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ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

RAMS ANALYSIS FOR RAILWAY VEHICLES

MASTER'S THESIS

NASSER ALMASHAME

Department of Mechanical Engineering
Mechanical Engineering Program

JULY, 2023

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Thesis Advisor: Prof. Dr. Tuncer TOPRAK

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APPROVAL PAGE

DECLARATION

I hereby declare with the respect that the study “RAMS Analysis For Railway Vehicles”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the References.

NASSER ALMASHAME

FOREWORD

In the almighty Allah, Most Generous, Most Merciful.

For finishing this thesis, Allah deserves all honor and blessings. I give thanks to God for all of the chances, challenges, and resources He has given me so I can finish the thesis.

First of all and primarily, I would like to express my thanks to my supervisor, Prof. Dr. Tuncer Toprak, for his guidance, comprehension, patience, and—most importantly—for giving me the encouragement and warm attitude I needed to finish this thesis. Having him as my supervisor has been a privilege and an honor.

My sincere gratitude to my entire family. Without the help of these people, this thesis would not have been possible. I want to express my gratitude to my gorgeous mother and my devoted father for their unwavering support throughout my voyage.

I would really like to thank my lecturers for all of their help and advice with this thesis.

My sincere gratefulness and go out to all of my dear friends and coworkers who involved by me and helped me through good times and bad.

July, 2023 NASSER ALMASHAME

RAMS ANALYSIS FOR RAILWAY VEHICLES

ABSTRACT

Railway vehicles and tracks are the integral parts of the engineering, railway RAMS incorporates reliability, availability, maintainability, and safety qualities related to the operating goals of a railway system into the intrinsic product design feature. It has recently become a fast-expanding engineering field due to its ability to deliver a specific railway traffic service in a timely, safe, and economical manner. Additionally, it has a significant chance to make railways more competitive with other modes of transportation, particularly with roads. Because of this, RAMS management becomes a big problem in today's international railway projects, and it rapidly spreads to domestic railway projects as well.

Developing a dependent diagnosing program will also be viable in this case; this programming tool will be used for Renewal Investment and Maintenance-RIMS. This programming tool will be named RIMS. RAMS analysis aims to establish various methodologies and techniques for evaluating RAMS measurements of components, infrastructure, and structures and to assist development and production engineers in incorporating these analyses into their engineering designs and various projects. Therefore, RAMS analysis must be incorporated into project operations to promote quality assurance of equipment and system engineering activities and should also be executed without complexity to be time and money productive.

An extensive introduction and presentation of RAMS are given in the introduction section. The various researches about this concept in engineering are well presented in the literature review section. Additionally, comprehensive examinations of some of the common techniques applied in RAMS are given in the analytical solution and numerical analysis sections. Subsequently, the results and discussion parts provide the various findings and recommendations for this engineering concept.

Keywords: RAMS, Program, Railway Vehicles, Maintenance, Reliability.

DEMİRYOLU ARAÇLARI İÇİN RAMS ANALİZİ

ÖZET

Bu tezde RAMS (Güvenilirlik, Kullanılabilirlik, Bakım Yapılabilirlik ve Emniyet) analizinin temel kavramları incelenmiş ve daha sonra yöntemin Raylı Sistemlere uygulanması irdelenmiştir. Bu kapsamda değişik bakım yöntemleri ve bilhassa İzleme Yöntemiyle Bakım (Condition Monitoring) hakkında detaylı bilgi ve raylı sistemler üzerine uygulama yöntemleri verilmiştir. Ayrıca uygulama ile ilgili araştırma sonuçları ve değişik teoriler incelenmiştir.

Demiryolu kuruluşlarının yararlanabilmeleri bakımından, araçların ve hatların bakıminda RAMS uygulamaları için gerekli bütün yöntemler ve metodolojiler verilmiş, yöntemin ilk uygulama aşaması için planlamalar anlatılmıştır. RAMS analizinin raylı sistemlere uygulanmasında gerekli olan Gerilme-Şekil Değiştirme Analizi, Titreşim ve Frekans Analizi konuları teorisi ve deneysel yöntemleriyle, uygulama örnekleri verilerek anlatırmıştır.

Anahtar Kelimeler : RAMS, Program, Raylı Sistemler, Bakım, Güvenilirlik.

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ABBREVIATIONS

AO	: Area of Operation
AP	: Advance Placement
FMEA	: Failure Mode and Effects Analysis
FPMK	: Failures per Million Kilometers
MTBF	: Mean Time between Failures
MTBM	: Mean Time between Maintenance
MTBSF	: Mean Time between Service Failures
OEM	: Original Equipment Manufacturers
RAMS	: Risk Assessment Method Statement

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I. INTRODUCTION

The RAMS (reliability, availability, maintainability, and safety) concept is an industrial method for ensuring safe operation in equipment and manufacturing by pinpointing parts or failure sources inside the system that can be improved. The primary goal of a RAM analysis in the industry is to use it as a judgment call technique to improve the system's availability and hence boost total profit while lowering expenditures. RAM analysis can be conducted on a variety of equipment and facilities in a multitude of sectors, such as petroleum & energy industries, sewerage water treatment, nuclear, processing, and many more. Reliability, availability, and maintainability are all important variables to examine when measuring the performance of industrial facilities.

However, physical security systems must be accessible around-the-clock, every day of the week, every day of the year. Repair costs and revenue loss arise from manufacturing systems experiencing system failures or component breakdowns. Security system outages/component failures result in expenses for both repairs and corrective actions, which often entail replacing the technology with pricey human observation or action.

Since RAMS analysis has a significant amount of potentiality, this method still contains some irrefutable gaps, most especially when it gets to the regularity surrounding the calculation techniques of this method. The primary objective of the RAMS analysis is to utilize operational details of equipment to carry out a detailed examination of all acquiescence listed in the operational statement of the equipment, usually the PN-EN 50126 (Graboń and Sitarz, 2018). In addition, the necessary information required by the RAMS analysis should be critically and attentively gathered by railway carriers. Consequently, the major objective of this thesis is to analyze the use of RAMS analysis in the entire process of railway transport.

A. RAMS in General

A strong Reliability, Availability, Maintainability, and Safety (RAMS) assessment process is a crucial component of any rail infrastructure project or asset management system. Then what is RAMS, and how do the various components interact? Only a small number of railway organizations have integrated RAMS management with railway systems engineering despite years of study and attention to the issue. Establishing a systematic RAMS management strategy for railway systems engineering from the system concept phase to the formation of engineering concepts, methodologies, techniques, and tools is the main issue of this work. Therefore, the goal of this research is to create a methodical approach for incorporating RAMS management into railway systems engineering.

A system integrity study is necessary for the design of crucial and complicated integration of big systems. Integrity of the engineering design also refers to the system and system component RAM (reliability, availability, and maintainability). In order to achieve the required integrity of the whole system, excellent engineering design is supported by analysis of these factors in combination. The idea of RAM is not new; it has been thoroughly discussed in several experiments and publications, and software tools are available to help with the analysis of complex systems. The majority of earlier research, however, has to do with products that are occasionally available but not used in industrial manufacturing processes or with those that are. Numerous military and space station systems have also benefited from RAM analysis.

Reliability can be defined as the likelihood that there won't be any failures over a specified period of time. The amount of time a system is deemed to be available when needed is known as availability, while the simplicity with which a system may be repaired after a breakdown is known as maintainability. Safety is the state of being shielded from risk, danger, or harm by an asset's safety function (in the context of this article and RAMS). An interlocking for signaling, for instance, makes sure that points and signals work together to route and move trains safely. There are numerous scholarly publications that discuss RAMS in great depth and with computations that can get pretty complicated. The safety function of a safety-related or safety-critical asset is based on good RAM, according to the idea that good reliability and maintainability offer good availability. A RAMS study ought to be carried out early on in a project, reviewed as it develops, and updated as necessary. Along with any important reasons of loss of availability or the safety function, this will indicate targets for RAMS. In order to meet the established goals, the study will also point out design or maintenance regime improvements.

The fundamental component of the assessment in the rail business today is reliability, availability, maintainability, and safety (RAMS) (Pimping, 2022). RAMS means cheaper operating and maintenance expenses as well as a safe, dependable, high-quality service for rail system operators. RAMS serves as a premium system and product for the rail system supplier. The foundation of many businesses' competitive advantage is RAMS. Furthermore, according to Koziol (2019), the current version of EN50126, which was authorized in 2017, has undergone a number of significant changes since the 1998 formal approval of the original version ("Railway Applications: The Specification and Demonstration of Reliability, Availability, Maintainability, and Safety (RAMS)"). With the modifications, the standard for managing the RAMS process for railway systems is now more consistent and effective.

B. R.A.M.S Acronym Relationship Assessment

Figure 1 depicts the link between dependability/reliability, availability, maintainability and functional safety. Since availability depends on dependability and maintainability, it lies at the top of the first triangle. Take into account the availability of an item that is extremely reliable yet difficult to maintain. This could be for a number of reasons, such as inadequate access or location, a lack of qualified workers, a lack of functional spare parts, or it could be an asset where it is challenging to pinpoint the exact failure. In rare circumstances, it might be necessary to fly in a replacement component or a qualified individual from another continent (and this has occurred on more than one occasion). In this case, the availability aim might not succeed.

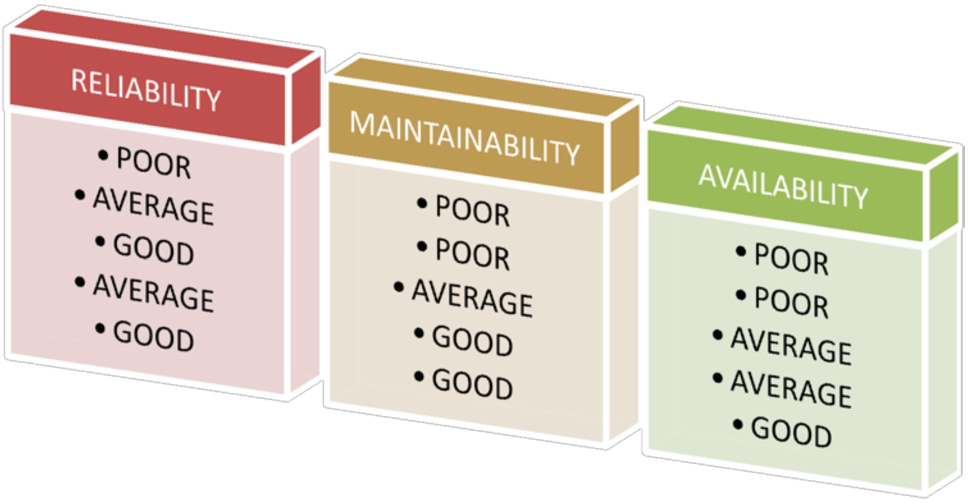


Figure 1: RAMS analysis

What can be done to increase reliability in order to provide better availability? In order to increase an asset's reliability, it is essential to determine why it fails. It is necessary to perform a root cause analysis using methods like Failure Mode and Effects Analysis (FMEA). The continuous evaluation, revision, and learning from failure reports required by asset managers and maintainers may also need hiring specialized engineering specialists to conduct independent forensic investigations. When assisting with third party investigations, some Original Equipment Manufacturers (OEM) could be defensive, but any unbiased investigation of a problem should be encouraged. We will build a better railway for everyone by working together and cooperating.

Let's now take a look at another extreme example of an asset that is extremely unreliable but has excellent maintainability, with a large number of competent, knowledgeable technicians and engineers readily available, as well as a large number of readily available spare parts that are simple to replace. In this case, it's possible that a piece of equipment with low dependability has adequate availability due to its good maintainability. The letter "A" also stands for affordability, and as good maintainability typically requires more in the way of skilled labor, spare parts, and support agreements, affordability must be taken into account in any RAMS study. If an asset performs a safety function, then its RAM must be at an adequate level to guarantee that the safety function is performed when necessary and that any asset failure results in the safety function (Pimping, 2022).

Therefore, a failed track circuit, for instance, requires that the protective signal return to red. Conferring to Park (2014), Figure 2 illustrates, in straightforward terms, the relationship between RAM and how reliability and maintainability impact availability. Though with safety-related and safety-critical assets, this could require a safety case and design change, with the proper verification, validation, and testing. Higher quality components could also be investigated to increase reliability.

Figure 2: Railway tracks (Rail Engineer 2021)

If any electronic assets are failing for no obvious cause, EMC immunization should always be investigated. Many of the electronic components found on railway vehicles date back to a time before current immunization guidelines were in place. It is not uncommon for new assets to be installed in equipment rooms with existing equipment, which, despite meeting modern requirements, may result in the failure of older equipment. This issue can become worse in the future as more and more contemporary electronic equipment is installed in older equipment rooms with subpar immunization protection.

C. RAMS Features

In RAMS there are numerous features from characteristics, objectives, and so on. The ease with which an asset can be put back into service after failure is determined by its maintainability. Consequently, it is necessary to have access to knowledgeable, well-trained personnel who are furnished with the appropriate equipment and spare parts. So, it's crucial for technicians to have adequate training so they can fault the asset. The maintenance organization should be consulted early on by a good project to define and scope the necessary training, and it's equally crucial that the maintainer stay in touch with the program during construction.

The maintainability of an asset refers to how easily it can be put back into service after a failure. Therefore, it's essential to have access to knowledgeable, well-trained people who are furnished with the appropriate equipment and spare parts. For technicians to be able to fault an asset, good training is therefore crucial. The maintenance organization should be consulted early on by a good project to determine the type of training that is needed. Equally crucially, the maintainer must stay in touch with the project throughout its development.

Furthermore, in RAMS, one option available to asset managers is reliability-centered maintenance (RCM). RCM determines the frequency of maintenance interventions based on the asset's criticality in relation to its function and historical reliability, rather than on time or mileage. Therefore, it should be examined more frequently if an asset is more likely to fail and the failure may negatively affect availability. Reliability can be increased by adding more redundancy to a system's architecture. When a critical asset fails, another one easily steps in if the design includes hot standby or load sharing. Reduced availability will only be postponed if processes are not in place to identify and fix non-service impacting failures.

Instead of being reduced, the failure. Because there is never a failure in their eyes, it may occasionally be necessary to remove a healthy asset from service in order to remedy the problem, and operators may be reluctant to help. With multiple Safety Integrity Level (SIL) processors, signaling interlocking’s are redundantly provided. So that they fail safely and do not lead to risky train routes, the interlocking systems must be properly developed and tested.

D. RAMS in Detecting Failures

Furthermore, an explanation in understanding RAMS pertaining failure detection will give an understanding of this research topic. In more and more engineering disciplines, remote condition monitoring is utilized to identify potential faults in advance of them happening so that an intervention can be made before an asset fails. The ability for specialists to safely check and predict "work arising" earlier and more precisely is made possible by increased remote monitoring with greater capability and smarter infrastructure. As a result, fewer workers on the track are put in danger, work can be planned earlier and more safely, and the railway is more dependable. Track circuit monitoring is a prime illustration of the advantages of remote condition monitoring. With intermittent errors, it can be challenging to pinpoint the underlying cause, which can lead to time-consuming fault-finding efforts and the application of ineffective "solutions" (Khan, 2018).

Based on the above analysis and explanation, a test/training rig should be established so that staff can hone their problem-solving abilities and obtain system training in addition to competency assessments. This could be at the OEM's facilities, on site, or at the maintainers' training school. The OEM or a third party can use this information to create and test replacement outdated parts for the asset during its useful life. Although test/training rigs are not cheap, they could be very helpful in ensuring that systems can be maintained for the duration of their useful lives.

The system's accessibility must be taken into account while it is being designed; both for technicians to have easy access to the site with their tools, test equipment, and spares, and for any parts that could require replacement. So, access to equipment cubicles may be required from the front, back, and sides. With common tools, it should be simple to remove objects and break electrical connections. Maintainability will also be aided by system assessments and remote diagnostic alarms. People should ideally be informed of the necessary intervention well in advance of their arrival if they must travel to the location.

Again, it is important to note that based on RAMS history and applicability, in order to improve maintainability, the maintenance organization must carefully plan and optimize the faulting cover. This needs to account for site travel at all hours of the day and every day of the week. Additionally, a 24/7 escalation procedure will be necessary for both telephone and on-site assistance. This might refer to internal, outside, and OEM support. No matter how capable and good a person is, it always benefits to get a second, unbiased view, especially when dealing with challenging or safety-related jobs. If you prepare for the worst, you might not need it, but if you don't, you will need it for sure, according to an engineer.

The establishment of a test/training rig for staff (figure 3) to hone their fault-finding abilities, acquire system training, and undergo competency evaluation should also be given consideration. This could be found on-site, at the OEM facilities, or at the maintainers training school. The OEM or a third party can use this information to create and test replacement outdated parts for the asset during its useful life. Although expensive, test/training rigs may be crucial in ensuring that systems can be maintained for the duration of their useful lives.

During the system's design, access must also be taken into account for technicians to have easy access to the site with their tools, test equipment, and spares as well as for any possible replacement parts to be accessible. Therefore, front, rear, and side access may be required for equipment cubicles. Electrical connections should be simple to unplug, and removal of objects should be simple with common tools. Maintainability will also be aided by remote diagnostic alarms and system evaluations. If people must travel to the location, it is ideal to inform them about the necessary intervention in detail before they leave as shown in figure 3.

Figure 3: Design and testing of railway (Rail Engineer 2021)

In detecting failures in RAMS, especially with safety-critical assets, independence is a crucial component of both design and testing. Verification and validation are crucial areas of independence in the creation and execution of projects. When doing this, specialized verification and validation engineers will evaluate RAMS as well as other project deliverables. Verification aims to determine whether a system, service, or product complies with a list of design requirements. A procedure known as [Are you creating it right?] is used to determine whether a system, service, or product complies with standards, rules, and specifications.

The goal of validation is to make sure that a system, service, or product satisfies the operational requirements of the user, who also has to be the maintenance. "Are you constructing the proper thing?" The secret to delivering systems that are dependable and maintainable as well as performing their safety role is to identify design issues and address them as early in the project as possible. This will help keep projects on schedule and under budget.

Last but not least, identification of desired or defined reliability criteria and component and system verification as part of the Systems Engineering process can offer a mechanism for design decisions that boost system availability and lower long-term maintenance and compensatory measures costs. Using RAM analysis throughout all design stages of physical security systems may appear to be a needless design and implementation expense. However, RAM analysis and assessment are crucial to guarantee that the design offers security at the lowest possible risk without the need for expensive rework and to give projected failure rates for operations and maintenance planning. It is possible to identify reasons of failure and make better plans for sustainment management by keeping RAM goals in mind throughout the design process.

As a logical extension, security may be built into the system by using Security by Design principles using RAM analysis during conceptual design. Since there could be more than one method to satisfy performance-based criteria, early comprehension of the design possibilities enables all stakeholders to comprehend compliance options and "trading space." The analysis is crucial for addressing design conflicts between safety (fail safe) and security (fail secure). As a consequence, the Competent Authority has a foundation upon which to decide when assessing the possibilities in terms of risk.

E. Basic Concept of RAMS

This part introduces significant conceptualizations used in Reliability, Availability, Maintainability, and Safety (RAMS) and shows their connections. The RAMS concept (reliability, availability, maintainability, and safety) is an engineering tool that provides safety in equipment operation and production by identifying elements or failure mechanisms inside the system that can be improved. Consequently, RAMS analysis is a technique for gaining access to a system's production and discovering likely reasons for reduced productivity. Additionally, RAM analysis aids in identifying the system's critical points so that the best solution can be found.

Firstly, the likelihood that the element will execute its needed function under appropriate circumstances for a specified time frame is defined as reliability, commonly designated as R. In addition, the task of maintaining that a system continues to run according to the necessary design and operational requirements is known as reliability. Secondly; the ability of an object to execute its needed function at a certain period or during a specified period of time is defined as availability. It is assigned the letter A. Thirdly, when a failed machine or system is repaired in line with the defined processes, maintainability is the likelihood that it will be returned to operational effectiveness within a given time frame. It is assigned the letter M. Subsequently, the last part in RAMS is safety, and it is designated the letter S. safety can be defined as the overall protection of persons and properties. The administration, management, and technological advancement of all types of the system and equipment production are all concerned with the concept of safety.

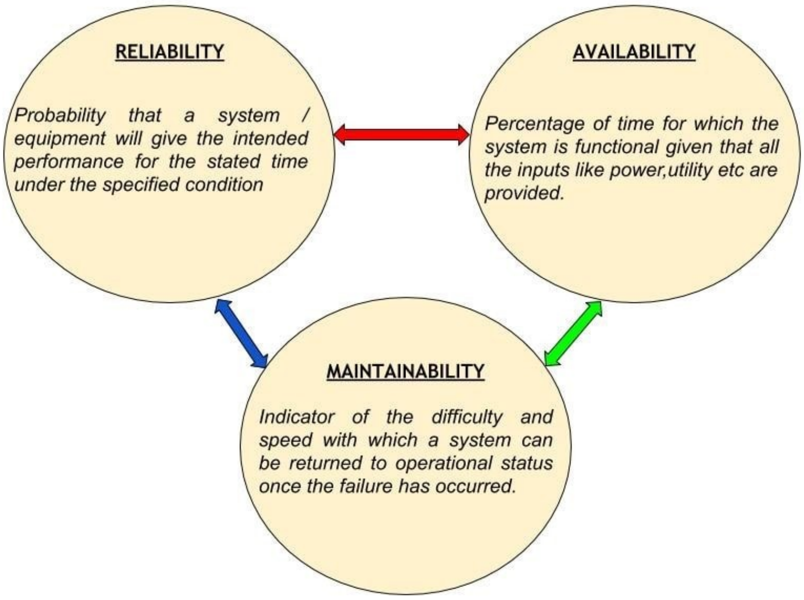


Figure 4: Basic concept of RAMS analysis (Simões, 2008)

1. Reliability

Reliability is the likelihood that a given element will execute its needed function under appropriate circumstances for a specified time frame. For example, in the field of industrial engineering, reliability is a branch of systems engineering that focuses on equipment's capacity to function without breakdown or failure.

A system or equipment is said to be reliable if it produces the desired results consistently when operated under the same conditions. For example, when a vehicle starts and operates consistently without breaking down or being repaired frequently, it is reliable.

Reliability helps in determining if a system can perform its intended function under some stated operating conditions over a specific period of time.

In RAMS analysis, reliability is the measure of the probability that a system or component will operate without failure over a specific period of time. It is typically expressed as a mean time between failures (MTBF) or failure rate (λ).

Reliability is applied in RAMS analysis to identify potential failures in a system and assess the likelihood of those failures. For example, studying the reliability of a power plant helps to predict and ensure there is no interruption in the power supply to consumers.

It also helps in estimating the impact of a failure on the performance of a system. This information is then used to optimize system design, maintenance, and operation. For example, the reliability of a transportation system is evaluated for use in minimizing downtime and ensuring the timely delivery of goods and services. Also, the reliability of a manufacturing process assists in ensuring the product quality is consistent and the products are not defective.

RAMS analysis is used in railway vehicles to evaluate the reliability of rolling stock components such as brakes, doors, and traction systems. This helps identify potential failure modes and optimize maintenance schedules to minimize downtime and improve operational efficiency.

2. Availability

Availability is the ability of a device to execute a specific function under defined conditions at a certain particular time or over a specified time span, providing that the necessary external resources are available. For example, in order to execute daily duties, data centers and hospitals rely on significant availability of their systems and no spontaneous interruption.

In RAMS analysis, availability is the measure of the ability of a system or component to perform its intended function when required, expressed as a percentage of the total time during which it is needed. It is used as a key performance indicator for many industries.

Availability is applied in RAMS analysis to evaluate the performance of a system or component in terms of its ability to meet operational requirements. For example, in a data center, it helps in ensuring that data and applications are accessible and operational at all times.

It helps in identifying factors that contribute to downtime. For example, in a manufacturing company, availability helps in identifying any issues that can lead to a breakdown which can then be prevented. This in turn ensures that the production goals are met and the products are delivered to customers on time.

Through availability, maintenance schedules can be optimized thus improving operational efficiency. For example, properly scheduling maintenance for the transportation systems ensures that passengers can travel to their destination on time. In the case of medical facilities like hospitals, availability ensures patients receive the necessary treatment in a timely manner.

Availability is a critical aspect of RAMS analysis in railway vehicles as it ensures that trains are available to operate when required. In this case, it is used in evaluating the availability of rolling stock components such as brakes, doors, and traction systems to ensure that they are available to operate when required.

Availability also helps in identifying factors that contribute to downtimes such as delays in repair or maintenance and developing strategies to address them. This helps to optimize maintenance schedules, minimize downtime and improve vehicle availability.

3. Maintainability

Maintainability is when maintenance is performed under given circumstances and with specified procedures and resources. The likelihood that a particular active maintenance operation for an item under specified conditions of use may be completed within a given period. For instance, Industrial maintenance focuses on recognizing and addressing maintenance concerns in order to prevent critical assets from failing suddenly, such as keeping all of the equipment in good operating order.

Maintainability refers to the ease with which a system can be repaired, serviced, modified, or updated over its lifetime to ensure its continued functionality. A maintainable system is one that can be easily serviced without requiring excessive time or effort. This includes both the ability to identify and diagnose problems quickly, as well as the ease of making necessary changes or updates to the system.

It includes a modular design that allows for easier maintenance and updates as individual components can be swapped out or updated as necessary, and clear documentation whereby detailed documentation of the system's design and functionality can help support and streamline maintenance activities.

Maintainability also involves testability where, if a system is easily testable, it can help in identifying and diagnosing problems more quickly, which leads to faster maintenance and updates.

Also, a system that is easily accessible to technicians makes maintenance activities more efficient.

Maintainability is an important consideration in the development and management of systems, as it can impact the overall cost and lifespan of a system. By designing and maintaining systems with maintainability in mind, organizations can ensure that their systems are able to adapt and evolve over time, improving their overall usefulness and lifespan.

In RAMS analysis, the analysis helps to identify potential areas of concern that could impact the overall reliability and availability of the system.

The maintainability of railway vehicles ensures the safe and efficient operation of trains. Factors like the accessibility of couplers, brakes, and train wheels as well as the replacement time taken in case of a failure are a consideration in maintainability.

By considering these factors, a system that is reliable, safe, and easy to service can be achieved. This in turn ensures that trains run on time and passengers can reach their destinations safely and efficiently.

4. Safety

Safety is defined as the overall protection of persons and properties. It is the status of a technical system's safety from an unexpectedly large risk of injury or death. Examples of safety faults in industries include electric shocks caused by malfunctioning electrical equipment and fall as a result of working at a height and many other safety hazards.

Safety of a system refers to the degree to which a system is free from harm, injury, or damage to people, the environment, or property. It is an important consideration in the design, implementation, and operation of many types of systems, including industrial processes, transportation systems, and medical devices.

Safety in a system may include; redundant components or backups which help to ensure that critical functions continue to operate in the event of a failure, and a fail-safe design which helps to prevent accidents or other hazardous situations.

Also, safety is achieved by standardized safety protocols which help to ensure that system operators are aware of potential hazards and know how to respond in the event of an emergency, proper training and carrying out inspections, regular checks, and maintenance.

Safety is a critical aspect of RAMS analysis in railway vehicles, as it is important to ensure that the vehicles are safe for passengers, crew, and others who may come into contact with them.

Railway vehicles should be designed to withstand collisions and minimize the risk of injury or damage in the event of an accident and should also be designed to prevent fires and minimize the risk of fire-related injuries or damage.

In addition, railway vehicles should have clear emergency exit routes and procedures to ensure that passengers and crew can evacuate quickly and safely in the event of an emergency and be equipped with signaling and control systems that help to prevent collisions and ensure safe operation.

By considering safety as part of RAMS analysis for railway vehicles, designers and operators can identify and address potential safety issues before they become a problem, ensuring that the vehicles operate safely and effectively.

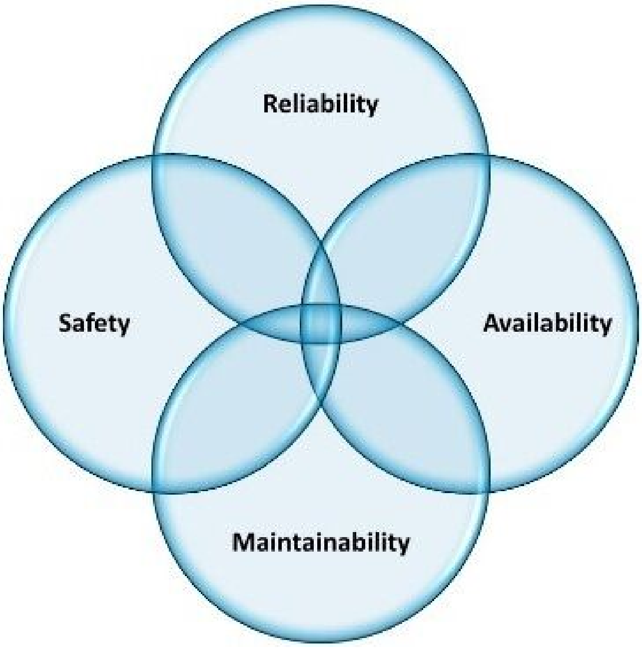


Figure 5: Basic function of RAM analysis

F. Railway Introduction and Railways Maintenance

Railways are a crucial part of transportation infrastructure across the world, serving both passenger and freight transportation needs. The first railway systems were developed in the 19th century and have since evolved into highly sophisticated and efficient systems.

The maintenance of railways is essential to ensure the safe and efficient operation of trains. Railways are subject to a wide range of environmental factors, including extreme temperatures, weather conditions, and wear and tear from heavy usage. Regular inspections of tracks, signaling systems, and other components are required to identify potential issues and defects that could compromise safety.

One of the most critical aspects of railway maintenance is track maintenance. The track is the foundation of the railway system, and it must be kept in excellent condition to ensure safe and efficient operations. Track maintenance involves regular inspection and maintenance of the rails, sleepers, and ballast. Track geometry, such as alignment, curvature, and elevation, must also be maintained within strict tolerances to ensure the safe and smooth movement of trains.

Signaling maintenance is another crucial aspect of railway maintenance. Signaling systems control the movement of trains and ensure safety by preventing collisions and accidents. Regular inspections and maintenance of signaling equipment are required to ensure that it is functioning correctly and accurately communicating information to train operators.

Rolling stock maintenance involves maintaining and repairing the trains themselves. This includes engines, carriages, and other components. Rolling stock maintenance is critical to ensure that trains are operating safely and efficiently. Regular inspections and maintenance of rolling stock can prevent breakdowns and minimize delays.

Modern railway maintenance has evolved to include advanced technologies such as sensors and data analytics. These technologies allow railway companies to monitor and analyze the performance of tracks, trains, and signaling systems in real-time. This enables maintenance teams to detect potential issues early and take action to prevent accidents or delays.

Therefore, the maintenance of railways is essential to ensure safe and efficient transportation. Track maintenance, signaling maintenance, and rolling stock maintenance are all critical aspects of railway maintenance. Advanced technologies such as sensors and data analytics are now used to improve railway maintenance and minimize the risk of accidents and delays.

II. LITERATURE REVIEW

There are various articles that relatively connect to this topic are discussed here as follows. First according El Elaoui et al. (2023), The major goal of the D-Rail initiative is to offer suggestions for reducing derailments by 8–12% and the associated costs by 10–20% across Europe. In order to choose the best safety measures and get the greatest benefits, an objective and unbiased procedure. Based on the conceptual framework for RAMS and LCC that was developed, the results of the risk assessment and RAMS analysis are described in this deliverable.

According to Hamad alawad et al. (2023), the study assesses the effectiveness of text by mining from accident history, gathering knowledge, learning from mistakes, and deeply coherent of the danger produced by analyzing fatality accidents for big and enduring size. Predictive accuracy for important accident information, such as the causes and hotspots at the rail stations, is provided by this intelligent text analysis. Furthermore, the development of big data analytics allows for a better understanding of the type of accidents than would otherwise be feasible without a significant amount of safety history and without using a focused examination of the accident reports. With the use of this technology, the railway industry's safety as well as other fields for safety applications would benefit greatly from a favorable new era of AI applications.

According to Dionysia varvarigou et al. (2023), the first safety orchestrator, STELAC, is at the center of this architecture. As the RAMS qualities that interact and affect safety, this orchestrator addresses anomalies relating to dependability, availability, maintainability, and integrity. In order to manage the interdependence between safety and cybersecurity, this orchestrator is also able to prevent functionality violations between the two. The implementation's findings demonstrate that STELAC is a successful methodology for utilizing the NFV architecture in railway systems safely and securely since it ensures safety influenced by the other aforementioned qualities and has low impact on decision-making time.

According to Yejing fan et al. (2023), this review study seeks to close the knowledge gap. The introduction starts with railroad communications systems. The overall system implications of the RAMS, EMI and IEMI are explored, and the accompanying effects on the signaling and communication systems are thoroughly reviewed. Examining current electromagnetic compatibility (EMC) techniques and discussing the difficulties in addressing the effects of RAMS, EMI and IEMI on signaling and communication systems. The directions for future research are then presented.

According to Jessada Sresakoolchai et al. (2023), the purpose of this study is to exploit RL's ability to lower carbon emissions caused by railway maintenance. The information acquired from the field data between 2016-019 was used to build the RL and RAMS model. The research area spans 30 km. The work uses Proximal Policy Optimization (PPO) to create the RL and RAMS model. The findings show that employing RL reduces carbon emissions from railway maintenance by 48%, resulting in a sizable reduction in carbon emissions, and reduces railway defects by 68%, which also greatly increases maintenance efficiency.

According to Fabio de Rezende Francisco et al. (2023), to assess the dependability of the doors subsystem, which had the most serious failures in 2019 (145 failures) that impacted passenger journey time. The results confirmed the viability and efficacy of the methodology by showing a 66% decline in subsystem dependability over a five-year period. This article's novelty originates from its creative suggestion of a methodology for managing crucial assets and systems by assessing the impact of failures on quality-of-service elements valued by rail customers.

Three trains crashed on June 2, 2023 in the eastern Indian state of Odisha's Balasore district. Near the Bahanaga Bazar train station, the Coromandel Express veered off the main line and onto the passing loop at full speed, colliding with a freight train.

The Coromandel Express was traveling at a high rate of speed when three of its 21 coaches derailed, colliding with the SMVT Bengaluru-Howrah Superfast Express on the next track. The collision resulted in a total of 294 fatalities and 1,175 injuries (Wikipedia, 2023).

Therefore, these several studies have investigated the use of RAMS analysis in the railway industry. These studies have shown that RAMS analysis can be an effective tool for improving the safety and efficiency of railway operations, particularly in developing countries. By identifying critical components and developing strategies to improve their reliability, maintainability, availability, and safety, we can create a more sustainable and efficient railway system.

III. THE APPLICATION OF RAMS ON MAINTENANCE OF RAILWAYS

After the highways, railway transport is the second most valuable means of transportation, and it is necessary for the long shipments along major transportation routes. Railways were the "forerunner" of modern mechanical conveyance. It had dominance on land transport since its inception and until the introduction of road transportation. Railways have influenced the economic, social, and political development of several countries worldwide.

Despite the fact that managing the railway system requires a lot of money compared to other routes of transportation, it is our dominant means of transport. A Transportation Management System is a management solution that handles truck or carrier dispatching, driver remuneration, driver records, billing, and policy compliance.

A transportation management system (TMS) is a technology-based logistics framework that assists businesses in organizing, actualizing, and optimizing the transportation of goods, tangible and intangible, transmitting or receiving, as well as ensuring that the shipping is consistent and that all necessary paperwork is readily accessible. Consequently, transportation management systems are crucial in supply chains, influencing every step along the way from organization to acquisition to distribution and system integration. A powerful system's broad and deep transparency makes for easier transportation implementation and scheduling, which leads to improved service quality.

A. Maintenance in general

Maintenance refers to the work performed to keep a machine, system, or structure in good working condition. It includes regular inspections, cleaning, repairs, replacements, and updates to prevent breakdowns and extend the lifespan of the equipment. The purpose of maintenance is to maintain or restore the equipment to its original functioning state, improve performance, increase safety, and avoid downtime and costly repairs (Stenström, 2014).

1. Importance of maintenance

Maintenance is important because it:

1. Increases safety: Regular maintenance helps to identify and fix potential safety hazards, reducing the risk of accidents and injuries.
2. Improves performance: Proper maintenance ensures that equipment is operating efficiently, reducing downtime and maximizing productivity.
3. Extends equipment lifespan: Regular maintenance can help extend the lifespan of equipment by preventing wear and tear, identifying potential problems early, and making repairs before more serious damage occurs.
4. Saves money: Regular maintenance can help avoid expensive repairs and replacement costs. It can also help to reduce energy consumption and increase efficiency, leading to lower operating costs.
5. Minimizes downtime: Regular maintenance can help to prevent equipment failure and minimize downtime, allowing operations to run smoothly and reducing the impact on productivity.

In summary, maintenance is a crucial aspect of equipment management and is necessary to ensure that equipment operates safely, efficiently, and effectively.

2. Types of maintenance

Three main types of maintenance, namely, run-to-breakdown maintenance, preventive maintenance (periodic maintenance), and predictive maintenance (condition monitoring) are explained here.

- **Run-to-breakdown maintenance**

Run-to-breakdown maintenance, also known as reactive maintenance, is a maintenance strategy in which equipment is operated until it fails, and then repairs are performed. This type of maintenance is often used when equipment is inexpensive, readily available, and easy to replace.

Examples of industries that commonly use run-to-breakdown maintenance include:

1. Agriculture: In some agricultural settings, equipment such as tractors and implements may be operated until they break down, and then repairs are performed.
2. Construction: In the construction industry, some tools and equipment, such as hand tools and small power tools, are often operated until they fail and then replaced.
3. Hospitality: In the hospitality industry, items such as small appliances and furniture may be used until they break down, and then replaced or repaired.
4. Retail: In the retail industry, store fixtures and equipment, such as cash registers and displays, may be operated until they fail and then replaced.

- **Advantages**

1. Cost effective for short term since few repair costs and minimum personnel are required for maintenance

- **Disadvantages**

1. Increased downtime since it means waiting for equipment to fail before taking any action, which may result in extended periods of downtime while repairs are made. This can negatively impact productivity and increase the risk of missed deadlines or lost revenue.
2. Higher repair costs because reactive maintenance often involves emergency repairs or replacing parts that have suffered more extensive damage.
3. Safety risks: Failing equipment can pose safety risks to workers and the surrounding environment. Reactive maintenance may not address these risks until after an incident has occurred, which can put people and assets at risk.
4. Reduced equipment lifespan: Running equipment until it fails can cause more extensive damage to the equipment over time, which can reduce its lifespan and increase the frequency of repairs.

Due to the limitations stated, a proactive maintenance strategy, such as preventive or predictive maintenance, may be more appropriate for more critical equipment and systems.

- **Procedures on how to apply reactive maintenance on railway vehicle maintenance:**

1. Identify the problem: When a problem is identified, the first step is to determine the cause of the issue. This may involve inspecting the vehicle and conducting tests to determine the root cause of the problem. For example, a train is experiencing a sudden loss of power, and passengers are reporting that the lights and air conditioning have shut off.
2. Determine the scope of the repair: Once the cause of the problem is identified, it's necessary to determine the scope of the repair required to fix the issue. This may involve replacing a single component or conducting more extensive repairs. For example, from the situation above, the inspection reveals that the train's power supply has failed. The scope of the repair required to fix the issue is determined to be extensive, as the power supply system needs to be replaced.
3. Conduct the repair: Once the scope of the repair is determined, the repair can be conducted. This may involve replacing a component, repairing a damaged area, or reconfiguring a system to address the problem. Then, the repair team replaces the train's power supply system, including the battery, alternator, and associated wiring. The replacement of the system takes several hours, and the train is taken out of service during this time.
4. Test the repair: After the repair is completed, it's important to test the system to ensure that the problem has been resolved. Here, the train's power supply is tested to ensure that the lights, air conditioning, and other systems are functioning correctly.
5. Monitor the system: After the repair is completed, it's important to monitor the system to ensure that the problem does not reoccur. Finally, the train's power supply system is monitored regularly to ensure that it is functioning correctly and that there are no signs of further problems.

The other examples of reactive maintenance activities for railway vehicle maintenance may include:

- Repairing a broken suspension component after an accident or impact

- Fixing an electrical system issue that causes the train's lights to flicker or not work
- Addressing a wheel alignment problem that causes the train to veer off track
- Replacing a damaged brake component that affects the train's ability to stop effectively
- Fixing an air conditioning system issue that results in passenger discomfort

By addressing issues through reactive maintenance measures like these, railway operators can minimize the impact of unexpected issues on their operations and maintain safety for passengers and staff. It's important to note that while reactive maintenance can address issues after they occur, it's still preferable to implement preventive maintenance measures to minimize the occurrence of problems in the first place.

- **Basic systems and equipment used for reactive maintenance in railway vehicle maintenance:**

1. Hand tools: Hand tools such as wrenches, pliers, screwdrivers, and hammers are used to remove and install components on railway vehicles. For example, a train's brake pads have worn down and need to be replaced. A mechanic uses a wrench to remove the old brake pads and install new ones.
2. Diagnostic tools: Diagnostic tools are used to identify problems with a railway vehicle's systems and components, including sensors, meters, and gauges. For example, a train's engine is not starting, and a mechanic uses a diagnostic tool to test the vehicle's electrical system and identify a faulty starter motor.
3. Welding equipment: Welding equipment is used to repair damaged metal components, such as broken frames or support structures. For example, a train's undercarriage has been damaged in a collision, and a welder uses welding equipment to repair the damage and restore the frame's integrity.
4. Lifting equipment: Lifting equipment such as jacks and cranes is used to lift and support railway vehicles during maintenance activities. For example, a train’s wheels need to be replaced and a crane is used to lift the vehicle off the track to facilitate the replacement process.

5. Cleaning equipment: Cleaning equipment, such as high-pressure washers, is used to remove dirt and debris from railway vehicles and their components. A mechanic uses a high-pressure washer to clean the wheels and ensure that they are functioning correctly.

By using these basic systems and equipment for reactive maintenance, railway operators can quickly address unexpected problems and minimize disruptions to their operations.**Preventive maintenance (periodic maintenance)**

Preventive maintenance (also known as periodic maintenance) is a type of maintenance strategy in which regular and planned maintenance activities are performed to prevent equipment failure and extend the lifespan of the equipment. The aim of preventive maintenance is to identify and address potential problems before they become critical, minimizing downtime and avoiding the need for more extensive repairs.

Examples of industries that commonly use preventive maintenance include:

1. Manufacturing: In the manufacturing industry, machinery and equipment, such as assembly lines and robots, are regularly inspected, lubricated, and maintained to ensure they are operating safely and efficiently.
2. Transportation: In the transportation industry, vehicles, such as buses, trains, and airplanes, are regularly inspected, serviced, and maintained to ensure they are safe and ready to operate.
3. Energy: In the energy industry, power plants, wind turbines, and oil rigs are regularly maintained to prevent equipment failures and ensure a reliable supply of energy.
4. Healthcare: In the healthcare industry, medical equipment, such as CT scanners and X-ray machines, are regularly maintained to ensure they are safe and effective for use in patient care.

Facilities Management: In facilities management, building systems, such as heating and cooling systems, electrical systems, and fire protection systems, are regularly maintained to ensure they are functioning properly and to avoid costly breakdowns and repairs.

- **Advantages:**

1. Increased equipment reliability and availability since it helps in identifying potential issues and addressing them before they lead to equipment failure.
2. Reduced downtime: Scheduled maintenance can be performed during planned downtime, reducing the risk of unplanned downtime and the associated costs of lost productivity, missed deadlines, and emergency repairs.
3. Lower repair costs: Addressing potential issues before they become major problems can reduce the cost of repairs and replacements, as minor repairs tend to be less expensive than emergency repairs or full equipment replacements.
4. Improved safety as it helps in identifying and addressing safety issues before they lead to accidents or injuries, thereby improving workplace safety.

- **Disadvantages:**

1. It requires time and resources to schedule and perform inspections, repairs, and replacements which can add to the operational costs.
2. Over-maintenance occurs when too much preventive maintenance is performed, which can lead to unnecessary costs and downtime.
3. Risk of missed issues: Even with scheduled inspections, potential issues can be missed, leading to unexpected equipment failure and downtime.
4. High cost of maintenance since it requires an investment in equipment, tools, and trained personnel, which can increase operational costs.

In conclusion, preventive maintenance is a proactive maintenance strategy that is used to minimize equipment failures and extend equipment lifespan. By regularly performing preventive maintenance, organizations can ensure that their equipment is operating safely and efficiently, minimizing downtime and reducing the need for costly repairs. Preventive maintenance is an essential aspect of railway vehicle, as it helps to identify potential problems before they turn into major issues, ensuring that the vehicles remain in optimal condition and operate safely.

- **Procedures on how to apply preventive maintenance on railway**

vehicle maintenance:

1. Develop a maintenance schedule: Establish a regular maintenance schedule that covers all aspects of the railway vehicle. The schedule should include regular inspections, testing, cleaning, and replacement of components as needed.
2. Conduct inspections: Conduct regular inspections of the railway vehicle to identify any potential issues. This includes inspecting the brakes, wheels, suspension, electrical systems, and other critical components.
3. Lubricate moving parts: Apply lubrication to moving parts such as bearings and axles to reduce friction and wear.
4. Clean components: Keep the components of the railway vehicle clean to prevent dirt and debris from accumulating and causing problems.
5. Replace components as needed: Replace any components that show signs of wear or damage, such as brake pads, bearings, or suspension parts.

Examples of preventive maintenance activities for railway vehicle maintenance may include:

- Regular inspection and replacement of brake pads and discs
- Checking and adjusting wheel alignment
- Lubrication of bearings and axles
- Regular inspection and replacement of suspension components such as shock absorbers
- Cleaning and inspection of electrical systems and wiring
- Inspection and maintenance of the air conditioning system in passenger trains

By implementing preventive maintenance measures like these, railway operators can ensure that their vehicles remain in optimal condition and operate safely, minimizing the risk of breakdowns and accidents.

- **Basic systems and equipment used for preventive maintenance in railway vehicle maintenance:**

1. Lubrication systems: Lubrication systems are used to ensure that moving

parts on railway vehicles, such as bearings, gears, and axles, remain lubricated and functioning properly. For example, a maintenance technician uses a grease gun to apply lubricant to the bearings and gears on a train's axles during a scheduled maintenance inspection.

2. Inspection tools: Inspection tools, such as borescopes and micrometers, are used to measure and inspect the condition of components, such as pipes, hoses, and electrical wiring. For example, a technician uses a borescope to inspect the interior of a train's engine and identify any signs of wear or damage.
3. Vibration analysis systems: Vibration analysis systems are used to measure and analyze the vibration levels of machinery and identify any signs of wear or damage. For example, a vibration analysis system is used to monitor the condition of a train's engine and detect any unusual vibration patterns that may indicate potential problems.
4. Condition monitoring systems: Condition monitoring systems are used to track the performance and condition of equipment over time and detect any signs of degradation or wear. For example, a condition monitoring system is used to track the performance of a train's braking system over time and detect any signs of wear or malfunction.
5. Cleaning equipment: Cleaning equipment, such as pressure washers and air compressors, is used to remove dirt and debris from railway vehicles and their components, preventing corrosion and other damage. For example, a maintenance crew uses an air compressor to blow debris and dirt out of a train's electrical components during a scheduled maintenance inspection.

By using these basic systems and equipment for preventive maintenance, railway operators can keep their equipment functioning at peak performance and reduce the risk of equipment failure and downtime.**Predictive maintenance (condition monitoring)**

Predictive maintenance (also known as condition monitoring) is a type of maintenance strategy in which equipment performance data is collected and analyzed to predict when equipment is likely to fail, allowing maintenance to be performed before an unplanned failure occurs. This approach to maintenance allows organizations to prioritize maintenance activities and minimize equipment downtime, resulting in increased efficiency and cost savings.

The performance of the machines is determined by measuring and analyzing some parameters while the machines are running.

Measurement Parameters:

1. Vibration
2. Temperature
3. Pressure
4. leakage
5. Noise
6. Oil analysis
7. Flow

Some physical parameters to be measured and their effect will be analyzed to find out the source of different machine faults. At the table below we see the relation of different physical parameters to different machine faults.

Parameter / Machine Fault	Tempe-rature	Pres-sure	Flow	Oil analysis	Vibra-tion
Out of Balance					×
Misalignment/ Bent Shaft	×				×
Damaged Rolling Elem. Bearings	×			×	×
Damaged Journal Bearings	×	×	×	×	×
Damaged or worn Gears				×	×
Mechanical Looseness					×

Figure 6: The relation of different physical parameters to different machine faults (Tuncer TOPRAK, 2023)

- **Measured Vibration Frequency Spectrum and its Relation with Machine Condition**

Each peak on the spectrum and its frequency is related one of the running part of the machine.

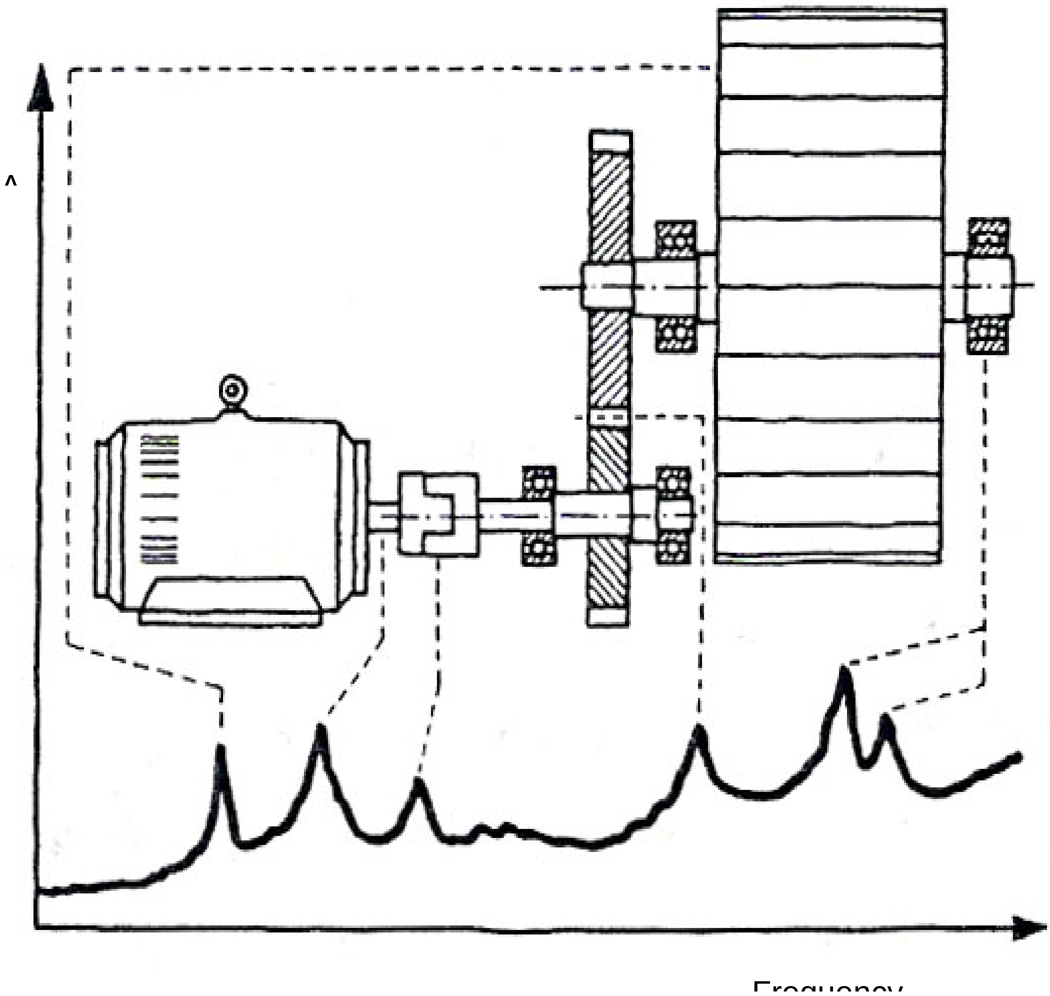


Figure 7: Measured vibration frequency spectrum and its relation with machine condition (Tuncer TOPRAK, 2023)

Factors causing vibration:

1. Unbalance
2. Misalignment of shafts
3. Looseness
4. Wear
5. Bearing damages
6. Belt damage
7. External influences
8. Gear boxl damage
9. Electric motor damage

10. Cavitation

Unbalancing

Static Unbalancing

1. A static balance occurs when the inertial axis of a rotating mass is displaced from and parallel to the axis of rotation. Static unbalances can occur more frequently in disk-shaped rotors. Only one plane receives balance correction. Static unbalance can be corrected by adding or removing weight in only one correction plane.
2. The vibration amplitude increases with the square of the velocity amplitude.
3. In the spectrum, an effective peak occurs at the rotational frequency.

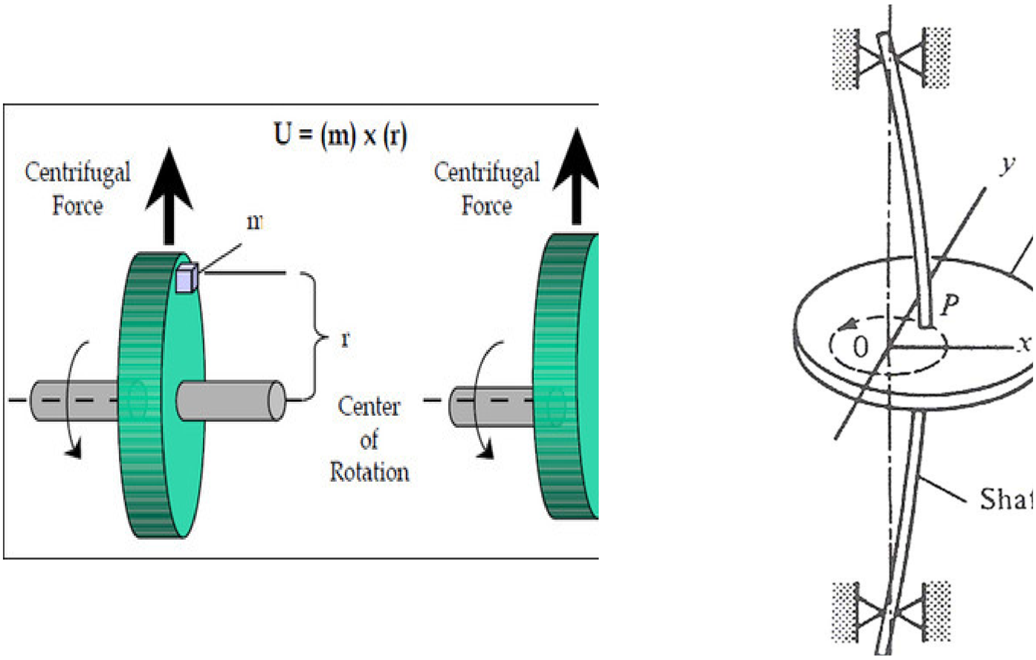


Figure 8: Static unbalancing on a disk (Tuncer TOPRAK, 2023)

Static unbalancing initiate vibration at the rotating frequency and its first harmonic as shown on the right hand side spectrum figure.

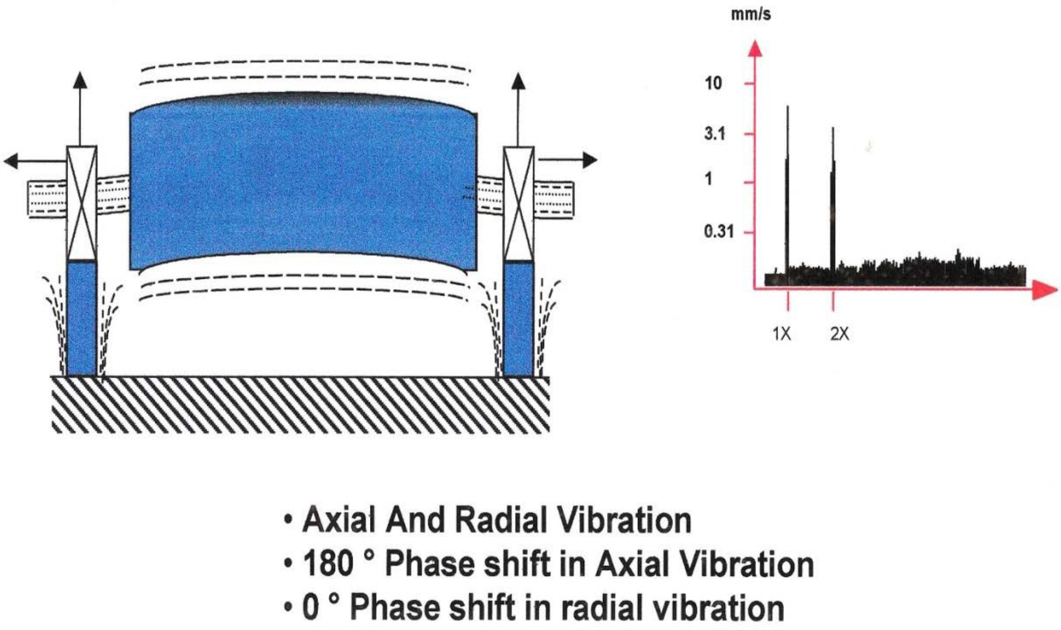


Figure 9: Static unbalancing (Tuncer TOPRAK, 2023)

- **Dynamic Unbalancing**

Unbalance can occur in almost anything that rotates and is the uneven distribution of mass around the rotating axis. A rotor is said to be out of balance when its center of mass is out of alignment with the center of rotation.

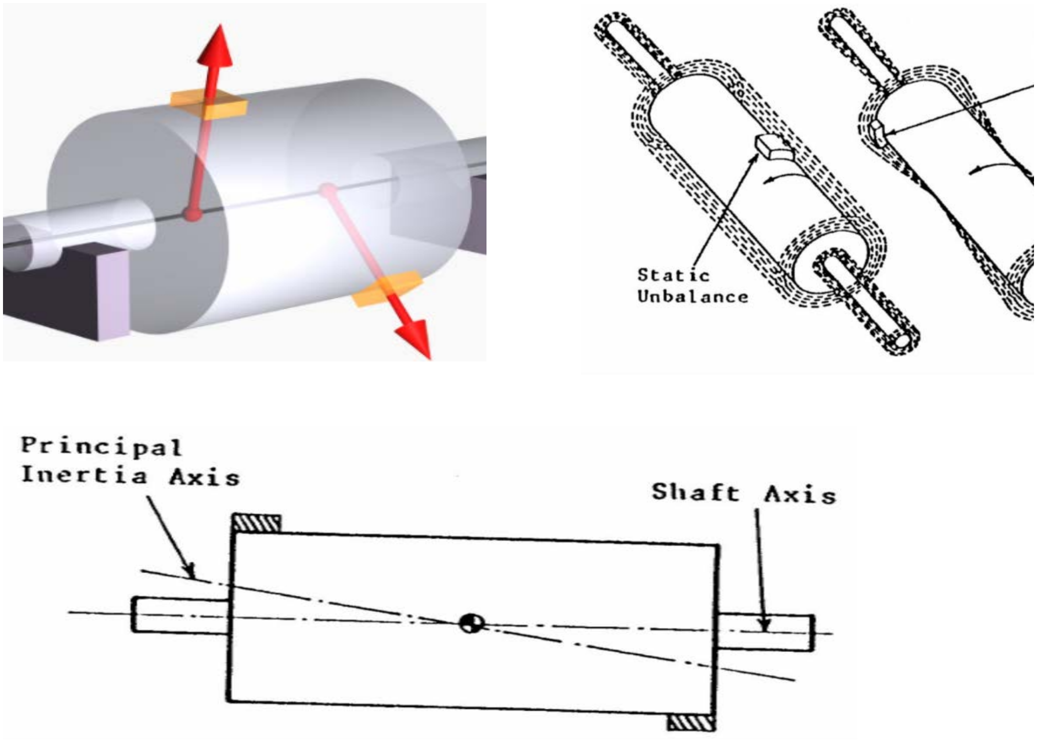


Figure 10: Dynamic (2 plane) unbalancing (Tuncer TOPRAK, 2023)

Unbalancing

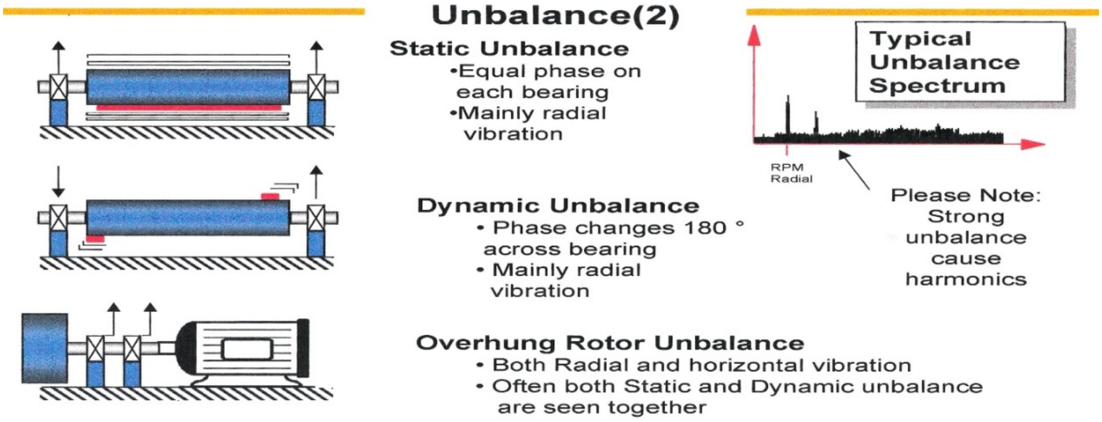


Figure 11: Unbalancing (Tuncer TOPRAK, 2023)

- **Misalignment of Shafts**

There are two major types of misalignment, parallel and angular. ***Parallel misalignment*** means that both shaft centerlines are parallel, but offset by some distance.

Angular misalignment, on the other hand, refers to a condition where the shaft centerlines are not parallel and intersect at an angle.

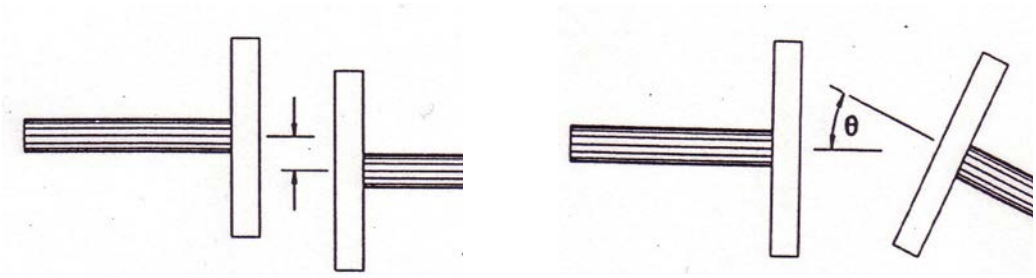


Figure 12: Parallel and angular misalignment (Tuncer TOPRAK, 2023)

- **Parallel and Angular Misalignment**

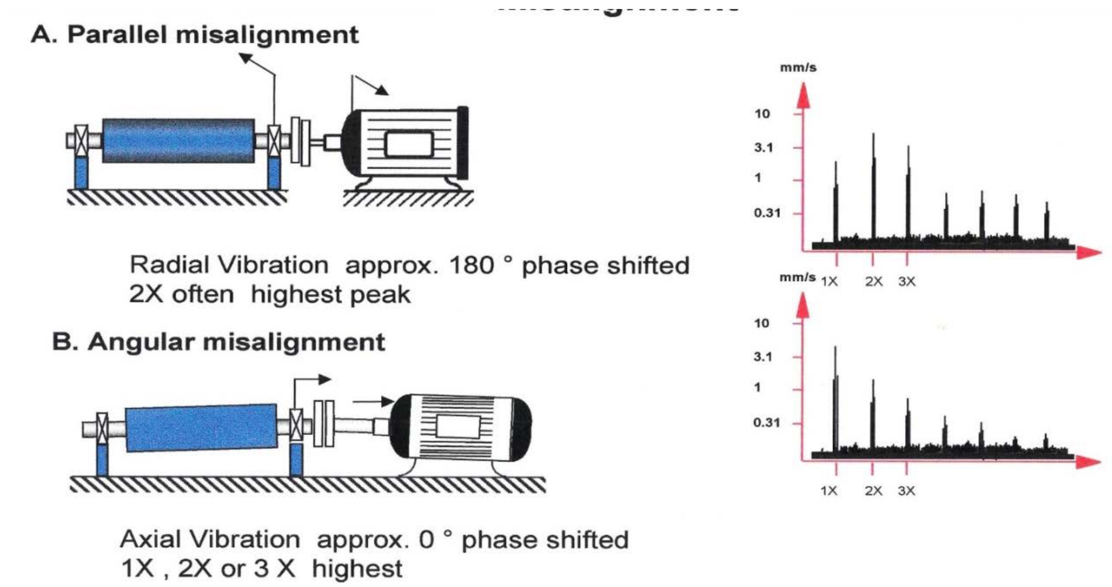


Figure 13: Parallel and angular misalignment condition (Tuncer TOPRAK, 2023)

- **Unbalancing**

1. High amplitude, rotational frequency vibration
2. Low amplitude axial vibration
3. No phase difference in different positions
4. Independent of temperature change
5. Vibration amplitude changes proportional to the square of the rotation frequency

- **Misalignment**

1. High amplitude axial vibrations
2. 180 degree phase difference in different positions
3. Vibration amplitude varying with temperature
4. Vibration amplitude and force do not change with rotational frequency

- **Mechanical Looseness**

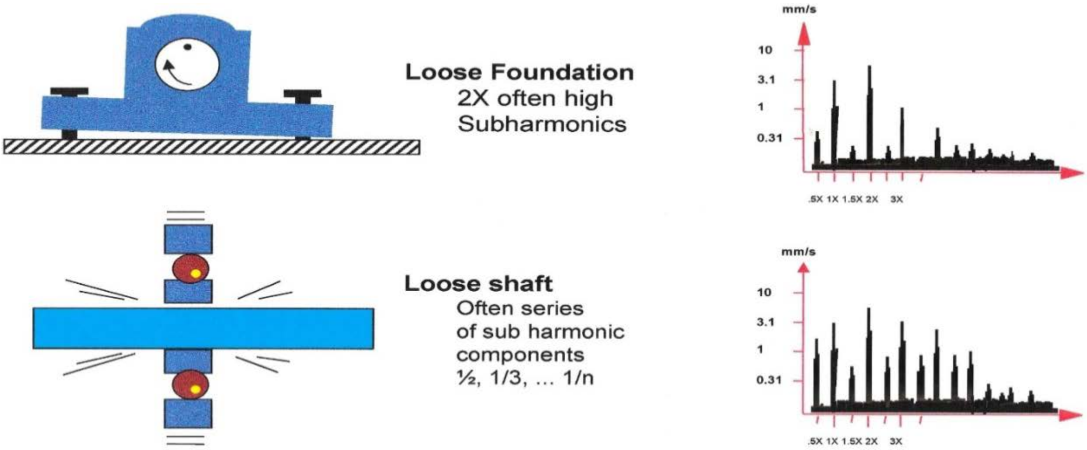


Figure 14: Mechanical looseness (Tuncer TOPRAK, 2023)

- **Ball Bearing Damages**

Defect can occur on;

1. Outer Race
2. Inner Race,
3. Balls
4. Cage

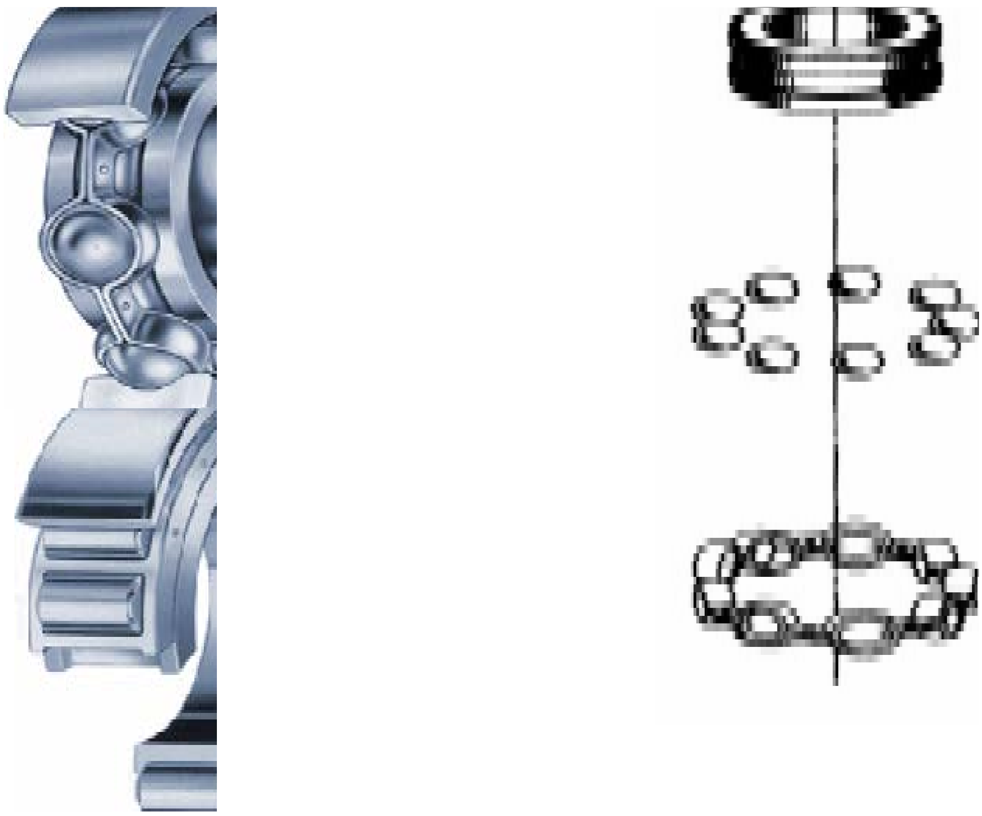


Figure 15: Ball bearing damages (Tuncer TOPRAK, 2023)

- **Ball Bearing Damages**

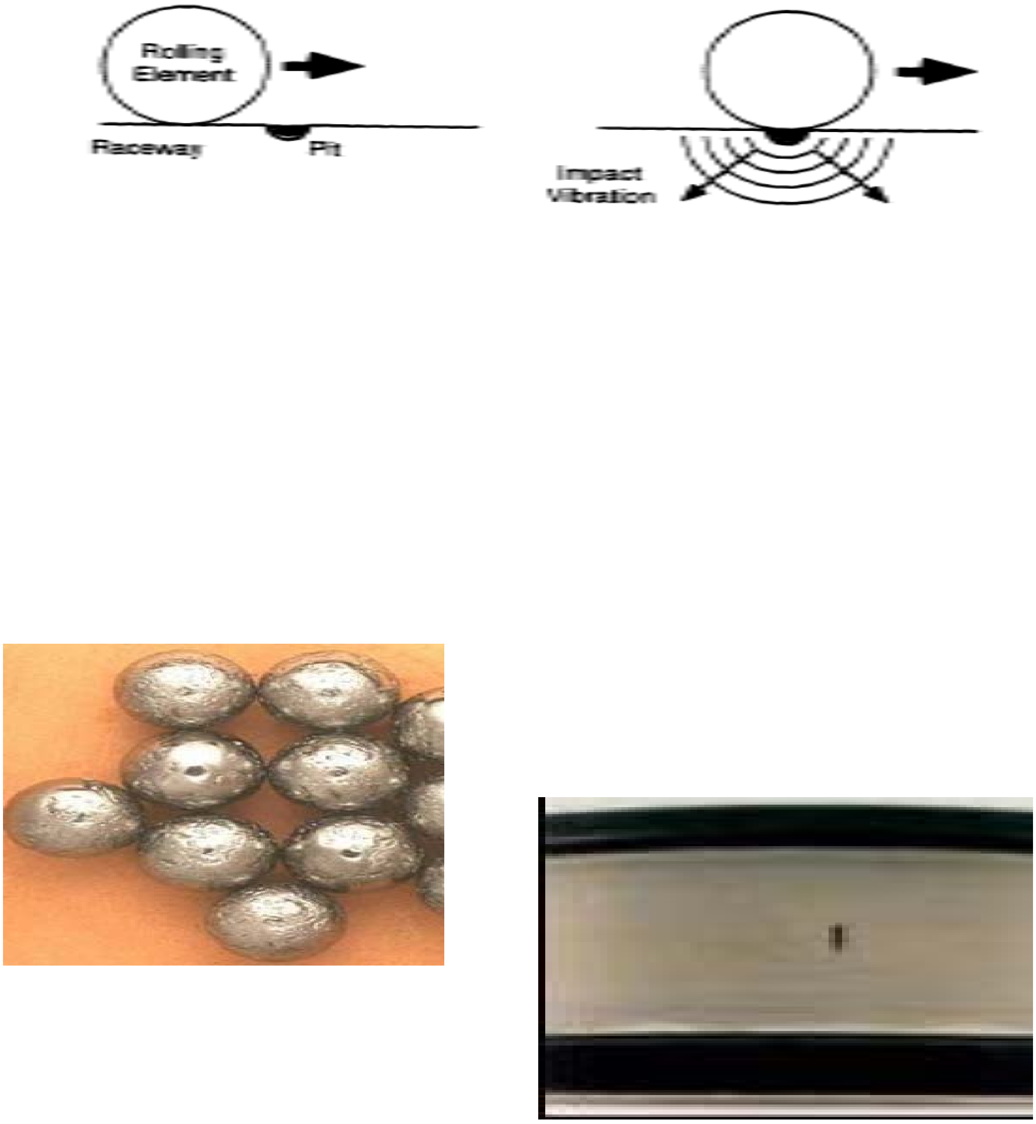


Figure 16: Ball bearing damages (Tuncer TOPRAK, 2023)

- **Damages (Crack or wearing) on ball bearing components**

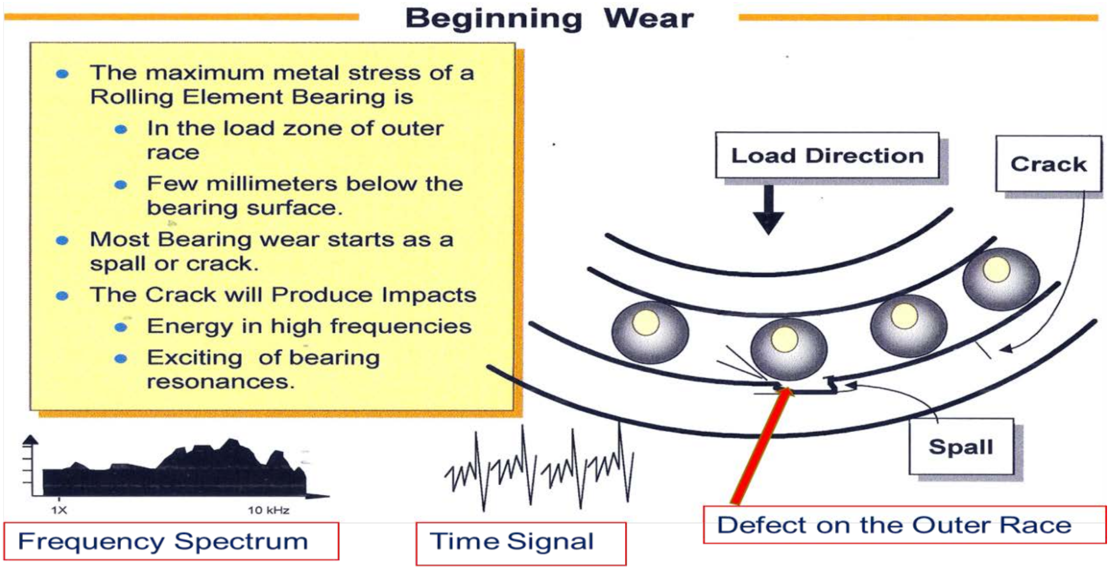
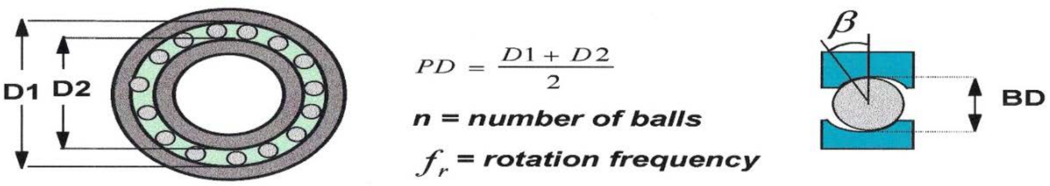


Figure 17: Damages (crack or wearing) on ball bearing (Tuncer TOPRAK, 2023)

Damage on different part of the ball bearing initiate vibration with different frequency. These frequencies are defined in terms of bearing parameters as shown below.



$$\text{BPFO} = \quad f_{outer}\ (Hz) = \frac{n}{2} f_r \left(1 - \frac{BD}{PD} \cos \beta\right)$$

$$\text{BPFI} = \quad f_{inner}\ (Hz) = \frac{n}{2} f_r \left(1 + \frac{BD}{PD} \cos \beta\right)$$

$$\text{BSF} = \quad f_{ball}\ (Hz) = f_r \frac{PD}{BD} \left[1 - \left(1 + \frac{BD}{PD} \cos \beta\right)^2\right]$$

$$f_{cage}\ (Hz) = \frac{1}{2} f_r \left(1 - \frac{BD}{PD} \cos \beta\right)$$

Figure 18: Frequencies are defined in terms of bearing parameters (Tuncer TOPRAK, 2023)

- **Belt Damages Initiate Vibration**

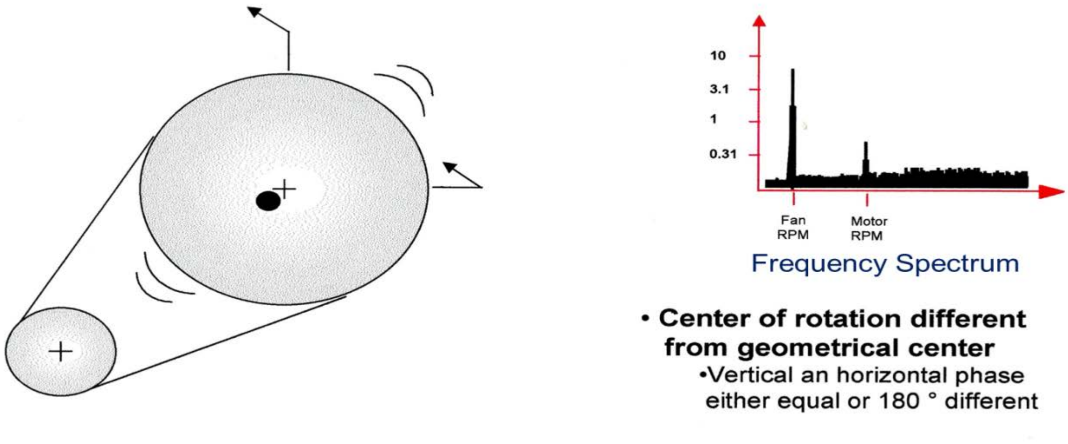


Figure 19: Belt damages initiate vibration (Tuncer TOPRAK, 2023)

- **Gear Box Damages**

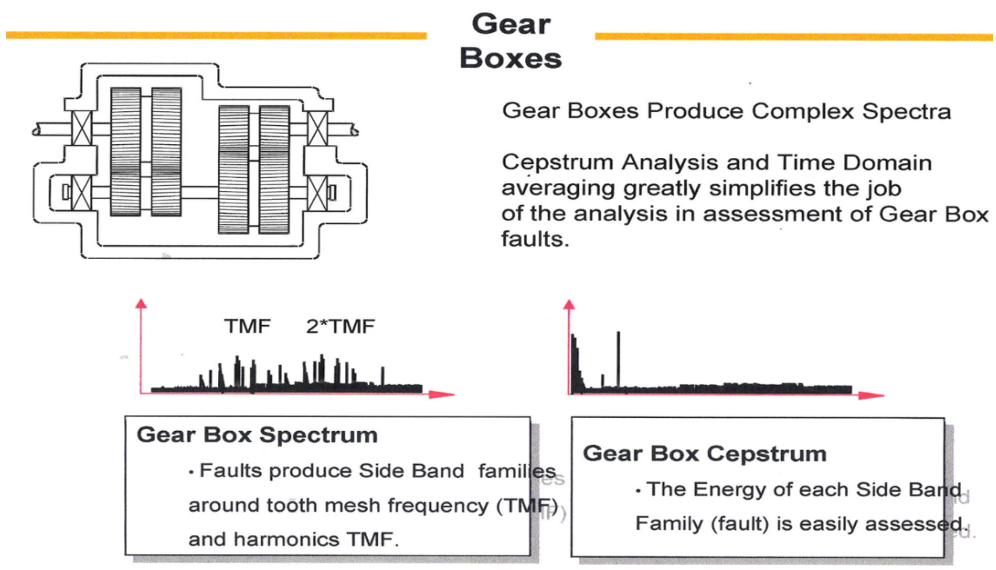


Figure 20: Gear box damages (Tuncer TOPRAK, 2023)

Each gear in a gear box rotates with different speed and damage on each gear initiate vibration with a frequency which is related to rotation speed of that gear.

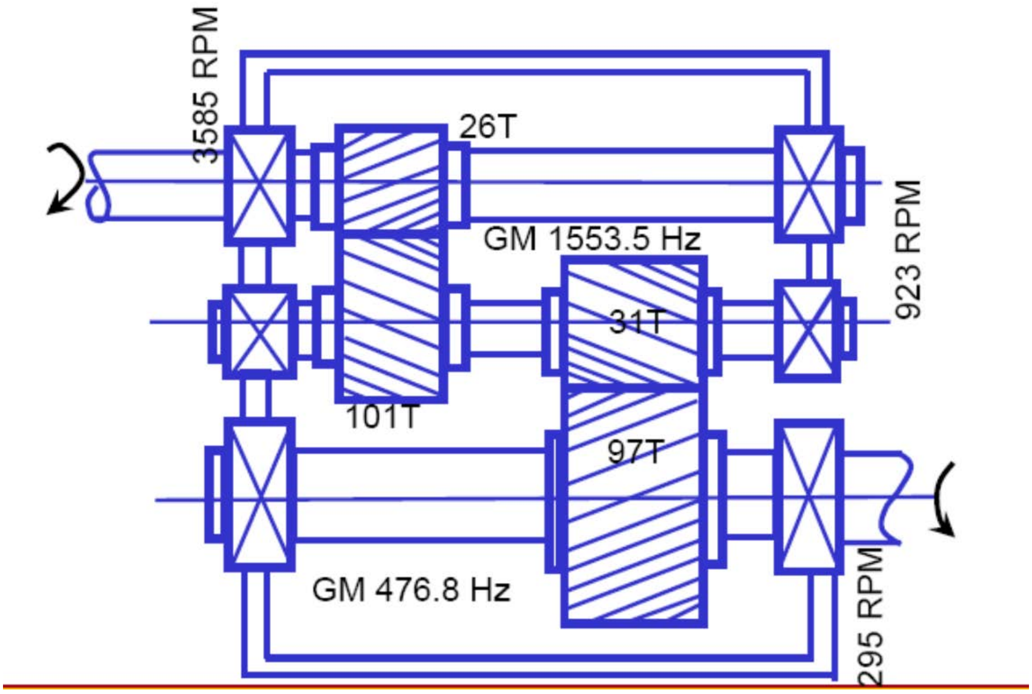


Figure 21: Gear box arrangement (Tuncer TOPRAK, 2023)

Frequency Spectrum of a Damaged Gear Box

Each peak on the spectrum is related with different gear in the box.

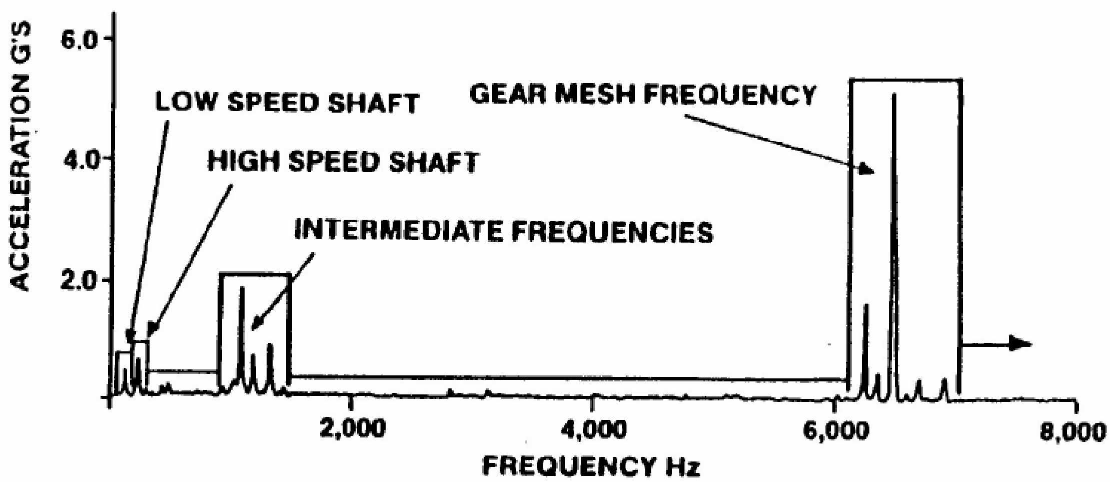


Figure 22: Frequency spectrum of a damaged gear box (Tuncer TOPRAK, 2023)

- **Damages on Electrical Motors**

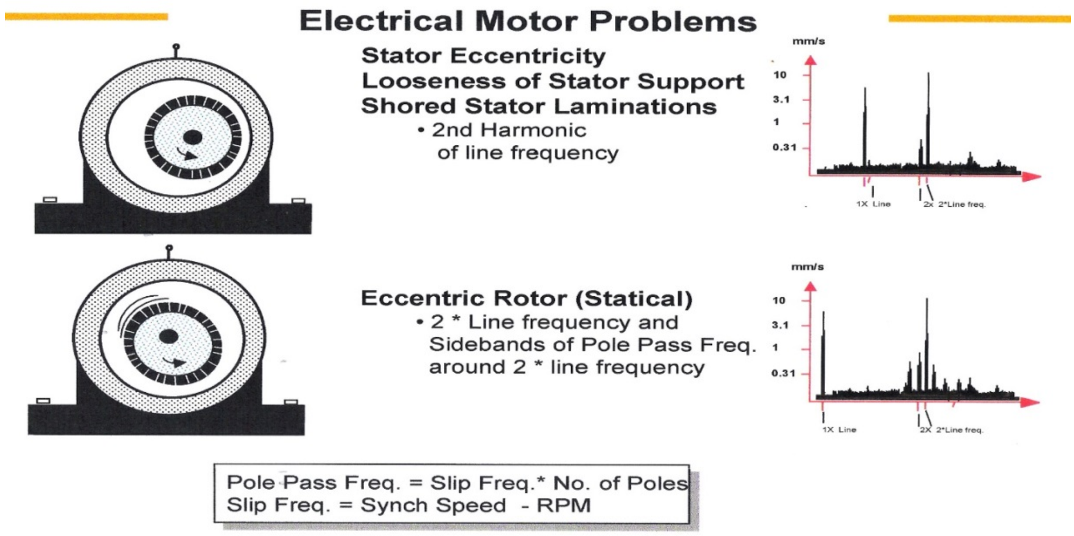


Figure 23: Damages on electrical motors (Tuncer TOPRAK, 2023)

- **Vibrations on Hydraulic Pump**

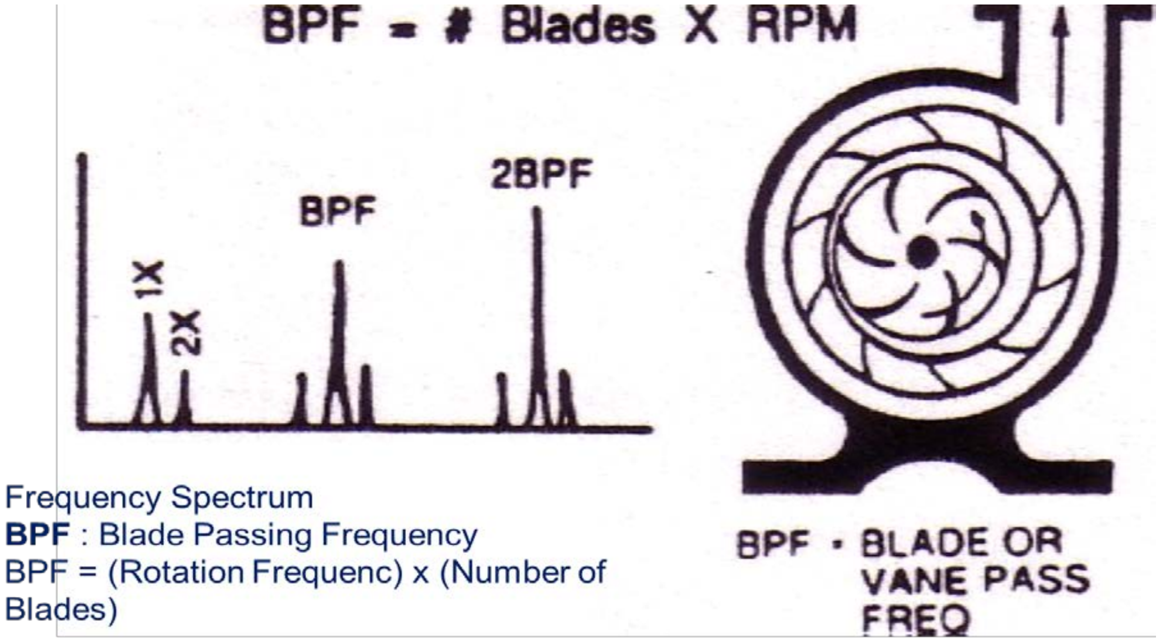


Figure 24: Vibrations on hydraulic pump (Tuncer TOPRAK, 2023)

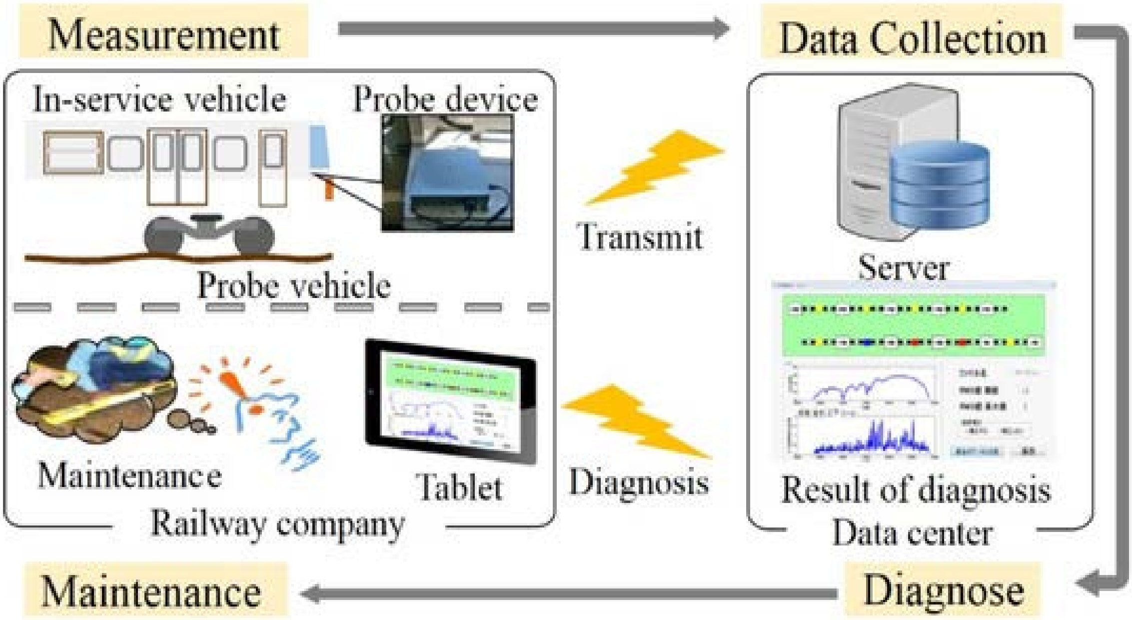


Figure 25: Condition monitoring procedure (Simões, 2008)

a. A Systematic Process of Machine Condition Monitoring and Fault Diagnosis

Most of the machines and systems in industry are the devices which have relative motion between various moving parts and this relative motion between parts causes vibration and noise. Rotating machinery involve various components such as bearings, gears, rotors, belt drives, pulleys, couplings, etc. These components generate vibration and noise even they do not contain any fault. Any fault in any of the machine components may lead to increase in vibration amplitude and may cause catastrophic damages.

Condition Monitoring of rotating machinery plays an important role to diagnose the faults in machines in early stages before they become critical and to avoid catastrophic losses. Condition Monitoring techniques are commonly used in fault detection of rotating machinery like pumps, electric motors, internal combustion engines, presses, etc.

There are number of Condition Monitoring techniques are available to monitor the condition of machines, which includes visual inspection, vibration signal analysis, oil analysis, wear analysis, temperature monitoring, acoustic emission analysis, motor current analysis, etc. Among these techniques, vibration signal analysis is one of the most versatile techniques.

A systematic condition monitoring process and planning of condition monitoring has different steps and requires skilled maintenance team and instrumentation. Skilled maintenance team will do measurement, data evaluation and diagnostic analysis. Basic instrumentation covers computer and softwares, multichannel data acquasion system, different types of transducers, sound level meter, laser cameras, video cameras, GPS, Gyro sensors, etc.

As a first stage, measurement team will complete the following tasks;

- Getting information about the system to be monitored
- Decide about the parameters to be measured
- Measurement points
- Measurement conditions
- Measurement period
- Related International standards and limits for the parameters
- Maintenance history of the system to be monitored

For defining the measurement points, experience of the measurement team and history of the machine plays important role. In an industrial plant, there will be different and number of machinery to be measured. Each machine will have several points to be measured and at each point measurement can be taken on different direction as it is shown on the following chart.

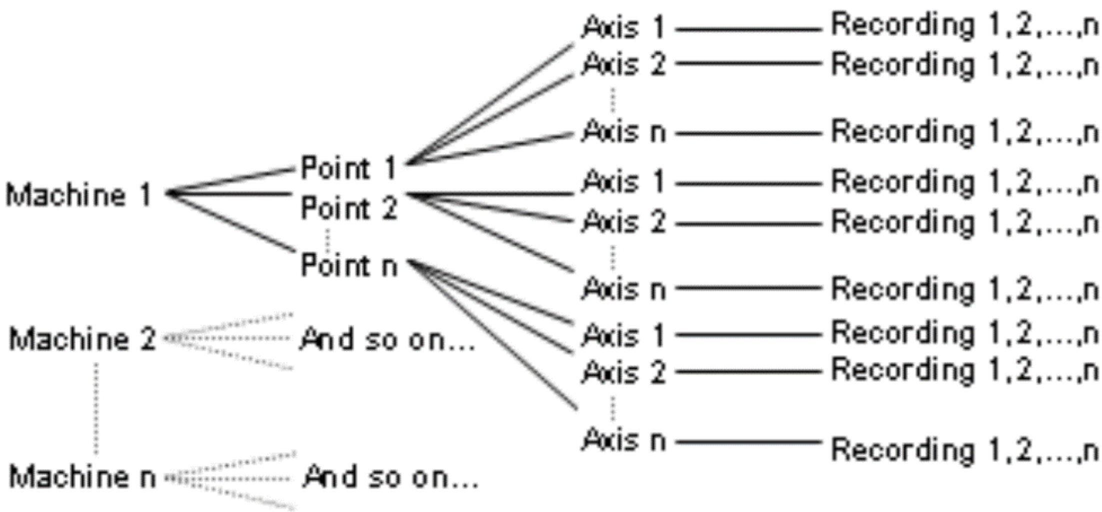


Figure 26: Machines to be monitored and measurement points (wickens, 2003)

First measurement data will be collected when the machines are in good conditions and this data will be stored to the computer as reference signal for each measurement location. After defining the measurement period, new data will be collected from each point with same condition and stored to the computer. A special computer software will evaluate the new data and compare with the reference signals and give an output report or a graph shown as below.

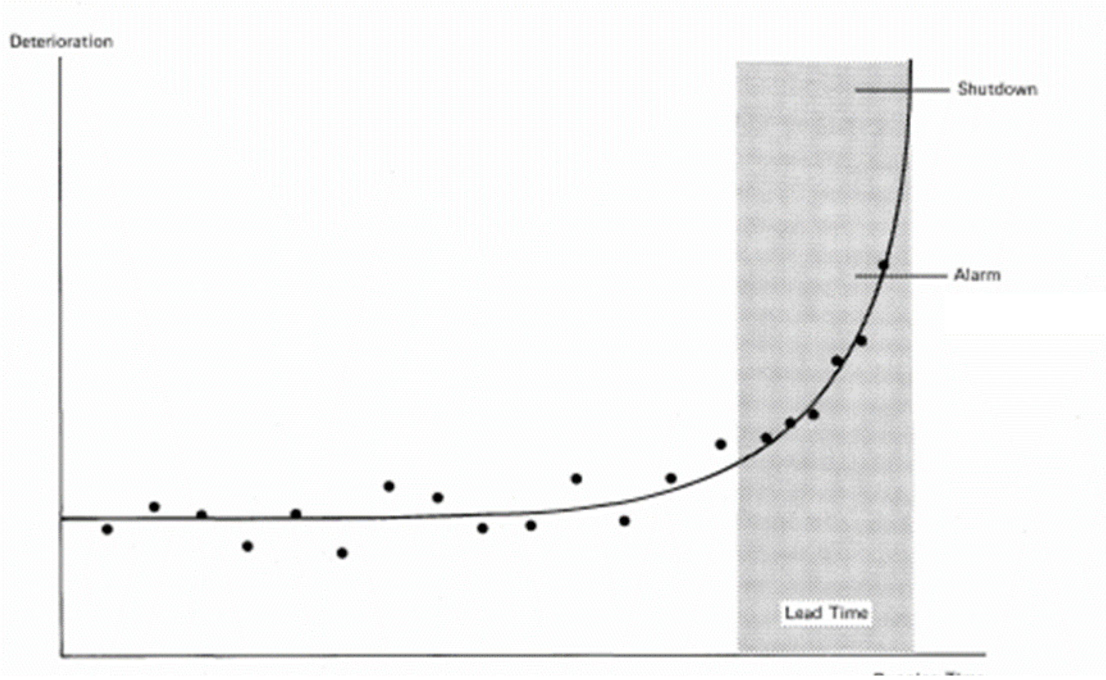


Figure 27: Trend of the machine performance at a point (wickens, 2003)

During the data evaluation;

- Existing condition of the system - Performance
- Trends of the measured parameters
- Expected time to failure
- Type of fault existing or developing
- Type of fault which caused failure

will be taken into account. The important point is, during the measuremnt and evaluations machines do not stop and continue production until the measured parameter value comes closer to the defined upper limit. After this point, diagnostic analysis will start to define the source of the progressing fault.

During the diagnostic analysis, especially vibration frequency analysis plays important role. Some examples of different machinery diagnosis shown below.

a) Condition Monitoring on a Turbine-Pump System

The frequency spectrum below was recorded from a turbine pump in a petrochemical plant. In the lower spectrum (second measurement) very distinct peaks were observed in multiples of rotation frequency. This is an example of a spectrum of typical looseness. Upper spectrum recorded after repair.

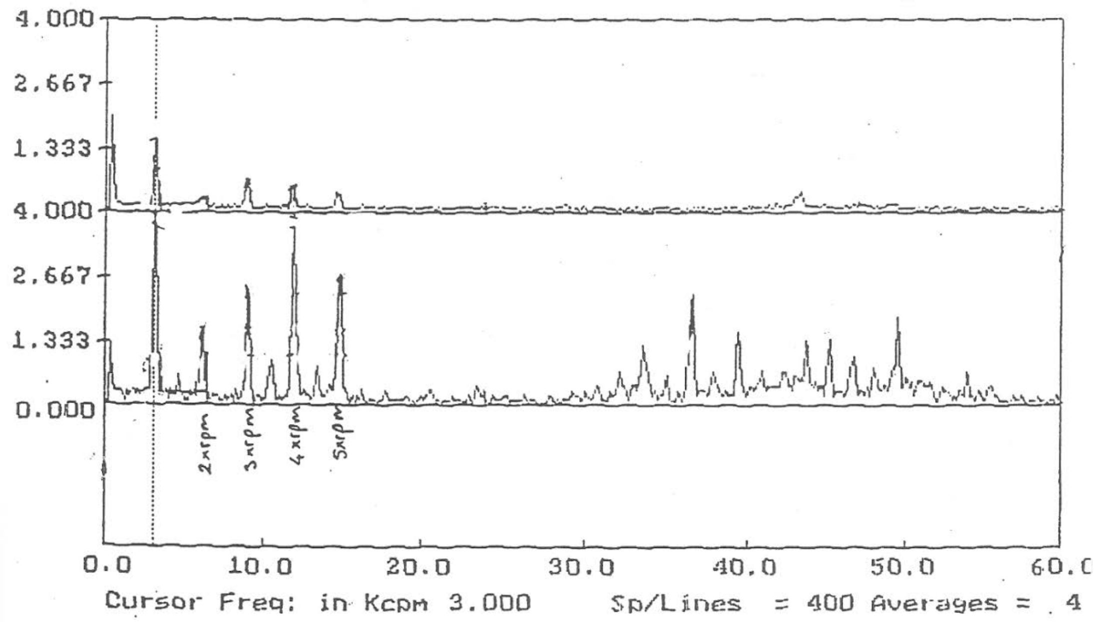


Figure 28: Frequency analysis on a turbine-pump (Wickens, 2003)

b) Vibration Problem on a Motorpump

In the motor-pump system, a large amplitude peak was observed in the spectrum taken over one of the bearings. Since the frequency of this peak is twice the rotation frequency, it is thought that it may be misalignment, not unbalance. In the examination, it has been determined that there is rezonancy problem. Natural frequency of the base is twice the rotation frequency.

The problem was solved by changing the natural frequency with the renovation on the base.

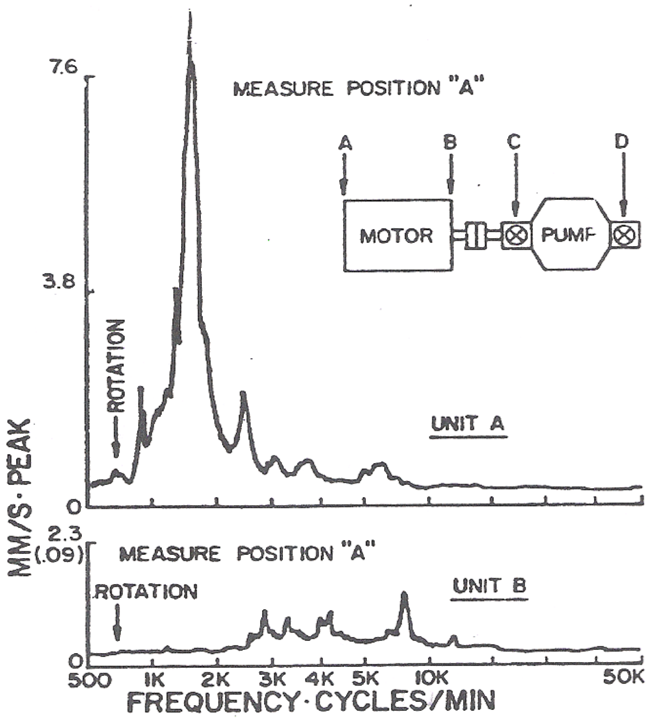


Figure 29: Vibration frequency analysis of a motor pump (Wickens, 2003)

c) Vibration on a Water Pump of a Steam Turbine

In the spectrum taken from the sliding (Plane) bearing of the water supply pump driven by the steam turbine, peaks were found at the rotation frequency and its multiple harmonics (multiples).

This spectrum is a good example for bed gap (Gap, looseness from wear)

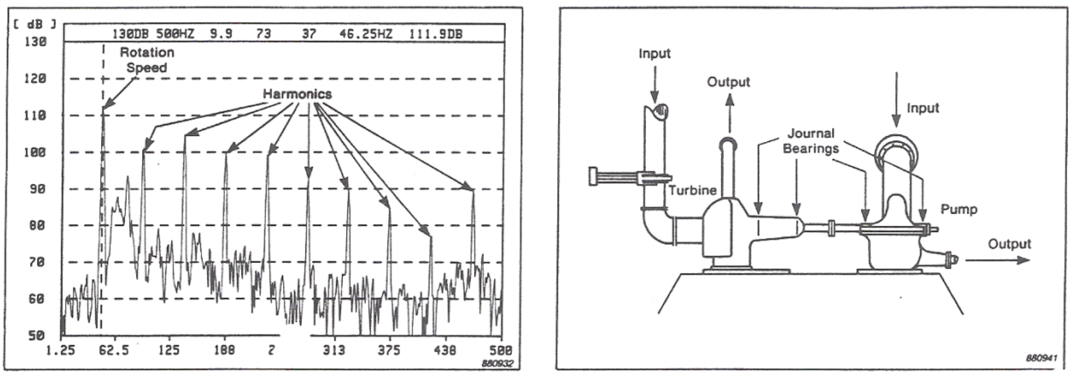


Figure 30: Vibration spectrum analysis on a water pump of a steam turbine (Wickens, 2003)

b. Modern Techniques for Condition Monitoring of Railway Vehicle Dynamics

Condition Monitoring and diagnostic analysis of railway system relies on sophisticated monitoring systems for maintenance and renewal activities. Practical applications of condition monitoring tools use sensors which are mounted either on the track or rolling stock. For instance, monitoring wheelset dynamics could be done through the use of track-mounted sensors, while vehicle-based sensors are preferred for monitoring the train infrastructure.

The dynamics of a railway vehicle represents a balance between forces acting at the wheel-rail interaction, suspension forces and inertia forces. The excessive response of the rail vehicle to track irregularities can result in poor guidance and ride quality which may increase wear on the wheel and rail, and can lead to derailment

Measurement of Wheel-Rail contact forces are very important for diagnostic analysis. For this purpose, one of the wheel sets is instrumented with strain gauges. During the motion at each instant of time contact forces at 3 directions can be measures. An instrumented wheel set is shown below.

Figure 31: Instrumented railway wheel set (Ngigi, 2012)

The practical application of condition monitoring of the train dynamics are done either through the employment of track-based sensors or vehicle-based sensors. Mostly, the track bed-based sensors are used to monitor the condition of wheelset, whereas, the rolling stock-based sensors are concerned with the monitoring of the rolling stock infrastructure.

The condition monitoring technique has considerably evolved over the years since it began as a measurement-oriented strategy. More emphasis now has been placed on computer-based stratagem. More reliance on computer systems is as a result of their efficiency in sending, storing and analysing large amount of data. Measuring instruments are using standard computer components and operating systems in order to be cost effective. These changes offer new possibilities for utilising condition monitoring of various system parameters and also, the integration of several disciplines in the field of condition monitoring and diagnosis which existed independent of one another.

In order for the railway industry to successfully implement condition-based maintenance, a good condition monitoring tool which can predict or detect incipient faults in real time is required. It has been accepted that, when a fault is imminent, there is certainly parametric deviation within the system. In such instances, parameter and state estimation techniques are more likely preferred for information extraction. Quite often direct measurements of parameters, especially for the rail vehicle dynamic system are not readily available due to several limitations, for example, high cost of implementation, or lack of adequate technology. Generally, condition monitoring for railway vehicle systems aids in reducing unscheduled downtime by allowing appropriate maintenance to be scheduled.

Today, most of the commercially available products for condition monitoring of railway vehicles are predominantly focused on the bogie system; this is because some of its critical components change their parameters rapidly when in operation and can pose safety related issues. The key concept here is the ability of the existing technology to monitor and identify these parameters in real time for condition monitoring and predictive maintenance purposes. Different sensor configurations are currently being implemented in the industry for monitoring railway vehicle parameters; but they mainly fall as either on-board (vehicle-based) or track-based systems as shown on the figure below.

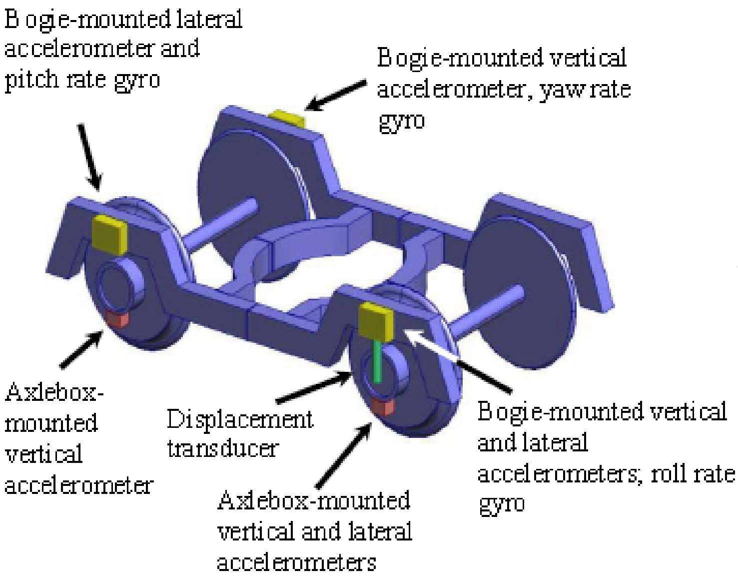


Figure 32: Bogie and wheelset sensor position (Ngigi, 2012)

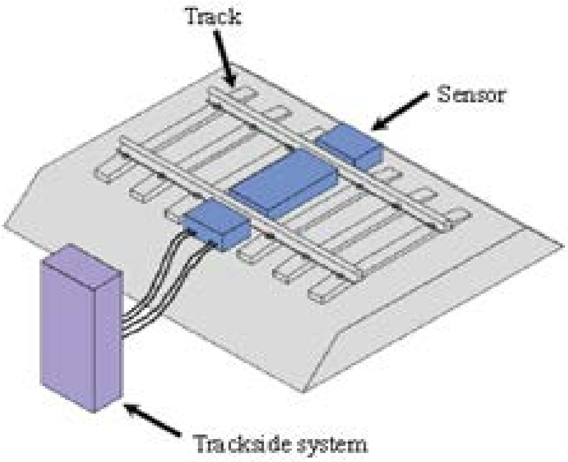


Figure 33: Trackside sensor configuration (Ngigi, 2012)

Examples of industries that commonly use predictive maintenance include:

1. Manufacturing: In the manufacturing industry, machinery and equipment, such as assembly lines and robots, are monitored for signs of wear and tear, such as vibration and temperature changes, to predict when maintenance is needed.

2. Transportation: In the transportation industry, vehicles, such as airplanes and ships, are equipped with sensors that monitor performance and provide data for predictive maintenance activities.

3. Energy: In the energy industry, power plants and wind turbines use predictive maintenance to monitor equipment performance, identify potential problems

early, and minimize downtime.

4. Healthcare: In the healthcare industry, medical equipment, such as MRI machines, is equipped with sensors to monitor performance and provide data for predictive maintenance activities.
5. Mining: In the mining industry, heavy equipment, such as drilling rigs and shovels, are equipped with sensors to monitor performance and provide data for predictive maintenance activities.

Advantages:

1. Reduced downtime because it helps in identifying potential equipment failures before they occur, allowing for scheduled maintenance during planned downtime instead of emergency repairs during unplanned downtime.
2. Lower maintenance costs: By predicting when maintenance is needed, predictive maintenance can help prevent unnecessary maintenance and reduce maintenance costs.
3. Increased equipment reliability and availability because potential issues can be identified and addressed before they lead to equipment failure.
4. Improved safety: Predictive maintenance can help identify and address safety issues before they lead to accidents or injuries, thereby improving workplace safety.

- **Disadvantages:**

1. High upfront costs because its implementation requires investments in technology, data analysis, and personnel training, which can be costly.
2. Complexity since it requires the use of sophisticated data analysis and monitoring tools, which can be difficult to implement.
3. Data quality: Predictive maintenance relies on accurate and reliable data to make accurate predictions, which can be challenging if the data is incomplete or of poor quality.
4. False positives and false negatives: Predictive maintenance can generate false positives (unnecessary maintenance) or false negatives (missed maintenance), which can lead to increased costs and risks.

Predictive maintenance is a proactive maintenance strategy that leverages technology and data analysis to minimize equipment downtime and maximize efficiency. By using predictive maintenance, organizations can reduce the frequency of breakdowns and avoid unplanned maintenance activities, saving time and reducing costs.

- **Procedures on how to apply predictive maintenance on railway vehicle maintenance:**

1. Collect data: Collect data on the performance of the railway vehicle and its components. This may involve sensors and monitoring systems that track things like vibration, temperature, and pressure.
2. Analyze data: Use analytics tools to analyze the data and identify patterns and trends that may indicate potential issues. This may involve using machine learning algorithms and predictive modeling techniques.
3. Predict maintenance needs: Based on the data analysis, predict when maintenance will be needed and what specific actions will be required. This may involve scheduling maintenance activities, ordering replacement parts, and allocating resources.
4. Conduct maintenance activities: Conduct the maintenance activities identified through the predictive maintenance process. This may involve replacing worn or damaged components, conducting cleaning and lubrication activities, and conducting inspections.

Examples of predictive maintenance activities for railway vehicle maintenance may include:

- Using sensors and monitoring systems to track vibration and temperature to predict when a bearing will fail and replacing the bearing before it causes a breakdown.
- Analyzing data from brake systems to identify patterns that indicate a component is likely to fail, and replacing the component before it fails.
- Using predictive modeling to identify patterns in track conditions that may cause problems for trains and scheduling maintenance to address the issues before they cause delays or accidents.

By implementing predictive maintenance measures like these, railway operators can proactively address maintenance needs, minimize the risk of breakdowns and accidents, and optimize the performance of their vehicles.

- **Basic systems and equipment used for predictive maintenance in railway vehicle maintenance:**

1. Sensors and monitoring systems: Sensors and monitoring systems are used to collect data on the condition and performance of equipment, such as temperature, pressure, vibration, and other indicators. For example, a train's braking system has sensors that collect data on the temperature and pressure of the brakes during operation, which can be analyzed to detect signs of wear or malfunction.
2. Data analytics software: Data analytics software is used to analyze data collected by sensors and monitoring systems to identify patterns and trends that can indicate potential equipment failures. For example, a data analytics software is used to analyze the data collected by a train's braking system sensors, and it detects that the temperature of the brakes is increasing, indicating that they may need maintenance.
3. Machine learning algorithms: Machine learning algorithms are used to learn from past data and predict future equipment failures, enabling proactive maintenance. For example, a machine learning algorithm is used to analyze historical data on a train's engine performance and predict when the engine is likely to require maintenance or repair.
4. Infrared thermography: Infrared thermography is used to detect hot spots or other anomalies in electrical systems or other equipment that could indicate potential failures. For example, Infrared thermography is used to inspect the electrical components of a train and detect any hot spots that could indicate a potential failure.
5. Remote monitoring: Remote monitoring allows maintenance technicians to monitor equipment in real-time, enabling them to detect potential issues before they become major problems. For example, remote monitoring is used to track a train's performance and detect any potential issues in real-time, allowing maintenance technicians to perform proactive maintenance before

the problem becomes significant.

By using these basic systems and equipment for predictive maintenance, railway operators can reduce downtime, increase equipment reliability, and improve overall operational efficiency.

B. Main Physical Parameters to be Monitored

1. Vibration

Vibration is a physical parameter that describes the movement of a mechanical system around its equilibrium position. In machinery, vibration is often caused by the rotating or reciprocating components of the equipment, such as motors, pumps, compressors, or gearboxes. Vibration monitoring is critical in identifying potential issues in rotating equipment, as abnormal vibration levels can indicate the presence of damage or wear.

Vibration monitoring involves the use of sensors or accelerometers that are attached to the equipment to measure the vibration levels. These sensors detect the acceleration of the equipment at various points, and this data is then analyzed to determine the frequency and amplitude of the vibration. In addition to monitoring the overall vibration level, it is also important to analyze the frequency spectrum of the vibration, as different frequencies can indicate different types of faults.

One of the primary benefits of vibration monitoring is that it allows maintenance teams to detect early signs of damage or wear in equipment. By continuously monitoring the vibration levels, maintenance teams can detect changes in the vibration signatures that may indicate the presence of a problem. For example, increased vibration levels may indicate that a component is out of balance, while high-frequency vibration may indicate the presence of bearing damage. By detecting these issues early, maintenance teams can take corrective action before they escalate into a major problem.

Another benefit of vibration monitoring is that it can help optimize maintenance schedules. By analyzing the vibration data over time, maintenance teams can determine the typical vibration levels for the equipment under normal operating conditions. Deviations from these levels can then be used to trigger maintenance activities such as lubrication, alignment, or bearing replacement. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

2. Temperature

Temperature is the level of thermal energy in a system. In predictive maintenance, monitoring the temperature of equipment is critical in identifying potential issues related to overheating, abnormal temperature fluctuations, or component failures. Temperature monitoring is particularly important for equipment that operates at high temperatures, such as engines, turbines, or furnaces.

There are several methods for monitoring temperature in equipment, including contact and non-contact methods. Contact methods involve attaching temperature sensors directly to the equipment, while non-contact methods use infrared thermography to measure the temperature of the equipment remotely.

Benefits of temperature monitoring it allows maintenance teams to detect early signs of overheating or abnormal temperature fluctuations. High temperatures can cause a range of issues, such as component failures, material degradation, or safety hazards. By continuously monitoring the temperature of equipment, maintenance teams can detect changes in temperature that may indicate the presence of a problem. For example, a sudden increase in temperature may indicate a coolant leak or a blockage in the cooling system.

Temperature monitoring can help optimize maintenance schedules. By analyzing temperature data over time, maintenance teams can determine the typical temperature levels for the equipment under normal operating conditions. Deviations from these levels can then be used to trigger maintenance activities such as cleaning, lubrication, or component replacement. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

3. Pressure

Pressure is the force exerted per unit area by a fluid or gas. In predictive maintenance, monitoring the pressure of equipment is critical in identifying potential issues related to leaks, blockages, or component failures. Pressure monitoring is particularly important for equipment that operates under high or low-pressure conditions, such as pipelines, boilers, or hydraulic systems.

There are several methods for monitoring pressure in equipment, including mechanical and electronic methods. Mechanical methods involve the use of pressure gauges or sensors that are attached directly to the equipment, while electronic methods use pressure transducers that convert pressure changes into electrical signals.

Benefits of pressure monitoring allows maintenance teams to detect early signs of leaks or blockages. Changes in pressure levels can indicate the presence of a leak or blockage in the system. For example, a sudden drop in pressure may indicate a leak in a pipeline, while a sudden increase in pressure may indicate a blockage in a valve or pump.

Another benefit of pressure monitoring is that it can help optimize maintenance schedules. By analyzing pressure data over time, maintenance teams can determine the typical pressure levels for the equipment under normal operating conditions. Deviations from these levels can then be used to trigger maintenance activities such as cleaning, replacement of worn or damaged components, or modification of the system design. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

Pressure monitoring is also important for ensuring safety in high-pressure environments. For example, in industrial settings such as oil and gas processing plants, monitoring the pressure of equipment and pipelines can help prevent accidents caused by over-pressurization or failure of equipment under high-pressure conditions.

4. Leakage

Leakage refers to the unintended escape of fluids or gases from equipment or systems. In predictive maintenance, monitoring for leaks is essential to identify potential issues related to component failure, equipment degradation, or safety hazards. Leakage monitoring is particularly important for equipment that operates under high-pressure conditions or involves hazardous substances, such as pipelines, storage tanks, or chemical processing equipment.

There are several methods for monitoring leaks in equipment, including visual inspections, ultrasonic testing, and gas detection. Visual inspections involve inspecting equipment and systems for signs of leaks, such as stains, corrosion, or moisture. Ultrasonic testing uses high-frequency sound waves to detect the sound of leaking fluid or gas, while gas detection involves using sensors to detect the presence of gas leaks in the environment.

One of the primary benefits of leakage monitoring is that it allows maintenance teams to detect early signs of leaks before they become larger issues. Small leaks can cause equipment degradation, reduce efficiency, and pose safety hazards. By continuously monitoring for leaks, maintenance teams can detect leaks early and take corrective action before they cause larger problems.

Leakage monitoring can help optimize maintenance schedules. By analyzing leakage data over time, maintenance teams can determine the typical leakage rates for the equipment under normal operating conditions. Deviations from these rates can then be used to trigger maintenance activities such as repairs or component replacement. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

Leakage monitoring is important for ensuring safety in hazardous environments. For example, in industrial settings such as chemical processing plants or refineries, monitoring for gas leaks can help prevent accidents and protect workers from exposure to hazardous substances.

5. Noise

Noise is a physical parameter that refers to unwanted sound or vibration in equipment or systems. In predictive maintenance, monitoring for noise is important to identify potential issues related to equipment failure, component degradation, or safety hazards. Noise monitoring is particularly important for equipment that operates in high-noise environments or involves moving parts, such as motors, fans, or pumps.

There are several methods for monitoring noise in equipment, including sound level meters, acoustic sensors, and vibration sensors. Sound level meters measure the intensity of sound in decibels, while acoustic sensors use microphones to detect noise levels in specific areas of equipment or systems. Vibration sensors, on the other hand, measure the vibration caused by equipment and can be used to detect changes in noise levels over time.

One of the primary benefits of noise monitoring is that it allows maintenance teams to detect early signs of equipment failure or degradation. Changes in noise levels can indicate the presence of worn or damaged components, misalignment, or other issues. For example, an increase in noise levels in a motor or pump may indicate a problem with bearings, while a decrease in noise levels may indicate a problem with the motor or fan speed.

Another benefit of noise monitoring is that it can help optimize maintenance schedules. By analyzing noise data over time, maintenance teams can determine the typical noise levels for the equipment under normal operating conditions. Deviations from these levels can then be used to trigger maintenance activities such as repairs or component replacement. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

Noise monitoring ensures safety in high-noise environments. For example, in industrial settings such as manufacturing plants or construction sites, monitoring for noise levels can help prevent hearing loss and other health hazards for workers.

Noise monitoring is a critical tool in predictive maintenance. By continuously monitoring for changes in noise levels, maintenance teams can detect early signs of equipment failure or degradation, optimize maintenance schedules, and ensure safety in high-noise environments. With the help of advanced analytics tools and machine learning algorithms, noise data can also be used to identify patterns and trends that can help improve equipment design and reliability over time.

6. Oil analysis

Oil analysis is a predictive maintenance technique that involves analyzing the physical and chemical properties of lubricating oils used in equipment or systems. Oil analysis is used to identify potential issues related to equipment degradation, component wear, or contamination. By analyzing oil samples at regular intervals, maintenance teams can detect early signs of problems and take corrective action before they cause larger issues.

There are several methods for oil analysis, including spectroscopy, viscosity measurement, and particle counting. Spectroscopy involves analyzing the chemical composition of the oil to detect the presence of contaminants or wear metals. Viscosity measurement involves measuring the thickness or flow of the oil, which can indicate potential issues with lubrication or contamination. Particle counting involves measuring the number and size of particles in the oil, which can indicate potential issues with component wear or contamination.

Oil analysis allows maintenance teams to detect early signs of equipment degradation or wear. Changes in the physical and chemical properties of oil can indicate the presence of contaminants, water, or wear metals. By analyzing oil samples at regular intervals, maintenance teams can detect these changes and take corrective action before they cause larger issues.

Oil analysis can help optimize maintenance schedules. By analyzing oil data over time, maintenance teams can determine the typical oil properties for the equipment under normal operating conditions. Deviations from these properties can then be used to trigger maintenance activities such as oil changes or component replacement. By scheduling maintenance activities based on the actual condition of the equipment, maintenance teams can optimize equipment performance while minimizing downtime and maintenance costs.

Oil analysis is also important for ensuring the quality of lubricating oils used in equipment or systems. Contaminated or degraded oil can lead to decreased efficiency, increased wear and tear, and equipment failure. By monitoring the physical and chemical properties of oil, maintenance teams can ensure that the lubricating oils used in equipment are of high quality and meet the manufacturer's specifications.

- **Comparison of the types of maintenance.**

In reactive maintenance, the equipment is only repaired or replaced after it has failed. It is characterized by minimal planning or upfront costs required; no scheduled maintenance tasks or inspections are needed. The limitations include increased downtime; higher repair costs; reduced equipment lifespan; potential safety risks.

In the case of preventive maintenance, maintenance involves scheduled inspections, repairs, and replacements to prevent equipment failure and keep it in good working condition. Its merits are increased equipment reliability; reduced downtime; lower repair costs; improved safety. The drawbacks are it requires a lot of time and resources required for planning and execution; over-maintenance can occur; potential for missed issues; costs of maintenance investments.

For predictive maintenance, data and analytics are used to predict equipment failure and schedule maintenance accordingly. The advantages are; reduced downtime; lower maintenance costs; increased equipment reliability; improved safety. The demerits are high upfront costs for technology and personnel training; complexity; potential issues with data quality; false positives and false negatives.

In summary, reactive maintenance is a reactive approach with minimal planning or costs, but it can lead to increased downtime, higher repair costs, and reduced equipment lifespan. Preventive maintenance is a proactive approach that can increase equipment reliability and reduce downtime, but it requires time and resources for planning and execution. Predictive maintenance uses data and analytics to predict equipment failure, which can lead to reduced downtime and lower maintenance costs, but it requires high upfront costs for technology and personnel training. Each approach has its advantages and disadvantages, and the best approach depends on the specific needs and resources of a business.

- **Establishing a maintenance program for railway vehicles.**

Maintenance of railway vehicles is crucial for ensuring their safe and efficient operation. To establish a maintenance program for railway vehicles, you need to consider the manufacturer's recommendations, regulatory requirements, and the vehicle's operating conditions.

The steps used in developing a maintenance program for railway vehicles include:

1. Identify the critical components of the vehicle: Identify the critical components that require periodic maintenance. These can include the engine, brakes, transmission, wheels, bearings, axles, and suspension.
2. Determine the maintenance intervals: Determine the maintenance intervals for each component based on the manufacturer's recommendations,

regulatory requirements, and the vehicle's operating conditions. For example, the engine may require an oil change every 10,000 miles, while the brakes may need to be inspected every 5,000 miles.

3. Develop a maintenance schedule: Develop a maintenance schedule based on the maintenance intervals determined in step 2. This schedule should include specific dates or mileage thresholds for each maintenance task.
4. Assign responsibilities: Assign responsibilities for performing the maintenance tasks to specific personnel or departments within the organization. Ensure that the personnel responsible for performing maintenance are trained and qualified to perform the necessary tasks.
5. Record keeping: Establish a system for recording maintenance activities, including the date of maintenance, the components serviced, and any repairs or replacements made. This record-keeping system will allow you to track the maintenance history of each vehicle and ensure that all maintenance tasks are completed on schedule.
6. Regular inspections: Conduct regular inspections of the vehicle to identify any potential maintenance issues before they become serious problems. These inspections should be conducted according to a schedule, and any issues identified should be addressed promptly.
7. Continuous improvement: Continuously monitor the effectiveness of the maintenance program and make adjustments as necessary to improve its efficiency and effectiveness.

By following these steps, one can develop a comprehensive maintenance program for railway vehicles that will help ensure their safe and efficient operation.

C. Railway maintenance

Railway infrastructure maintenance refers to the upkeep and repair of the physical components of a railway system, including tracks, bridges, tunnels, signals, and electrification systems. This maintenance ensures that the railway is safe and operational for trains to run smoothly. Superstructure maintenance refers to the maintenance of the structures above the tracks, such as station buildings and platforms, canopies, and footbridges. Both types of maintenance are crucial for the safe, efficient, and reliable operation of the railway system (Park, 2013).

Maintenance is necessary due to the wear of components with the passing of trains and to improve the ride comfort of passengers or to improve safety levels due to the risk of derailment, etc. (Simões, 2008). Preventive maintenance is used for safety-related maintenance actions and corrective maintenance is used for comfort-related actions.

Rail defects maintenance is 5-15 times more frequent than track-defects maintenance. Geometrical characteristics' restoration in the lines with average traffic loads, performs after loads of 40 to 50 million tons, while rail replacements or grinding actions occur after about 500 to 600 million tons. Track geometry corrections consist of reshaping the ballast layer (tamping, ballast regulation) and its stabilization (compacting of ballast, the addition of chemical binders). Ballast problems of weed intrusion are solved by ballast cleaning operations. Rail-centered maintenance includes rail grinding and re-profiling (correction of rolling contact fatigue defects which exist on the rolling surface), and weld straightening. Full replacement of the rail lengths affected is required for some rail defects after a certain degree of development.

Railway maintenance is essential for ensuring the safe and efficient operation of railway systems. Maintenance can be divided into two main categories: maintenance of railway infrastructure and maintenance of railway superstructure.

1. Maintenance of Railway Infrastructure:

Railway infrastructure includes the tracks, signals, bridges, tunnels, and other structures that make up the railway network. Maintenance of railway infrastructure is critical for ensuring the safe and efficient operation of the railway system.

Track maintenance involves inspecting and repairing the rails, sleepers, ballast, and other components of the track. This includes maintaining proper alignment and level of the track, replacing worn or damaged components, and ensuring that the track is free from debris and other hazards.

Signal maintenance involves inspecting and repairing the signaling system that controls the movement of trains along the track. This includes maintaining proper signaling equipment, replacing worn or damaged components, and ensuring that the signaling system is functioning properly.

Bridge and tunnel maintenance involves inspecting and repairing the structures that allow the track to cross over waterways, roads, and other obstacles. This includes maintaining the integrity of the structures, repairing any damage, and ensuring that they are safe for train traffic.

2. Maintenance of Railway Superstructure:

Railway superstructure includes the rolling stock, such as locomotives, passenger coaches, and freight wagons, which operate on the railway tracks. Maintenance of railway superstructure is critical for ensuring the safe and efficient operation of the rolling stock.

Rolling stock maintenance involves inspecting and repairing the mechanical and electrical components of the locomotives, coaches, and wagons. This includes maintaining proper lubrication, replacing worn or damaged components, and ensuring that the rolling stock is safe for operation.

Brake system maintenance involves inspecting and repairing the braking system that allows the train to slow down and stop. This includes maintaining proper brake components, replacing worn or damaged parts, and ensuring that the brake system is functioning properly.

Electrical system maintenance involves inspecting and repairing the electrical components of the rolling stock. This includes maintaining proper wiring, replacing worn or damaged components, and ensuring that the electrical system is functioning properly.

Therefore, maintenance of railway infrastructure and superstructure is essential for ensuring the safe and efficient operation of the railway system. By regularly inspecting and repairing the various components of the railway system, we can ensure that trains can operate safely and efficiently, reducing the risk of accidents and delays.

- **Laser Beam Technology**

Laser beam scanning technology is commonly used in railway vehicle maintenance to perform non-destructive testing of wagons and components. The technology involves the use of a laser scanner that emits a beam of light to scan the surface of the wagon or component. The scanner captures the reflected laser light to create a 3D model of the object being scanned.

The use of laser beam scanning in railway vehicle maintenance allows for the detection of defects and damage that may not be visible to the naked eye. The technology can detect cracks, corrosion, and other types of damage in the wagon structure, wheels, axles, and other components.

Daily checking of wagons and components using laser beam scanning in depots involves the following steps:

1. Preparation: The wagon or component is positioned in a specific area where it can be easily scanned. The scanner is set up and calibrated to ensure accurate measurements.
2. Scanning: The laser scanner is used to scan the surface of the wagon or component. The scanner moves along the surface, emitting a beam of laser light, and capturing data about the surface features.
3. Analysis: The data collected by the scanner is analyzed using software to create a 3D model of the wagon or component. The model can be used to detect any defects or damage in the structure or components.
4. Reporting: The results of the scan are reported to the maintenance team. Any defects or damage detected are documented, and a plan is developed for repairs or maintenance.

The use of laser beam scanning in daily checks of wagons and components in depots provides a fast, accurate, and non-destructive way to detect defects and damage. This helps to ensure the safety of railway operations and prevent costly breakdowns or accidents.

3. Visual and ultrasonic inspection

Visible defects from outside in the rails mainly cause ride comfort. Traditional visual inspection can be done to observe the track constituents' condition and track geometry. Then the spotted defects which are not caused by internal discontinuities in the rail can be corrected. Video or photo imaging inspection systems are used in modern tracks instead of traditional visual inspection.

The internal structure of the rails is assessed using ultrasonic inspection. Defects caused by internal discontinuities in rails that are not visible from the outside can be located with this method. As some internal discontinuities may result in brittle failure, ultrasonic inspection is very important for security reasons. Disruption of regular train traffic can be avoided by having regular maintenance operations by using ultrasonic inspection to detect failures in the early stages. Hand-held devices or special ultrasonic trains are used in ultrasonic inspection (Figure).

Ultrasonic trains with fast inspection speeds are used in long stretches of rail networks while hand-held devices are used in switches, joints, and bridges, and for detailed measurements of the sections indicated by the ultrasonic trains. EURAILSCOUT UST96 ultrasonic train can measure at a maximum speed of 100km/h with more than 95% fault accuracy and 1-meter distance sensitivity.

(a) (b)

Figure 34: Ultrasonic measurement, (a) hand-held devices: euraiscout SPG 2, MT95, and geismar SIRIUS, (b) eurailscout UST96 ultrasonic train (Simões, 2008).

D. Measurement and Checking of wearing on Rail Surface and Roughness

The measurement and checking of wearing on rail surfaces and roughness is an important aspect of railway maintenance. Regular measurement and maintenance of the rail surface and roughness can help to ensure the safe and efficient operation of the railway system.

1. Measurement of Rail Surface Wearing

Rail surface wearing can be measured using a variety of methods, including visual inspection, ultrasonic testing, and wear gauge measurement. Visual inspection involves visually inspecting the rail surface for signs of wear, such as uneven wear, cracks, or other damage. Ultrasonic testing involves using ultrasonic waves to measure the thickness of the rail and identify any areas of wear or damage. Wear gauge measurement involves using a wear gauge to measure the depth of the wear on the rail surface.

2. Checking Roughness of Rail Surface

Rail surface roughness can be measured using a variety of methods, including the use of a roughness meter or a profilometer. A roughness meter is a handheld device that measures the roughness of the rail surface by running a stylus along the surface and recording the movement of the stylus. A profilometer is a more advanced device that uses a laser or other measurement technology to measure the roughness of the rail surface in greater detail.

3. Maintenance of Rail Surface and Roughness

Maintaining the rail surface and roughness involves regular inspection, cleaning, and repair. This includes removing any debris or other obstructions from the rail surface, repairing any damage or wear, and ensuring that the rail surface is properly lubricated. Lubrication of the rail surface can be achieved using various methods, including the application of grease or other lubricants, or the use of friction modifiers.

Regular maintenance of the rail surface and roughness is critical for ensuring the safe and efficient operation of the railway system. By measuring and checking the wear and roughness of the rail surface, and implementing regular maintenance and repair, we can help to ensure that the railway system remains safe and efficient for years to come.

4. Rail grinding/ reprofiling

Rolling contact fatigue (RCF) defects in the rail surface are corrected for proper fail profile by rail grinding while it eliminates surface-initiated cracks in an early stage. Further, rail grinding indicates corrugations, and correct or prevent wheel burns, shelling, head checks, spalling, plastic flow and tongue lipping. Machines equipped with rotating stones and stones oscillating longitudinally are the two types of machines used for rail grinding (Figure). This movement of the stones against the rail smoothest the rail surface. Rail reprofiling is used when rail grinding is insufficient to correct highly developed defects.

(a)

(b)

Figure 35: Rail grinding equipment, (a) TMS rail grinding unit, (b) fairmount rail grinding machine (Simões, 2008).

5. Weld correcting

STRAIT (Straightening of Rail welds by Automated Iteration) principle using two displacement transducers to measure the step between rail ends on the weld is one possible solution to correct weld defects. Rail welding is an important aspect of railway maintenance, as it helps to join two sections of rail together and create a continuous track. However, welding defects can occur over time, which can compromise the safety and efficiency of the railway system. Some common welding defects include:

1. Flash butt welding defects: These defects can occur due to poor alignment of the rail ends or inadequate welding parameters, resulting in poor weld penetration and insufficient bonding between the rails.

2. Thermite welding defects: These defects can occur due to inadequate pre-heating of the rail ends or poor welding parameters, resulting in poor weld penetration and insufficient bonding between the rails.

3. Gas welding defects: These defects can occur due to inadequate shielding of the weld area or poor welding parameters, resulting in poor weld quality and insufficient bonding between the rails.

To address welding defects, various maintenance techniques can be employed, including the STRAIT (Straightening of Rail welds by Automated

Iteration) principle. The STRAIT principle uses two displacement transducers to measure the step between rail ends on the weld, allowing for correction of any defects through automated iteration.

Other maintenance techniques include:

1. Grinding: This involves removing any defects or irregularities on the rail surface using a grinding machine. Grinding can help to improve the smoothness and stability of the rail surface, reducing the risk of derailments and other accidents.
2. Welding repair: This involves repairing any defects or damage in the rail welding using various welding techniques, such as flash butt welding, thermite welding, or gas welding. Welding repair can help to restore the integrity and strength of the rail, reducing the risk of failure or breakdown.
3. Replacement: In cases where welding defects are severe or cannot be repaired, it may be necessary to replace the entire section of rail. Rail replacement involves removing the defective rail section and installing a new one, ensuring the integrity and safety of the railway system.

Overall, maintaining the quality and integrity of rail welding is critical for ensuring the safety and efficiency of the railway system. By employing various maintenance techniques, such as the STRAIT principle, grinding, welding repair, and replacement, we can help to ensure that the railway system remains safe and reliable for years to come.

6. Rail replacement

Replacement of part of or all track elements can be done using manual techniques or fully automated track renewal cars. Rail replacement is an important aspect of railway maintenance, as it helps to ensure the integrity and safety of the railway system. Replacement of part of or all track elements can be done using manual techniques or fully automated track renewal cars.

Manual Techniques: Manual techniques for rail replacement involve the use of manual labor and equipment to remove and replace the rail and other track elements. This can include using hydraulic jacks and cranes to lift and move the rail sections, using hand tools and welding equipment to repair or replace damaged rail sections, and using ballast tampers and compactors to ensure proper track alignment and stability.

Manual techniques are often used for small-scale repairs or replacements, such as replacing a single rail section or repairing a small section of track. These techniques can be labor-intensive and time-consuming, but they can be cost-effective and efficient for smaller projects.

Fully Automated Track Renewal Cars: Fully automated track renewal cars are a more advanced and efficient method for rail replacement. These cars are equipped with a range of specialized equipment and technology, including cranes, hydraulic jacks, and welding equipment, which allows them to remove and replace entire sections of track with minimal human intervention.

Fully automated track renewal cars can be used for large-scale track replacements, such as replacing entire sections of track or upgrading the railway system to a new standard. These cars are highly efficient and can complete the replacement process in a matter of hours, reducing the downtime and disruption to railway operations.

Overall, rail replacement is a critical aspect of railway maintenance, and the choice of technique will depend on the scale of the replacement project, the available resources, and the required level of efficiency and cost-effectiveness. By employing the appropriate techniques for rail replacement, we can help to ensure the safety, reliability, and efficiency of the railway system for years to come.

7. Rail lubrication

The purpose of rail lubrication is the reduction of wear, especially in the gauge face corner of curves with low radii, reduction of railway locomotive fuel consumption, and noise levels. But, as lubrication may cause RCF defects to develop due to the presence of fluids (fluid entrapment) and migration of lubricant material from the gauge face corner to the rail head surface, leading to wheel slipping, serious care must be paid. On-bogie mounted systems, or track-side permanent systems with automatic grease dispensing units are used for this purpose.

Railway tracks are subject to high levels of wear and tear due to the heavy loads carried by trains and the constant friction between the train wheels and the rails. Rail lubrication is used to reduce this wear and tear, especially in the gauge face corner of curves with low radii. The lubrication helps to reduce the friction between the train wheels and the rails, which in turn reduces the amount of energy required to move the train, leading to a reduction in fuel consumption and noise levels.

The advantages of rail lubrication include:

1. Reduced wear and tear: Rail lubrication helps to reduce wear and tear on the rails, leading to longer rail life and reduced maintenance costs.
2. Reduced energy consumption: By reducing the friction between the train wheels and the rails, rail lubrication can help to reduce the amount of energy required to move the train, leading to lower fuel consumption and reduced emissions.
3. Reduced noise levels: The reduction in friction between the train wheels and the rails can also help to reduce the noise levels generated by passing trains, leading to a quieter environment for nearby communities.

However, there are also some potential disadvantages to rail lubrication:

1. Risk of RCF defects: Rail lubrication can cause RCF (rolling contact fatigue) defects to develop due to the presence of fluids and the migration of lubricant material from the gauge face corner to the rail head surface. This can lead to wheel slipping and other safety issues.
2. Maintenance requirements: Rail lubrication systems require regular maintenance to ensure that they are functioning properly and to prevent the buildup of excess grease on the rails.

Overall, rail lubrication can be an effective way to reduce wear and tear on railway tracks and improve the efficiency and safety of the railway system. However, it is important to carefully consider the potential advantages and disadvantages of rail lubrication and to choose an appropriate lubrication system that minimizes the risk of RCF defects and other safety issues.

- **Maintenance of railway vehicles**

Maintenance of railway vehicles is a crucial aspect of ensuring their safe and efficient operation. This may include the following practices;

a. Carrying out preventive maintenance to prevent equipment failures before they occur. It includes regular inspections, lubrication, cleaning, and replacement of parts that are prone to wear and tear. For example, the replacement of brake pads, inspection of wheel bearings, and cleaning of air filters.

b. Conducting corrective maintenance when a problem occurs. It involves identifying the root cause of the problem and taking corrective action to fix it. For example, repairing damaged electrical wiring or replacing a broken window.

c. Carrying out predictive maintenance using advanced technologies to detect potential failures before they occur. It includes the use of sensors and monitoring equipment to detect changes in equipment performance or other abnormalities. For example, using vibration analysis to detect potential problems in bearings or using infrared thermography to detect electrical problems.

d. Performing condition-based maintenance by assessing the condition of the equipment to determine the need for maintenance. It includes the use of diagnostic equipment to monitor equipment performance and identify potential problems. For example, using oil analysis to determine the condition of engine oil or monitoring the wear of brake components.

In conclusion, proper maintenance of railway vehicles is important for ensuring their safe and efficient operation. It helps to prevent accidents, reduce downtime, and extend the lifespan of the equipment.

E. Application of RAMS to railways

The failure information from a system is used to develop probability distributions for the system’s ability to perform its intended functions in RAMS analysis and consists mainly three elements, namely, RAMS database, failure modes, and methods and tools for RAMS analysis (Patra, 2009). An important factor in RAMS analysis and the management of the system is the use of failure and maintenance data. RAMS data collected should support all types of RAMS analysis, the life cycle perspective of the system, and the maintenance phase. The traffic and track geometry databases should be considered with the failure and maintenance databases for an effective analysis of RAMS.

F. Railway maintenance standards

There are mainly three railway technical standards, namely, compulsory standards which focus on safety, design standards which complement the compulsory standards, and optional standards to increase production efficiency, elimination of trade barriers, etc. (Zhang et al., 2020).

1. Detailed information about the standard EN50126

EN 50126 is a European standard that specifies the requirements for the safety and reliability of railway applications. It provides a framework for the management of the RAMS (Reliability, Availability, Maintainability, and Safety) aspects of railway systems, including the planning, design, development, testing, operation, and maintenance of these systems.

The standard is organized into four main parts:

1. Part 1: The standard provides general guidelines for the management of the RAMS aspects of railway systems. It covers the planning, organization, and control of the RAMS process and provides guidance on the allocation of RAMS targets and responsibilities.
2. Part 2: This part of the standard focuses on the requirements for the RAMS assessment of railway systems. It covers the methods and tools that should be used to assess the RAMS performance of these systems, including hazard analysis, risk assessment, and safety integrity level (SIL) determination.
3. Part 3: This part of the standard provides guidance on the RAMS requirements for the design and development of railway systems. It covers the design principles and methods that should be used to ensure that railway systems are reliable, available, maintainable, and safe.
4. Part 4: The final part of the standard provides guidance on the RAMS requirements for the operation and maintenance of railway systems. It covers the procedures and techniques that should be used to ensure that railway systems continue to operate safely and reliably throughout their lifecycle.

Overall, EN 50126 provides a comprehensive framework for the management of the RAMS aspects of railway systems, and it is widely used by railway operators, manufacturers, and regulatory authorities throughout Europe. By following the guidelines and requirements set out in this standard, railway organizations can help to ensure the safety, reliability, and availability of their systems, while minimizing the risks and costs associated with these operations.

Several compulsory technical standards for the construction, operation, and maintenance of railway networks for safety available for some countries are given in Table 1.

Table 1. Compulsory railway standards (Zhang et al., 2020).

Country	Compulsory standard
Japan	Regulations on Railway Structure
Germany	Regulations on Railway Construction and Operation
France	Official Administrative Regulations on Safety and Commercial Services on Nationwide and Regional Railway Lines
UK	Railway Safety Principles and Guidance
USA	FRA (Federal Railroad Administration) Regulations (State safety participation regulations, etc.)
EU	EU Directives (COUNCIL DIRECTIVE 96/48/EC on the interoperability of the trans-European high speed rail system, etc.)
Turkey	DECREE LAW No:655 (in 2011) - Directorate General for Regulation of Railways and the Law No: 6461 on Liberalization of Rail Transport in Turkey was entered into force on 1 May 2013. Example: The different types of passenger service available in Turkey are: High-speed (Hızlı Tren): High-speed rail services and TCDD's premier service. Mainline (Anahat): Intercity trains operating between major cities. International (Uluslararası): Trains operating on international routes, toward Europe or the Middle East. Regional (Bölgesel): Trains operating within their respective districts. Commuter (Banliyö): Commuter trains, currently operating in Ankara and İstanbul.
KSA	All equipment must comply with the requirement of The Communications and Information Technology Commission (CITC) specification GEN001, be safe and must not adversely affect other electrical equipment. Example: The different types of service available in Saudi Arabia are: 1. Passenger Trains 2. Real Estate 3. Freight 4. Mashaer Metro Train

The voluntary and optional standards for railway sectors are as given in

Table 2. Main voluntary and optional standards of the world (Zhang et al., 2020).

Type	Organization	Description
International standards	ISO (International Organization for Standardization)	ISO Standards 45 “Railway Engineering” 45.020: Railway engineering in general 45.040: Materials and components for railway engineering 45.060: Railway rolling stock 45.080: Rails and railway components 45.120: Equipment for railway construction and maintenance
	IEC (International Electrotechnical Commission)	Technical Committee 9 (Electric railway equipment) IEC 60077: Railway applications IEC 60349: Electric traction IEC 60494: Rules for pantographs of electric rolling stock IEC 60850: Supply voltages of traction systems IEC 61375: Electric railway equipment
Regional standards	European Committee for Standardization (CEN) and the European Committee for Electro technical Standardization (CENELEC)	“EN (EURO NORM)” for European countries
National standards	Individual countries have respective organizations for standardization	U.S.A. - ANSI U.K. - BS ((*BS EN 50126-1:1999 Railway Applications — The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) — Part 1: Basic Requirements and Generic Process*), (*PD CLC/TR 50126-2:2007 Railway Applications — The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) — Part 2: Guide to the Application of EN 50126-1 for Safety*), (*PD CLC/TR 50126-3:2008 Railway Applications — The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) — Part 3: Guide to the Application of EN 50126-1 for Rolling Stock RAM*), (*BS EN 50126-1:2017 Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Part 1: Generic RAMS Process*), (*BS EN 50126-2:2017 Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Part 2: Systems Approach to Safety*)) Germany - DIN France - NF Japan - JIS Philippines - PS
Group standards	UIC (International Union of Railways) At present there are 134 railway enterprises	UIC CODE 100: Passenger and Baggage Traffic 200: Freight Traffic 300: Finance, Accountancy, Costs, Statistics 400: Operating (including RIV and RIC Regulations) 500: Transport Stock 600: Traction 700: Way and Works 800: Technical Specifications 900 Information Technology, Miscellaneous

IV. RESULTS AND DISCUSSION

RAM analysis has been proved in several studies and research to assist reduce maintenance costs by enhancing equipment reliability, functionality, and maintenance performance. Specifically, this thesis aims to examine the failure and repair datasets of railway systems to construct a model of a railway engineering system that reduces unavailability and increases the system's availability. This research aims to detect significant equipment failures in the system's infrastructure so that management and replacement parts methods may be optimized to maximize availability.

A. Conclusions

In conclusion, this thesis has been able to address the concept of RAMS (Reliability, Availability, Maintainability, and Safety) and how it can be applied in the maintenance of railway lines. Subsequently, this thesis has introduced the concept of condition-based maintenance and capacity evaluation with a specific connection to railway system engineering maintenance. In addition, the goals of this research study were to establish many theories and procedures, as well as provide possible methodologies for RAMS management, in order to ensure the successful implementation of RAMS management into railway systems engineering.

All recommended management models, methods, and methodologies have been shown to assist railway companies in developing and executing RAMS administration throughout the system's initial planning stage. In RAMS analysis for railway vehicle various case studies and analysis is done which includes the stress strain analysis, frequency analysis and vibrational analysis. All this analysis is done on the computational tool which is called MATLAB. The stress strain relations describe the reliability of the railway vehicle. The stress strain relationship gives many mechanical properties such as strength, toughness, elasticity, yield point, strain energy, elongation in loads. Stress and strain are the physical properties of the system.

Similarity vibrational analysis is one of the most used methods to measure the health of the machinery. Vibration data can be used to diagnose the faulty parts of the machinery. It also helps to identify the alignment of the various parts of the system such as bearings and shafts. After the vibrational analysis and stress strain analysis, frequency analysis is also done for the maintenance of the railway tracks. The objective of the railway tracks' maintenance is for the safety of the railway vehicles.

The train body and the track/soil are both affected by the vibration that is created at the wheel/rail interaction. Vehicle vibration must be minimized since it impacts passenger comfort, which is frequently a key need for track construction (particularly on high-speed lines). As a result, trains are frequently equipped with two suspension systems linked by a bogie. The first suspension system links the wheel to the bogie, while the second suspension system links the bogie to the automobile body. Originally, this design was mostly employed on high-speed trains to increase passenger comfort, but it is now becoming widespread on other train types, like intercity locomotives. Because the high-speed market is geared toward business, passenger comfort is frequently stressed on certain lines.

Contrarily, passengers are often not transported on freight lines, therefore comfort is not a top concern. Because of this, it's crucial that the train offers a workspace, especially for business travelers. A time domain multibody modeling approach can be used to simulate vehicle vibration. For instance, a numerical model was created to simulate the vibrations caused by a high-speed train crossing a bridge. A comfort index and maximum acceleration criterion were used to evaluate the model's outputs, and it was discovered that rail roughness significantly affected passenger comfort.

B. Recommendations

The following recommendations for future study are listed in prolongation of the work that has already been done in this study:

- The evaluation process is targeted at decreasing failures. (About what?) Therefore, knowing the deformations of a system, including rail, which is critical to preserving its integrity, is at the heart of reliability improvement.

As a result, Commuter rail should examine and research innovative rail maintenance and authentic analyzed technologies that do not impact track availability.

- The railway engineering system maintenance approach should be flexible, not static, and should not be dependent on historical events or the opinions of senior professionals. This is sensitive to variations in rail mechanics as unit loads, increased traffic, and track velocities continue to rise.

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RESUME

Nasser Almashame

Professional Profile

My passion is engineering. Since the formation of my career, I have been fortunate to develop skills in many professions, from fabrication and welding, product design and manufacturing. One of my main interests is exploring new technologies and methods of integration into existing systems for the benefit of continuous improvement.

Work experience

- Mechanical Engineer Internship (Aramco)
- Jan 2020 - Mar 2020

I worked for Aramco in the refinery maintenance department. In addition, I took some E-learning courses in how to deal with equipment and environment safety measurement. Furthermore, I have dealt with many things on the field such as heat exchangers, boilers, pumps, fans, bolts, and steam turbines.

EDUCATION

B.S of Mechanical Engineering

Prince Mohammed Bin Fahd University

GPA: **2.78/4**

AlKhobar, KSA

from Aug 2015 To Dec 2019

Projects

Senior Design Project

- (From 2019 September to 2019 December)
- We have built a radial jet engine and done a research about designing and building jet-engines. A simple turbojet engine was designed, and construction in this project using a large diesel car turbocharger on a small-scale level. The turbocharger serves as an integrated compressor & turbine assembly that is suitably manipulated and carefully converted into an open cycle constant pressure gas turbine.

Certificates

- Basic Motor Theory in the 17th Aug 2020
- Saudi Council of Engineers I have attended an online course on Basic Motor Theory provided by Grundfos and the Saudi Council of Engineers (SCE). The course provided rich information regarding the theory, covering different aspect of the Motors such as: Electrical motor basics and it output power, Standards for AC motors, and Motor protection.

Languages.

- Arabic (Native)
- English (Fluent)
- Turkish

Personal Skills

- Microsoft Office
- Leadership
- Decision making