed to signal light block sections, etc. Passengers demand higher comfort levels both ergonomically and those dynamically transferred from the track and the rolling stock.

These constant demands for higher traffic volumes, increased train speeds and heavier axle loadings all result in an exponential increase in maintenance requirements but the time available for maintenance is consequentially further reduced.

This requires a more scientific lifecycle approach to infrastructure maintenance management. It also requires increased performance from mechanised construction, maintenance and renewal machines (referred to as mechanised maintenance machines for short in this book) to keep the infrastructure reliable, available, maintainable, affordable and safe within the shorter and fewer available maintenance windows.

The objective of this book is therefore to address the optimisation of maintenance management from a mechanised railway track infrastructure maintenance perspective. There will be a strong emphasis on the selection criteria for machine types, features and mix of machines based on a large number of influencing factors over the life of the infrastructure from concept to renewal.

The book consists of three interlinking parts. Part 1, chapters 2 to 6 deals with the optimisation of maintenance management whereas Part 3, chapters 8 to 14 deals with the selection criteria of mechanised infrastructure maintenance machines which also highlights the change in selection criteria through the life of the infrastructure. Part 2 describes the maintenance activities which links Parts 1 and 3.

Part 1: Optimisation of Maintenance Management

The book starts by defining railway infrastructure as a complex system consisting of various interdependent subsystems. It continues to define the infrastructure system within the principles of Systems Engineering which is a multidisciplinary field of engineering that studies complex systems over their entire life. CHAPTER 2 also assists in defining the various infrastructure components that will be referred to in this book.

A lifecycle approach is central to maintenance management and decision making which warrants a whole chapter (CHAPTER 3) dedicated to this concept. In this book the infrastructure is viewed from four life phases; feasibility and design phase, construction and commissioning phase, operation and maintenance phase and renewal phase. Disposal is disregarded as a lifecycle phase. Each of the phases is discussed in detail. The selection criteria for mechanised maintenance machinery changes with each phase of the infrastructure life and the chapter highlights how important it is that the maintenance plan and the selection of machines starts right at the very beginning of the feasibility stage. In this chapter a systems v-model has been developed specifically to address the lifecycle phases of railway infrastructure. The chapter also looks at infrastructure lifecycle costs.

In order to understand the life phases and the changing selection criteria of machinery it is necessary to understand how the infrastructure deteriorates (CHAPTER 4). The influence of standards, maintenance tactics, strategies, the maintenance plan and the threshold for minimum allowable track condition has on deterioration are considered. Finally, how the infrastructure fails and what the failure mechanisms, rates and modes are described.

The concepts of systems, systems engineering and lifecycle costs are brought together in CHAPTER 5 looking at infrastructure maintenance management as a process with inputs, processes and outputs. 'Inputs' include mechanised maintenance machinery, financial budgets, knowledge of the infrastructure and other resources. It is during the 'process' that maintenance is carried out which includes analysis of the infrastructure condition, maintenance planning, maintenance execution, material replacements, maintenance engineering and renewal. The 'outputs' that are desired are an infrastructure that is reliable, available, maintainable and safe at the lowest possible cost of ownership.

Due to the inherent dangers of infrastructure maintenance, most maintenance activities can only be carried out in a train free maintenance window (CHAPTER 6). Creating these maintenance windows comes with a great opportunity cost for income generating trains on high capacity lines. The more efficiently these windows can be utilised, the lower the infrastructure lifecycle cost will be. Efficient utilisation requires a scientific approach to maintenance management and the correct selection of machine types, features and production.

Part 2: Infrastructure Maintenance Activities

CHAPTER 7 addresses all the maintenance activities that can be mechanised and the machinery that is suitable and available for the purpose. This chapter links parts 2 and 3.

Part 3: Selection Criteria of Mechanised Infrastructure Maintenance Machines

In the third part of the book all the criteria that will influence the selection of machinery are discussed:

- **CHAPTER 8 –** Infrastructure criteria which include infrastructure material used, design, condition and network features with regards to length, topography and curves
- **CHAPTER 9 –** Operating criteria which include signalling systems, operating methods, train detection systems and single vs double lines
- **CHAPTER 10 –** Throughput criteria which include capacity, headway between trains, axle loading and train speeds
- **CHAPTER 11 –** Environmental criteria which include waste, visual pollution, water pollution, air pollution, noise, vibration and climatological conditions
- **CHAPTER 12 –** Safety Criteria which include risk management and occupational health and safety management
- **CHAPTER 13 –** The influences of machine ownership
- **CHAPTER 14 –** The influences of the maintenance organisation
- **CHAPTER 15 –** The influence of machine features
- **CHAPTER 16** summarises all the criteria and influencing factors in a decision making model

Within this book there are several intentional repetitions from previous chapters to ensure that each of the chapters can be read logically without having to do too much cross reverencing. There may also be several repetitions and references in this book to the 'Basic Principles of Mechanised Track Maintenance' (Zaayman, 2017) which should be read in conjunction with this book. Zaayman (2017) describes at length all infrastructure components, what their functions are and how they should be maintained with a focus on mechanised maintenance.

Systems engineering is an interdisciplinary field of engineering and engineering management that specifically addresses large complex systems such as railway infrastructure design and management over its life. The infrastructure can also be seen as a subsystem to a larger system, the railway, and the interaction between the systems/subsystems is the field of focus for systems engineering.

The Systems Engineering Body of Knowledge (SEBoK) defines three types of systems engineering (SEBoK, 2017): Product Systems Engineering (PSE); Enterprise Systems Engineering (ESE) and Service Systems Engineering (SSE); the latter which covers most civil infrastructure systems including railway infrastructure.

Systems engineering has been graphically illustrated by many models that show the steps to make up a systems engineering approach. The V-model is the best known of these models and can be applied in many different industries though it is best known for use in the software development industry. Figure 12 is general description of the V-model adapted by the author for railway track infrastructure construction projects.

The left horizontal leg is the start of the infrastructure lifecycle where the need has been identified for the construction or reconstruction of a railway line. Down the left leg of the 'V' the needs identification is defined through a number of steps by compiling the requirements into a scope, specifications and ultimately into a final design. During this process the feasibility is systematically evaluated at several phases using a coordinated process during which the project can be terminated at any phase should the study show that the project is not viable for whatever reason such as economics, the environment, etc. Every step will be **verified** against the original requirements and approved specifications, standards and various laws and regulations. Planning for mechanisation of construction and maintenance plays a very important role during this process.

Verification in context is the test as to whether or not the system complies with regulations, requirements, specifications, etc., in other words, "are you constructing it right?"

At the bottom of the 'V', project execution (construction) takes place according to the approved designs.

On the right leg of the 'V' the constructed infrastructure is tested and the integration of all the systems (overhead electrification system, signalling system and track system) confirmed. Once the system passes all tests, commissioning takes place where the construction is verified against the designs. **Validation** will also take place against the original specifications and requirements.

Validation in context is the test whether or not the system meets the needs of the customer and stakeholders as identified in the specification in other words "are you constructing the right thing?" This could either be a physical measure or a performance measure once the system is operational. Validation can be described as 'qualification' which is the test to demonstrate that the system meets its specified requirements and performance.

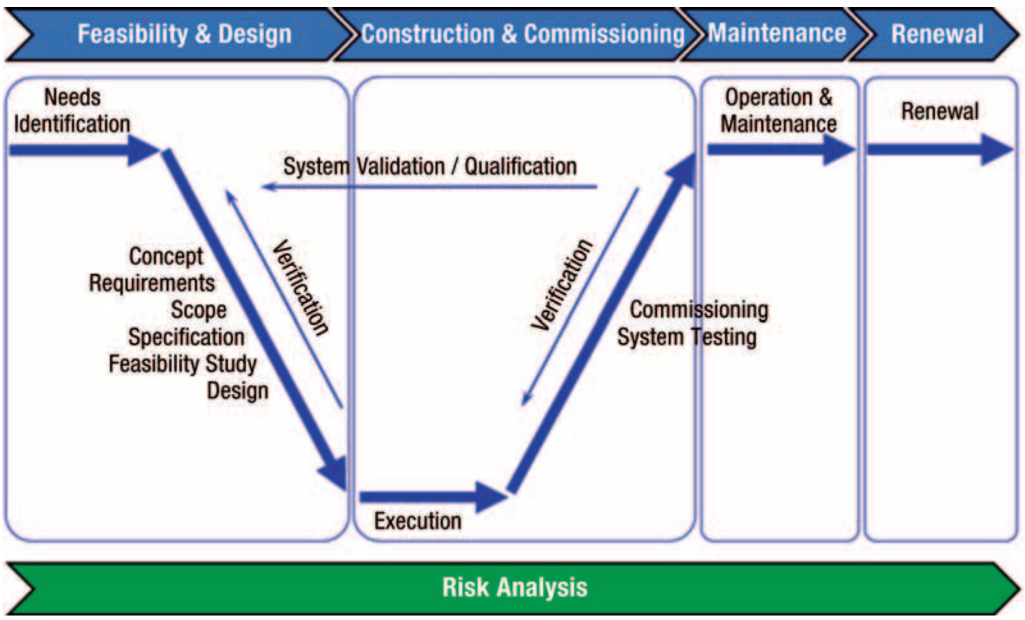


Figure 12: Systems Engineering Basic V-Model

After commissioning the railway line goes into operation during which maintenance is required for the life of the infrastructure. During the operating phase the performance of the infrastructure should be measured against the original identified needs. A reasonable time should elapse before evaluation, typically one year. Most of this book focuses on this part of the infrastructure life (maintenance) which is the longest part of the infrastructure lifecycle (30 to 50 years) where more than 70% of the lifecycle cost will be spent (Ebersöhn, 1997) and where most of mechanised maintenance machinery is designed to work.

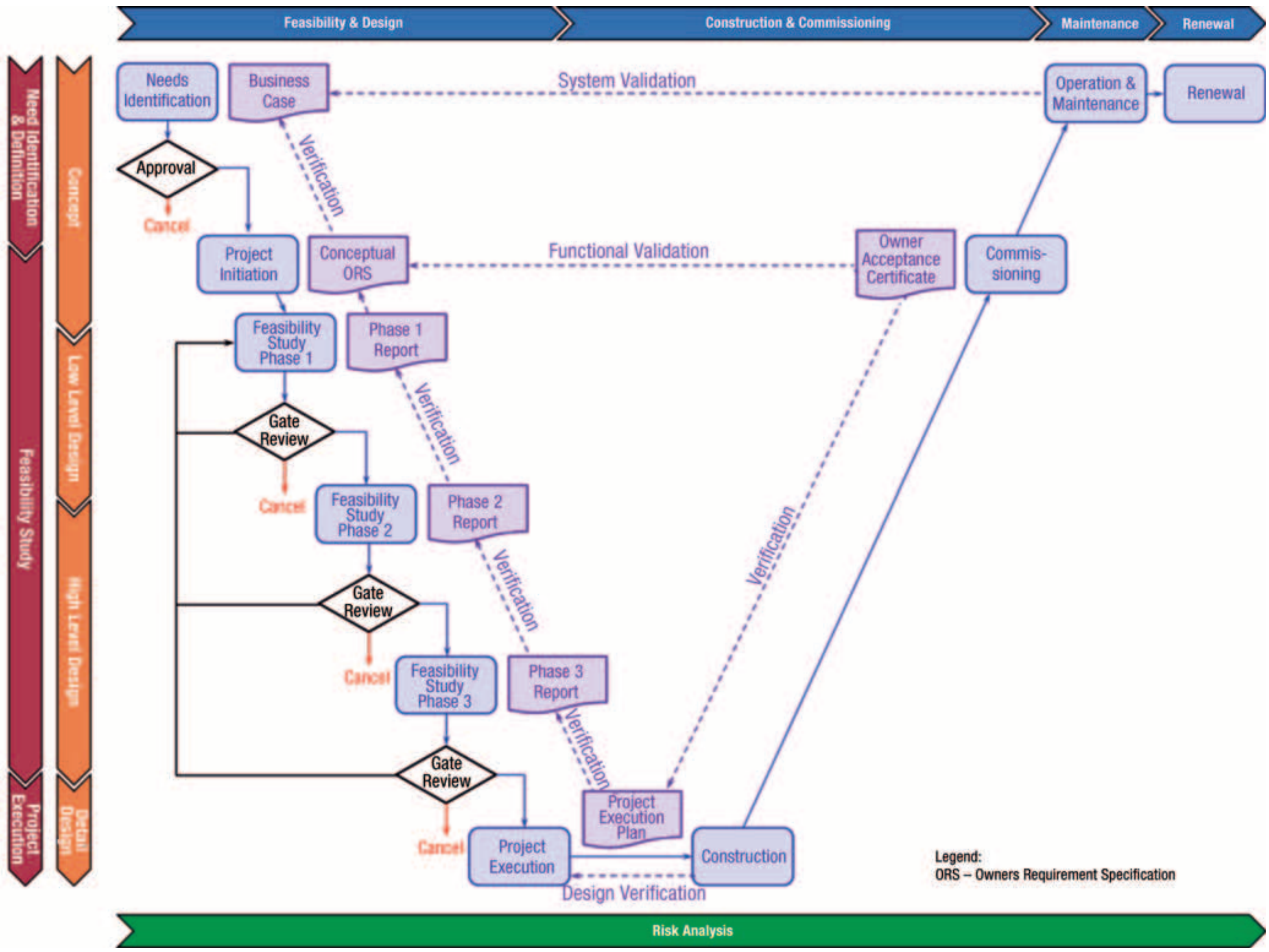
Towards the end of the life of the infrastructure, renewal will be required. The V-model will not be repeated unless the original scope has been changed such as increased throughput, higher axle loading or speed. In Figure 13 the author developed a detailed v-model specifically for railway infrastructure feasibility investigation, design and construction.

Risk analysis is central to the systems engineering process as it takes place at every phase and level. Risk analysis is the process of identifying, quantifying and analysing what can go wrong in the execution of the project. Risk analysis includes activities such as risk assessment (identifying, evaluating, and measuring the probability and severity of risks) and risk management (deciding what to do about risks). See detailed discussion in CHAPTER 12.

The blue blocks represent the flow of the process and the purple blocks the high level documentation that supports that phase of the process.

The process starts with the identification of the need and defining the scope in the Owners Requirement Specification (ORS). The feasibility in terms of various criteria needs to be confirmed before large financial outlays are made.

Figure 13: V-Model Adapted for Infrastructure Lifecycle (Detailed)



If potential failures are detected in the formation (Figure 16 'B'), the track is nearing the end of its economic life and would require renewal. The P-F Interval illustrated (Moubray, 1997) is discussed in more detail in CHAPTER 4 paragraph 7.2. However, depending on the track alignment, topography, climate, length etc., the formation on some sections of the line may have a remaining life beyond the original design horizon. Track renewal using modern mechanised methods can therefore become an integral part of track maintenance effort starting during the late life stage which blurs the distinction between the track life phases and stages. The demand for ballast cleaning could potentially be reduced as track renewal starts.

7. RENEWAL PHASE

If the railway line will be used well beyond the original design horizon, track renewal (Figure 16) using mechanised methods may have to start prematurely during the late life stage to prevent track failure, speed restrictions or uneconomical expenditure on emergency work.

Modern track renewal and formation rehabilitation machines are able to achieve production of long distances of as much as 60 metres in a single occupation and open the line for normal traffic afterwards. Refer to CHAPTER 15 paragraphs 15 and 16.

If renewal and rehabilitation machines are not available, labour intensive methods using earthmoving machines or semi-mechanised methods can be used as described by Zaayman (2017), chapter 20 paragraph 2 and chapter 21 paragraphs 4.1 and 4.2. These methods are very slow and very disruptive to traffic since the line will remain closed for a very long time potentially running into several weeks depending on the distance to be rehabilitated or the distance between turnouts.

Using highly mechanised methods, the distinction between the production phase and renewal phase becomes vague. Over time the homogeneity of the line will disappear with recently rehabilitated sections and other sections that have been rehabilitated years before where local conditions dictated such. Sections of the line may be in different life stages. This complicates mechanised maintenance and a new approach towards maintenance may have to be considered.

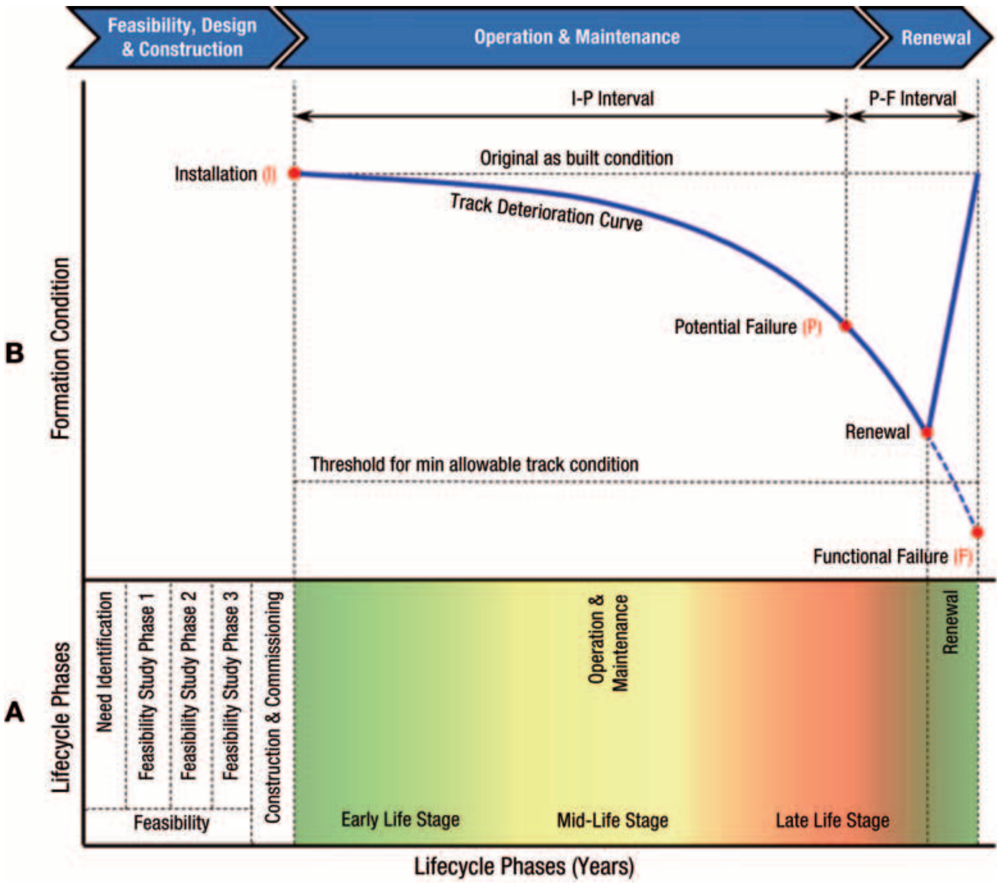


Figure 16: Potential Failure of the Formation Indicates End of Track Life [Adapted from Haas et.al (1994), Ebersöhn (1997) and Moubray (1997)]

Where rehabilitation starts too late, the level of formation failure may exceed the maximum depth beyond the capability of mechanised methods (approximately 1,200 mm below top of rail). In these cases, labour intensive methods using earthmoving machines become the only alternative. This is a classic example where either neglect or the perception of savings by starting a maintenance or rehabilitation activity late has very much the opposite effect. The labour intensive methods will prove to be very expensive if the cost to traffic is considered due to long line closures.

8. LIFECYCLE COSTS AND COST ANALYSIS

8.1. Introduction

Infrastructure 'lifecycle costs' can be defined as the total costs of the asset during its economic life. This comprises the phases of feasibility study, design, construction, operation and maintenance and renewal (as illustrated in Figure 17) discounted to present day or time of initial investment.

The total costs include:

- consulting engineering costs,
- track material costs for construction,
- track construction contract costs (as applicable),
- infrastructure measuring recording and inspection costs,
- mechanised maintenance costs,
- material replacement costs,
- maintenance department overhead costs, and
- disposal or recycle costs of individual track components replaced during maintenance such as ballast spoil, sleepers and rails.

'Economic life' can be defined as the period of time the asset is useful and is shorter than the asset's physical life (in the case of railway track infrastructure which can still be utilised very long after the end of its economic life). It is the period of time until the maintenance costs have reached a predetermined percentage of the renewal costs (see CHAPTER 4 paragraph 2 Figure 24). This would be based on the threshold for minimum allowable track condition (CHAPTER 4 paragraph 5).

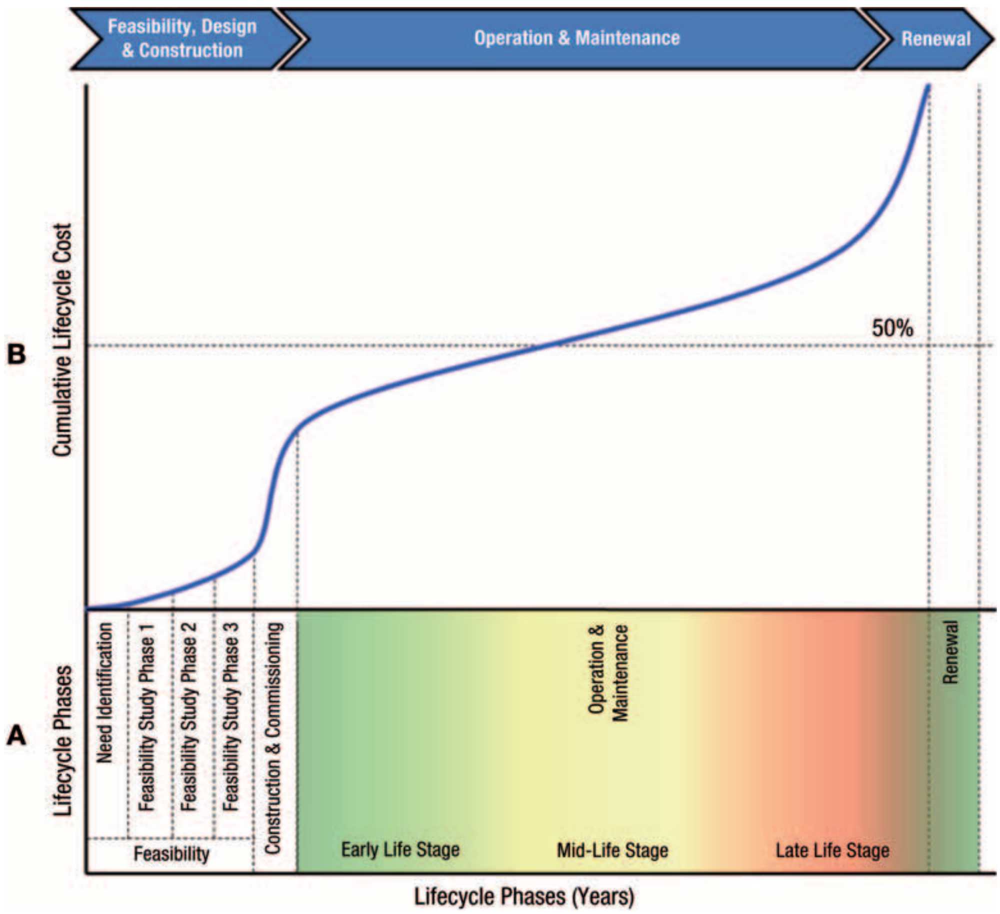


Figure 17: Lifecycle Phases and Lifecycle Costs [Adapted from Haas et.al (1994) and Ebersöhn (1997)]

explanation of maintenance standards. This is also the application for spot tamping. It is very important that corrective maintenance be catered for in the machine selection criteria. For example, one high production tamping machine may be adequate to achieve the required tamping rate on a very long line. However, when corrective or emergency maintenance is required a long distance away from where the machine may find itself, regular travelling along the line may prevent the machine for achieving its required production.

- Material replacement will become necessary towards the mid-life stage due to normal fatigue and wear of the individual components. Ballast replenishment is not seen here as material replacement, although ballast cleaning could be seen as renewal, the cost of which can potentially be capitalised. The rail, fastenings, rail pads, turnout crossing and blades, turnout machines, overhead contact wire, etc. have finite life spans that may expire several times within the track life horizon. At first some material may be replaced prematurely due to opportunity. For example, if rail pads are being replaced at the end of their functional life, the opportunity may be used to replace the fastenings too, even if it is premature due to the limited available maintenance windows and the cost of another window at a later stage. Towards the late life stage track components are likely only to be replaced as a corrective measure to prevent an emergency as the track is allowed to deteriorate towards renewal.

8.7. The Effect of Underinvestment in Maintenance on Lifecycle Cost

Infrastructure maintenance comprises a large percentage of any railway's operational expenditure. When financial difficulty is experienced, the maintenance budget will often be one of the first budgets to be reduced. The track deterioration curve in CHAPTER 4 paragraph 2 Figure 24 was based on the hypothesis that the necessary maintenance input in financial terms has been allowed for. The question arises as to what the case will be if the investment in maintenance is inadequate. This might be reflected by a maintenance intervention at a point below the threshold or an inability to restore the track to its best possible condition.

Figure 22 illustrates how the overall deterioration curve will drop down much sharper than if timely and sufficient maintenance was carried out. The life expectancy of the track has been drastically reduced as illustrated by the distance between 'a4' and 'b4'. In addition, the costs required to renew the track will greatly exceed the costs that would have been required if timely and sufficient maintenance were carried out as depicted by the curve 'b3–b2'.

The longer the deterioration curve (a2 versus b2), the longer the life of the track and the lower the track lifecycle cost will be resulting in lower freight costs and greater competitiveness on world markets for exports from the country in question, or in the case of commuter transport, cheaper fares and greater competitiveness with other modes of transport.

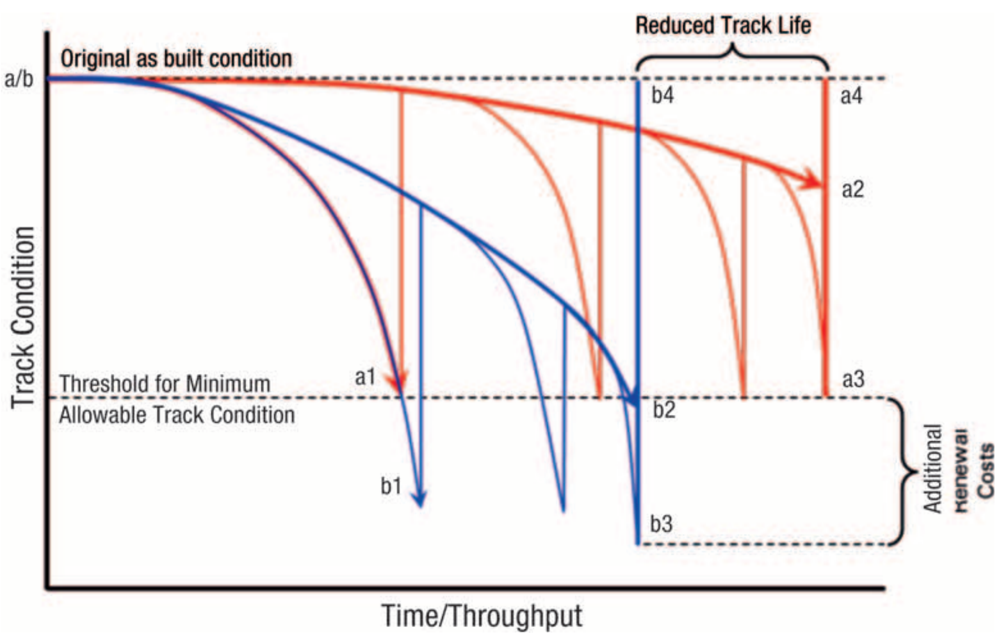


Figure 22 : Track Deterioration Curve with Inadequate Financial Investment (Adapted from Zaayman, 2017)

The effect of such an underinvestment in maintenance was highlighted during the RT-CAP research project in the Southern African Development Community (SADC) countries which was carried out by Plasser South Africa and sponsored by Austria during the 1990's (Zaayman, 2017).

The maintenance cost curve of Figure 23 is based on the theoretical and practical relationship of under-investment in maintenance of the assets and the resultant intervention cost. The derailments and speed orders (speed restrictions) are the quality indicators which follow as a result of the above mentioned relationship.

A well planned and executed track maintenance strategy will aim to sustain the track condition at a predetermined equilibrium level. This equilibrium level can be measured in various different ways such as number of defects per kilometre or a standard deviation (see CHAPTER 4 paragraph 2.4.2 for condition indices) which would be the most scientific measure. It implies that the financial input is adequate to sustain the overall track condition at the predetermined equilibrium level.

An inadequate financial input is illustrated by the maintenance cost curve MC which drops to below the equilibrium level, i.e. the financial input is inadequate to maintain the predetermined track condition. The deteriorating track condition will force speed orders (speed restrictions) to be imposed at an increasing number. The number of derailments will also increase.

The loss of customers due to poor punctuality as a result of the speed restrictions as well as the cost of derailments, all of which are indirect lifecycle costs, will force the railway administration to reverse the negative trend to ensure the continued functioning of the track. This point of intervention is illustrated by MC2. The shaded area between the equilibrium line and the maintenance cost curve depicts the accumulated backlog costs.

To bring the track condition back to the equilibrium level, a huge intervention cost is required over a short period of time. This becomes a capital expenditure, as opposed to operational expenditure, for which there is very seldom money available. The value of the intervention costs greatly exceeds the backlog value ("saved" amount) due to the knock-on damage to the infrastructure by the deteriorating track. If the indirect costs of derailments, reduced traffic due to speed restrictions and loss of business are added to the intervention costs, the increase in the lifecycle cost of the track is astronomical. This could have been prevented by small incremental maintenance expenditure.

Re-investment in maintenance will be depicted by the line MC2 to MC3 which indicates an acceleration in expenditure and renewal cost. After the peak maintenance cost expenditure level (MC3) has been reached, maintenance expenditure can be allowed to slow down until it levels off at the equilibrium level, at which point the level of derailments and speed orders will also follow to reach an acceptable level.

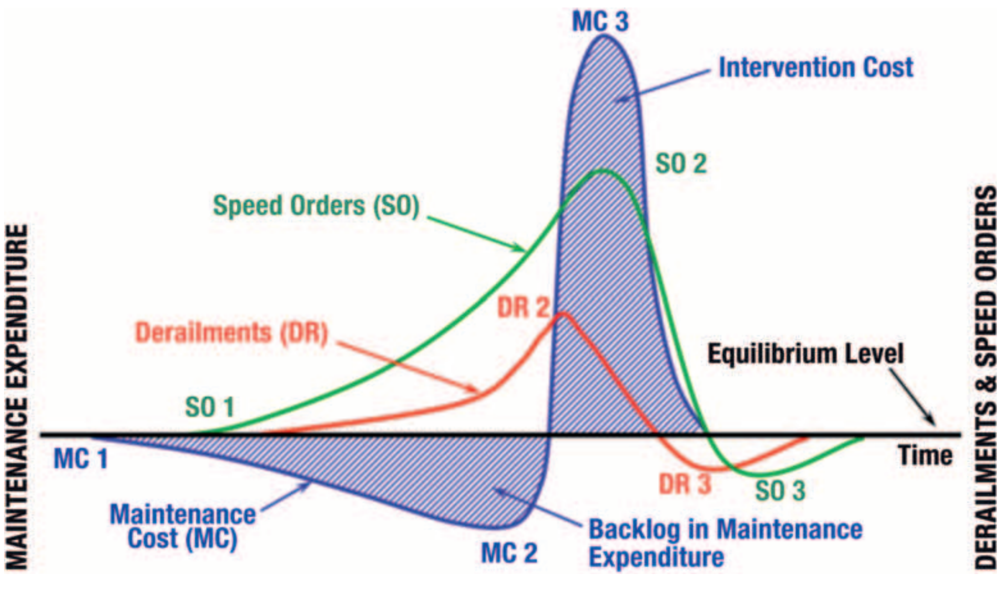


Figure 23 : Maintenance Cost Curve (From RT-CAP Project, Zaayman, 2017)

If the threshold for maintenance intervention is set at a low track condition value as indicated by the line 'threshold 1' on Figure 27, the effect of maintenance intervention at the low value will be hardly noticeable at first but the track's service life will be reduced by the knock-on effect caused by the poor track condition.

For example, if the track roughness threshold limit, as measured and calculated by a track recording vehicle and represented as a TQI value, is set too low before tamping takes place, the roughness will cause higher dynamic loading of the track which will break concrete sleepers, damage the rails and cause crushing of the ballast, which in turn will result in fines in the ballast bed retaining moisture; eventually resulting in damage to the formation, reducing the life of the track exponentially.

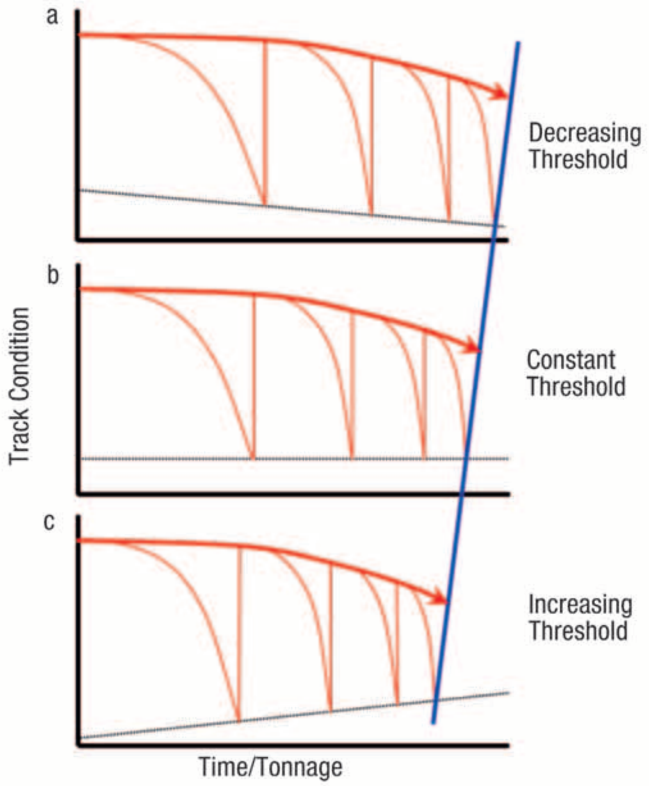


Figure 28 : The Effect of the Various Thresholds on Lifecycle (Adapted from Veit, 2004)

Veit (2004) provides some of the vital technical and economical correlations of track based on a project adopted by the Austrian Railways since 1996. His evaluation showed that the quality level achieved after maintenance was lower than it would have been if maintenance had been implemented sooner (such as at threshold 2 in Figure 27). Intensive maintenance efforts at a later stage to extend the service life proved uneconomical.

It is however not only the level at which the threshold is set that is of significant economic importance. Veit's research has also shown that the threshold should not be set at a fixed value but should rather be linked to the age of the track to achieve the longest possible track life.

The general tendency by maintenance managers is to maintain a constant threshold for maintenance intervention throughout the life of the track (see curve 'b' on Figure 28). With a constant threshold, maintenance intervention will always take place when the track condition has reached a predetermined level, irrespective of the age of the track.

However, in practice it is more likely that an increasing threshold will be found (curve 'c' in Figure 28) which means that while the track is new, the available maintenance budget is concentrated on other sections where the track condition is poor. Initially the effect of this cannot be seen. As the track ages, the threshold has

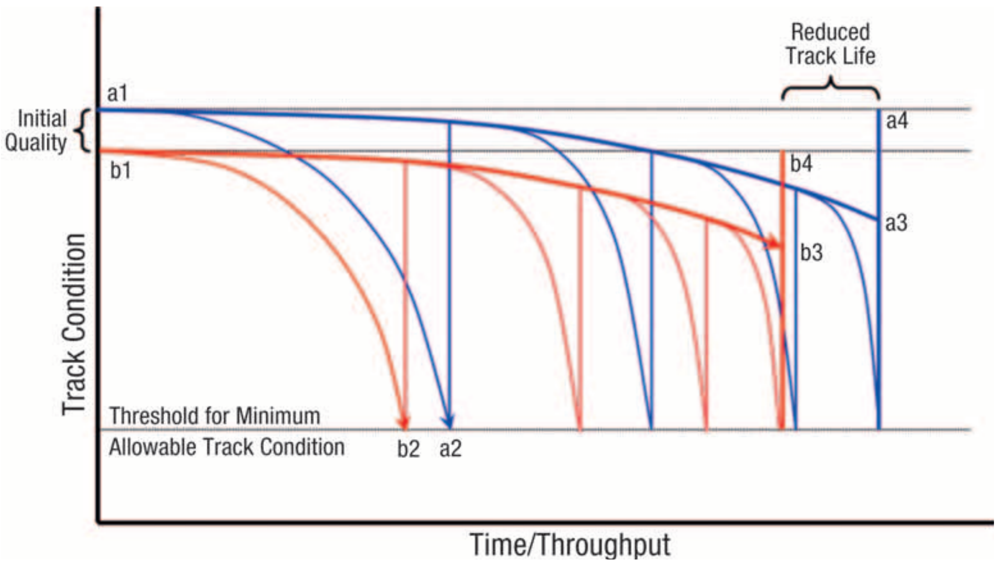


Figure 29 : The Effect of Initial Quality in Construction on the Deterioration Curve (Adapted from Zaayman, 2017)

to increase due to the increasing wear of all the track components, to maintain a reasonable availability and track life. However, the knock-on effect referred to earlier has already taken its toll and will negatively impact on the life of the track.

Veit's project has however proved that the most economical approach to track maintenance is when resources are invested in high levels of maintenance and high threshold level in the earlier stages of the track life. In other words, a long service life and lowest lifecycle cost can be expected when the threshold for maintenance intervention is at its highest while the track is still new. The threshold is then gradually reduced towards the end of the track life (curve 'a').

6. INITIAL QUALITY

Decisions made during the planning, design and construction phases of the track have far reaching consequences for the deterioration rate and lifecycle cost of the track structure (as discussed in CHAPTER 3 paragraph 8.3). This point is illustrated in Figure 29. If a lower initial quality of the track was selected with the use of lower standard track components or construction methods to save money in construction costs (the drop from 'a1' to 'b1'), the track will deteriorate quicker as illustrated by the curve 'b1–b2'. The maintenance cycles will be shorter and track renewal will therefore also be required sooner (the difference between 'a4' and 'b4'), resulting in a reduced track life, higher traffic costs and lower competitiveness. Therefore, the higher the initial quality the longer the track life will be and the lower the lifecycle costs.

7. FAILURE

7.1. Introduction

Railway track infrastructure is a complex system consisting of various interdependent components. Failure of one component can bring the entire infrastructure to a standstill. On high capacity commuter lines, it may cause many commuters to be late for work and cause severe discomfort to commuters and indirect costs to the economy. On high capacity lines, especially heavy haul lines, where train slots work according to a fixed schedule, lost train slots cannot be caught up again. The loss in revenue due to the loss of a train slot can be many times the cost of the cause of the failure.

A study done by the author on the iron ore heavy haul line in South Africa calculated that the revenue loss of one train to the economy of South Africa was equal to the purchase price of a tamping machine at the time. **The decision regarding the purchase of a mechanised maintenance machine should therefore not be based on the cost of the machine but the cost of not having the machine.**

All track components will fail sooner or later. Understanding failure characteristics such as probability patterns, causes, modes, etc. and predicting when and how components will fail and preventing such failure through maintenance or replacement is what will make the system reliable and reduce the overall deterioration rate. Failure prediction is part and parcel of lifecycle cost estimations.

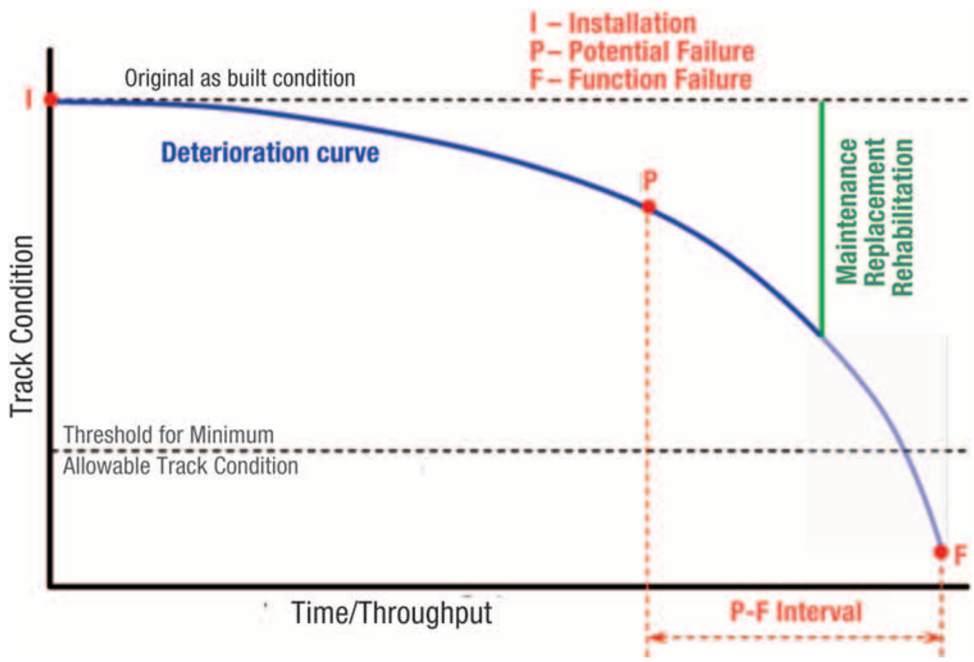


Figure 30: P-F Interval
(Adapted from Moubray 1997)

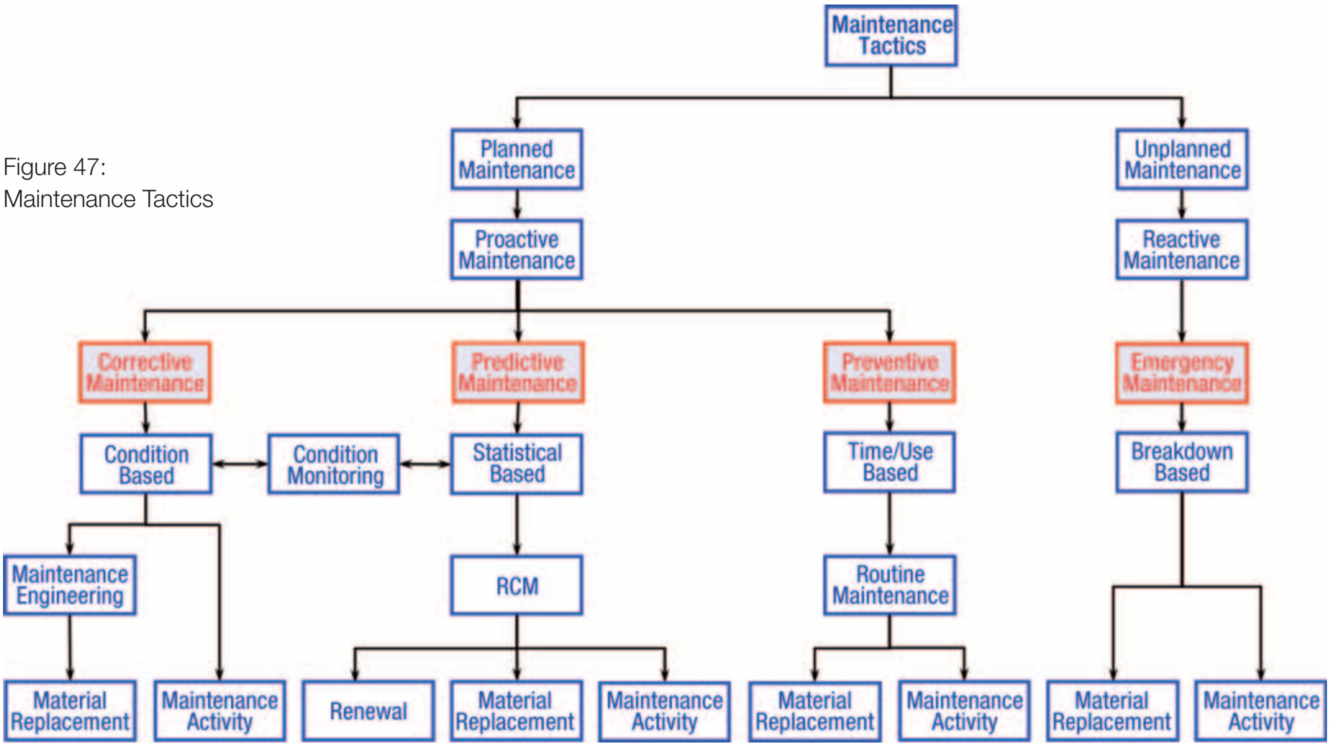


Figure 47:
Maintenance Tactics

2.3.7. Infrastructure Material Replacement Strategy

Maintenance windows are generally in short supply and if the opportunity cost of traffic is considered, together with the administrative and overhead costs for planning and arranging maintenance windows, early replacement of components such as pads when fastenings are replaced may have long term financial benefits.

It may also be a strategy to replace rails on main lines before they wear down to a minimum since they may still be in a good enough condition to be used on branch lines or sidings or to be transposed outside of a curve.

2.3.8. Maintenance Windows

The number of time slots or length or frequency of available maintenance windows may not always be a strategy but part of the initial planning for the through-put of the line. Maintenance windows using train slots are not the only maintenance opportunities available (see CHAPTER 6). Other opportunities that may form part of the maintenance strategy include:

- Working in-between trains if the headway between trains, train protection systems and operating rules allow such activities.
- The use of a complete shutdown for a number of days has proved to be very effective on some freight lines, especially single lines where the disruption is at its greatest yet still proves economical.
- Sharing of maintenance windows by all disciplines is a prerequisite for effective maintenance which requires planning and scheduling to be carried out collectively (including train operations).

2.3.9. Detailed Maintenance Activity Strategies

At the lower levels where individual maintenance activities are planned, the strategy should provide guidelines or rules such as, grinding cycles if not dictated by wear standards, cleaning of drains, cleaning of overhead electrification equipment insulators, greasing of equipment, etc. In this case the strategy could merely refer to a maintenance manual which is kept up to date and approved by senior management or standard specifications.

2.4. Maintenance Tactics

2.4.1. Introduction

Maintenance tactics, also referred to as maintenance types (EN 13306, 2010), are the means and activities by which the maintenance strategy is carried out.

Maintenance tactics, as defined in this book, can be divided between either ‘planned’ or ‘unplanned’ maintenance (Figure 47).

Unplanned maintenance in context refers to reactive emergency maintenance or component replacements to return the system to a functional state if a component has either failed or is about to fail. Planned proactive maintenance refers to maintenance which aims to avoid component failure in the first place.

Ideally the majority of resources employed should be towards proactive planned maintenance activities as these are the only tactics that will extend the life of the track and will keep unplanned maintenance to a minimum, making the track more reliable and available. However, various unpredictable factors such as natural disasters, derailments, etc. will result in an actual maintenance tactic somewhere between proactive and reactive maintenance.

Planned maintenance can be of a corrective, predictive or preventive nature. Definitions for each of these tactics vary substantially in literature, especially between industry segments. There is however a golden thread which this book attempts to draw on that would be applicable for railway infrastructure maintenance. This is a more in-depth study of maintenance tactics than those explained in Zaayman (2017), chapter 6 paragraph 5 and may therefore have some discrepancies.

In the following paragraphs the different maintenance tactics in Figure 47 will be discussed and brought into context with maintenance standards (CHAPTER 4 paragraph 4), the hypothetical track deterioration curve (Figure 48 below and CHAPTER 4 paragraph 2.1) and the P-F interval curve (Figure 49 below and CHAPTER 4 paragraph 7.2).

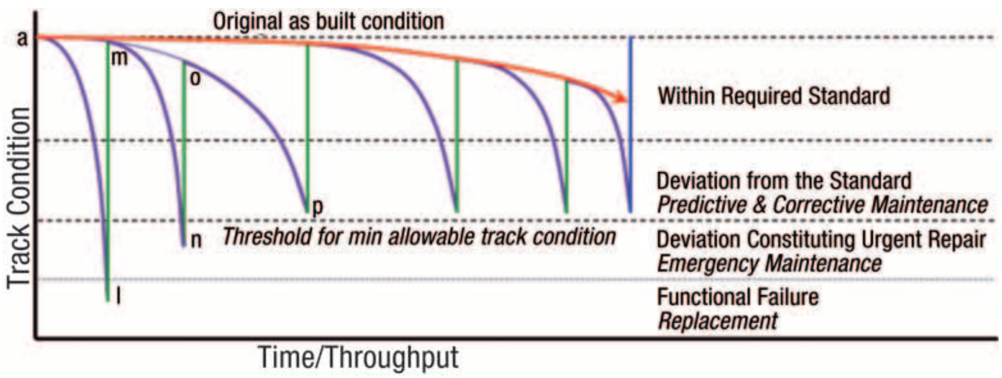


Figure 48: Expansion of the Hypothetical Track Deterioration Curve

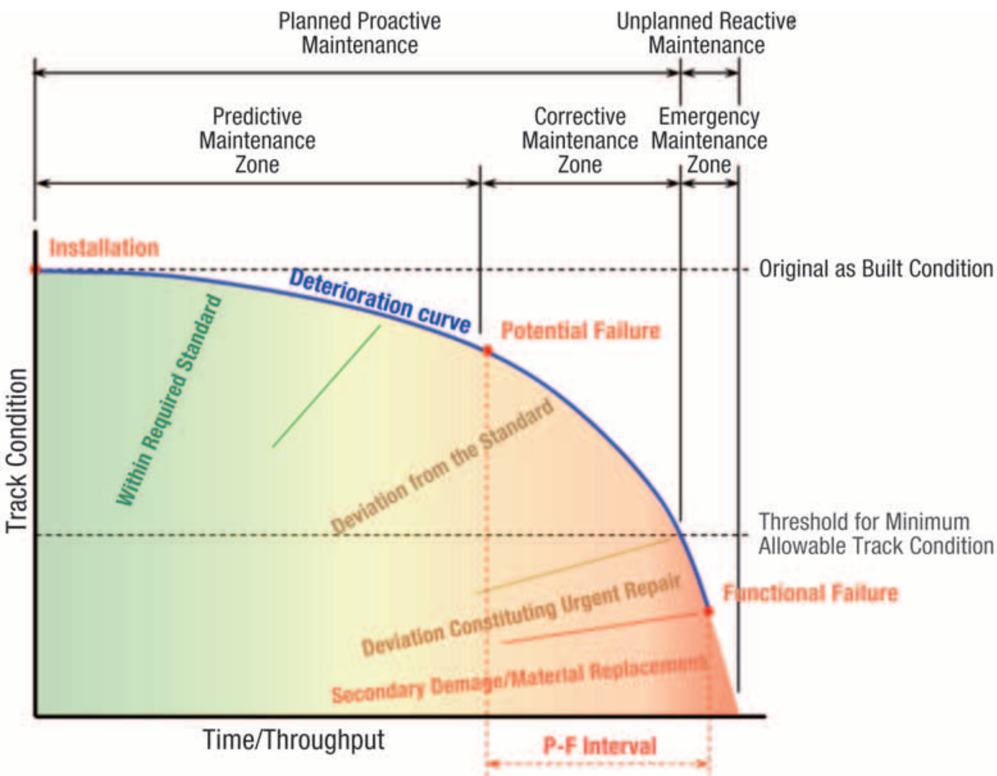


Figure 49: Expansion of the P-F Interval Curve

CHAPTER 8
INFRASTRUCTURE CRITERIA

1. INTRODUCTION

This chapter investigates the influence of the infrastructure on the selection of the type of machine, machine features, machine production and mix of machines in order to effectively manage the condition of the infrastructure.

2. INFRASTRUCTURE MATERIAL

2.1. Introduction

The quality of track material plays a significant role in the life expectancy of the track as well as the maintenance cycles that can be expected. Improvements in technology must always be considered during the design phase or when material replacements are scheduled since there may have been technological improvements that could extend maintenance cycles. A good example is the use of under sleeper pads which is a relatively new invention for which the effectiveness for reducing tamping cycles has been proven in many research projects of late.

The additional costs of higher quality or better technology must be weighed against the cost of maintenance and the availability of maintenance windows.

2.2. Rails

Technology has had a major influence on rails in terms of increased life expectancy and reduced maintenance requirements. One of the most important advances of rail technology in the past half century must be the move towards continuous welded rail as it eliminates highly maintenance intensive rail joints (refer to Zaayman, 2017 chapter 3 paragraphs 2.4 to 2.8). Where rail joints are still in track on older lines the additional maintenance costs with regards to maintaining the joints (removal and greasing on an annual basis) and the shorter tamping and ballast cleaning cycle due to high dynamic loading at the joints must be considered in the budgets, human resource requirements and of course the number of or production of mechanised maintenance machinery units required.

In recent years the rolling techniques of rails have improved substantially with the age old problem of hydrogen inclusions in the rail causing cracks and rail breaks having been eliminated. When the flash-butt welding capacity is considered and these machines are used for repairing rail breaks, the type of rail in the line must be considered.

Improved rolling techniques have also resulted in longer rail lengths from the mill. Longer rails mean fewer welds and fewer potential built-in defects. However, there are only a few shipping liners that can carry these long rails and not all harbours have the facilities to offload them. Furthermore, specialised rail carrying trains are required (refer to CHAPTER 15 paragraph 14.2 and Zaayman, 2017 chapter 3 paragraph 2.9) to avoid unnecessary stressing of the rails.

Short rails of 12 to 18 metres are still available and a decision to purchase such, especially if it is from lessor known or unproven suppliers, is often politically or financially motivated. They are simpler to transport and may be cheaper but the additional welds required and (especially if they are to be welded in track) the additional time required or the suspect quality of the rails can prove to be an expensive mistake. The length of rails delivered to site must be considered for the required flash-butt welding capacity.

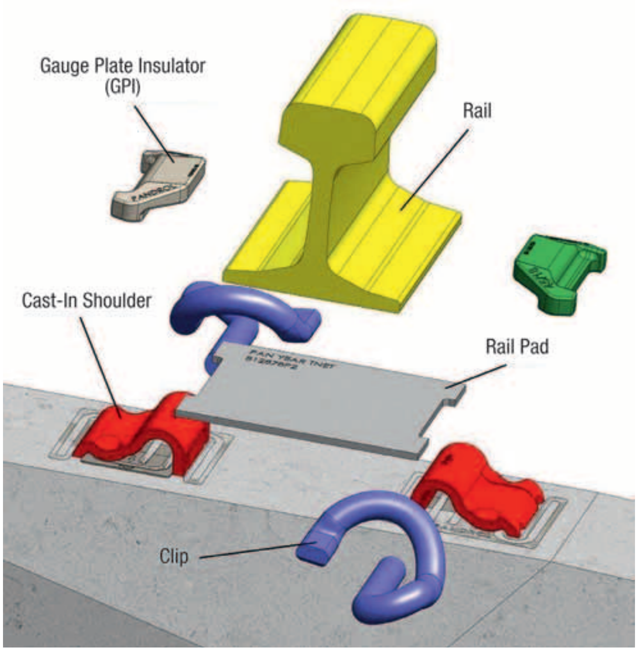
In the past few decades alloys of steel were used extensively to increase the wear rate of rails due to ever increasing demands. Chrome-manganese rails were once very popular due to their lower wear rate but they also came with disadvantages such as being more prone to rail breaks as the rail ages and they required special processes for welding. With technology advances, rails for high capacity demands have moved towards head hardened rails which exhibit similar ductility as standard grade rails, but with the heat treated head have high resistance to wear. Head hardened rails today can achieve as much as 2 billion metric tons on tangent track.

Rail profiles have also not changed much since the early 1900's. What, however, has changed is the profile weight as axle loading and speeds keep on increasing and profile weights increase as well to compensate. Profile weights of 70kg/m are available today. The heavier the rail the more the tamping machine is put under strain and the better quality, design and size (especially wheelbase, see Figure 81) of machine is required.

2.3. Fastenings

The primary function of fastening systems (Figure 80) is to hold the rail firmly against the sleeper, maintaining gauge and preventing creep and roll over. Refer to Zaayman (2017) chapter 3 paragraph 4.

As axle loading and train speeds increased over time, the demand on fastenings also increased. See CHAPTER 7 paragraph 5. All modern railways today use elastic type fastenings of which the most used types are from proven sources providing high quality products. Technology advances have been incorporated in various aspects of fastenings but the one aspect that affected maintenance machinery was the development of a fastening that can be fitted or removed by mechanised methods such as the Pandrol Fastclip. Plasser & Theurer renewal machines, for example, can have equipment fitted that will mechanically remove and install Fastclip fastenings as part of the mechanised track renewal process.



2.4. Rail Pads

Rail pads (Figure 80) have an important function to absorb some dynamic loading and to prevent rail creep. Refer to Zaayman (2017) chapter 3 paragraph 4. On heavy haul lines standard rail pads had short life spans which resulted in the development of higher quality pads for these demanding conditions.

When considering the maintenance window requirements the type of pads in the line must be considered for their expected life.

Replacing rail pads is not mechanised and new ones can be installed in-between train traffic or combined with rail or rail fastening replacements.

2.5. Sleepers

The primary functions of the sleepers are to hold gauge and to transfer the vertical, lateral and longitudinal loads over a greater area of the ballast. Refer to Zaayman (2017) chapter 3 paragraph 3.

Though timber sleepers are still very common, most new high capacity and high speed lines across the world use pre-stressed concrete sleepers, even on turnouts, for their various advantages.

Technology improvements in sleepers that have an influence on track maintenance are under sleeper pads which have been proven to reduce the tamping cycle. Where the availability of maintenance windows is of major concern, installation of under sleeper pads can be considered and the type and number of tamping machines be adjusted accordingly.

Other advances in sleeper technology that are notable from a maintenance perspective are H-frame and other sleeper designs that spread the load over a wider area and therefore have less impact on the ballast. Where these sleepers are installed, the effect on tamping cycles must be proven before changes can be considered to resource requirements.

Figure 80: E-Clip Rail to Sleeper Fastening
(Courtesy Pandrol South Africa)

from the reusable stones and must be disposed of as waste. Giving due consideration to the harmful pollutants in them (paragraph 3), there are areas where it can be used safely as filling material for roads and may even have a monetary value.

iv. During track renewal and formation rehabilitation, depending on the process used (Zaayman, 2017 chapter 20) large volumes of reusable ballast may be excavated and removed to disposal sites using material conveying systems. Often this ballast has not been screened to separate the reusable ballast from the fines. Consideration should always be given to screening and even washing of this material for reuse and return the usable material back to the track which is made easy using the Plasser & Theurer MFS range of material conveying systems (see Figure 119, Figure 120, CHAPTER 15 paragraph 10 and Zaayman, 2017 chapter 15).

Figure 119: Ballast Cleaning Machine Spoiling Waste into Material Conveying Systems

Figure 120: MFS Material Conveying Systems Removing Ballast Cleaning Spoil to an Approved Disposal Site

Figure 121: Trackside Fauna and Flora must be Considered (Courtesy HT Höne)

4.6. Dispose

Disposal is the last resort once recycle, reuse or repair is no longer possible. Most track material is contaminated with harmful substances (paragraph 3) and will require responsible disposal, often according to legislated requirements, to environmentally approved sites where the contamination is less likely to harm water sources such as a high water table, streams or rivers or where contamination of the soil can result in further pollution.

Spoil material separated from reusable ballast is the most difficult of all track waste material to be removed. It is not practical to pick up the spoil after it has been tipped to the side of the track. It is therefore advisable to use material conveying systems such as the Plasser & Theurer MFS material conveying hoppers which are designed to efficiently receive the spoil from the ballast cleaning machine and to offload the entire load from all the wagons simultaneously within 6 minutes at an approved site (Figure 120).

5. VISUAL POLLUTION

Visual pollution is defined as the whole of irregular formations and may refer to everything altered by human activities that are unattractive and affects people’s ability to enjoy or appreciate the view and vista (Jana & De, 2015).

Rails, sleepers or disposed fines after ballast cleaning at the side of the railway line are unsightly and creates negative images of the railway as a mode of transport. A well maintained wayside of the track will also create a more appealing view for the public. This can be achieved by keeping weed growth under control and even the planting of trees and shrubs.

Figure 122: Hybrid Mechanised Maintenance Machine (Regulating Machine) Operating from the Overhead Electrification System (Courtesy Plasser & Theurer)

Figure 123: Example of Open Wagons of Iron Ore

6. SOIL POLLUTION

Soil pollution refers to contamination of the soil with harmful substances from sources such as those described in paragraph 3.

The focus of track maintenance regarding the environment should be more on preventive measures rather than clean-up methods and to be considerate towards wayside fauna and flora. This is especially true for ballast cleaning by not tipping material to the side of the track but removing all ballast cleaning spoil to approved sites where the soil pollution will be minimal (Figure 121).

Biodegradable oils and lubricants should be considered for mechanised machinery as well as the lubrication of rails and turnouts to minimise soil pollution.

7. WATER POLLUTION

Water pollution refers to the contamination of water bodies such as streams, rivers, groundwater, etc. with harmful substances. In the track environment the release of harmful products would normally not be direct (unless as a result of a train accident) but rather as a result of pre-existing soil pollution.

During rain the water draining through the ballast bed will be contaminated with the harmful substances in the ballast bed as described in paragraph 3. The contaminated rain water can collect in side drains and contaminate rivers and streams where the drain runs off at the end of a cutting, for example. This should be considered when side drains are designed or maintained.

Harmful liquid substances in large quantities leaking from trains may leach to groundwater and surface water and cause soil pollution. Cognisance should be taken of such occurrences and remedial steps taken.

Effective drain cleaning will go a long way to prevent water pollution. Refer to CHAPTER 7 paragraph 15 for detail on types of drains and their maintenance.

8. AIR POLLUTION

Air pollution refers to the presence or release of gasses or particulates, whether in solid or in liquid form into the atmosphere which is harmful to the environment and its ecosystem and may cause discomfort to humans. From a mechanised maintenance machinery perspective the following are the main sources of air pollution:

8.1. Exhaust Gasses

Many major cities around the world are experiencing a serious major problem with air pollution due to industry produced gasses and exhaust emissions from vehicles to the extent that vehicles either pay high taxes or are banned from city centres. Diesel powered engines produce acid gases such as sulphur dioxide carbon monoxide and nitrogen oxide together with particulates. The latter is the cause of the unpleasant odour of diesel fumes.

CHAPTER 13
MACHINE OWNERSHIP

1. INTRODUCTION

Modern mechanised track inspection, construction, maintenance and renewal machines (referred to as mechanised maintenance machines for short) are characterised by the use of sophisticated hydraulic and electronic circuits. These machines are working under severely harsh conditions making it a challenge to achieve reasonable reliability to ensure that production targets can be achieved so as to limit the number of maintenance windows and machines required.

Maintenance of the machines is naturally key to their reliability and therefore many of the principles mentioned in this book for infrastructure maintenance applies to the maintenance of machines too. There are various factors that determine how effectively the maintenance can be carried out such as spares availability, training and skill of staff and commitment of staff. The ownership, operating and maintenance functions of the machines have shown to have a major influence on all of these factors.

Heavy on-track machines are extremely specialised and often customised to the specific needs of the client. For this reason design and manufacturing costs are relatively high and it is essential that initial investment be made in the best available quality and technology. Not only will this approach ensure the best return on investment but the output of the machine will be consistent and of the best production, quality and durability if efficiently operated and maintained. It is therefore imperative that all criteria and entire life cycle costs be considered when investing in new machines.

2. TYPE OF MACHINE OWNERSHIP

The type of ownership in context basically refers to a strategy of either in-house, outsourced or a combination of in-house and outsourced mechanised infrastructure maintenance. Each strategy has certain advantages or disadvantages.

EN 13306 (2010) defines maintenance outsourcing as "contracting out of all or part of the maintenance activities of an organisation for a stated period of time".

2.1. Machines owned, operated and maintained by the railways

Going back in history, this is where most mechanised maintenance started; machines were designed and built by entrepreneurial manufacturers and sold to railway companies who owned, operated and maintained their own machines. Mechanised track maintenance only started gaining momentum in the mid 1940's and only became popular in the mid 1950's and was relatively unsophisticated compared to modern machines. Maintaining and operating these machines was therefore quite simple.

From about the 1970's the standards for track quality and durability increased dramatically, driven by the demand for higher train speeds, higher axle loads and shorter maintenance windows. Machine manufacturers responded with ever increasing machine production capabilities and features offered thereby increasing the machine size and sophistication of systems, especially hydraulics and electronics.

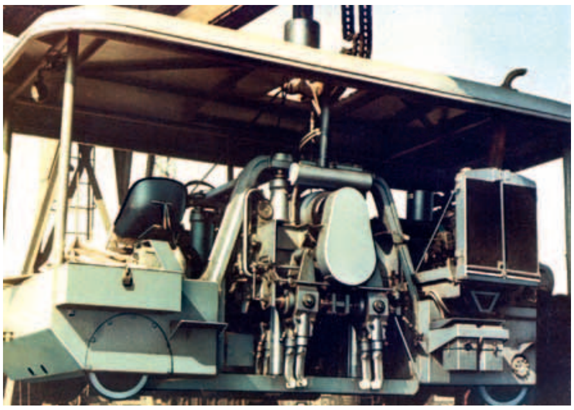


Figure 137: Plasser & Theurer Tamping Machine 1953

Figure 138: Plasser & Theurer Tamping Machine 2017

and lowered individually (Figure 161). This technology can in addition be combined with tilting tines to achieve unparalleled versatility (Figure 162). The split units are locked together when plain track tamping is done.

- The lifting units must be capable of lifting the track in restricted areas. Universal tamping machines therefore have lifting units with hooks in addition to rollers to lift restricted track.

- Due to the long sleepers in turnouts spanning across two tracks, third rail lifting is required to reduce the stress on fastenings and for accurate and effective tamping and compaction across the entire sleeper. An additional synchronised lift at the curved closure rail distributes the weight of the sleeper and rails across three lifting points and eliminates the turning moment which reduces the lifting force at the middle rail. On many railways the use of third-rail lifting devices is prescribed in its regulations.

- Though tilting or split units prevent tines from hitting obstructions in turnouts, the areas between the obstructions must also be tamped for which universal tamping machines need slewing tamping unit frames. This allows the tamping units to slide laterally across the track to find the best place in the track to enter the ballast. Depending on the machine model, the tamping unit frames slide on guide columns to allow either double slewing or single slewing reach.

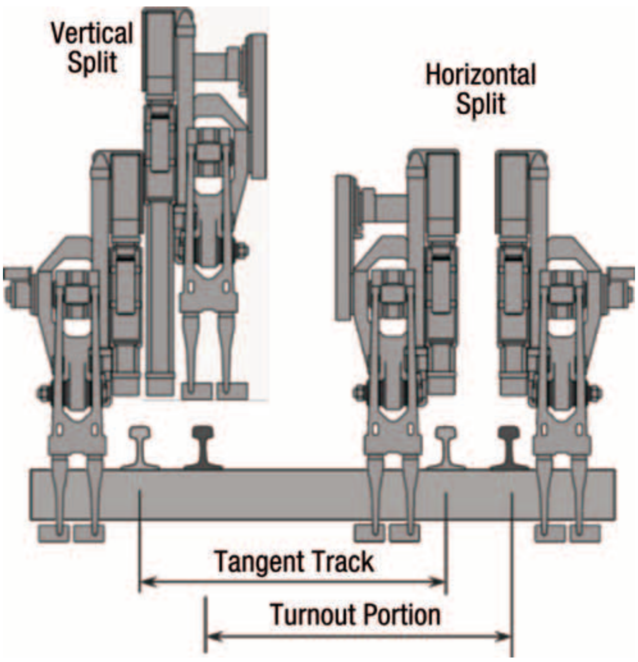


Figure 161: Split Units


Figure 162: Split Units with Tilting Tines
(Courtesy Plasser & Theurer)


Figure 163: Three Rail Lifting
(Courtesy Plasser & Theurer)

On double slewing systems the guide columns are mounted to an auxiliary frame which can be slewed beyond the frame of the machine (Figure 164). In single slewing systems the guide columns are attached to the main frame of the machine.

- An additional feature of modern universal tamping machines is that of rotating the tamping units through the angle of the skew sleepers of the turnout. These tamping units are mounted to a turntable that ensures right angles to the sleeper when the turnout portion is tamped. This avoids potential squaring of the skew sleepers and improves production times.

5.2.3. Spot Tamping Machines

Correcting vertical or horizontal alignment defects over a short distance (from just a few metres to a couple hundred metres) can be very costly if a production tamping machine is called from its production tamping. This would often be where there are underlying causes of accelerated deterioration such as formation failure, heavily fouled ballast and poor drainage or curves which deteriorate faster than the tangent track on either side.

Correcting such spots requires specialised machines (Figure 165) which are generally of lower production capacity and equipped with specialised measuring equipment to address short distance defects.

5.2.4. Hand-held Vibratory Tamping Machines

Even with the best of universal tamping machines there are still areas within a turnout which the tamping units cannot reach. Hand-held vibratory tamping machines are used to tamp these areas.

Hand-held machines can also be used for lifting recurring slacks (vertical alignment defect over short distances coving just a few metres) until the root cause of the problem can be addressed. If spot tamping machines are not available it is not economical to move production tamping machines to these areas.

Figure 164: Slewing and Rotating Auxiliary Frame (Courtesy Plasser & Theurer)

Figure 165: Unimat Sprinter (Courtesy Plasser & Theurer)

Figure 166: Hand-Held Vibratory Tamping Machines (Courtesy Robel Bahnbaumaschinen)

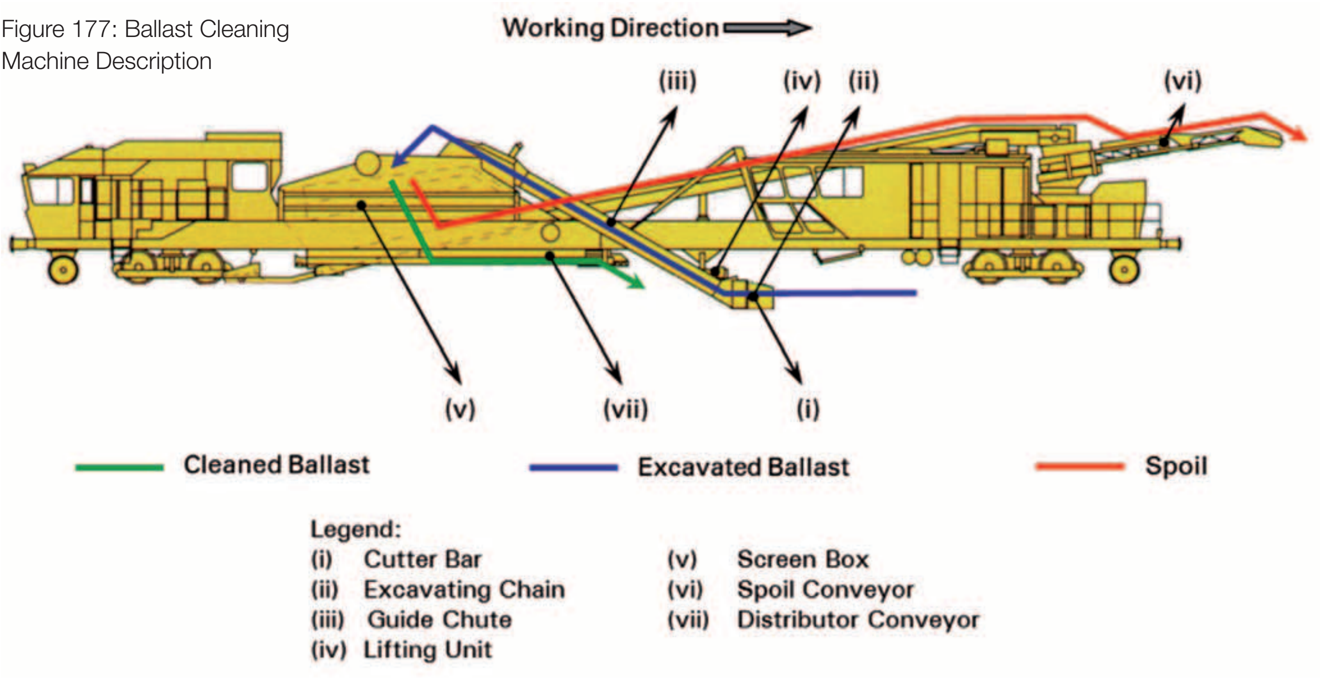
6. DYNAMIC TRACK STABILISING MACHINES

Ballast maintenance such as tamping and ballast cleaning disturbs the ballast bed and increases the total volume of void spaces between the ballast stones below the sleeper and at the sleeper head.

After ballast maintenance, research has shown that just 3 to 5% of the sleeper surface is in contact with the ballast (concrete sleepers). The track's resistance to lateral forces will therefore be greatly reduced. Some of the ballast stones will now also lie in an unstable position in relation to one another with only their corners and edges touching due to the greater void space (Figure 167).

The track's initial subjection to traffic at normal speed can therefore have a detrimental effect. To overcome this risk, the customary practice has been to let trains compact the track bed with their weight when passing at a restricted speed for a period of time after maintenance.

Figure 177: Ballast Cleaning Machine Description



is conveyed to hopper units (spoil and material conveying machines) for removal to environmentally approved spoiling sites.

Ballast cleaning machines fall in several categories that are defined by its production rate and specialised features that make it capable of additional functions such as turnout or tunnel cleaning (wide or narrow cutterbar).

Figure 178: URM 700 Universal Ballast Cleaning Machine (Courtesy Plasser & Theurer)

9.1. Production

Depending on the machine model, the chain is between 200 mm and 350 mm high. Higher chains can remove more material thereby increasing the production capability of the machine. However, larger volumes of excavated material also require faster processing of the material for which larger surface area screens are required. Because the screens are mounted at an angle, the surface area is limited by the height of the vehicle structure gauge of the particular railway in question. To increase surface area high production ballast cleaning machines are therefore equipped with double screen boxes (Figure 175).

9.2. Specialised Features

Some ballast cleaning machines can be fitted with wider cutter bars and extendable chutes for turnout screening. These machines may however still experience difficulty when screening crossings or slips, especially on multiple lines such as metro lines where various different S&C units can be right on top of one another. A universal ballast cleaning machine (Plasser & Theurer URM 700 for example, see Figure 178) is specially designed for this purpose employing a sword like cutting chain with infinitely variable cutting widths up to 6,100 mm. The machine can also be used for ballast cleaning in plain tracks or for shoulder cleaning alone. Due to the fast and independent installation and removal of the excavating guide bar, the URM 700 can also work cost-effectively on short sections of track (spot cleaning) which has not been possible before.

10. SPOIL AND MATERIAL CONVEYING WAGONS

The unusable ballast material (spoil) screened out from the ballast cleaning process is contaminated with toxic herbicides for weed control, it is also contaminated with oil, grease and other contaminants that fell from or were spilled from railway wagons and locomotives which can and have been known to cause environmental pollution when tipped to the side of the track (Figure 179). Refer also to CHAPTER 11. Spoiling to the side also has various other disadvantages requiring spoil removal systems such as the MFS material conveying system to work with ballast cleaning that will not negatively influence the ballast cleaning machine's production. See Zaayman (2017) chapter 15.

The MFS is an open, high-sided hopper wagon, with a floor-mounted main conveyor belt which covers the entire width of the hopper and wear resistant sheets on the inner sides of the hopper. Each MFS wagon is equipped with its own diesel engine to drive the conveyor belts. The rotation speed of the conveyor belt can be controlled. In addition, the hopper wagon is equipped with a slewing transfer conveyor belt at the one end which operates independently from the floor conveyor belt to either transfer its load forward (Figure 181) or discharge its load to the side (Figure 181).

There are a few options which allow the MFS to carry out additional functions. MFS wagons can be fitted with crawler tracks in addition to rail bogies which allow the machine to move into an excavation under its own power (Figure 182). MFS wagons have also been equipped with unloading chutes to offload ballast and where double lines are available MFS wagons can be used to offload backfill material into the excavation

Figure 179: Ballast Cleaning Machine Tipping to the Side (Courtesy Plasser South Africa)

Figure 180: Ballast Cleaning Machine Spoiling into Spoil and Material Conveying Systems (Courtesy Plasser South Africa)

Figure 181: Discharging to the Side

Figure 183: Offloading Backfill Material

Figure 182: System Equipped with Crawler Tracks

The winch unit is the main working unit of this machine. It consists of a hydraulically-powered storage drum holder or holders (depending on the model), the tensioning device/s consisting of friction winch reels which are electronically controlled to install the contact wire at the final operating tension and a telescopic lifting mast/s with a guiding roller head that lifts the cable to the final height of the installation. There is also an auxiliary cable winch is provided to feed the new wire/s through the friction winch reels and to pull the wire/s towards the attachment points on the mast pole at the beginning of the process.

19. OTHER MACHINES

Over and above the main stream mechanised construction, maintenance and renewal machines mentioned in the above paragraphs, many other machines have also been developed for specialised functions such as track lorries, bridge inspection machines (Figure 210) and vacuum scraper-excavating machines (Figure 211).

Figure 211: Vacuum Scraper-Excavator
(Courtesy Plasser & Theurer)

Figure 210: Bridge Inspection Track Motor Vehicle
(Plasser & Theurer)
(Courtesy Plasser & Theurer)

Railway track infrastructure is a complex system consisting of various subsystems which require incremental maintenance from all engineering disciplines; all of whom are competing for the limited time and number of available maintenance windows.

The constant demand for higher traffic volumes, increased train speeds and heavier axle loadings all result in an exponential increase in maintenance requirements but the time available for maintenance is as a result even further reduced. This requires a more scientific lifecycle approach to infrastructure maintenance management. It also requires increased performance from mechanised construction, maintenance and renewal machines to keep the infrastructure reliable, available, maintainable, affordable and safe within the short available maintenance windows.

The objectives of this book are to address the optimisation of infrastructure maintenance management and to provide a model with selection criteria for maintenance machinery and their features for the prevailing circumstances.

The **e-book** is available upon registration. Users of devices with a pdf reader (PC, tablet, smartphone) will have electronic access to all the terms and references through a search function.

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